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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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CONTENTS

RADIOLOGICAL PROTECTION OF PEOPLE AND THE ENVIRONMENT IN THE EVENT OF A LARGE NUCLEAR ACCIDENT

ICRP PUBLICATION 14X

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Abstract-This publication provides a framework for the protection of people and the environment in the case of large nuclear accidents, drawing on the experience of Chernobyl and Fukushima. The immediate response is an emergency exposure situation, while longer term post-accident rehabilitation is considered as an existing exposure situation. A nuclear accident inevitably creates new circumstances and consequences for the health and well-being of people, both in the immediate vicinity of the facility and beyond. Although actions to reduce radiation exposure can be relatively straightforward, the implementation of protection should take careful account of all hazards and implications, both radiological and non-radiological, in order to provide reasonable and sustainable living conditions. In both exposure situations, these objectives are achieved using the fundamental principles of justification of decisions and optimisation of protection with reference levels. An emergency response is characterised by rapid and responsive decision making and actions, often with very little information. This response must rely on emergency preparedness based on actions that most closely match the actual situation. The decision to terminate urgent protective actions will need to reflect the prevailing circumstances as time progresses. Once the situation is under control, the process of recovery can begin. In this process, individual lifestyles become a key factor to control radiation exposure. It is the role of the authorities to provide the conditions and means for sharing of expertise and information to enable individuals to make informed decisions about their own lives, and to develop a radiological protection culture. ICRP recommends that authorities should involve key representative stakeholders to participate at all stages in emergency and recovery management.

Keywords: Emergency exposure situation; Existing exposure situation; Justification; Optimisation; Reference level; Stakeholder involvement; Radiological protection culture; Chernobyl; Fukushima

MAIN POINTS

- **To organise activities and actions, the Commission distinguishes between an emergency response, managed as an emergency exposure situation, and transitioning to a recovery process, managed as an existing exposure situation.**

- **The principle of optimisation of protection applied with reference levels, considering all impacts (radiological, non-radiological, social, economic, and environmental), is essential to mitigate the consequences during the emergency response and to improve living conditions in affected areas during the recovery process.**

- **For protection of responders and the population during the emergency response, the reference level should not generally exceed 100 mSv, while recognising that higher values may be necessary to save lives and for the prevention of catastrophic conditions.**

- **For people living in long-term contaminated areas during the recovery process, progressive reduction in exposure will result from continuing optimisation of protection. Reference levels should be selected to support this progressive improvement, taking into account the progress already achieved. Levels should be within or below the Commission's recommended 1–20-mSv band taking into account the actual distribution of doses in the population and the tolerability of risk for the long-lasting existing exposure situations, and would not generally need to exceed 10 mSv per year. The objective of optimisation of protection is a progressive reduction in exposure to levels on the order of 1 mSv per year.**

- **For protection of the public and the environment during the recovery process, the Commission recommends a 'co-expertise' approach in which authorities, experts, and stakeholders work together to share experience and information in affected communities, with the objective of developing a practical radiological protection culture to enable individuals to make informed decisions about their own lives.**

EXECUTIVE SUMMARY

(a) A nuclear accident inevitably creates new circumstances and consequences for the health of affected people and the environment. The accident may itself be the result of another hazardous event with large consequences, but the radiological impact is likely to be the dominant concern due to its unknown character and alarming image, despite the fact that other impacts may present immediate and serious risks depending upon the situation and the extent to which emergency planning has accounted for all of the hazards.

(b) For a large nuclear accident, the Commission recommends making a distinction between the emergency response and the recovery process. From a radiological protection point of view, the emergency response is managed as an emergency exposure situation, and the recovery process is managed as an existing exposure situation. The Commission also recommends making a distinction between on-site (damaged installation) and off-site (affected areas). These recommendations may be applicable to other types of events, with due consideration of the differences that inevitably exist between a nuclear accident and other types of events.

(c) Considering the loss of control of the source at the facility and uncertainty regarding the intensity, duration, and extent of contamination, characterisation of the radiological situation on-site and beyond is essential to guide protective actions, and should be conducted as quickly as possible.

(d) A large release of radioiodine in the case of a nuclear accident can result in high thyroid exposures due to inhalation or ingestion. Specific efforts should be made to avoid, or at least reduce, intakes of radioiodine, and radioiodine levels in the thyroid should be monitored, particularly in children and pregnant women.

(e) Radiation exposure may be relatively straightforward to reduce, although it is impossible to remove it completely. In emergency and existing exposure situations, the objectives of radiological protection are achieved using the fundamental principles of justification of decisions and optimisation of protective actions. Implementation should take careful account of all hazards and implications, both radiological and non-radiological, in order to provide reasonable and sustainable living conditions for all those affected, including decent lifestyles and livelihoods.

(f) The principle of justification ensures that decisions about the implementation of protective actions have a positive benefit in terms of exposure reduction, although this may induce potentially significant societal, economic, and environmental disruptions. The overall result is more good than harm for affected people and the environment.

(g) The principle of optimisation of protective actions applied with reference levels aims to maintain and reduce all exposures as low as reasonably achievable, taking into account economic, societal, and environmental factors. This is essential to mitigate consequences during the emergency response, and to improve living conditions in affected areas during the recovery process.

(h) People involved in direct management of the emergency response and the recovery process are diverse in terms of status and degree of preparation and training regarding radiation: emergency teams (firefighters, police officers, medical personnel, etc.), workers (occupationally exposed or not), and other people such as elected representatives or voluntary citizens. The term 'responder' is appropriate for all of these categories.

(i) For protection of responders and the population during the emergency response, the reference level should not generally exceed 100 mSv, while recognising that higher levels may be necessary in exceptional circumstances to save lives and prevent further degradation of the facility leading to catastrophic conditions. The initial reference levels may be applicable for a short period, and should not generally exceed 1 year. Lower reference levels may be selected based on the situation in accordance with the gravity of the accident.

(j) For protection of responders after the urgent emergency response, the reference level should not exceed 20 mSv per year. For people living in long-term contaminated areas following the emergency response, the reference level should be selected within or below the Commission's recommended band of 1–20 mSv for existing exposure situations, taking into account the actual distribution of doses in the population and the tolerability of risk for the long-lasting existing exposure situations, and there is generally no need for the reference level to exceed 10 mSv per year. The objective of optimisation of protection is a progressive reduction in exposure to levels on the order of 1 mSv per year.

(k) Management of the recovery process in affected areas is complex, and includes actions implemented by national and local authorities, economic factors, and self-help protective actions taken by residents.

(l) In the recovery process, individual lifestyles are a key factor to control radiation exposure of those living and working in affected areas. The Commission recommends that authorities, experts, and stakeholders should work together in a 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 about the most appropriate approaches to maintaining their exposures as low as reasonably achievable given the radiological, societal, and economic situation. Individual measurements with suitable devices, together with relevant information, are critical to implement the process.

(m) Every practicable effort should be made to avoid severe and long-term consequences in the case of a nuclear accident. As there is no time to undertake detailed assessments of the actual situation once an emergency response begins, the Commission recommends that emergency and recovery plans should be prepared in advance. Such plans should comprise a set of consistent actions, adapted to local conditions at nuclear sites, that account for the infrastructural, logistical, societal, economic, environmental, and other factors that will affect the impact of the event and its response.

(n) A nuclear accident is an unexpected event that profoundly destabilises people and society, generates great complexity, and requires mobilisation of considerable human and financial resources. Beyond the legitimate fear 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, are 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 need to be mobilised to cope with the issues facing all affected individuals and organisations.

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 planning protective actions after a nuclear accident. 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). *Publication 82* (ICRP, 1999), on protection of the public in situations of prolonged radiation exposure, was the first publication to address long-term actions.

(2) Building on the experience of management of 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 long-term recovery 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 first series 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 some of 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 dialogue in Fukushima Prefecture on the rehabilitation of living conditions after the Fukushima nuclear accident with local residents; professionals; representatives of villages, towns, the prefecture, national agencies, and non-governmental organisations; and experts and residents of Belarus and Norway (ICRP, 2016; Lochard et al., 2019). The objective of this dialogue 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 recovery process, and to improve future ICRP recommendations. The dialogue highlighted the wide diversity of human and environmental consequences of the accident, its indirect economic and societal impacts, the influence of early decisions on evolution of the situation, the complexity of the return of evacuees and resumption of agricultural activities, the disturbances to daily life associated with the use of radiological criteria as hard-line boundaries, the crucial role of engaging stakeholders, and the importance of respecting the dignity of affected people.

(5) The purpose of this publication is to integrate in a single document both the Chernobyl and Fukushima experience with respect to the radiological protection of all affected individuals and the environment.

1.2. Scope and structure of the publication

(6) This publication was to recommend application of the system of radiological protection in emergency and existing exposure situations related to radiological accidents, respectively. While *Publications 109* and *111* were intended to deal with all exposure situations resulting from a nuclear accident or a radiation emergency, this publication focuses on the protection of people and the environment in the case of a large nuclear accident. Such an accident results when there is severe damage to the reactor core and significant releases of radioactive material into the environment, impacting widespread areas (IAEA, 2013). Specific consideration of radiological emergencies and malicious acts are outside the scope of this publication. Nevertheless, many of the recommendations will have some applicability to these situations, and the Commission is considering the preparation of a separate publication to further elaborate considerations for such events.

(7) The present recommendations emphasise the importance of the justification of protective actions during the early phase of a nuclear accident, notably related to the sensitive issues of protection of responders and evacuation of populations. They address the termination of these actions, and the crucial role of characterisation of the exposure situation in the intermediate phase for preparation of management of the long-term phase. They underline the role of the 'co-expertise process' for the rehabilitation of living conditions of affected people during the recovery process. They also clarify the ethical, societal, and environmental dimensions to be considered in the definition and implementation of protection.

(8) Section 2 deals with general considerations concerning the timeline of the accident, its effects, and the relevant principles for the radiological protection of people and the environment related to its successive phases. Section 3 describes the Commission's recommendations that apply to the early and intermediate phases, and Section 4 describes those applying to the long-term phase. Section 5 provides a short overview for emergency and recovery preparedness. Section 6 gives key conclusions. Annexes A and B describe the key aspects of implementation of radiological protection adopted to manage the consequences of the Chernobyl and Fukushima accidents, respectively, in the light of the present recommendations.

(9) The recommendations given in this publication for the protection of people and the environment during the emergency response and the recovery process of a large nuclear accident supersede all previous recommendations (ICRP, 1984, 1991, 1999, 2009a,b).

2. GENERAL CONSIDERATIONS

2.1. Timeline for managing a nuclear accident

(10) For managing a large nuclear accident, it is convenient to distinguish between the emergency response (early and intermediate phases) and the recovery process (long-term phase). In the 2007 Recommendations (ICRP, 2007), the Commission considered three different exposure situations: existing, planned, and emergency. For implementation of the system of radiological protection, the Commission considers the emergency response as an emergency exposure situation, and the recovery process as an existing exposure situation. The Commission recognises that various international and national organisations have adopted different 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 stage of an accident response, sometimes called the 'acute phase' or the 'urgent response phase', is characterised as the period during which radionuclides are released into the environment. Depending upon the type of accident, there may be a period of time between the start of an accident and the release of radioactive material. It is during this early phase that various protective actions need to be taken promptly in order to avoid or reduce radiation exposures.

(12) The intermediate phase of the accident response, sometimes called the 'transition phase', starts when the source of the release has been stabilised and further significant accidental releases are unlikely. The response in this phase focuses on characterising the radiological situation on-site and off-site in order to decide the best course of actions to protect people and the environment.

(13) The long-term phase begins on-site when the source is considered to be sufficiently secured, and the exposure situation is sufficiently characterised to enable commencement of work to dismantle 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 the implementation of long-term protective actions to accompany the rehabilitation of living conditions in areas where people are allowed to stay or expected to return. Living conditions include health, economic, societal, and environmental considerations.

(14) 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 areas.

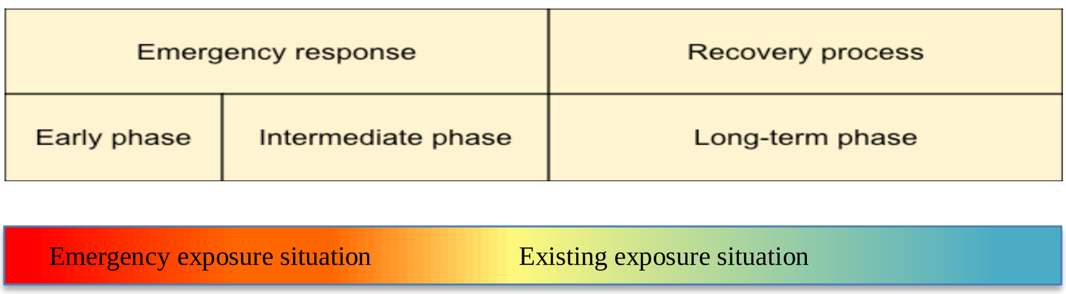

Fig. 2.1. Timeline of a large nuclear accident.

2.2. Consequences of a large nuclear accident

(15) Large nuclear accidents generate complex situations that affect all dimensions of individual and social life. First and foremost, concerns about the potential health impacts of radiation are likely to dominate due to its unknown character and alarming image, despite the fact that other impacts may present immediate and serious risks depending upon the situation and the extent to which emergency planning has accounted for all of the hazards. Radiological impacts are directly related to the level of exposures received by responders and the population. Past experience has revealed that all aspects of daily life of the inhabitants and the environment, as well as all social and economic activities, are affected, generating very complex situations (UNDP/UNICEF, 2002). These situations cannot be managed with radiological protection considerations alone; factors related to psychology, health, environment, education, culture, ethics, political governance, etc. also need to be considered. The present recommendations focus on the basic radiological protection principles to be applied during the emergency response and the recovery process in order to protect people and the environment against radiation. However, past experience has demonstrated that, to respond to the complexity of the situation, these principles cannot be implemented without consideration of other important factors to justify decisions and optimise protective actions (see Section 2.3).

2.2.1. Radiation-induced health effects

(16) There are two key categories of radiation-induced health effects: severe tissue/organ damage (also called ‘tissue reactions’ or ‘deterministic health effects’) and cancer and heritable diseases (also called ‘stochastic health effects’).

2.2.1.1. Severe tissue/organ damage

(17) Severe tissue/organ damage is directly attributable to radiation exposure, irreversible in nature, and severely impairs the quality of life of exposed individuals. Such damage may occur soon (hours to months) or a considerable time (years to decades) after exposure. Severe tissue/organ damage is characterised by a threshold dose, below which the reaction is assumed not to occur (<1% incidence), and above which the severity of effect increases with dose. Table 2.1 shows threshold doses for selected tissue reactions. More details can be found in *Publication 118* (ICRP, 2012a).

Table 2.1. Dose thresholds for selected tissue/organ damage.

Effect	Threshold
Fatality (within weeks)	2–3 Gy acute dose to the whole body 4–8 Gy protracted over 1 week 10–14 Gy in 1–3 months assuming good medical care
Skin burn (within hours to days)	5 Gy acute dose to the skin
Permanent sterility (females)	3 Gy acute dose to the ovaries
Increased risk of circulatory disease (decades later)	0.5 Gy to the whole body
Cataract induction (decades later)	0.5 Gy to the lens of the eye

(18) Acute organ doses up to approximately 100 mGy (0.1 Gy) produce no functional impairment of tissues. At higher doses, the risk of tissue reactions becomes increasingly important and there is increased likelihood of serious damage. As it is prudent to take uncertainties in the current estimates of thresholds for deterministic effects into account, the Commission considers that short-term or annual doses rising towards 100 mSv for whole-body exposure almost always justify the consideration of protective actions.

(19) Recent additional evidence of non-cancer effects comes from studies of cancer patients receiving radiotherapy and the atomic bomb survivors in Hiroshima and Nagasaki. These studies indicate an increased risk of mortality from circulatory disease associated with doses of several hundreds or thousands of mGy to the heart (Little, 2002). The situation at lower doses is less clear. The Commission judges that a threshold dose of 500 mGy is appropriate to avoid radiation-induced circulatory disease.

2.2.1.2. Cancer and heritable diseases

(20) Cancer and heritable effects for which the probability of occurrence increases with dose and severity is independent of the dose received are assumed, for the purpose of radiological protection, to have no threshold.

(21) The increased risk of cancer was reported after the second half of the 20th century in 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 more cases of cancer occurred among these populations compared with unexposed populations with similar characteristics (UNSCEAR, 2006).

(22) There is reliable scientific evidence that whole-body exposures on the order of ≥100 mSv can increase the probability of cancer occurring in an exposed population. Below 100 mSv, the evidence is less clear. The Commission prudently assumes, for purposes of radiological protection, that even small doses might result in a slight increase in risk. 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% risk of fatal cancer typically seen in populations worldwide (ICRP, 2007; Ogino, 2014).

(23) Although heritable (genetic) effects have been seen in animals, there is no direct evidence that exposure of humans to radiation leads to excess heritable disease. However, 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

(24) In the case of a very severe release 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 (IAEA, 2006; UNSCEAR, 2008). In time, there are 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 cause for 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).

(25) 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. However, 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

(26) The sudden presence of radioactive contamination, perceived as undesirable, illegitimate, and dangerous, in the living environment of humans creates an unprecedented complex situation. It profoundly upsets the well-being of individuals and the quality of life of affected communities; raises many questions, concerns, and fears; generates numerous views; and exacerbates 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 significant decrease in the number of inhabitants, especially young people, as illustrated in Chernobyl and Fukushima.

(27) 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 the compensation system.

(28) 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, such as education, transport, health care, community support, public space, information, public safety, sport, recreation, and art and culture, are all affected.

(29) The Chernobyl and Fukushima nuclear accidents had similar consequences in terms of the societal impact of the presence of radioactive contamination in affected areas. Beyond the widespread fear of radiation in all segments 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.

(30) In the longer term, even when affected people understand and learn to deal with the radiological situation and regain their autonomy and livelihood, the fear of being abandoned by the authorities and the rest of the nation, and the negative image of affected areas, remain problems that handicap social dynamism. A nuclear accident also has societal consequences in areas that are not affected directly by contamination. Management of reception of the evacuees, especially in the emergency response, raises questions of an organisational nature and a human nature. Past experience has shown that a nuclear accident generates an attitude of rejection towards affected areas, people living there, and goods produced there. This attitude has been observed to cause discrimination, notably against young people (Sawano,

2018). In this context, it is important to rebuild and maintain solidarity between affected people and the rest of the nation and the world.

2.2.4. Economic consequences

(31) 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 services sectors in connection with activities in affected areas. With the global nature of economics, impacts may be seen nationally and internationally.

(32) Radiological contamination is likely to affect critical infrastructure directly, such as utilities, public transportation, communication systems, and food and water supplies. This impacts 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.

(33) Companies maintaining their economic activity in affected areas or those newly operating, including those involved in the emergency response and recovery process, may face additional obstacles related to the presence of contamination. Workplaces, staff, and products can all be affected. Moreover, the image of these companies and their products may be affected.

(34) Change in the local demography is another significant factor influencing the global economy of affected areas. These economic consequences induce significant additional costs that need to be supported by local and national public budgets for several years.

2.2.5. Psychological consequences

(35) 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 recovery process. 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 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 exposure, as reported by several studies following the Chernobyl and Fukushima nuclear accidents.

(36) These studies highlight sociopsychological and psychosomatic disorders associated with the emergency response of the accident and during the recovery process. This is further complicated in cases where an external devastating event contributed to the situation, as occurred in Fukushima. For instance, an elevated rate of depression and post-traumatic stress disorder has been reported among the emergency 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, 2011, 2014; Harada, 2015; IAEA, 2015a; Sususki, 2015; Maeda, 2017).

(37) 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.

(38) Experience has also shown that, at a psychological level, the response of each individual is highly dependent on his/her own situation and experience, and can evolve over time: some people may suffer with depression, others may resign themselves to the situation and eventually adopt an indifferent attitude, 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

(39) As mentioned above, in addition to radiation-induced health effects, the accident may induce significant societal, economic, and psychological disturbances in the daily lives of affected populations. These disturbances, including those induced by the protective actions themselves (e.g. evacuation), have direct consequences on the lifestyle of affected populations. Several studies have reported an increase in health issues associated with these lifestyle changes following the Chernobyl and Fukushima nuclear accidents (Hasegawa, 2015).

(40) For instance, during the months following the Fukushima nuclear accident, a general increase in mortality was observed (excluding deaths due to the earthquake and tsunami), especially among elderly people (Morita et al., 2017). This increase cannot be attributed to the direct health effects of radiation, although it is a direct consequence of the accident.

(41) In the longer term, other secondary health issues were observed in populations affected by the Chernobyl accident (Luccioni, 2016). After the Fukushima accident, there was a significant increase in the number of reported cases of diabetes, notably in people aged approximately 40–65 years. This increase concerns people affected by the accident both within and outside the contaminated areas. In addition, an increased risk of circulatory diseases was observed (Tsubokura, 2018). Other chronic diseases have also been reported in the first years after an accident, such as hyperlipidaemia and hypertension. The health of young children has also been affected, such as a significant increase in obesity due to restriction of outdoor activities (Nomura, 2016; Ono, 2017). Considering the level of exposure of the affected population, these disorders cannot be considered as direct radiation-induced health effects but are linked to a change in lifestyle resulting from the accident.

2.3. Principles for protection of people and the environment

(42) 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, and cancer and heritable diseases are reduced to the extent reasonably achievable, and the frequency of deleterious radiation effects on biota is prevented or reduced. These objectives should be pursued considering the potential adverse effects of radiation exposure on humans and biota, and the societal, economic, and psychological

consequences of the accident and its management as described above. This means preserving, to the extent possible, the health and well-being of all affected individuals, decent working conditions for responders on-site, quality of life of affected communities off-site, and biological diversity in affected areas.

(43) For emergency and existing exposure situations, the fundamental protection principles to guide action are the justification of decisions and the optimisation of protection. For implementation of the optimisation principle, the Commission recommends using reference levels to guide decision making concerning protective actions.

(44) The principle of individual dose limitation does not apply because the sources of exposures on-site and off-site are no longer under control in the case of an accident. Under these conditions, it is difficult to predict, with sufficient precision, the doses that will be received by exposed people, and to guarantee compliance with dose limits established for planned exposure situations.

(45) Once an emergency situation 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, 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 situation requires adequate interaction between affected countries and international co-operation, notably to address trade issues and protection of nationals (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 more effectively compared with the initial phase of the accident.

(46) In the emergency response to an accident, consideration of protection of non-human species may not be an immediate priority if human food chains and human exposures are seriously affected (ICRP, 2014). However, the Commission recommends that appropriate measures should be taken to protect pets and livestock, and specific arrangements should be developed in the emergency preparedness planning process to preserve their welfare. Further, even where concerns about human exposure predominate, consideration should be given to the environmental consequences of the possible protective actions. This is particularly true regarding the choice of actions to decontaminate the environmental medium (e.g. soil), as this is likely to affect the organo-mineral fertility of the soil in the long term, and introduce disruption in biodiversity.

(47) During the recovery process, as the radiological situation is better characterised, it may be possible to consider actions to protect species which are likely to be threatened by contamination in the long term. Special provisions may also be necessary to safeguard 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, the need for actions to be taken, and the inherent value of evaluation of the environment (NCRP, 2018).

2.3.1. The justification of protective decisions

(48) 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 goal to do good (principle of beneficence) while avoiding doing harm as much as possible (principle of non-maleficence), as stated in *Publication 138* (ICRP, 2018). In emergency and existing exposure situations, the

principle of justification is applied when deciding whether to take action 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 conservative approach to consider the inevitable uncertainties concerning the situation on-site as well as off-site, and bearing their potential negative consequences in mind.

(49) Justification thus goes far beyond the objective of radiological protection, which is to avoid or reduce exposure, as it may also have various health, psychological, societal, economic, environmental, and political consequences. Thus, justification falls under the overall ethical goal of societies, which is to contribute to the health and well-being of individuals and the quality of life of affected communities, with preservation of biodiversity and sustainable development representing an integral part.

(50) Responsibility for judging justification usually falls on the authorities to ensure an overall benefit, in the broadest sense, to society, and thus not necessarily to each individual. However, there are many aspects of the justification decision that can be usefully informed by organisations or individuals outside the authorities. Therefore, the Commission recommends involving key stakeholders in public consultation processes for the justification of decisions whenever possible, including necessary expertise in various areas such as evacuation logistics, transportation, medical care, community infrastructure, provision of necessary services, support for business interests, etc. (NEA, 2006).

(51) For emergency response decisions, in the event of a nuclear accident, especially in the early phase, the need to act quickly is not conducive to stakeholder involvement. However, it is possible to involve stakeholders beforehand regarding preparation for emergency situations. As the intermediate phase progresses, there are increasing opportunities to involve stakeholders in the decision-making process. For the long-term phase, past experience has clearly demonstrated the need to involve stakeholders, particularly representatives of local authorities, professionals, and inhabitants of affected communities, in the decision-making process to improve the effectiveness and durability of protective actions.

(52) 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 in response to 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 more coherent and effective protection is ensured by addressing the justification of the overall protection strategy, taking into account the benefits and drawbacks of the protective actions already implemented when deciding on the best course of action. In many cases, the summation of benefit and harm from a series of justified individual protective actions will also result in a net benefit. However, in some cases, particularly for large nuclear accidents, the addition of complementary protective actions could result in more harm than good due to the accumulation of significant social disruption.

(53) In a broader sense, the protection strategy should try to preserve the health of individuals and the quality of life of affected communities whose situation is altered by the accident to a greater or lesser extent. It is thus important to assess the individual and collective impacts of each protective action in order to judge the good and harm that each may produce. The relevance of a protection strategy should ultimately be judged by balancing the level of residual exposure with the health, psychological, societal, economic, and cultural effects on affected people, and the direct and indirect impacts on the environment.

(54) During the emergency response, justification first applies to the decision on whether or not to take actions to avoid or reduce exposures. Justification then applies to each individual protective action decided during the early and intermediate phases. Among these decisions, those concerning the evacuation of populations and their sheltering are the most delicate from the point of view of justification. 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).

(55) During the recovery process, justification applies first to the fundamental decision of the authorities concerning the future of areas affected by the radioactive releases. This decision marks the beginning of the long-term phase. It is based on several considerations (e.g. residual level of contamination, ability to ensure the sustainability of economic and societal activities, etc.), and has to be taken in co-operation with affected individuals and local communities. It is necessary to decide, among other things, the areas where the population is not allowed to stay in view of the high levels of exposure and the difficulty to maintain acceptable living conditions, and the areas where, given the exposure situation, people are allowed to live permanently if they wish. Such decisions should consider the possibility of maintaining the infrastructure, economic, and social services necessary to ensure the well-being of individuals and the quality of life of affected communities. This should be accompanied by the establishment of criteria for living conditions, including setting numerical radiological protection criterion, to decide whether to relocate the population or to allow individuals to stay. Several geographical areas can be defined for which ad-hoc protective actions can be implemented according to a graduated approach depending on the level of contamination and economic, societal and environmental considerations. This was the approach adopted by the authorities after the Chernobyl and Fukushima nuclear accidents (see Annexes A and B).

(56) For the management of long-term contaminated areas after a nuclear accident, the authorities may consider terminating or maintaining some of the protective actions implemented during the emergency response, and introducing other protective actions. The decision about whether to introduce these new actions depends on several criteria, including residual levels of exposure in the residing population, feasibility of implementing these actions, and potential impact of these actions on the quality and sustainability of living conditions in the area.

(57) Worldwide experience after nuclear and non-nuclear accidents shows that nations and individuals are not willing to readily abandon affected areas. 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 sustainable living conditions, including respectable lifestyles and livelihoods.

2.3.2. The optimisation of protective actions

(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, with restrictions on individual exposures. This principle, which is the cornerstone of the radiological protection system, means that all individual exposures,

and their magnitude, should be kept as low as reasonably achievable, taking into account economic, societal, and environmental factors. It aims to avoid unnecessary exposure (prudence), fair distribution of exposure among exposed individuals (justice), and treating people with respect (dignity). Prudence, justice, and dignity are core ethical values that underlie the system of radiological protection, particularly the optimisation principle (ICRP, 2018).

(59) To meet the Commission's recommendations, optimisation should consider the radiological, socio-economic, and environmental characteristics of the exposure situation, as reflected by the views and concerns of stakeholders, and the ethical values that govern radiological protection (ICRP, 2018). As such, implementation of the optimisation process requires good understanding of the exposure situation at stake, and the relevant information and data characterising this situation in order to choose the best protective actions given the particular circumstances.

(60) When implementing the optimisation process, it should be remembered that the radiological contamination is not only unexpected but also unwelcome, and it impacts all stakeholders. Although removal of contamination is desirable, it may not be possible or optimal.

(61) 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).

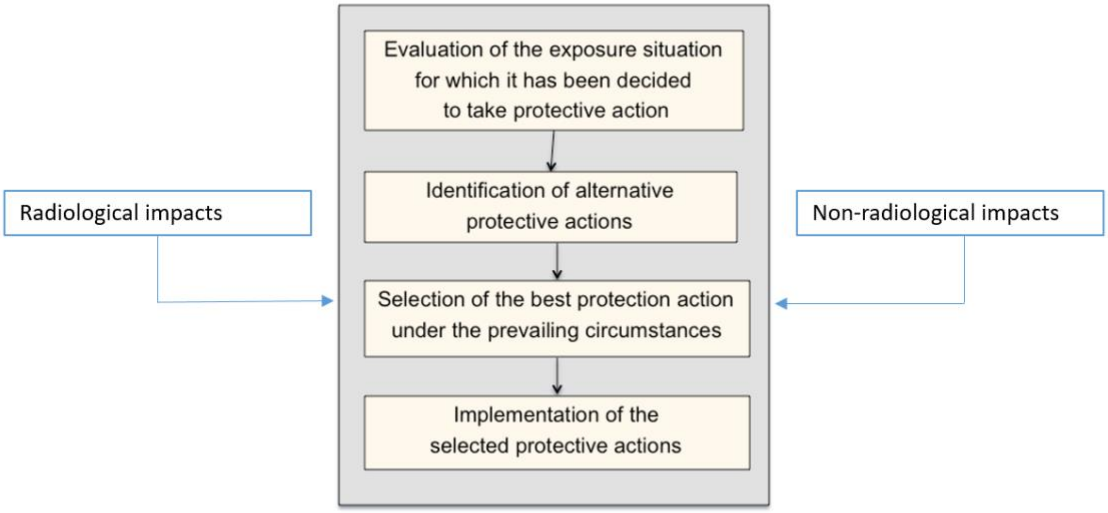

Fig. 2.2. The optimisation process.

(62) Comparison of justified protective actions is a key feature of the optimisation process, which must entail careful consideration of all of the characteristics of the situation. Decision-aiding techniques may be used by authorities to guide the selection of protective actions. Advice on applying these techniques has been provided in *Publications 37* (ICRP, 1983), *55* (ICRP, 1990), and *101* (ICRP, 2006). In the process of selecting protective actions, the Commission recommends that the views and concerns of stakeholders should be considered. The Commission emphasises the importance of considering all of the impacts of a protective action, not just the radiological concerns. Moreover, 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 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).

(63) 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 keep or reduce exposures as low as reasonably achievable. It is the authorities' responsibility to provide good guidance, and to support implementation by organisations and individuals. Organisations (e.g. in the agricultural sector) and individuals (with responsibilities or concerned citizens) will be involved in the practical implementation of protective actions. Hence, the government, or the responsible authority, will need 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.

(64) 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 be made for non-radiological consequences, given uncertainties such as the conditions of infrastructures or the reaction and behaviour of the population. For this reason, protective actions that are considered to be justified are initially implemented in a generic way. As characterisation of the radiological situation progresses, it is possible to adjust 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.

(65) Due to the complexity of the socio-economic situation resulting from a nuclear accident, the implementation of optimisation during the emergency response and the recovery process should recognise the many value judgements concerning the importance or the priority to be given to protection of particular groups of the population or to particular social and economic activities. The Commission recommends paying particular attention to children and pregnant women, for whom radiological risks may be greater than for other groups of individuals. Strategic social and economic activities should also be the subject of specific protection provisions in implementation of the optimisation process.

(66) The optimisation process must recognise that there are inevitable conflicting interests, and seek to reconcile the differences and needs of various groups. For example, producers of goods, services, and food will wish to continue production, but their ability to do so is affected by the willingness of consumers to receive and purchase these items. Another example is the desire of the local area 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 regaining the confidence of all people in relation to the affected area. One of the characteristics of radiation exposure in the event of an accident is the large distribution of exposures received by the individuals on-site, and also in the areas affected by the radioactive releases (see Annexes A and B). Generally, the majority of people receive relatively low exposures, but a fraction of the affected individuals may receive more significant exposures. A few individuals (particularly responders) 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 exposure 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) For the implementation of optimisation during an emergency response and recovery process, the Commission recommends using reference levels to guide actions to reduce individual exposures and limit inequities. 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 as one measure of the effectiveness of the protective actions implemented. This residual dose corresponds to the dose added by the accident, and does not include the natural background exposure. As the best protective option 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 dose. Optimised protection is the result of an evaluation that carefully balances the detriment from the exposure with the relevant economic, societal, and environmental factors. Thus, the best option is not usually the one resulting in the lowest residual dose level for individuals (ICRP, 2007, Para. 219).

(68) Once the emergency response 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 particularities, 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 of people 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 will progressively contribute 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 in non-affected areas (see Annexes A and B).

(69) During the recovery process, 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, etc.). Behaviour and lifestyle largely depend on individual circumstances, resources available, and willingness and ability of the individual 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 (see Section 4.3.2).

(70) As radiological protection assumes, in the face of uncertainty, 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 risks that might be present (see Section 2.2.2). Furthermore, there is generally a limit 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 measurements.

(71) 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 do so, by providing information, answering questions, and assisting in measurements and in interpretation of the results. 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).

(72) A strategy for protective actions should be prepared by 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

(73) For the protection of people in emergency and existing exposure situations, the Commission recommends using reference levels to guide practical implementation of the optimisation process. Reference levels, expressed in terms of individual effective dose (mSv), are selected to scope the protection strategy, taking into account the distribution of individual doses as well as economic and societal considerations characterising the situation. They reflect the level of ambition to reduce and maintain exposure as low as reasonably achievable in the given circumstances. The objective is to ensure that when implementing protective actions, the range between the highest and lowest individual exposures is reduced, and all exposures are kept as low as reasonably achievable below the reference levels, or at least remain in the order of these levels.

(74) Experience has shown that reference levels were sometimes used during the emergency response and the recovery process as dose limits. The Commission maintains its position that reference levels are not regulatory limits that should not be exceeded, but are values to guide the optimisation process. The reference level should primarily be selected to identify the more highly exposed individuals, and thus may well be exceeded by some individuals as the optimisation process begins or continues (see Annexes A and B).

(75) The use of reference levels in emergency and existing exposure situations is illustrated in Fig. 2.3. This figure shows the evolution of the distribution of individual doses with time as a result of natural processes and the implementation of protective actions. When the optimisation process starts, a fraction of the exposures may be above the selected reference level according to the ambition of the public authorities. The priority is then to identify the most exposed people and reduce their exposure. Thus, over time, the number of people receiving exposure above the reference level should decrease, and only a few people with typical behaviours are likely to receive exposure exceeding the reference value. Eventually, the dose distribution will be very narrow and the average exposure will be well below the reference value.

(76) 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. The Commission recommends that, to be effective, the process of selecting and re-evaluating the value of the reference level should be adapted to the circumstances and, in particular, should consider the distribution of individual exposures. It is, therefore, not appropriate to use an a-priori fixed reference value. In addition, the Commission recommends including, where feasible, the views of all relevant stakeholders on the level of ambition to be achieved by selection of the reference level.

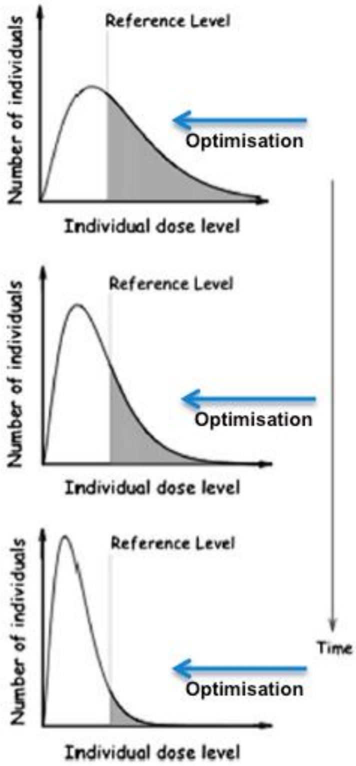

Fig. 2.3. Use of a reference level and evolution of the distribution of individual exposures with time as a result of implementing the optimisation process.

(77) To enable the selection of appropriate values for the reference levels, the Commission recommends ranges of values, taking into account considerations on the tolerability of risk for emergency and existing exposure situations. For the optimisation of protective actions during the emergency response, the Commission recommends that the reference level for restricting exposures of the affected population and the emergency responders should generally not exceed 100 mSv. This may be applied for a short period, and should not generally exceed 1 year. This is because, at doses of the order of a few hundreds of mSv, there is an increased likelihood of deterministic effects and a more significant risk of cancer (ICPR, 2007, Para. 236). Much lower levels may be appropriate for the response to events that would only result in low exposures. However, there may be situations where it is not possible to expect to keep all doses below or in the range of 100 mSv, such as in very severe accidents when high acute exposures can be received within minutes or hours, and when faced with taking actions under exceptional circumstances in order to prevent further degradation of the facility leading to catastrophic conditions, or saving human lives (see Annexes A and B).

(78) Early in an emergency, when the radiological situation on-site and off-site is still largely unknown and may be changing rapidly, it is appropriate to use the reference level of the scenario developed during the preparedness exercises that best matches the characteristics of the current accident. However, there is no guarantee that the situation will evolve as expected and that exposures will remain lower or of the same order (see Section 3). As such, during the intermediate phase when characterisation of the radiological situation progresses, it will be necessary to re-assess the situation and determine whether the reference level

should be adjusted. It should be noted that maintaining exposure below or in the range of 100 mSv effective dose is no guarantee of the absence of excess incidence of thyroid cancer in a population when there has been intake of radioiodine. In case of a possible intake of radioiodine, specific protective actions should be implemented (see Section 3.4.1.3).

(79) For the optimisation of protective actions during the recovery process, the Commission recommends that the reference level for restricting the exposures of recovery responders should not exceed 20 mSv per year on-site and off-site. This value, which corresponds to the upper value of the 1–20-mSv per year band recommended for existing exposure situations, is considered appropriate by the Commission for protection of individuals directly involved in the remediation actions of the recovery process (see Section 4.2).

(80) For people living in long-term contaminated areas following the emergency response, the Commission recommends that the reference level should be selected within or below the Commission's recommended 1–20-mSv band taking into account the actual distribution of doses in the population and the tolerability of risk for the long-lasting existing exposure situations, and would not generally need to exceed 10 mSv per year, with the objective to reduce exposure progressively to levels on the order of 1 mSv per year. In *Publication* 111 (ICRP, 2009b), the Commission recommended selection of the reference level in the lower portion of the 1–20-mSv band. The current recommendation, that the selected reference level would not generally need to exceed 10 mSv, clarifies this position. As noted in Section 2.2.1.2, whole-body exposure on the order of 100 mSv can increase the number of cases of cancer seen among exposed populations. The Commission considers that annual exposures of the order of 10 mSv during the first years of the recovery process, added to exposure received during the emergency response, could lead to total exposures greater than 100 mSv in a relatively short period of time for some affected people. Therefore, it is not recommended to select reference levels beyond 10 mSv per year when it is estimated that such exposures could continue for several years, which may be the case once the recovery phase starts. In addition, experience from Chernobyl and Fukushima has shown that for exposure levels of the order of 10 mSv per year, it is difficult – given the multiple societal, economic, and environmental negative consequences associated with the long-lasting presence of contamination, and the numerous restrictions imposed on everyday life by the protective actions – to maintain sustainable and decent living, working, and production conditions in affected areas (see Annexes A and B).

(81) The Commission recommends that some types of protective actions should be maintained during the recovery process as long as a significant proportion of the affected population receive exposures above 1 mSv per year, a level that is close or similar to exposure situations in non-affected areas (ICRP, 2009b, Para. 50). Depending on the accident scenario, this could take several years, or even decades, because exposure of people living in contaminated areas depends largely on their living conditions, which cannot be strictly controlled, and it is therefore not possible to guarantee that all individual doses will be kept in the range of 1 mSv per year in the long term. If radiological protection is implemented appropriately, past experience has shown that, after a few years, the combined effect of radioactive decay and protective actions will result in exposures below 1 mSv per year or in the order of this level for a large majority of the people who live and work in areas where they are authorised to reside. Only a small fraction of the population is likely to receive higher exposures (of the order of a few mSv per year) (see Annexes A and B).

(82) For protection of the environment in emergency and existing exposure situations, the Commission recommends the use of Derived Consideration Reference Levels (DCRL) to prevent or reduce the frequency of deleterious effects on fauna and flora in affected areas. DCRLs are defined in terms of a band of dose rates for reference animals and plants (RAPs) within which there is likely to be some chance of deleterious effects for the considered RAP.

(83) In general, environmental impacts may not be an immediate priority during the early phase of an accident, and there may be little easily accessible information on the specific animals and plants concerned, resulting in the optimisation process being difficult to implement rapidly. However, DCRLs may be useful in communicating the implications of the situation to stakeholders, particularly in relation to environmental conditions where humans have been removed from the area, and food chains leading to human exposure have been discontinued. As the radiological situation becomes better characterised, these environmental reference values may be of use in helping to understand the likely radiological consequences of proposed protective actions on biota as part of the input into decision making during the optimisation process. The environmental reference values will also have value during emergency planning in order to help frame considerations of the potential consequences of proposed protective actions in the different phases of the accident on the environment. In this case, the DCRLs can be used to aid this process. If dose rates are within or above a given DCRL, the Commission recommends that consideration should be given to reduce exposures, assuming that the costs and benefits warrant further effort.

3. EMERGENCY RESPONSE

3.1. Characteristics of the early and intermediate phases

(84) The Commission recommends managing the emergency response to 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 source or from intentional misuse of a source, require urgent and timely actions in order to avoid or mitigate undesirable exposure. Emergency exposure situations may be characterised by one or more of the following features: significant uncertainty concerning current and future status of the source or sources; uncertainty about pathways and exposures; rapidly changing radiological and non-radiological conditions; and potentially very high exposures. Emergency exposure situations arising from large nuclear accidents result in exposure of on-site personnel within the facility, as well as off-site exposure of members of the public.

(85) An emergency exposure situation may be of very short duration (hours or days), or it may continue for an extended period of time (weeks, months, or years). The accident 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 reduce the impact of the radioactive release to the environment. During the intermediate phase, the release is brought under control progressively, and on-site, the radiological situation becomes better characterised. Off-site, there is still uncertainty about exposures and the future for affected areas. Therefore, the intermediate phase generally lasts longer off-site than on-site (see Annexes A and B).

(86) For a large nuclear accident, the highest exposures will generally occur during the early phase when the source is out of control. The Commission recommends that effort should be made to avoid the occurrence of direct severe tissue/organ damage both on-site and off-site. Planning to protect the public located in the area surrounding the nuclear power plant should prioritise the prevention of these injuries over the reduction in stochastic health effects. To be effective, urgent protective actions (e.g. evacuation, sheltering, iodine thyroid blocking, restrictions on local food and water supplies) need to be implemented promptly. There is no time to undertake detailed exposure assessments of the actual event in real time. It is therefore necessary to determine, in advance, a set of internally consistent actions to be taken promptly, and the geographic extent to which these actions should be applied (Callen et al., 2017).

(87) Urgent protective actions taken before any significant release will avoid the occurrence of direct serious injuries and will generally also prevent or significantly reduce radiation exposures that would cause risks of cancer and heritable diseases (stochastic health effects). Although such decisions are generally taken in situations of great, if not complete, uncertainty, it is very important to consider aspects beyond radiological protection when considering the benefit and harms/drawbacks of taking urgent protective actions. These should include: physical factors for populations with special needs, such as medical patients; psychological stress caused by urgent actions; social stress caused by evacuation plans that do not attempt to keep family units together or in close proximity; and insufficient information provision, even if information is simply an explanation of what is not known. While difficult to balance radiological and non-radiological health effects against the benefits

of protective actions, planning should attempt to do so to assist decision makers in selecting optimised protection strategies.

(88) The immediate use of preplanned protection strategies will be necessary with very little information about exposures, and with very limited stakeholder involvement beyond the emergency response authorities and those responsible for the site that is causing the emergency. The inherently unpredictable nature of nuclear emergencies, and their tendency to evolve rapidly, could result in situations that do not match the assumptions that were used to develop the optimised protection strategies during the preparedness and planning stage. Generally, decisions to modify the emergency plan during the course of an accident should only be taken if the planned response proves to be significantly inappropriate, in which case the new strategy should be justified and optimised.

(89) During the early phase, the Commission recommends that affected people should be informed by all available channels, including radio, television, text messages, emails, and social media. Information should be spread quickly and continuously regarding: what is known; what is not known; reasons for the urgent protective actions taken; what will be done to provide information updates; where to get more information; and what processes will be used to gather and consider the views of those affected to inform decisions on the termination of urgent protective actions.

(90) As more information on the radiological situation becomes available during the intermediate phase, it may be prudent to modify the geographical or temporal spread of the initial protective actions, and to introduce other less urgent protective actions. During this phase, several key actions should be undertaken to characterise the exposure situation in order to obtain adequate knowledge of where, when, and how people are exposed and will be exposed in the future. This can be undertaken by gathering relevant information from monitoring, sampling, and analysis. The characterisation enables informed planning and implementation of longer-term protective actions, such as the establishment of detailed environmental monitoring programmes, long-term health surveillance, development of decontamination strategies, and plans for the long-term management of radioactive waste.

3.2. Radiological characterisation

3.2.1. Exposure pathways

(91) In the event of a large nuclear accident, exposures may be incurred by various pathways, leading to external and/or internal exposures. 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.

(92) In the case of an accidental atmospheric release, it is likely that initial exposures will be at a relatively high level due to the inhalation of short-lived radioactive products present in the plume. This is usually followed by a time period lasting days or weeks when iodine dominates internal exposure from direct contamination on crops and transfer to milk, and external exposure 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 caesium.

(93) 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 rainfall 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. 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 will dominate as the principal contributors to both human and biota exposure (see Annexes A and B).

(94) Radionuclide intake by humans may arise from consumption of vegetables, meat, and milk from contaminated farms; fish from contaminated rivers and lakes; and wild berries and mushrooms from contaminated forests. The transfer to animals and derived products will depend 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 will 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 elevated intake in some individuals.

(95) 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 the overall exposure. Among them, the transfer of radioactive material into seafood should be considered as a possible primary source of internal exposure to the public.

(96) Non-human biota can receive both external and internal exposures. As with people, 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 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 lower trophic level plants and animals, and from inadvertent ingestion of radionuclides on the ground.

(97) As with people, radionuclide contamination levels and composition will change spatially and over time, resulting in different exposure levels to biota. Understanding how specific biota of interest 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

(98) 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. Sufficient 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. Radiation aerial monitoring also provides useful information on the degree and extent of environmental contamination in the case of widely affected areas.

(99) In addition to environmental monitoring of ambient dose rates, measurements of radionuclide concentrations (particularly caesium and iodine) in air should be made. This type of information enables the estimation of internal exposure due to the inhalation of radioactivity. Concerns regarding internal and external exposures arising from deposited radioactive material in the environment require plans to measure soil surface concentrations as input to 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.

(100) In the intermediate phase, 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 in charge of the emergency response, affected stakeholders will want to map their own radiological situation using radiological 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 recovery process. Resources should be preplanned to support such data collection by stakeholders, particularly by helping those affected to understand the relevance of such data to make their own protective decisions.

3.2.2.2. Individual monitoring

(101) 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 only require health surveillance. These decisions will be based on limited monitoring information and will concentrate on the identification of those with an urgent need for treatment. In the first few hours, it will 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) can be made to determine exposures.

(102) 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 monitor radioiodine content of the thyroid rapidly in children (up to approximately 15 years old at time of exposure) and pregnant women in order to get 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 8-day half-life of iodine-131, 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.

(103) During the intermediate phase, a whole-body counter can be used to provide measurements of contamination 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 child's situation, and options for adjusting their diet (Hayano, 2014). Over time, important pathways of exposure can change, and this needs to be considered when prioritising people for whole-body counter measurements.

(104) Measurement data should be collected centrally and made available as soon as possible to all relevant organisations in charge of management of the emergency response in order to assist them in making protective decisions. For the sake of accountability and transparency, the Commission recommends that this information should also be made available to members of the public, accompanied by clear explanations.

(105) Medical monitoring programmes that are focused on people affected by a radiation emergency should consider two target groups: people who developed clinical conditions during the emergency; 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 long-term complications. Conversely, the main purpose of epidemiological follow-up in the second group is the detection of adverse effects or diseases that are potentially related to radiation exposure (e.g. cancer).

3.3. Protection of emergency responders

(106) Individuals who may be involved in the emergency response are diverse in terms of 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. The Commission considers that the term 'emergency 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 exposure of the emergency responders should be managed as closely as possible to that of exposed workers, but 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 covered by the emergency response, 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 emergency response, the Commission recommends distinguishing between on-site (damaged installation) and off-site (affected areas) actions, and distinguishing between the two phases of the emergency (early and intermediate) for the management of emergency responders.

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

(107) The first responders to be involved on-site are workers from the damaged plant awaiting specialised 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 as in the planned exposure situation prevailing 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. Those who are involved in the response should be managed as emergency 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 support of the workers at the installation. This may include specialised emergency teams working under the responsibility of their own organisations, or other facilities workers 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.

(108) The justification of decisions that may affect the exposure of emergency responders should be taken in light of 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 cause to the responders. Given the uncertainties that characterise the state 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. As the radiological situation of the facility during the initial phase of the emergency situation is largely unknown and unstable, implementation of the optimisation of protection for the responders is complicated. Many actions are undertaken without being able to estimate a priori the 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 will be received by the responders, and to guarantee that the activity is within pre-established dose 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 according to the rapidly evolving characteristics of the situation and the type of responder. The Commission recommends that decisions concerning responders should be based on the full characteristics of the exposure situation, and in the context of other hazards that may also be present.

(109) The Commission recommends that some workers in nuclear installations should be trained and prepared to participate in a dedicated emergency team under the responsibility of the operating management, either at each site or at national level. 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. During the early phase of the emergency response, the Commission recommends using a reference level ≤100 mSv to control exposures. Exposures above that level would only be justified in exceptional circumstances in order to save lives and prevent further degradation of the facility leading to catastrophic conditions. Exposures of emergency responders should be assessed and recorded. Individual protective equipment should be used as necessary. Medical care and subsequent health surveillance (either for health, scientific, or reassurance purposes) should be provided as required, particularly in the case of exposures likely to induce deterministic effects. Pregnant women and young persons

under 18 years of age should not be considered for teams of emergency responders operating on-site during the early phase.

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

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

(111) These emergency 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 and the risks incurred, and the protection (e.g. any protective equipment) to be provided. These responders should intervene knowingly and with informed consent.

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

(113) For the protection of emergency responders off-site during the early phase of the emergency response, the Commission recommends using a reference level ≤100 mSv to control exposures according to the circumstances. As for on-site, exposure above the reference level off-site would be justified only under exceptional circumstances, such as the prevention of severe radiological consequences for the population or the environment, or to save human lives. The doses should be assessed and recorded for emergency 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 under 18 years of age should not be considered for teams of emergency responders operating off-site during the early phase.

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

(114) On-site, the intermediate phase of the emergency response starts when the source is declared stabilised by the authorities (with no more or just a few releases, and a limited risk of further source deterioration), and 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 or contractors are involved in characterising the situation and regaining control of the source. Both are under the responsibility of the operating management of the damaged installation, without prejudice of the responsibility of each employer. As the site is damaged, contaminated, and weakened, the working conditions may be unprecedented and difficult. Any error or unforeseen circumstance may result in a new state of emergency. However, the

organisation of work and the management of exposures will be improving progressively. In such circumstances, workers are still considered as emergency responders, although management of their exposures is no longer the same as in the early phase.

(115) The Commission recommends that any new worker entering the site should be identified, trained, and equipped for the task assigned, and must formally give their informed consent. Many of these workers 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 represents a small part of their working life-time. 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 culture. As these responders work in difficult and stressful conditions, specific attention has to be devoted to ensuring that they have decent working and housing conditions. The individual dose of any emergency responder should be monitored and recorded, and each responder should be informed about the exposure received.

(116) As in the early phase, the Commission recommends the use of reference levels, adapted to the situation, up to 100 mSv per year, 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 under 18 years of age should not be involved as emergency responders on-site during the intermediate phase.

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

(117) Off-site, the intermediate phase starts when the urgent protective actions for protection of the population are lifted, 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 during this phase are: characterisation of the radiological situation; setting up of infrastructures for radiological control of foodstuffs and health surveillance of the population; and 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.

(118) The Commission recommends organising protection for off-site responders in a manner that more closely resembles that used during routine activities. The responders involved should be registered and informed about the tasks and risks incurred (right to know). Their dose should be assessed, and the information should be communicated to interested responders, and kept, as far as possible, on an individual basis. The Commission recommends using a reference level ≤20 mSv per year to control individual exposures according to the circumstances. A lower reference level is recommended for responders off-site during the intermediate phase 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.

Table 3.1. Reference levels for emergency responders.

	Emergency exposure situation	
	Early phase	Intermediate phase
On-site		
Dedicated teams (for radiological intervention)	≤100 mSv*	≤100 mSv per year*
Emergency teams (fire, police, rescue, medical) Plant and outside workers	Exceptional circumstances†	May evolve with circumstances
Off-site		
Emergency teams		n/a
Skilled workers	≤100 mSv*	≤20 mSv per year*
Other responders	Exceptional circumstances†	May evolve with circumstances

*Previously, the Commission recommended selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendation recognises that the most appropriate reference levels may be lower than this band under some circumstances.

†The Commission continues to recommend to take all practicable actions not to exceed exposure in the order of 1 Gy to avoid severe deterministic effects for responders involved in exceptional circumstances during the early phase of the emergency response (ICRP, 2012a).

3.3.5. Management of emergency responder exposures

(119) In *Publication 103* (ICRP, 2007, Para. 236), the Commission explained that ‘At doses higher than 100 mSv, there is an increased likelihood of deterministic effects and a statistically significant risk of cancer. For this reason, the Commission considers that the maximum value for a reference level is 100 mSv incurred either acutely or in a year. Exposure above 100 mSv […] would be justified only under extreme circumstances […].’ As a consequence, the total exposure from all activities other than lifesaving or the prevention of further degradation of the facility into catastrophic conditions for an emergency worker should be guided by a reference level of 100 mSv for the duration of the emergency response. However, given the possibility of extremely difficult and unpredictable intervention conditions essential to regain control of the installations, particularly during the early phase, it is important to bear in mind that a very limited number of responders may receive exposures >100 mSv in total, or exceptionally in the range of a few hundred millisieverts. The Commission recommends that appropriate and sustainable medical surveillance should be provided for responders with exposures >100 mSv during the emergency response.

(120) 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 (NCRP, 2018). Arrangements for dose records should ideally be made as part of the planning for a response, and should include agreement between the responsible authorities, operator, employers, and workers. Before returning to regular work, the responder should, as appropriate, receive a medical examination.

(121) The Commission also recommends that emergency workers who wish to return to their normal activities and occupations when the emergency response is declared 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

3.4.1. Protective actions for the early phase

3.4.1.1. Evacuation

(122) Evacuation represents the rapid, temporary removal of people from an off-site area to avoid or reduce short-term radiation exposure from all exposure pathways that could be sufficiently high to result in severe tissue/organ damage (tissue reactions) and a high 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.

(123) Evacuation is a short-term protective action and its continuation should be justified by a continuing hazard. Such hazard might be the failure to control the source of the release, a significant risk of a further accident or release, or persistence of an elevated radiation exposure level in the environment. Generally, evacuation is not recommended for a period longer than 1 week. If the radiological conditions require the continued absence of people for a longer period of time, the action should be considered as temporary relocation and be justified and optimised accordingly.

(124) 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 inappropriate for certain populations, such as patients in hospitals and nursing homes, as well as elderly people, if it is not well planned (Tanigawa, 2012). Experience has also indicated that spontaneous and/or voluntary evacuation may occur whether or not 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 emergency planning.

(125) Once populations have been evacuated from areas, decisions will need to be made regarding their resettlement, as evacuation areas are usually only equipped for short-term accommodation, such as in public buildings. Depending on the radiological circumstances in evacuated areas, evacuated populations may be allowed to return home quickly or may be temporarily relocated for a further period.

(126) The Commission recommends that those authorities in charge of the emergency response, together with the evacuees and the authorities and professionals of the concerned communities, should be closely involved in the complex decision-making processes regarding returning to the evacuated area. This should be conducted in a transparent manner, on the basis of all available information on the radiological situation, the living conditions in the areas for which a return is envisaged, and the social and economic issues of being displaced for a long period of time.

3.4.1.2. Sheltering

(127) Beyond the geographic limits of evacuation zones, some groups will also require urgent protective actions to reduce their exposures in case of the possible passage of an airborne radioactive plume above their homes. These groups will be recommended to shelter by remaining indoors, sealing windows and doors if possible, and awaiting further instructions. An order or a recommendation to evacuate could follow sheltering if the radioactive deposits following passage of the plume result in high exposures.

(128) 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 beyond the geographic limits that have already been ordered to evacuate may not be sufficient to prevent potential serious health effects, and should be undertaken in conjunction with iodine thyroid blocking if possible. Sheltering is easy to implement but, in most cases, cannot be carried out for a long period of time. Therefore, monitoring should be performed promptly wherever sheltering is in place in order to locate and evacuate people from areas of high risk.

(129) For certain facilities where evacuation is not the best option for protection (e.g. health facilities with elderly people or patients in a critical condition), sheltering may be the preferable action during the early phase of an accident response, at least until proper arrangements have been made for these individuals. The staff that remain in the facilities to take care of the sheltered people need to be trained and equipped as emergency responders during the emergency preparedness process. 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.

3.4.1.3. Iodine thyroid blocking

(130) 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. If stable iodine is administered at the time of exposure to radioactive iodine, the effectiveness of thyroid blocking is more than 90%. If taken 4 h after exposure, protection is reduced by half, and after 24 h, the administration of stable iodine provides no protection. Although its effectiveness decreases with time, a single administration of stable iodine is usually sufficient for adequate protection for 24 h. 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.

(131) 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 predistribution. At the dosage recommended by the World Health Organization (WHO, 2017), the overall benefits of

thyroid blocking with potassium iodine during the emergency response will outweigh the risks of side effects in all age groups. Adverse effects of potassium iodine on thyroid function are more common in individuals with pre-existing thyroid disorders other than cancer. These disorders are more common in older adults and the elderly than in children and young adults.

3.4.1.4. Decontamination of people

(132) Personal decontamination is the complete or partial removal of radioactive material from a person by a deliberate physical, chemical, or biological process. Urgent personal decontamination may be advised to reduce exposures to external radiation from contamination on skin or inadvertent ingestion of such contamination. This measure may be particularly useful for protecting emergency responders. It is unlikely that individual decontamination will 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

(133) Ingestion of contaminated food may be an important exposure pathway soon after the accident for people residing in affected areas. It may also be of great concern to consumers outside the area, who fear that contaminated products from these areas will be placed on the market. Therefore, it is prudent to take actions as soon as possible in the early stage of the emergency to protect people and the image of the products. Protective actions at this stage can include: preventing contamination of feed and livestock; and banning or restricting consumption of agricultural, fishery, hunting, and gathering products, and water, in potentially affected areas. Control of all food products leaving affected areas may be necessary, and this control may take a few days to implement. In the event of banning or restriction of the consumption of foodstuffs from affected areas, authorities should ensure the supply of non-contaminated water and foodstuffs to affected people, including responders dealing with the event.

(134) Control of the radiological quality 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 potentially contaminated pasture. In addition, they should be instructed not to eat fresh vegetables, fruit, or other food that may have been outside during the release and thereby contaminated.

3.4.2. Protective actions for the intermediate phase

3.4.2.1. Temporary relocation

(135) Experience from the Chernobyl and Fukushima nuclear accidents has demonstrated that releases can result in very complex deposition patterns that require consideration of temporary relocation. Temporary relocation is the planned removal of people for an extended period of time (e.g. weeks, months, or several years depending on the characteristics and extent of the contamination) to avoid doses from radioactive material deposited on the ground or resuspended, or where essential food and water is significantly contaminated and cannot be replaced easily. Temporary relocation involves the movement of people either from short-

term reception centres or directly from their homes to temporary accommodation that can meet all of their basic needs and where living conditions can be properly supported.

(136) The physical risks associated with temporary relocation are relatively small compared with those for evacuation, as the action can be undertaken in a controlled manner, whereby there would be time to work with each household, allowing for them to move out gradually. Temporary relocation is, however, associated with psychological effects. Several studies carried out after the Fukushima accident showed significant increases in the incidence of depression and post-traumatic stress disorder among relocated residents of Fukushima Prefecture (Oe et al., 2017; Ohto et al., 2017).

(137) 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, or simply the desire to establish settled social patterns back home. Conversely, there may be concerns about returning home, such as lack of employment opportunities; need to repair or reconstruct abandoned houses; insufficient infrastructure such as schools, hospitals, and shops; and persistent concerns about radiation.

3.4.2.2. Foodstuff management

(138) In the intermediate phase, radiological characterisation of food production and its potential evolution depending on season, radionuclides, environmental characteristics, etc. will allow the definition of a more detailed and adapted strategy for foodstuff management. For this purpose, it is also necessary to assess the overall impacts on the life of local communities (e.g. agricultural, cultural, image, societal, economic considerations). 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 should be based on directly measurable levels of radionuclides in foodstuffs (expressed as Bq kg^{-1} or Bq L^{-1}). The radiological monitoring of foodstuffs, based on these criteria, is key to facilitate their exchange inside and outside affected areas, while guaranteeing protection of the people.

(139) The Commission acknowledges that fixing such radiological criteria is complex and requires appropriate implementation of the optimisation principle to balance the apprehension of people to consume products that may be contaminated, even at very low levels, with the desire to maintain agricultural activities in affected areas. All of the relevant stakeholders need to be involved in setting the radiological criteria: authorities, farmers' unions, food industry, retailers, non-governmental consumer groups, and representatives of the general population (Kai, 2015). In-depth debate at national level is needed to maintain a degree of solidarity in the country.

(140) Guideline levels have been developed by the Codex Alimentarius Commission for use in international trade (FAO/WHO, 2006). These levels are based on a dose criterion of 1 mSv per year assuming that a maximum of 10% of the diet consists of contaminated food. The assumptions may not be valid for some local communities; hence, the radiological criteria for foodstuffs may be set below the Codex guideline levels. Conversely, if the contamination only affects a small 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 with the local stakeholders, as was the case in Norway with reindeer meat produced by the Sami population after the Chernobyl accident (Skuterud et al., 2005).

(141) Consequently, the radiological criteria for foodstuffs set for managing the local situation may be specific and different from those adopted for international trade. Those for managing the local situation will most likely evolve as the prevailing circumstances change and the radiological quality of foodstuffs improves.

(142) In the intermediate phase, the radiological quality of foodstuffs can be improved by many protective actions that aim to reduce the transfer of radionuclides in the food chain from farm to fork (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 will depend on the physical and chemical properties of the radionuclides released, season of the year, and the types of land use affected (Bogdevitch, 2012).

(143) In addition to foodstuff management, water supplies 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

(144) Commodities other than foodstuffs may also be contaminated following a nuclear accident, such as contamination of cars and buses used for transporting evacuees. Although the contamination of commodities may not be a significant exposure pathway, it will be viewed as important by the stakeholders, and the commodities may need to be managed. The type of management will depend on the level of contamination, type of commodity, number of commodities, and circumstances of use.

3.4.2.4. Decontamination of the environment

(145) While the removal of contamination from surfaces and soils can be very effective to reduce exposure, it 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.

(146) The decontamination of buildings (public and private), roads and paved areas, open spaces, recreational areas, and agricultural land will start during the intermediate phase and, depending on the size of the areas affected, may continue into the recovery process. Priority should be given to places where people spend their time and exposures are at their highest. For these decontamination actions, the Commission recommends applying the principle of optimisation, taking into account the expected reduction in exposure and the associated economic, societal, and environmental impacts, to ensure that negative consequences do not outweigh the intended benefits. Therefore, development of the decontamination strategy should be carried out in close consultation with the affected population.

3.4.2.5. Management of business activities

(147) As mentioned above (see Section 2.2.4), the economic activities of different companies are affected by a nuclear accident. During the intermediate phase, companies located in the vicinity of the damaged nuclear installation may need to establish protective actions, such as organising the management of their employees and families living in affected

areas, setting up dedicated actions to preserve their activity in contaminated areas or to transfer it outside these areas, and ensuring the radiological monitoring of their products.

(148) The first step relies on characterisation of the radiological situation for companies that are not familiar with radiation protection issues. The support of experts and adequate guidelines, including radiological criteria, are required to provide the general framework and identify the exposure pathways associated with occupational activities in the post-accident context.

(149) Depending on the level of contamination, some economic activity could be maintained in affected areas, with or without specific decontamination of the site. In any case, the employers would have to ensure an adequate environment for their staff and production, inside or outside the affected areas, and to take care of the possible evolution of contamination.

(150) Chronic exposure to employees may arise from economic activity maintained in affected areas as well as at home. Apart from particular cases, these employees are not meant to be considered as occupationally exposed. However, it may be relevant to implement a monitoring programme for themselves and possibly for their families. This monitoring programme should cover the different exposure pathways, both in the workplace and at home.

(151) Following a nuclear accident, a large number of producers would be challenged by the presence of radioactivity. The producers would have to demonstrate that their products are not affected by the contamination, notably for export. In some cases, the products or the activities themselves could be affected (e.g. quarries, forest activities, tourism), so a decision will need to be made about whether or not to maintain the activity, in addition to the potential implementation of protective actions to maintain exposures as low as reasonably achievable.

(152) For economic activities in affected areas, in order to ensure protection for workers, their families, and consumers, there is a need to develop a radiological protection culture and implement dialogue processes involving different stakeholders.

3.5. Preparation for the long-term phase

3.5.1. Termination of protective actions

(153) Protective actions implemented during the emergency response should be withdrawn when they have achieved their desired effect, or when their continued application is no longer justified (i.e. will cause more harm than good in the broadest sense). Sheltering and evacuation during the early phase should normally be withdrawn once official confirmation has been issued that the radioactive releases have stopped and that further unplanned releases are unlikely. However, experience shows that, in practice, the lifting of emergency protective actions is a difficult task that raises many problems. Withdrawal of emergency protective actions is resource intensive, and requires co-ordination and support of various teams in charge of assisting affected people and characterisation of the radiological situation off-site. It also requires effective communication mechanisms, provision of medical services, and the implementation of decontamination actions if required.

(154) Sheltering for periods of more than 1 or 2 days is 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. If the radioactive releases from the damaged facility last for

several days, the confinement of people inside buildings becomes untenable to maintain, and authorities have to organise evacuation of the people concerned. In this case, evacuation should be undertaken while the radioactive releases continue, and special protective actions should be taken to reduce external and internal exposures of evacuees as much as possible. This is a delicate operation that requires development in advance during the preparedness and planning stage.

(155) 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 in its simplest form would be a return to normal living conditions, whereby people are able to ventilate their properties and go outside to undertake their day-to-day activities without radiological restriction. However, before this can happen, monitoring information is required to determine whether exposures from external irradiation or 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 continuing sheltering may pose unacceptable or inadequately defined risks.

(156) Evidence from past accidents suggests that the initial evacuation during the early phase may need to be followed by the implementation of further evacuation or relocations (see Annexes A and B). This is the case when characterisation of the radiological situation initiated at the end of the releases reveals heavily contaminated areas outside the initial evacuation zone, and authorities have to order an evacuation or relocation of the inhabitants of these areas to prevent high exposures. Depending on the levels of contamination in evacuated areas, the authorities may decide to temporarily relocate the evacuated populations until more detailed characterisation of the areas and decontamination measures are taken to lower the exposure levels. In cases when the exposure levels are so high as to preclude sustainable living conditions in a reasonable period of time, authorities may decide to relocate the population permanently.

(157) Advising people who have been evacuated or temporarily relocated that they are allowed to return home requires an assessment of their future exposures and the associated risks. These assessments should be based on measurements of exposure rates and environmental contamination, predictions on the evolution of individual exposures, and capability to improve the radiological situation. Environmental monitoring data coupled with realistic modelling can be used to predict future exposure to adults and children who intend to return to the affected area. In order to decide whether or not to return to the affected area, evacuees will need to know the expected magnitude of their exposure; the degree to which these exposures may be further improved; and if sustainable living conditions, including respectable lifestyles and livelihood, will be possible.

(158) The Commission recommends that a functioning physical infrastructure, capable of addressing the health and well-being needs of the evacuees, should be available before their return. With this in place, individuals have a basic right to decide whether or not to return. All decisions about whether to remain in or leave an affected area should be respected and supported by the authorities, and strategies should be developed for resettlement of those who either do not want or are not permitted to move back to their homes.

(159) The Commission also recommends that all stakeholders should be closely involved in the decision-making processes for the lifting of emergency protective actions. However, 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. Decisions on allowing evacuees and those who have been temporarily relocated to return to their homes will involve a more extensive dialogue with the affected people and the authorities and professionals in their communities. As well as information about the accident and its potential radiological consequences, it is important to provide inhabitants with full details about the living conditions they will face if they choose to return to their homes. They are entitled to expect the support of experts in radiation protection and access to appropriate medical services to meet their concerns (Miyazaki, 2017).

3.5.2. Decision about the future of affected areas

(160) 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 gravity, 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 given the expected levels of exposure and the ability to recover sustainable and decent living conditions in a reasonable timeframe. Such decision should be duly justified based on all the information available concerning the radiological situation, and the state of infrastructure and services in these areas.

(161) The decision to allow evacuated people to return may be accompanied by the authorities setting a radiation protection 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 emergency response. The Commission does not recommend any specific value for this radiation protection criterion. If any is selected, it should be consistent with the guidance concerning the management of existing exposure situations (see Section 4). The decision on permanent relocation should be taken by the authorities on a case-by-case basis, taking into account the current level of exposure, the level foreseen in the near future following protective actions, and the conditions and means to maintain sustainable societal and economic living conditions of the affected population in contaminated areas.

(162) If a radiological protection criterion is selected to allow people to live in affected areas, selection of this criterion, and selection of the initial reference level for implementing the optimisation of long-term protective actions in these areas, should be discussed and decided together to ensure consistency.

(163) Clearly, it is not easy for a government and its people to make a decision to permanently (or at least for the foreseeable future) remove people from an area and to forbid its use. As such, the radiological, health, social, economic, and political implications of this will need to be discussed in a broad and transparent fashion before a decision is reached. Generally, radiological considerations would be used to delineate the boundary of such areas, although existing geographic or jurisdictional boundaries may also be considered for social reasons.

3.5.3. Moving from the emergency response to the recovery process

(164) The end of the emergency response and the beginning of the recovery process after a nuclear accident are substantiated by the decision by the authorities to allow people to live permanently in affected areas, if they so desire. The Commission recommends that this decision 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 conditions.
- Responsibilities of the authorities responsible for managing the emergency response have been transferred to local level. This transfer 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 evaluation and monitoring system, including appropriate mechanisms for collecting, storing, and using data.
- Appropriate mechanisms have been put in place to involve affected people, who are willing to do so, in assessing and improving their radiological situation and that of their communities with the support of local authorities and professionals.

4. RECOVERY PROCESS

4.1. Characteristics of the long-term phase

(165) The recovery process begins on-site when the authorities in charge of the emergency response consider that the damaged facility is secured. Off-site, the recovery process 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.

(166) Experiences from Chernobyl and Fukushima have shown that beyond the consideration of radiological aspects, recovery after a large nuclear accident is a complex process in which all dimensions of individual and community life are involved and interlinked. These two extremely socially disruptive accidents clearly demonstrated that management of the long-term phase based solely on principles and criteria of radiological protection was not sufficient to respond to the challenges faced by individuals and communities in affected areas. Such management is insufficient to rehabilitate 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 considerations are an essential input to the recovery process, they should be used as appropriate for rehabilitation of the living conditions of affected individuals and communities.

(167) As in most existing exposure situations, the level of exposures of people residing in affected areas is largely driven by their individual behaviour, 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 and work undertaken in particular areas affected by contamination; and
- individual habits, particularly the diet of each individual, which could be significantly dependent on his/her socio-economic situation.

(168) Experience has shown that large differences in levels of exposure may exist between neighbouring villages, within families in the same village, or even within the same family according to diet, lifestyle and habits, and occupation. These differences generally result in a skewed dose distribution where a few individuals receive a larger exposure than the average. It must be remembered that the reference level will apply to these few individuals, while the majority of people will be substantially below the reference level.

(169) For the sake of controlling exposure in long-term contaminated areas, different exposed groups of populations may need to be considered. Generally, the typical population groups are:

- the rural population – farmers or families with small holdings who reside and work in affected areas, and are assumed to derive some of their food from locally grown products; and

- the urban population – people who inhabit houses constructed in a built-up area, and who generally derive the majority of their food outside the affected area.

(170) People working in affected areas are generally in the same situation as the general population. However, some groups of workers may be involved in activities that will increase their exposure, such as foresters and employees of sawmills in a forest region, and recovery responders (i.e. people involved in the response to the situation during the recovery process).

(171) People residing, working, or eventually settling down in affected areas should be duly informed about the radiological situation. They should receive adequate support from authorities and experts, not only to ensure adequate protection against the potential health consequences of the radiation, but also to guarantee sustainable living and working conditions, including respectable lifestyles and livelihoods.

(172) 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, will need to constantly 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 further improve the situation.

4.2. Protection of recovery responders

(173) During the long-term phase on-site, the recovery process aims to dismantle the damaged installation, including management of the corresponding waste. The exposure situation is characterised and the source is mostly under control, although unforeseen situations may occur at any time. For the management of recovery responders on-site, the Commission recommends setting a reference level ≤20 mSv per year, and applying the requisites for occupational exposure, as relevant. Many recovery 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. The Commission recognises that unexpected circumstances in the environment at the damaged facility may challenge the reference level. In that case, great care is needed when preparing and conducting the work in order to keep exposures as low as reasonably achievable.

(174) Off-site, the tasks to be undertaken by responders during the recovery process aim to continue and complete the cleaning and decontamination of buildings and the environment initiated during the emergency response. They 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. The exposure situation is well characterised and the exposures are generally lower than on-site. As in the intermediate phase, many groups of people may be involved in implementation of protective actions, including the residents themselves. The Commission considers that the exposure of these residents should be considered as public exposure, and should be managed using the same requisites as for the general population.

(175) For workers 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 prevailing

circumstances. When protective actions are implemented in a restricted area where exposures may be higher (not open to the public), it is recommended to treat the exposures using a reference level ≤20 mSv per year. However, when protective actions are implemented in areas of lower exposure, such as in public areas, the Commission recommends that the reference level should be within the 1–20-mSv per year band, and would not generally need to exceed 10 mSv.

(176) For people employed for various economic activities in an affected area, the Commission recommends that they should be treated as members of the public, and managed like the general population of the area, considering that it is the responsibility of their employer to provide them with appropriate information on radiation risk and self-protection.

4.3. Protection of the public and the environment

(177) Management of the long-term phase relies on implementation of a set of protective actions that continue and complement actions implemented during the emergency response. The goal is to maintain and/or reduce all exposures to as low as reasonably achievable given the societal, economic, and environmental factors shaping the lives of the individuals and communities residing and working in affected areas. The protective actions should be implemented with the aim of equitable treatment by avoiding large differences between the average level of exposure (which is generally low) and the highest exposures using reference levels. The protective actions include those driven 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.

(178) In order to be effective, the reference level for protection of the public selected at the end of the intermediate phase, when the authorities take their decision on the future of affected areas, should correctly reflect the radiological situation based on the characterisation process, and consider the socio-economic factors. 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 impair the societal conditions and economic activities of the areas, and be counterproductive. Selection of the reference level to manage the recovery process is a complex decision that requires a large amount of information and must be informed by societal and ethical value judgements (ARPANSA, 2017). Due to this complexity, the Commission recommends that, when preparing the decision on selection of the reference value, stakeholders who will be confronted with the situation should be involved as much as possible.

(179) For areas significantly impacted by the radiological material or where radioactive waste or contaminated materials have been disposed or stored, a specific characterisation with regard to environmental protection should be performed. On this basis, protection of the environment is implemented using Derived Consideration Reference Levels (DCRL) (see Section 2.3.3). In addition, beyond radiological considerations, protective actions for protection of the public, such as soil decontamination, can have a significant impact on the environment. This should be taken into account in the justification and optimisation of protective actions.

4.3.1. Protective actions for the long term

(180) Recovery of long-term contaminated areas involves keeping or/and reducing external and internal exposures as low as reasonably achievable given the prevailing circumstances. This can be achieved by removing the contamination present in the environment (decontamination), or by implementing collective and individual protective actions to control external and internal exposures (e.g. shielding, quality control of food products).

(181) The protective actions available for the recovery process are many and varied; they may be used in isolation or in combination as part of a broader strategy, such as in the agricultural domain (Bogdevich et al., 2012). Some actions with a generic character may be applied identically and systematically throughout affected areas, and others will 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. Other options may generate large amounts of waste or may only be effective at certain times of the year or under particular conditions. Consequently, the development of a recovery strategy will involve evaluating, selecting, and combining protective actions based on input from a wide range of stakeholders.

4.3.1.1. Decontamination including waste management

(182) Decontamination actions of buildings and public places (e.g. schools) and the environment near to dwellings start in the transition phase of the off-site emergency response, but can continue for some time (several years) during the long-term phase. Authorities may prefer a case-by-case approach or may adopt a systematic programme for all affected areas. Decontamination, which involves total or partial removal of radioactivity deposited on surfaces and objects, can be more or less effective depending on the situation. In addition, it inevitably generates the production of radioactive waste in greater or lesser quantities, which requires management. The environmental impact of such management should be considered.

(183) The Commission recommends that decontamination actions should be carried out in close consultation with the residents and users of dwellings, buildings, gardens, public and recreational areas, and land in order to identify the areas that contribute significantly to exposures or are of primary concern for these people. These exposures will depend on how people occupy or use the premises to be decontaminated. Use of the selected reference level for the long-term phase should help to prioritise the decontamination actions to be implemented.

(184) The issue of waste is part of the overall decontamination strategy, and should be considered in decisions concerning the adoption and definition of such a strategy. The main origins of waste after an accident off-site are materials from cleaning and decontamination of affected areas, agriculture (e.g. removed soils, contaminated 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. Non-radioactive waste generated by the decontamination strategy should also be considered.

(185) The generation of radioactive waste during decontamination should be considered carefully, taking into account available disposal routes and possible alternatives. The consequences of protective actions such as food bans and restrictions can include a build up of organic waste that is difficult to dispose of safely, from a biological perspective, regardless of the radiological hazard posed.

(186) In the recovery process, 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 will need to be adapted given the large quantities, the radiological characteristics, and the nature of the waste generated by the decontamination processes. Specific management 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, etc. Both radiological protection and societal, environmental, and economic considerations characterising the situation after an accident should be taken into account.

(187) For the management of radioactive waste generated by decontamination actions, the Commission recommends that the relevant reference levels set for public or environmental exposure should be used as a criterion, 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).

(188) The Commission recommends performing surveillance of decontamination waste storage and disposal sites 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 storage and disposal sites.

4.3.1.2. Radiation monitoring

(189) At the beginning of the recovery process, the radiological characterisation has already been engaged in the previous phase to identify the spatial distribution and levels of radioactive contamination. Once the future of affected areas is set by authorities, it is important to follow the evolution of the radiological situation in order to adapt protective actions if necessary. Continuation of radiological characterisation in affected areas should be complemented by the establishment of a system for monitoring the external and internal exposure of individuals. For the authorities, the monitoring system in the recovery process will help to fulfil several objectives: to obtain data on the actual contamination of affected areas and its evolution; to control the concentration of radionuclides in foodstuffs; and to provide information to the public on external ambient dose rates by using devices displaying the results in different places. For the public, the purpose of this monitoring system is to allow each person to have access to his/her exposure, and also to know where, when, and how they are exposed. 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 the monitoring system.

(190) The effectiveness of the monitoring system relies on its ability to cope with the specificities of the local affected area. The Commission recommends that a system should be established by the authorities to record all measurements and to analyse them as much as possible; this is particularly important to determine potential groups at risk. The sustainability of such a system will require the establishment of continued maintenance and training programmes by national and local authorities.

(191) Experience shows that the pluralism of organisations involved in implementation of the radiation monitoring system (authorities, expert bodies, local and national laboratories, non-governmental organisations, private institutes, universities, local stakeholders, nuclear

operators, etc.) is an important factor in favour of confidence in the measurements among the affected population.

4.3.1.3. Foodstuff management

(192) The control of ingestion pathways is an important component of the protection strategy for the public. However, maintaining long-term restrictions on the production and consumption of foodstuffs may affect the sustainable development of affected areas, and therefore calls for appropriate implementation of the optimisation principle.

(193) During the long-term phase, foodstuff management should be addressed in broad terms, considering not only radiological protection factors, but also issues such as food supply and replacement for contaminated foods; waste management of contaminated foodstuffs; and societal, environmental, and economic factors characterising the situation in affected areas. Reconciling the interests of producers and the population with those of consumers and the food distribution sector from outside the contaminated areas has to be considered carefully. Representatives of the affected population, national and local authorities, farmers' unions, food industry, food distribution, consumer non-governmental organisations, etc. should be involved in a thorough debate at regional and national levels to determine the optimal protective actions required to manage contaminated foodstuffs.

(194) Experience shows that maintaining radiological monitoring of foodstuffs in the long-term phase is useful to gradually restore the confidence of distributors and consumers inside and outside affected areas (Strand et al., 1992; Skuterud et al., 2012). In addition, the provision of devices to local communities for self-monitoring radiation levels in local agricultural produce, food from private gardens, and food gathered from the wild (e.g. forest mushrooms, vegetables, wild game, etc.) should contribute to the implementation of self-help protective actions and development of a radiological protection culture.

4.3.1.4. Management of business activities

(195) During the recovery process, 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 expectations of the different stakeholders. This monitoring should contribute to vigilance in the long term, allowing confirmation of the quality of working conditions and production, as well as implementation of protective actions if necessary.

(196) Some companies that evacuated during the emergency response 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. The protection of employees should be managed as explained in Section 4.2. It is also essential to provide the means for maintaining and further developing a radiological protection culture for people working in affected areas, as well as for consumers inside and outside these areas.

4.3.1.5. Health surveillance

(197) Whatever the level of exposures in affected areas, experience shows that the presence of contamination and its potential health impacts in the long term remain a widespread concern among the population. It is essential to respond to this concern with

consideration of prudence and dignity in order to ensure decent living conditions (Oughton et al., 2018).

(198) In the long-term phase, health surveillance should be composed of three main components (adapted from WHO, 2006):

- the follow-up of people – expected to be few – who have received exposures during the emergency response that have resulted in clinically significant deterministic effects (e.g. skin burns, cataracts, etc.) or sufficiently high levels of exposure to justify preventive surveillance;
- health monitoring of the general population, which consists of investigation for potential adverse effects (mainly incidence of radiation-induced cancers), and social and psychological consequences of the accident. A subcategory of health monitoring is the follow-up of potentially sensitive subgroups (e.g. children, pregnant women); and
- epidemiological studies to provide information on the possible radiation health effects in the long term for the exposed population.

(199) For the first category, 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.

(200) 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 potentially affected populations. Its implementation requires the development of health surveys, health databases, and mechanisms for providing information and access to health support.

(201) 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, 2018). In this regard, a long-term thyroid health monitoring programme should only be conducted for those individuals exposed in utero or during childhood or adolescence with 100–500 mGy absorbed dose to the thyroid.

(202) The Commission recommends developing a multi-disciplinary approach to health surveillance, and involving stakeholders, as much as possible, in the design and follow-up of the health surveillance programme. It also recommends the need to be prepared to take appropriate actions in case of any suspicion changes in the health status of the population.

(203) In addition to health monitoring, the development of epidemiological studies should be considered cautiously to address the concerns of the affected population (WHO, 2006).

4.3.2. The co-expertise process

(204) As mentioned above, implementation of the optimisation process in the long-term phase should include actions driven by authorities at national and local levels, and self-help protective actions implemented by affected populations (ICRP, 2016). Central and local governments, together with experts, may play a crucial role in providing support and mechanisms for strengthening the involvement of, and co-operation between, stakeholders.

(205) To achieve such involvement and co-operation in the context of the post-accident situation, the Commission recommends promoting the 'co-expertise process' in affected areas. This process of co-operation between experts and local stakeholders aims to share local knowledge and scientific expertise for the purpose of assessing the radiological situation and

developing actions to protect people and the environment, and to improve living conditions. Experiences from Chernobyl and Fukushima have demonstrated the effectiveness of this process (Liland et al., 2013; Lochard, 2013; Ando, 2018; Takamura, 2018).

(206) Such a process takes time, requires means of measurement, and can only be envisaged with the support of radiological protection experts or professionals who are committed to working sustainably with the population (Gariel et al., 2018). The co-expertise process is a step-by-step approach (see Fig. 4.1). It contributes to empowerment of the local population, and represents part of the development of a radiological protection culture among all involved stakeholders.

4.3.2.1. Steps of the co-expertise process

(207) *Establishing a dialogue*. The first step is to engage in a dialogue with a group of people from a community affected by the accident. Within this dialogue, affected people and experts share their own knowledge, experience, and vision of the situation and its consequences for daily life, including questioning, 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.

(208) *Joint characterisation of the radiological situation.* The second step aims to make the radioactivity 'visible', and to make people aware of when, where, and how they are exposed in their daily life. For this purpose, specific monitoring should be developed based on measurements performed by the authorities and/or by affected people (self-monitoring). Sharing information about the results allows affected people and experts to better understand the local situation, and to put it into perspective taking into account radiological criteria and comparison with other exposure situations.

(209) *Defining and implementing protection strategies.* The third step aims to define protective actions responding to the actual situation, while remaining pragmatic and reasonable in accordance with the optimisation principle. A protection strategy includes actions driven by the authorities, and self-help protective actions implemented by the affected population. In identifying possible protective actions taking into account the characteristics of the local situation, the co-expertise process allows affected individuals to make informed decisions to protect themselves. The experience gained through this process may conduce to review the protective actions implemented in the community by the authorities, including radiological criteria.

(210) *Implementing local projects.* The fourth step in the co-expertise process is to identify and implement local projects at the level of affected communities. These projects, which may be of a very different nature (educational, social, cultural, environmental, economic, etc.), should consider the radiological situation, and should be implemented with the aim of improving the protection of people and the environment, as well as living and working conditions. 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.

Fig. 4.1. The co-expertise process.

(211) The co-expertise process is powerful to empower affected people regarding radiation and how to protect themselves, and thus to develop the radiological protection culture needed to face the consequences of the nuclear accident. This process relies on values and proper behaviours: accountability, transparency, inclusiveness, prudence, equity, and dignity (ICRP, 2018).

4.3.2.2. Radiological protection culture

(212) The co-expertise process facilitates the emergence of a radiological protection culture among local communities. This culture should be practical (to help people to address their daily life concerns), and comprise a set of knowledge, skills, and resources enabling people to:

- interpret the results of measurements – ambient dose rates, internal and external doses, contamination of products;
- orient themselves in relation to radioactivity in everyday life by understanding where, when, and how they are exposed;
- build their own benchmarks about radioactivity;
- 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 implemented themselves and those implemented by the authorities.

(213) The development of a radiological protection culture is based on a learning process dedicated to the practice of radiological protection for local communities to improve their daily lives. Thus, scientific knowledge underpinning radiological protection is mobilised at the service of this learning process.

(214) Combined with the co-expertise process, a radiological protection culture enables people to restore their autonomy regarding decisions, which was seriously impaired at the

time of the accident. It contributes to reconnect people and develop solidarity between them, and allows people to look to the future with confidence.

4.4. Evolution and termination of recovery protective actions

(215) In the long-term phase, over time, the impact of protective actions, combined with the natural processes of radioactive decay, will gradually reduce exposures of people, fauna, and flora. As a result, years after a radiation accident (or even decades in the case of a severe accident), it is advisable to consider the effectiveness of protective actions in order to decide whether to maintain, modify, or withdraw them gradually. This decision should be taken with the involvement of the relevant stakeholders. The withdrawal of protective actions does not prevent monitoring in order to remain vigilant about the radiological situation and its evolution.

(216) As a wide range of recovery actions can be implemented over different timescales, it is not necessary to withdraw all actions simultaneously; an action can be withdrawn when it has achieved its purpose, or if its continued application would cause more harm than good in the broadest sense.

(217) Reducing exposures below the reference level may not automatically lead to termination of the recovery strategy, provided that there is still room for improvement based on optimisation of protection.

5. EMERGENCY AND RECOVERY PREPAREDNESS

(218) In the event of a nuclear accident, emergency and recovery preparedness is an important factor in decisions concerning the protection of people and the environment. For the emergency response, this preparation relies on the development of preplanned protection strategies for postulated scenarios, based on hazard assessment. For the recovery process, preparedness should aim to identify the vulnerability of potentially affected areas, and develop guidelines that are sufficiently flexible to cope with the real situation as appropriate. A prerequisite to preparedness is to acknowledge 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 involved in the case of an accident. Although it is difficult to ask the population to be prepared in advance for the occurrence of a nuclear accident, the Commission recommends that key representative stakeholders should participate in emergency and recovery preparedness.

(219) Planning for the emergency response needs to involve the responsibilities of different organisations, methods for communication and co-ordination between them and internationally during the response, and a framework to guide decision making. More detailed plans should contain development of the overall protection strategy, selection of appropriate individual protective actions with criteria for initiating those actions that need to be implemented promptly, deployment of the necessary equipment for monitoring, supporting the implementation of protective actions, communicating with those at risk, training, and exercising the plans. The relevant national authorities need to determine the detail of planning that is appropriate for different situations. Planning will need to be flexible in order to respond appropriately to an accident, although there will be no time for planned urgent actions to be modified. This is particularly true for evacuation (see Section 3.2.4.1).

(220) Preparedness of the recovery process has to be considered before the occurrence of an accident and during the emergency response. Indeed, decisions implemented in the emergency response may have an impact on subsequent decisions and actions in the long-term phase. Recovery preparedness should include the development of a programme to improve living conditions, which is characterised by protection strategies that also include actions driven by the authorities at national and local levels, and self-help protective actions implemented by the affected population. For these strategies to be successful, authorities should provide the necessary infrastructure as well as practical guidance for their implementation (Duranova et al., 2016; Schneider et al., 2018).

(221) The Commission notes that details of emergency and recovery preparedness are within the scope of the international and national bodies that hold such responsibilities, and that these organisations have prepared detailed requirements and guidance for implementation (IAEA, 2015a; NEA-OECD, 2018). It is not for the Commission to specify details, beyond providing a reminder of the factors that are important in considerations, and the need to consider all hazards – both radiological and non-radiological – explicitly. An honest and open assessment of the short- and long-term implications of the actions on health and welfare is needed, and specific planning must take place for certain populations, including medical patients, schools, correctional institutions, etc.

6. CONCLUSIONS

(222) A nuclear accident is an unexpected event that profoundly destabilises people and society, generates great complexity, and requires mobilisation of considerable human and financial resources. Beyond the legitimate fear 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, are 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 need to be mobilised to cope with the issues facing all affected individuals and organisations.

(223) In such a context, the role of radiological protection is primarily 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. This is achieved through implementation of a set of protective actions that should begin in the first hours following the start of the emergency, and last for several decades.

(224) Experience from the nuclear accidents in Chernobyl and Fukushima 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 emergency response and the recovery process can also be a source of negative consequences and additional complexity.

(225) 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 effects of radiation and the general objective of rehabilitating living conditions and the quality of life of affected communities. 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 reference levels to select and implement protective actions, taking into account the societal, economic, and environmental dimensions that characterise areas affected by contamination.

(226) The reference levels recommended by the Commission for optimisation of protection of people in the case of nuclear accidents are summarised in Table 6.1. The relevant reference levels recommended by the Commission for biota are presented in *Publication 124* (ICRP, 2014).

Table 6.1. Reference levels for optimisation of the protection of people in the case of nuclear accidents.

	Emergency exposure situation	Existing exposure situation
Public	≤100 mSv*	≤10 mSv per year *,† The long-term goal is to reduce exposures to the order of 1mSv per year
Responders (see Table 3.1)	≤100 mSv* Could be exceeded in exceptional circumstances‡	≤20 mSv per year *

*Previously, the Commission recommended the selection of reference levels in the band of 1–20 and 20–100 mSv or mSv per year for existing and emergency exposure situations, respectively. The current recommendation recognises that the most appropriate reference level may be lower than the corresponding band under some circumstances.

†This clarifies the previous recommendation of the Commission to select a reference level for the optimisation of protection of people living in long-term contaminated areas in the lower part of the 1–20-mSv per year band (see Section 2.3.3.3).

‡The Commission continues to recommend taking all practicable actions not to exceed 1 Gy to avoid severe deterministic effects for responders involved in exceptional circumstances during the emergency response (ICRP, 2012a).

(227) Finally, the Commission emphasises the crucial importance of involving stakeholders in implementation of the optimisation process. Experience from Chernobyl and Fukushima has shown that radiological protection experts and professionals engaged in the emergency response and recovery process should, beyond mastering the scientific basis of radiological protection and its practical implementation, interact with affected people in accordance with the core and procedural ethical values underpinning the radiological protection system (ICRP, 2018). They should adopt a prudent approach to manage exposures, seek to reduce inequities, 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 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 allow them to make informed decisions about their protection and their life choices (i.e. respecting their dignity).

REFERENCES

Ando, R., 2016. Measuring, discussing, and living together: lessons from 4 years in Suetsugi. Ann. ICRP 45(1S),75–83.

Ando, R., 2018. Trust – what connects science to daily life. Health Phys. 115, 581–589.

ARPANSA, 2017. Guide for Radiation Protection in Existing Exposure Situations, Radiation Protection Series G-2, Australian Radiation Protection and Nuclear Safety Agency, https://www.arpansa.gov.au/sites/g/files/net3086/f/rpsg-2-existing-exposure.pdf

Bogdevitch, I., 2012. Fertilization as a remediation measure on soils contaminated with radionuclides ^{137}Cs and ^{90}Sr. In Fertilizing Crops to Improve Human Health: a Scientific Review. Volume 3 Risk Reduction. IPNI, Norcross, GA; IFA, Paris, pp. 275–290.

Bromet, E.J., Havenaar, J.M., Guey, L.T., 2011. A 25 year retrospective review of the psychological consequences of the Chernobyl accident. Clin. Oncol. 23, 297–305.

Bromet, E. J. 2014. Emotional consequences of nuclear power plant disasters. Health Phys. 106, 206–210.

Callen, J., Homma, T., 2017. Lessons learned in protection of the public for the accident at the Fukushima Daiichi nuclear power plant. Health Phys. 112, 550–559.

Duranova, T., Raskob, W. and Schneider, T., 2016. Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe. Key results of the PREPARE European research project. Radioprotection, Volume 51, HS2.

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

Gariel, J.C., Rollinger, F., Schneider, T., 2018. The role of experts in post-accident recovery: lessons learnt from Chernobyl and Fukushima. Ann. ICRP 47(3/4), 254–259.

Harada, N., Shigemura, J., Tanichi, M., et al., 2015. Mental health and psychological impacts from the 2011 Great East Japan Earthquake Disaster: a systematic literature review, Disast. Milit. Med. 1, 1.

Hasegawa, A., Tanigawa, K., Ohtsuru, A., et al., 2015. Health effects of radiation and other health problem in the aftermath of nuclear accidents, with an emphasis on Fukushima. Lancet 386, 479–488.

Hayano, R.S., Yamanaka, S., Bronson, F.L., et al., 2014. BABYSCAN: a whole body counter for small children in Fukushima. J. Radiol. Protect. 34, 645.

IAEA, 2006. Chernobyl Forum: Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine. Second revised version. International Atomic Energy Agency, Vienna.

IAEA, 2013. The International Nuclear and Radiological Event Scale. 2008 Edition. International Atomic Energy Agency, Vienna.

IAEA, 2015a. Chapter 4.4.6. Non-radiation effects: Mental health. The Fukushima Daiichi Accident. Tech. Vol. 4. Radiological Consequences. International Atomic Energy Agency, Vienna.

IAEA, 2015b. Preparedness and Response for a Nuclear or Radiological Emergency. IAEA Safety Standards Series No. GSR Part 7. International Atomic Energy Agency, Vienna.

IAEA, 2018. Arrangements for the Termination of a Nuclear or Radiological Emergency. IAEA Safety Standards Series No. GSG-11. International Atomic Energy Agency, Vienna.

ICRP, 1983. Cost–benefit analysis in the optimization of radiation protection. ICRP Publication 37. Ann. ICRP 10(2/3).

ICRP, 1984. Protection of the public in the event of major radiation accidents – principles for planning. ICRP Publication 40. Ann. ICRP 14(2).

ICRP, 1990. Optimization and decision making in radiological protection. ICRP Publication 55. Ann. ICRP 20(1).

ICRP, 1991a. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21(1–3).

ICRP, 1991b. Principles for intervention for protection of the public in a radiological emergency. ICRP Publication 63. Ann. ICRP 22(4).

ICRP, 1999. Protection of the public in situations of prolonged radiation exposure. ICRP Publication 82. Ann. ICRP 29(1/2).

ICRP, 2006. The optimization of radiological protection: broadening the process. ICRP Publication 101. Ann. ICRP 36(3).

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 38(2–4).

ICRP, 2008. Environmental protection: the concept and use of reference animals and plants. ICRP Publication 108. Ann. ICRP 38(4–6).

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

ICRP, 2009b. Application of the Commission's recommendations to the protection of people living in long-term contaminated areas after a nuclear accident or radiation emergency. ICRP Publication 111. Ann. ICRP 39(3).

ICRP, 2012a. ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs – threshold doses for tissue reactions in a radiation protection context. ICRP Publication 118. Ann. ICRP 41(1/2).

ICRP, 2012b. Report of ICRP Task Group 84 on initial lessons learned from the nuclear power plant accident in Japan vis-à-vis the ICRP system of radiological protection. Available at: http://www.icrp.org/docs/ICRP%20TG84%20Summary%20Report.pdf

ICRP, 2014. Protection of the environment under different exposure situations. ICRP Publication 124. Ann. ICRP 43(1).

ICRP, 2016. Proceedings of the International Workshop on the Fukushima Dialogue Initiative. Ann. ICRP 45(2S).

ICRP, 2018. Ethical foundations of the system of radiological protection. ICRP Publication 138. Ann. ICRP 47(1).

Kai, M., 2015. Experience and current issues with recovery management from the Fukushima accident. Ann. ICRP 44(1S),153–161.

Liland, A., Skuterud, L., 2013. Lessons learned from Chernobyl accident in Norway. In: Oughton, D., Hansson, S.O. (Eds.), Radioactivity Social and Ethical Aspects of Radiation Risk Management in the Environment, Vol. 9. Elsevier, Amsterdam, pp. 159–176.

Little, M.P., Azizova, T.V., et al., 2012. Systematic review and meta-analysis of circulatory disease from exposure to low-level ionizing radiation and estimates of potential population mortality risks. Environ. Health Perspect. 120, 1503–1511.

Lochard, J., 2013. Stakeholder Engagement in Regaining Decent Living Conditions after Chernobyl. In: Oughton, D., Hansson, S.O. (Eds.), Social and Ethical Aspects of Radiation Risk Management, Radioactivity in the Environment, Vol. 9. Elsevier, Amsterdam, pp. 311–331.

Lochard J., Schneider T., Ando R. et al., 2019. An overview of the dialogue meetings initiated by ICRP in Japan after the Fukushima accident. Radioprotection 54(2): 87–101.

Luccioni, C., Kornevich, O., Rozhko, A., et al., 2016. Health check-ups of children living in a Belarus district contaminated after the Chernobyl accident. Radioprotection DOI: 10.1051/radiopro/2016.

Maeda, M., Oe, M., 2017. Mental health consequences and social issues after the Fukushima disaster. Asia Pac. J. Publ. Health 29, 36S–46S.

Miyazaki, M., 2017. Four and a half years of experience of a clinician born and raised in Fukushima: discrepancy found through dialogues and practices. Ann. ICRP 45(2S), 23–32.

Morita, T., Nomura, S., Tsubokura, M., et al., 2017. Excess mortality due to indirect health effects of the 2011 triple disaster in Fukushima, Japan: a retrospective observational study. J. Epidemiol. Commun. Health 71, 974–980.

NCRP, 2018. Management of Exposure to Ionizing Radiation: Radiation Protection Guidance for the United States. National Council on Radiation Protection and Measurements, Bethesda, MD.

NEA, 2006. Stakeholders and Radiological Protection: Lessons from Chernobyl 20 years after. NEA No. 6170. Nuclear Energy Agency, Paris.

Nisbet, A., Watson, S., Brown, J., 2015. UK Recovery Handbooks for Radiation Incidents 2015, Version 4. PHE-CRCE-018. Public Health England, London. Available at: https://www.gov.uk/government/publications/uk-recovery-handbooks-for-radiation-incidents-2015

Nomura, S., Blangirdo, M., Tsubokura, M., et al., 2016. School restrictions on outdoor activities and weight status in adolescent children after Japan's 2011 Fukushima Nuclear Power Plant disaster: a mid-term to long-term retrospective analysis. BMJ Open 6, e013145.

OECD/NEA, 2000. Methodologies for Assessing the Economic Consequences of Nuclear Reactor Accidents. Organisation for Economic Co-operation and Development/Nuclear Energy Agency, Paris.

OECD/NEA, 2018. Experience from the fifth international nuclear emergency exercice (INEX-5). Organisatin for Economic Co-operation and Development/Nuclear Energey Agency, Paris.

Oe, M., Takahashi, H., Maeda, M., et al. 2017. Changes of posttraumatic stress responses in evacuated residents and their related factors: a 3-year follow-up study from the Fukushima Health Management Survey. Asia Pac. J. Publ. Health 29, 182S–192S.

Ogino, H., Hattori, T., 2014. Calculation of background lifetime risk of cancer mortality in Japan. Jpn. J. Health Phys., 49, 194-198.

Ohto, H., Yasumura, S., Maeda, M., et al., 2017. From devastation to recovery and revival in the aftermath of Fukushima's nuclear power plants accident. Asia Pac. J. Publ. Health 29, 10S–17S.

Ono, A., Isojima, T., Yokoya, S., et al. 2017. Effect of the Fukushima earthquake on weight in early childhood: a retrospective analysis. BMJ Paediatr. Open 2, e000229.

Oughton, D., Albani, V., Barquinero, F., et al., 2018. Recommendations and Procedures for Preparedness and Health Surveillance of Populations Affected by a Radiation Accident. SHAMISEN Project. ISGloblal Publisher. Available at: https://www.isglobal.org/en/-/recommendations-and-procedures-for-preparedness-and-health-surveillance-of-populations-affected-by-a-radiation-accident.

Sawano T., Nishikawa, Y., Ozaki A., Leppold C., Tsubokura M. 2018. The Fukushima Daiichi Nuclear Power Plant accident and school bullying of affected children and adolescents: the need for continuous radiation education. J. Radiat. Res. 59, 381–384.

Schneider T., Andronopoulos S., Camps J., Duranova T., Gallego E., Gering F., Isnard O., Maître M., Murith C., Oughton D., Raskob W. - The work programme of NERIS in post-accident recovery. Annals of the ICRP – Vol. 47 – N° 3-4, pp. 221-228, October 2018.

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

Skuterud, L., Thorring, H., 2012. Averted doses to Norwegian Sami reindeer herders after the Chernobyl accident. Health Phys. 102, 208–216.

Strand, P., Selnæs, TD., Bøe, E., et al., 1992. Chernobyl fallout: internal doses to the Norwegian population and the effect of dietary advice. Health Phys. 63, 385–392.

Suzuki, Y., Yabe, H., Yasumura, S., et al., 2015. Psychological distress and the perception of radiation risks: the Fukushima health management survey. Bull. WHO 93, 598–605.

Takamura, N., Orita, M., Taira, Y., et al., 2018. Recovery from nuclear disaster in Fukushima: collaboration model. Radiat. Prot. Dosim. 182, 49–52.

Tanigawa, K., Hosoi, Y., Hirohashi, N., et al., 2012. Loss of life after evacuation: lessons learned from the Fukushima accident. Lancet 379, 889–891.

Togawa, K., Ahn, H.S., Auvinen, A., et al., 2018. Long-term strategies for thyroid health monitoring after nuclear accidents: recommendations from an expert group convened by IARC. Lancet Oncol. 19, 1280–1283.

Tsubokura, M., 2018. Secondary health issues associated with the Fukushima Daiichi nuclear accident, based on the experiences of Soma and Minamisoma Cities. J. Natl. Inst. Publ. Health 67, 71–83.

UNDP/UNICEF, 2002. The Human Consequences of the Chernobyl Nuclear Accident: a Strategy for Recovery. United National Development Programme, New York.

UNSCEAR, 2006. Sources and Effects of Ionizing Radiation. Vol. I. Report to the General Assembly with Scientific Annexes. United Nations, New York.

UNSCEAR, 2008. Sources and Effects of Ionizing Radiation. Vol. II. Effects. United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly with Scientific Annexes. United Nations, New York.

UNSCEAR, 2013. Sources and Effects of Ionizing Radiation. Vol. I. Effects. United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly with Scientific Annexes. United Nations, New York.

WHO, 2006. Health effects of the Chernobyl accident and special health care programmes. In: Bennett, B., Repacholo, M., Carr, Z. (Eds.), Report of the UN Chernobyl Forum, Expert Group 'Health'. WHO Press, Geneva, p. 160.

WHO, 2017. Iodine Blocking: Guideline for Use in Planning for and Responding to Radiological and Nuclear Emergencies. World Health Organization, Geneva.

ANNEX A. CHERNOBYL

A.1. Introduction

(A 1) The accident at the Chernobyl nuclear power station occurred at approximately 01:24 h on 26 April 1986 during a low-power engineering test of the Unit 4 reactor. Safety systems had been switched off, and improper, unstable operation of the reactor allowed an uncontrollable power surge to occur, resulting in successive steam explosions that severely damaged the reactor building and completely destroyed the reactor (UNSCEAR, 2000).

(A 2) The radionuclide releases from the damaged reactor occurred mainly over a 10-day period, but with varying release rates. The highest release took place on the first day. There followed a 5-day period of declining releases, then the release rate of radionuclides increased until Day 10, after which the releases dropped abruptly, thus ending the period of intense release. The radionuclides released in the accident deposited with greatest density in the regions surrounding the reactor in the European part of the former USSR. Radioactive contamination of the ground was found, to some extent, in practically every country of the northern hemisphere (UNSCEAR, 2000).

A.2. Early phase

A.2.1. Protection strategy for the early phase

(A 3) Prior to the Chernobyl accident, two published documents had summarised the protection strategy regarding dose limitation and radiological criteria to be applied in the event of a radiation emergency. The Standards of Radiation Safety (SRS-76, 1977) introduced the dose limits for workers and members of the public, and the 'Criteria for decision making on measures to protect the public in the event of a nuclear reactor accident' (Ministry of Public Health, 1983) were developed to provide radiological protection of the public in the event of a nuclear reactor accident. According to these criteria, two types of dose had to be considered: the whole-body dose due to external exposure, and the thyroid dose from radioactive isotopes of iodine due to internal exposure (Table A.1). The duration of the early phase of an accident was not formally established when the criteria were approved. With respect to internal exposure to the thyroid, both inhalation and ingestion intakes were included. The criteria presented in Table A.1 were developed in order to prevent acute health effects and to reduce the probability of stochastic health effects among the exposed population.

(A 4) The early phase of the accident started on 26 April 1986 and ended on 5 May 1986, by which time the release of radionuclides into the environment had decreased by several orders of magnitude. The most commonly considered urgent protective actions in a nuclear accident are sheltering, evacuation, intake of stable iodine to block the thyroid, and restrictions on the consumption of foodstuffs.

(A 5) However, at the time of the Chernobyl accident, the state government had a substantial impact on the timing and scale of implementation of emergency mitigation actions in the early phase of the accident. This was due to attempts to downplay the consequences of the accident, classify the information on radiological conditions, and prevent local authorities from making decisions. The Government Commission on Mitigation of the Consequences of the Chernobyl Accident had been created by the afternoon of April 26. This Commission, chaired by the Deputy Prime Minister of the former USSR, included various specialists (physicians, specialists in emergency situations and in radiation protection, etc.) as well as government officials. Although experts in all aspects of emergency situations were involved in the activities of the Government Commission, only government officials had the right to make decisions.

Table A.1. Criteria used to make decisions on the countermeasures to be taken to protect the public in the event of a nuclear reactor accident (Ministry of Public Health, 1983).

Parameter	Action level[‡]	
	A[*]	B[†]
Whole-body dose from external exposure, Gy	0.25	0.75
Absorbed dose to thyroid from intake of radioiodines, Gy	0.25–0.30	2.5
Time-integrated concentration of ^{131}I in ground-level air, kBq s L^{-1}		
Children	1480	14,800
Adults	2590	25,900
Total integrated intake of ^{131}I with foodstuffs, kBq	55.5	555
Maximum concentration of ^{131}I in fresh milk, kBq L^{-1}, or in daily diet, kBq day^{-1}	3.7	37
Ground deposition density of ^{131}I on pasture, kBq m^{-2}	25.9	259

[*]If the projected dose estimates and the levels of radioiodine contamination do not exceed Action Level A, there is no need to introduce any countermeasure.

[†]If the projected dose estimates or the levels of radioiodine contamination reach or exceed Action Level B, it is recommended that the proper countermeasures (sheltering, evacuation, and intake of stable iodine) should be introduced with urgency.

[‡]If the projected dose estimates or any level of radioiodine contamination exceed Action Level A but do not reach Action Level B, the decision to apply countermeasures depends on the actual reactor situation and on local conditions.

A.2.2. Urgent protective actions

A.2.2.1. Sheltering

(A 6) A recommendation on sheltering was announced by the Government Commission on the day of the accident (26 April 1986) for the residents of Pripyat, located approximately 3 km from the reactor site, where most of the nuclear power station workers resided with their families. Approximately 25% of the total population of 50,000 residents of Pripyat limited the time spent outdoors (Likhtarev et al., 1994). Residents in rural settlements within 30 km of the nuclear power station (30-km zone) were not officially notified of the occurrence of the Chernobyl accident. Therefore, there was no recommendation to stay indoors as much as possible.

(A 7) On 27 April 1986, between 14:30 and 17:45 h (37–40 h after the accident), all residents of Pripyat were evacuated due to continuation of radionuclide release from the damaged reactor and an increase in exposure rates in various parts of the town. The authority of Kiev Oblast[1] involved 1200 buses and three trains in the evacuation. In total, it is estimated that 49,360 people were evacuated: 33,460 by bus, 2200 by train, 5100 by private car, and 8600 moved themselves **(**Alexakhin et al., 2004). The evacuees were only allowed to take very limited belongings, mainly documents, etc., and pets. It was thought that the people were leaving Pripyat for a restricted period of time and would subsequently return. The evacuated people were moved to different areas and settlements of Ukraine, primarily located in Kiev Oblast. Approximately 5000 people, staff of the Chernobyl nuclear power station, stayed in Pripyat; these people were relocated to holiday houses within the 30-km zone on 28 April 1986.

(A 8) In the first few days following the accident, an extensive campaign of measurements of exposure rates was undertaken around the Chernobyl nuclear power station. As a result, the first map of exposure rates was prepared by 1 May 1986 by Goskomhydromet staff. According to the projected dose estimates calculated on the basis of the measured exposure rates, no evacuation was required for the overwhelming majority of the population in the 30-km zone (the criteria on whole-body dose from external irradiation in Table A.1). However, another factor, related to the reactor situation, was also taken into account: a large increase in the temperature of the fuel that remained in the reactor core was observed on 30 April 1986. The possibility that the bottom of the core would be breached, resulting in important releases of radioactive material if the core were to interact with the pressure suppression pool beneath the reactor, could not be excluded. Having analysed the existing situation, the specialists at Kurchatov Institute, Moscow did not exclude the worst-case scenario. The whole-body dose estimates calculated for the population showed that the potentially affected area, where serious deterministic effects could occur, could extend as far as approximately 30 km from the damaged reactor. As the evolution of the situation at the reactor and the meteorological conditions were unpredictable, on 2 May 1986, the Government Commission made the decision to evacuate the entire population from the 30-km zone. This evacuation (49,355 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.2.2.2. Intake of stable iodine

(A 9) Potassium iodide (KI) pills had not been pre-distributed to people living in the areas neighbouring the Chernobyl nuclear power station. Hence, on 26 and 27 April 1986, medical officers went from door to door and to schools and kindergartens in Prypiat providing members of the public with KI pills. The percentage of residents who took KI pills had 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 was effective. Distribution of KI pills in villages within the 30-km zone was initiated at approximately the same time as evacuation. According to the results of interviews of people living in the 30-km zone, the distribution of KI pills occurred mainly on 1–4 May 1986 in Belarus and on 2–7 May 1986 in Ukraine (UNSCEAR, 2000). However, this was too late and had little effect. In rural areas outside the 30-km zone, stable iodine was not used during the early phase of the accident (Uyba et al., 2018).

[1] An Oblast is a political unit approximately equivalent to a state in the USA.

A.2.2.3. Restrictions of the consumption of foodstuffs

(A 10) Due to the lack of notification of the public about the actual scale and radiation hazard of the Chernobyl accident in the first days after the accident (until 5 May 1986), no restrictions were made on the consumption of contaminated foodstuffs during the early phase of the accident. The residents of contaminated areas consumed cows' milk contaminated with ^{131}I, and this resulted in high doses to the thyroid, especially among small children.

A.2.3. Emergency responders

(A 11) The highest doses were received by approximately 600 emergency workers who were on the site of the Chernobyl nuclear power station during the night of the accident. The most important exposures were due to external irradiation, as the intake of radionuclides through inhalation was relatively small in most cases. Acute radiation sickness was confirmed for 134 emergency workers. Forty-one of these patients received whole-body doses from external irradiation <2.1 Gy. Ninety-three patients received higher doses and had more severe acute radiation sickness: 50 patients with doses of 2.2–4.1 Gy, 22 patients with doses of 4.2–6.4 Gy, and 21 patients with doses of 6.5–16 Gy. The skin doses from beta exposures evaluated for eight patients with acute radiation sickness ranged from 10 to 30 times the whole-body doses from external irradiation. Their doses were estimated mainly using clinical dosimetry methods (i.e. on the basis of blood components and/or cytogenetic parameters of blood lymphocytes) (UNSCEAR, 2000).

A.3. Intermediate phase

A.3.1. Protection strategy for the intermediate phase

(A 12) By the time of the Chernobyl accident, the concept of temporal annual limits relating to the restriction of long-term accidental exposure had been developed in the former USSR (SRS-76, 1977). Based on the actual radiological conditions following the accident, the Main State Sanitary Physician of the USSR adopted the following temporary dose limits for the public:

- on 12 May 1986, a whole-body equivalent dose of 100 mSv (50 mSv for external irradiation and 50 mSv for internal irradiation) for the first year following the accident (from 26 April 1986 to 25 April 1987);
- on 23 April 1987, an annual dose of 30 mSv (10 mSv for internal irradiation) for the second year following the accident; and
- on 18 July 1988, annual doses of 25 mSv (8 mSv for internal irradiation) for the third and fourth years following the accident. Therefore, a dose to members of the general public of up to 173 mSv was allowed from the time of the Chernobyl accident until 1 January 1990.

(A 13) On 22 November 1988, the USSR Scientific Committee for Radiation Protection recommended a limit of 350 mSv for the lifetime effective dose resulting from the Chernobyl fallout for members of the public. The USSR Government, looking for international acceptance of this lifetime dose limit, asked the International Atomic Energy Agency (IAEA) to provide its international expertise (IAEA, 1991). In 1990–1991, a team of independent international experts visited the USSR to evaluate the actual radiological consequences of the

Chernobyl accident; and consider the concepts, methodologies, and estimates of radiation doses to the population provided by the USSR scientists. IAEA noted that the implemented or planned countermeasures were too stringent from the point of view of radiation protection considerations, and suggested that the 350-mSv lifetime dose limit was too severe (IAEA, 1991). However, the 350-mSv limit was rejected by the state officials due to pressure from the public and mass media.

(A 14) By the end of 1991, the USSR had split into 15 separate countries. Of these, Belarus, Ukraine, and the Russian Federation had been strongly affected by the accident. Each of these three countries implemented their own national policy for radiation protection of the public, but all were influenced by the 1990 ICRP recommendation to adopt an annual effective dose limit for the public of 1 mSv in regulated situations.

A.3.2. Radiation monitoring

(A 15) The aim of radiation monitoring is to characterise the radiological situation. The radiation monitoring system available at the time of the Chernobyl accident included extensive exposure rate measurements, radiometric measurements of foodstuffs, and spectrometric measurements of selected environmental samples. In order to gather necessary data, intensive campaigns were initiated in Belarus, Ukraine, and the Russian Federation on measurements of exposure rates, as well as ground deposition densities of biologically important radionuclides: short-lived ^{131}I and long-lived ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$. Due to the delay in initiating extensive spectrometric measurements, data on ^{131}I measurements in soil samples were lacking.

A.3.3. Levels of contamination

(A 16) Radioactive contamination of the ground was found, to some extent, in practically every country of the northern hemisphere. Contaminated areas (where the average ^{137}Cs deposition densities exceeded 37 kBq m^{-2}) were found in many European countries. It is estimated that 13 European countries have a contaminated area (^{137}Cs of 37–185 kBq m^{-2}) more than 160,000 km^2 in size. Higher levels of contamination (^{137}Cs >185 kBq m^{-2}) were found in Belarus (19,100 km^2 with ^{137}Cs of 185–555 kBq m^{-2}), Ukraine (7200 km^2 with ^{137}Cs of 555–1480 kBq m^{-2}), and the Russian Federation (3100 km^2 with ^{137}Cs >1480 kBq m^{-2}).

A.3.4. Levels of exposure

(A 17) In May–June 1986, a large monitoring study of ^{131}I thyroid content of the public was conducted in the three most contaminated countries (Belarus, Ukraine, and the Russian Federation). In total, direct thyroid measurements had been performed for >400,000 people by the end of June 1986, including more than 200,000 people in Belarus, approximately 150,000 people in Ukraine, and 45,000 people in the Russian Federation (Zvonova et al., 1993; Likhtarev et al., 1996; Stepanenko et al., 1996; Gavrilin et al., 1999; Uyba et al., 2018).

(A 18) Consumption of fresh cows' milk from animals who had been put to pasture before the accident was the main pathway of radioiodine intake for the majority of residents. This resulted in large thyroid doses, especially of children living in rural areas in the vicinity of the damaged reactor. A high percentage of residents with direct thyroid measurements (approximately 50%) among those who lived in the most contaminated areas allowed reliable estimation of individual thyroid doses, which enabled comparison with the criteria for Action

Levels A and B to apply countermeasures (see Table A.1). A substantial number of small children (≤3 years old) from evacuated and non-evacuated villages in the three southern regions of Gomel Oblast received thyroid doses >2.5 Gy (Action Level B – which is recommended should not be exceeded), representing approximately 55% and 30%, respectively (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).

(A 19) A typical contribution of short-lived radioiodines to thyroid dose for the public is within a few percent of the dose to the thyroid from ^{131}I following the Chernobyl accident. The main short-lived radioiodines in terms of internal dose to the thyroid for the public are ^{133}I and ^{132}I (due to the intake of ^{132}Te and its radioactive decay to ^{132}I in the body) (Gavrilin et al., 2004).

(A 20) Since 1987, the doses received by the populations of contaminated areas have resulted essentially from external exposure from ^{134}Cs and ^{137}Cs deposited on the ground, and internal exposure due to contamination of foodstuffs by ^{134}Cs and ^{137}Cs. The average effective doses from ^{134}Cs and ^{137}Cs that were received during the first 10 years after the accident by the residents of contaminated areas are estimated to be approximately 10 mSv. The median effective dose was approximately 4 mSv, and it is estimated that approximately 10,000 people received effective doses >100 mSv. The lifetime effective doses are expected to be approximately 40% higher than the doses received during the first 10 years following the accident.

A.3.5. Protective actions

A.3.5.1. Relocation

(A 21) Relatively high exposure rates were measured in approximately 40 Belarusian and Ukrainian villages located outside the 30-km zone (UNSCEAR, 2000). In order to restrict external exposure to the population during the first year following the accident, delineation of contaminated areas ('zoning') was performed depending upon the value of exposure rate decay corrected to 10 May 1986. The criteria to delineate affected areas were approved by the Main State Sanitary Physician of the USSR on 12 May 1986:

- >20 mR h^{-1} – the exclusion zone, the area from which the residents were removed permanently;
- 5–20 mR h^{-1} – the temporal evacuation zone, the area to which the relocated residents were supposed to return after normalisation of radiological conditions; and
- 3–5 mR h^{-1} – the strict control zone, the area from which children and pregnant women were removed for the summer of 1986.

(A 22) As the temporal evacuation zone was formed based on geographical principles and radiation criteria, in August 1986, the Government Commission ordered Goskomhydromet, the Ministry of Public Health, and the Ministry of Defence of the USSR to conduct detailed radiation monitoring of the 47 less contaminated settlements located in southern and western parts of the evacuation zone. This was to determine the possible need to re-evacuate the residents (to return the residents back to their homes). According to the monitoring results, re-evacuation was recommended for the residents of 27 rural settlements (12 in Belarus and 15 in Ukraine) after the construction of shelters. The basic radiation criteria for re-evacuation were: radionuclide deposition densities and exposure rate less than 555 kBq m^{-2} of ^{137}Cs deposition density, 111 kBq m^{-2} of ^{90}Sr deposition density, 3.7 kBq m^{-2} of ^{239,240}Pu deposition density, and 0.2 mR h^{-1} of exposure rate decay, corrected to September 1986. Meeting these criteria guaranteed that the total dose (external plus internal) to the re-evacuated populations would not have exceeded the dose limit for 1987 (30 mSv) with a factor of 1.5–2.

(A 23) According to the recommendations of the Ministry of Public Health and Goskomhydromet of the USSR, 12 Belarusian settlements had been re-evacuated by the winter of 1986–1987 (after construction of shelters and decontamination of settlements). However, the Ukrainian authorities considered that re-evacuation of the residents inside the 30-km zone would be economically and socially undesirable, and did not support re-evacuation.

A3.5.2. Restrictions on the consumption of foodstuffs

(A 24) During the first few weeks after the accident, the most important radionuclide was ^{131}I, the concentration of which was as high as 37–370 kBq L^{-1} in some milk samples. In order to control ^{131}I concentrations in foodstuffs, the first temporal permissible levels (TPLs) of ^{131}I in foodstuffs (3.7 kBq L^{-1} for milk and water, 18.5–74 kBq kg^{-1} for dairy products and leafy vegetables) were adopted by the Main State Sanitary Physician of the USSR on 6 May 1986. Milk with a contamination level exceeding the TPL was processed into milk products (butter, cheese, etc.), which could be stored until ^{131}I decayed to negligible levels. On 30 May 1986, the Main State Sanitary Physician of the USSR revised the TPLs and decreased them significantly to total beta activity of 0.37 kBq L^{-1} for milk and water, and 0.37–18.5 kBq kg^{1} for other foodstuffs. The chronology of change of TPLs for drinking water and foodstuffs from May 1986 to 1993 is given in Alexakhin et al. (2004).

A.3.6. Decontamination

(A 25) Decontamination of the settlements included removing contaminated soil; replacing it with 'clean' soil; dismantling items which could not be cleaned; asphalting streets, roads, and pavements; replacing roofs; and burying the generated waste at temporary storage areas. Decontamination work commenced at the end of May 1986. It was undertaken primarily by the chemical branch of the USSR armed forces and the civil defence forces, and was carried out according to the zone of radioactive contamination in which the settlement was located. Standards for the levels of surface radioactive contamination of various areas (buildings, transportation facilities, etc.) began to be established in 1986, and these were intended to be used as criteria for the completeness of the decontamination effort. The permissible levels of contamination were based on the radiation dose limits for the whole body and skin. The creation of standards for surface contamination had several goals, including the introduction of corresponding sanitary–hygienic measures. Changes in the permissible levels of surface contamination for various types of items in settlements are presented in Alexakhin et al. (2004).

(A 26) Decision making on decontamination was based primarily on two criteria: (i) the radioactive contamination zone in which the item was located (almost all of the decontamination work was conducted in the obligatory resettlement zone); and (ii) the social and economic significance of the decontaminated item. Some decisions were based on the fact that the established standard for surface contamination had been exceeded.

(A 27) From 1986 to 1987, a major improvement in the situation was achieved through a radical reduction of exposure rates in various frequently visited sites in different settlements. This resulted in reducing the external dose for various professionals and some age groups (e.g.

children) by an average of 30%. By 1989, full decontamination of settlements had been virtually completed. Assessment of its efficiency showed that, on average, it did not exceed 10% (Alexakhin et al., 2004).

(A 28) Experience of the application of countermeasures following the Chernobyl accident clearly showed the importance of elaborating a general strategy and undertaking a cost–benefit analysis in the intermediate and late phases of an accident. Ineffective and expensive countermeasures should be avoided. For example, decontamination of settlements was widely applied in contaminated areas of the former USSR during the first years after the accident; this required huge resources and had relatively low effectiveness with regard to external dose reduction. Due to a lack of clear strategy, intensive decontamination was conducted in many settlements located in the 30-km zone and other contaminated areas. However, according to a further decision of the state authorities, the 30-km zone and some other highly contaminated areas were determined as ‘exclusive uninhabited territories’, so the huge resources spent on decontamination of these settlements were in vain. In another example, numerous expensive countermeasures were put in place in the months and years after the accident to protect water systems from transfers of radionuclides from contaminated soils; however, these were generally ineffective. Moreover, the above countermeasures led to relatively high exposures of the workers implementing these mitigation activities.

A.3.7. Emergency responders

(A 29) The dose limits for external irradiation varied with time and with the category of personnel. According to national regulations established before the accident (SRS-76, 1977), for civilian workers, in 1986, the dose limit of 0.05 Sv could be exceeded by a factor of up to 2 for a single intervention and by a factor of 5 for multiple interventions with agreement with the personnel. The maximum dose allowed in 1986 was 0.25 Sv. In 1987, the annual dose limits for civilian personnel were lowered to 0.05 or 0.1 Sv depending on the type of work performed on the site. However, a dose of up to 0.25 Sv was allowed by the Ministry of Health for a limited number of workers for the implementation of extremely important interventions. In 1988, the annual dose limit was set at 0.05 Sv for all civilian workers, except those involved in decontamination of the engine hall inside the sarcophagus; for these workers, the annual dose limit was set at 0.1 Sv. From 1989 onwards, the annual dose limit was set at 0.05 Sv for all civilian workers, without exception (Kryuchkov et al., 2011). It is important to stress that 0.05 Sv was the annual dose limit for workers in a planned exposure situation according to the national regulations at the time (SRS-76, 1977); therefore, these civilian workers were managed as if they were workers in a planned exposure situation. For military workers, a dose limit of 0.5 Sv, corresponding to radiation exposures during war time, was applied until 21 May 1986, when the Ministry of Defence lowered the dose limit to 0.25 Sv (Chvyrev and Kolobov, 1996). From 1987 onwards, the dose limits were the same for military and civilian personnel.

(A 30) An official registry of recovery operation workers was established in 1986. This registry included estimates of doses due to external irradiation, which was the predominant pathway of exposure for the recovery operation workers. The registry data showed that the average recorded doses decreased from year to year, from approximately 0.17 Sv in 1986 to 0.13 Sv in 1987, 0.03 Sv in 1988, and 0.015 Sv in 1989. It was generally difficult, however, to assess the validity of the results that had been reported for a variety of reasons, including: (i) different dosimeters were used by different organisations, without any intercalibration; (ii) the large number of recorded doses that were very close to the applied dose limit; and (iii) the large number of rounded values, such as 0.1, 0.2, or 0.5 Sv. Nevertheless, it seemed reasonable to assume that the average effective dose due to external gamma irradiation to recovery operation workers in the years 1986–1987 was approximately 0.1 Sv (UNSCEAR, 2000).

(A 31) Due to the abundance of ^{131}I and short-lived radioiodines in the vicinity of the reactor during progression of the accident, recovery operation workers 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 workers, thyroid doses for the recovery operation workers were estimated to average 0.21 Gy, assuming a single intake on the date of the accident and no use of stable iodine. The median value for thyroid dose:effective dose ratio was estimated to be 0.3. It should be kept in mind, however, that internal doses due to intakes of ^{131}I were negligible, in comparison with external doses, for exposures that occurred after May 1986 (UNSCEAR, 2000).

A.3.8. Participation of stakeholders

(A 32) There was no early notification of the public about the actual radiological situation following the Chernobyl accident. On the contrary, the results of measurements of exposure rate, deposition density of various radionuclides, etc. were classified. As such, the public lost confidence in information from the federal and local authorities. Radiation data only became accessible to the public 1 year after the Chernobyl accident. The years following the Chernobyl accident (late 1980s and early 1990s) coincided with the collapse of the USSR, when socio-economic conditions deteriorated drastically. Federal and local authorities tried to provide the affected population with actual information regarding radiological conditions and radiation hazards, but lack of radiation knowledge and previous behaviour of the authorities meant that it was not possible for confidence to be restored effectively. Continued efforts of the authorities to be in open contact with the public, and to involve stakeholders in decision-making processes regarding the application of countermeasures, improved the situation.

A.4. Long-term phase

A.4.1. Radiation monitoring

(A 33) Individual radiation monitoring was widely applied in contaminated areas based on the use of thermoluminescent dosimeter measurements to assess individual dose from external exposure, and whole-body counting measurements to assess individual dose from internal exposure. Effective doses from external exposure for members of the public have been estimated in Belarus, the Russian Federation, and Ukraine on the basis of: (i) the large number of measurements of exposure rates and radionuclide concentrations in soil carried out in contaminated areas; and (ii) population surveys on indoor and outdoor occupancy as a function of age, season, occupation, and type of dwelling, as well as on the basis of direct measurements with thermoluminescent dosimeters. Effective doses from internal exposure from ^{134}Cs and ^{137}Cs for members of the public have been estimated by two methods: (i) estimation of dietary intake from measured concentrations in foods and standard consumption assumptions; and (ii) whole-body counting (UNSCEAR, 2000).

(A 34) The Ministry of the Environment, Protection of Nature, and Reactor Safety of Germany organised a campaign of whole-body counting in Belarus, the Russian Federation, and Ukraine. ^{137}Cs whole-body content was monitored in approximately 300,000 people from 1991 to 1993 (Hill and Hille, 1995). For 90% of people monitored, the internal effective dose rates from ^{137}Cs were found to be <0.3 mSv year^{-1}.

A.4.2. Long-term protective actions

A.4.2.1. Long-term or permanent relocation

(A 35) Wide-scale relocation was conducted in Belarus and Ukraine in the 1990s. In Belarus, the populations of all villages in the primary relocation zone (i.e. where ^{137}Cs deposition density exceeded 1480 kBq m^{-2}) were relocated from 1991 to 2000. Over the same time period, almost 300,000 people were relocated or self-moved from areas where ^{137}Cs deposition density exceeded 37 kBq m^{-2}.

A.4.2.2. Agricultural protective actions

(A 36) Extensive countermeasures were applied to agricultural production in contaminated areas in Belarus, the Russian Federation, and Ukraine according to four relatively distinct phases, as follows (Alexakhin et al., 2004).

- During the first phase (1986–1987), while extensive radiological monitoring of agricultural products was being conducted, some expensive countermeasures that were not justified from economic or radiological viewpoints were applied.
- During the second phase (1988–1990), balanced implementation of countermeasures was undertaken on the basis of classification of the agricultural lands into three zones according to ^{137}Cs deposition density: <555 kBq m^{-2}, 555–1480 kBq m^{-2}, and >1480 kBq m^{-2}. In the intermediate zone, a range of countermeasures, including radical improvement of grassland, application of ferrocyn to cows, feeding pigs with uncontaminated fodder before slaughter, application of mineral fertilisers to potato fields, etc., were applied in order to restore agricultural production. In the zones in the Russian Federation with ^{137}Cs >1480 kBq m^{-2}, agricultural production was terminated.
- During the third phase (1991–1997), a full-scale set of countermeasures was applied in regions where agricultural production did not meet the radiological standards.
- During the final phase (1998 to the present time), there has been a progressive return to normal conditions, defined as annual dose <1 mSv. The rehabilitation of agricultural lands with ^{137}Cs contamination >1480 kBq m^{-2} has also been considered.

(A 37) The countermeasures applied in the intermediate and late phases of the Chernobyl accident to agricultural production in contaminated areas in Belarus, the Russian Federation, and Ukraine allowed for aversion of the internal collective dose of approximately 12,000–19,000 man-Sv for the period 1986–2006, or 30–40% of the internal collective dose that would have been received without the use of countermeasures (excluding thyroid dose) (Fesenko et al., 2007).

A.4.3. Health surveillance

A.4.3.1. Follow-up of people with clinically significant deterministic effects

(A 38) Following the Chernobyl accident, 134 people were diagnosed with acute radiation syndrome. Of those people with acute radiation syndrome, 28 people died within a few months after the accidents, 95% died of people had received whole-body doses >6.5 Gy. Underlying bone marrow failure was the main contributor to all deaths during the first 2 months after the accident. Patients with acute radiation syndrome are under clinical surveillance at the Burnasyan Federal Medical Biophysical Centre in Moscow, and are being followed-up by the Ukrainian Research Centre of Radiation Medicine in Kiev (UNSCEAR, 2008).

A.4.3.2. Health monitoring programme

(A 39) After the Chernobyl accident, compulsory registration and continuous health monitoring of recovery operation workers and residents of the most contaminated areas, including their offspring, were initiated throughout the USSR. Up to the end of 1991, the All-Union Distributed Clinico-Dosimetric Registry had recorded information on 659,292 people. After the dissolution of the USSR into independent states, national Chernobyl registries continued to operate, but independently. Changes in national registration criteria, compensation laws, dose reconstruction methods, and follow-up mechanisms increasingly limited the comparability of data from the different national sources. More detailed registries of exposed populations existed in the Russian Federation (Registry of Professional Radiation Workers, Registry of Military Workers, and the cohort of helicopter pilots and crew) (UNSCEAR, 2000). A number of specialised population-based registries were set up in Belarus, the Russian Federation, and Ukraine, including those for thyroid cancer and haematological malignancies.

(A 40) For more than 3 years after the Chernobyl accident, the USSR considered efforts to mitigate its consequences as an exclusively internal matter. International collaborations started to develop in 1990, and have since played a substantial role in assessment of the health consequences of the Chernobyl accident, such as the International Chernobyl Project by IAEA, the International Programme on the Health Effects of the Chernobyl Accident by the World Health Organization, and the International Programme of Screening of Children following the Chernobyl Accident by Sasakawa Memorial Health Foundation.

A.4.3.3. Epidemiological studies

(A 41) A number of epidemiological (cohort and case–control) studies were conducted in Belarus, the Russian Federation, and Ukraine. In general, these studies considered one or more of the following groups: evacuees, residents of contaminated areas, and recovery operation workers. Studies of late health consequences of the Chernobyl accident have focused on, but not been restricted to, thyroid cancer in children, and leukaemia and other cancers in recovery operation workers and residents of contaminated areas. The following health effects have been studied: (i) the occurrence of solid tumours, other than thyroid cancers, in workers or residents of contaminated areas; (ii) thyroid abnormalities in affected populations; (iii) somatic disorders other than thyroid; (iv) immunological status; and (v) adverse pregnancy outcomes.

A.4.3.4. Participation of stakeholders

(A 42) In 1986, the All-Union Institute of Agricultural Radiology founded a branch in Gomel, the present-day Research Institute of Radiology, to address the problems of agricultural production in contaminated areas, develop recommendations on 'clean' foodstuff production, and inform the public on the safety of living in such areas. In 1991, Gomel State Medical Institute was founded to train healthcare specialists who will be engaged in addressing health issues in the region. Gomel is also home to the Republican Centre of Radiation Medicine and Human Ecology, built in the late 1990s. During the same period, the Research Institute of Radiobiology of the Academy of Sciences was relocated to Gomel from Minsk. Thus, Gomel is a central point for the most important scientific and educational establishments involved in studying the post-Chernobyl consequences, developing recommendations for residents about how to live safely in affected areas, and training specialists for assignments in these areas.

A.4.4. Evolution and termination of recovery actions

(A 43) In the Russian Federation, recommendations on criteria and requirements to allow transition of settlements contaminated due to the Chernobyl accident from the recovery phase to normal living conditions have been prepared by a group of scientists from Saint-Petersburg Research Institute of Radiation Hygiene under the leadership of Prof. I.K. Romanovich (Barkovskii et al., 2012). The recommendations provide radiological and non-radiological criteria that need to be met in order to terminate long-term countermeasures, and to transit to normal living conditions, when no restrictions in terms of the radiological factor are presented.

(A 44) The radiological criterion is expressed in a numeric form – the average effective dose to the critical group of residents (10% of the most exposed residents) in a considered settlement should be <1 mSv $year^{-1}$. The considered dose is related solely to the Chernobyl component of annual exposure.

(A 45) The non-radiological criterion is to meet the requirements to have agricultural activities in the considered settlement area without any restrictions and without any application of special protective actions.

(A 46) The following additional requirements should be met.

- A plan for transition of the residents to normal living conditions, with identification of the expected date of that transition on the basis of radiation monitoring. Such a plan should be updated at least once every 5 years.
- Five years prior to the expected date of transition to normal living conditions, a programme with a set of activities providing that transition, which does not reduce the living standards of the public, should be elaborated for the considered settlement. Such a programme should be presented to the residents. Residents should be informed of the results of implementation of such a programme on an annual basis.
- After the transition to normal living conditions, radiation monitoring should be continued, as well as assessment of the annual dose from the Chernobyl component of exposure. Those members of the public whose individual effective dose due to the Chernobyl accident exceeds 70 mSv should be registered.

(A 47) However, the recommendations on the termination of recovery actions and transition to normal living conditions have not been realised in practice in the Russian Federation. They are still only recommendations. The local authorities of areas with settlements designated officially as 'contaminated settlements' are resistant to the withdrawal of this status, as this will result in the cessation of monetary compensation to the residents, and the local authorities fear social protests. Thus, in the Russian Federation, there are no legal regulatory documents determining the transition of settlements from contaminated areas to normal living conditions, and no such transitions have occurred to date.

A.5. Timeline

(A 48) Timing of the phases in the Chernobyl accident is described in Table A.2. As described in Section 2.1, transition from an emergency exposure situation to an existing exposure situation does not necessarily take place at the same time for all areas.

Table A.2. Timing of the phases in the Chernobyl accident.

Phase		
Off-site	Early phase	26 April–5 May 1986 (end of massive radioactive releases)
	Intermediate phase	5 May 1986– May 1991 [adoption of laws on the legal status of contaminated areas in Belarus (February), Ukraine (February), and the Russian Federation (May)]
	Long-term phase	First semester of 1991 onwards
On-site	Early phase	26 April–5 May 1986 (end of massive radioactive releases)
	Intermediate phase	5 May 1986–November 1986 (achievement of construction of the sarcophagus)
	Long-term phase	November 1986 onwards

A.6. References

Alexakhin, R.M., Buldakov, L.A., Gubanov, V.A., et al., 2004. Large radiation accidents: Consequences and protective countermeasures, Edited by L.A. Ilyin and V.A. Gubanov. IzdAT Publishing House, Moscow.
Barkovskii, A.N., Bruk, G.Ya., Kaduka, M.V., et al., 2012. Criteria and requirements to provide the procedure for transition of the settlements contaminated due to the Chernobyl accident from the recovery phase to normal living conditions of the residents. Methodical recommendations. MP 2.6.1.0055-11. Rospotrebnadzor, Moscow (in Russian).
Chvyrev, V.G. and Kolobov, VI., 1996. Organization of the radiation-hygiene operations conducted by the military personnel to decontaminate the Chernobyl reactor after the 1986 accident. Military Medical Journal 4: 4-7 (in Russian).
Fesenko, S.V., Alexakhin, R.M., Balonov, M.I., et al., 2007. An extended critical review of twenty years of countermeasures used in agriculture after the Chernobyl accident. Sci Total Environ 383:1–24.

Gavrilin, Yu.I., Khrouch, V.T., Shinkarev, S.M., et al., 1999. Chernobyl accident: reconstruction of thyroid dose for inhabitants of the Republic of Belarus. Health Phys;76:105-19.

Gavrilin, Yu., Khrouch, V., Shinkarev, S., et al., 2004. Individual thyroid dose estimation for a case-control study of Chernobyl-related thyroid cancer among children of Belarus – Part I: 131I, short-lived radioiodines (132I, 133I, 135I), and short-lived radiotelluriums (131mTe and 132Te). Health Phys 86, 565-85.

Hill, P. and Hille, R., 1995. Meßprogramm der Bundesrepublik Deutschland. Ergebnisse der Ganzkörpermessungen in Rußland, Weißrußland und der Ukraine in der Zeit vom 13. Mai bis 6. Oktober 1992. Report Jül-3042.

IAEA, 1991. International Advisory Committee. The International Chernobyl Project. Assessment of radiological consequences and evaluation of protective measures. Technical Report. International Atomic Energy Agency, Vienna.

Kryuchkov, V.P., Kochetkov, O.A., Tsoviyanov, A.G., et al., 2011. Chernobyl accident: doses to the emergency responders, accidental monitoring, dose reconstruction. FMBC Publishing House, Moscow.

Likhtarev, I.A., Chumack, V.V., Repin, V.S., 1994. Analysis of the effectiveness of emergency countermeasures in the 30-km zone during the early phase of the Chernobyl accident. Health Phys. 67, 541-4.

Likhtarev, I., Sobolev, B., Kairo, I., et al., 1996. Results of large scale thyroid dose reconstruction in Ukraine. In: The radiological consequences of the Chernobyl accident. Proceedings of the first international conference, Minsk, Belarus, 18-22 March 1996 Eds: Karaoglou A, Desmet G, Kelly GN and Menzel HG. EC report EUR 16544 EN. Luxembourg; 1996;1021-34.

Ministry of Public Health, 1983. Criteria for decision making on measures to protect the public in the event of a nuclear reactor accident. Adopted by the Ministry of Public Health of the USSR. 04.08.1983 (in Russian).

Nadtochiy, P., Malinovskiy, A., Mogar, A.O., et al., 2003. Experience of liquidation of the Chernobyl accident consequences. Kiev: Svit (in Ukrainian).

Savkin, M.N. and Shinkarev, SM., 2007. Prospective use of individual emergency monitoring of the public – lessons from Chernobyl. International Journal of Emergency Management (IJEM) 4:408-20.

Shinkarev, S., Voillequé, P., Gavrilin, Yu., et al., 2008. Credibility of Chernobyl thyroid doses exceeding 10 Gy based on in-vivo measurements of 131I in Belarus. Health Phys 94:180-7.

SRS-76, 1977. USSR Ministry of Health, Standards of Radiation Safety SRS-76. Moscow: Atomizdat (in Russian).

Stepanenko, V., Gavrilin, Yu., Khrouch, V., et al., 1996. The reconstruction of thyroid dose following Chernobyl. In: The radiological consequences of the Chernobyl accident. Proceedings of the first international conference, Minsk, Belarus, 18-22 March 1996 Eds: Karaoglou A, Desmet G, Kelly GN and Menzel HG. EC report EUR 16544 EN. Luxembourg; 937-48.

UNSCEAR, 2000. United Nations. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, 2000 Report to the General Assembly. Annex J. Exposures and effects from the Chernobyl accident. United Nations, New York.

UNSCEAR, 2008. Sources and Effects of Ionizing Radiation. Vol. II. Effects. United Nations Scientific Committee on the Effects of Atomic Radiation report to the General Assembly with scientific annexes, United Nations, New York.

Uyba, V., Samoylov, A., Shinkarev, S., 2018. Comparative analysis of the countermeasures taken to mitigate exposure of the public to radioiodine following the Chernobyl and Fukushima accidents: lessons from both accidents. J. Radiat. Res 59(S2), ii40-47.

Zvonova, I.A. and Balonov, M.I., 1993. Radioiodine dosimetry and prediction of consequences of thyroid exposure of the Russian population following the Chernobyl accident. The Chernobyl Papers :71-126.

ANNEX B. FUKUSHIMA

B.1. Introduction

(B 1) 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. The severe ground motions and the large tsunami led to severe damage to Fukushima Daiichi nuclear power plant, owned by Tokyo Electric Power Company (TEPCO), which is located approximately 250 km north-east of Tokyo. There were six boiling reactors at the Fukushima site; Units 1–3 were in operation and Units 4–6 had been shut down for periodic inspection outage.

(B 2) All off-site power supply was lost because of the earthquake, and the tsunami caused flooding of all power panels, except for one diesel 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 explosions in the reactor buildings of Units 1, 3, and 4. As a result of these explosions, a large quantity of radioactive material was released into the atmosphere, and was deposited on land and in the ocean.

B.2. Early phase

B.2.1. Urgent protective actions

(B 3) The evacuation of people from the vicinity of Fukushima Daiichi nuclear power plant began in the evening of 11 March 2011, with the evacuation zone 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 zone was extended to 20 km. All of these decisions were implemented based on analysis of the situation at each unit and the possible global evolution at the level of the plant. The evacuation process was complicated due to damage caused by the earthquake and tsunami, and the resulting communication and transportation problems. There were also significant difficulties encountered when evacuating patients from hospitals and nursing homes within the 20-km evacuation zone, which resulted in more than 50 deaths (NERHQ, 2011a). However, the evacuation of approximately 78,000 residents from the 20-km zone was complete by 15 March 2011

(B 4) On 15 March 2011, people living within a 20–30-km radius of the plant were ordered to shelter because of further failures at the plant, including smoke at Unit 2, and an explosion and a fire at Unit 4. Due to difficulties associated with the provision of food and the maintainance of acceptable living conditions, the national government recommended voluntary evacuation for residents in the sheltering areas on 25 March 2011 (NERHQ, 2011a).

(B 5) An order of administration of stable iodine was issued for those who were being evacuated from the 20-km zone on 16 March 2011. However, the local government did not follow this instruction because the national government had already confirmed the completion of evacuation of the 20-km zone. As the local government had distributed stable iodine tablets to the municipalities around the plant, a few municipalities instructed their residents to take the tablets. Thus, iodine thyroid blocking was not implemented uniformly, primarily due to the lack of detailed arrangements between national and local governments (ICAFN, 2011).

(B 6) When high radionuclide concentrations were detected in samples of tap water, milk, and leafy vegetables beyond the 20-km zone, the national government began to issue restrictions on the distribution and consumption of specific foodstuffs and drinking water for which the concentrations exceeded the provisional regulation values on 21 March 2011. These values were adopted from the criteria in the regulatory guide by the Nuclear Safety Commission. In April 2011, the national government reviewed an inspection plan and determined how to set and lift these restrictions to allow the distribution of food to the affected population (NERHQ, 2011a).

(B 7) On 22 April 2011, the area outside the 20-km zone for which it was estimated that the projected dose within 1 year of the accident could reach 20 mSv was designated as the 'deliberate evacuation area'. The national government issued an order that relocation of people from the deliberate evacuation area should be implemented in approximately 1 month. The criterion for relocation was selected by the government with consideration of the 20–100-mSv per year band of reference levels for emergency exposure situations recommended by ICRP. In addition, the sheltering areas within the 20–30-km zone were designated as 'evacuation-prepared areas in case of emergency', and the existing 20-km evacuation zone was established as a 'restricted area' with controlled re-entry (NERHQ, 2011a).

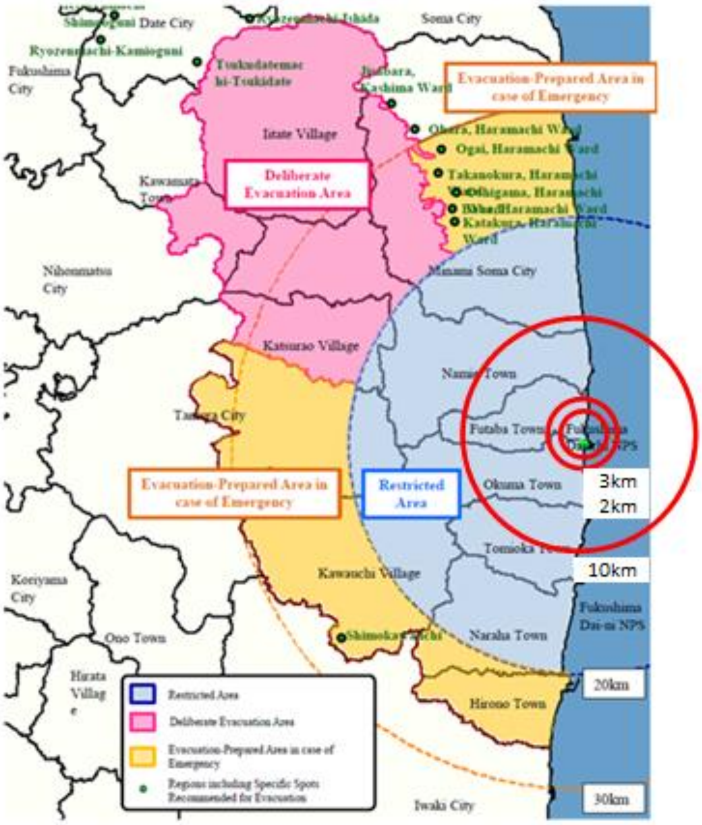

Fig. B.1. Areas and locations for which urgent protective actions were ordered in 2011.

(B 8) At the same time, the national government had to make decisions regarding the re-opening of schools (after the school holidays) outside the evacuation zone, where high levels of radiation had been detected in the school yard. On 19 April 2011, the national government decided to restrict the outdoor activities of children at schools where the annual dose could exceed 20 mSv per year. This provisional criterion was selected with consideration of the 1–20-mSv band of reference levels recommended by ICRP for managing existing exposure situations. However, this value was equivalent to the annual effective dose of 20 mSv established for the deliberate evacuation area by the national government. Consequently, the public protested strongly, claiming that this criterion to ensure the safety of children was too high when set at the same level for areas requiring relocation. In May 2011, the national government issued a notification to Fukushima Prefecture to reduce the dose to children at schools from April 2011 to March 2012 to 1 mSv, and offered financial support for decontamination to schools with dose rate measurements >1 μSv h^{-1} (ICAFN, 2011).

B.2.2. Emergency responders

(B 9) Different types of emergency responders supported the on-site and off-site emergency response. On-site emergency responders included power plant personnel employed by TEPCO or subcontracted, as well as personnel from the Self-Defence Force, firefighters, and police officers. Off-site emergency workers included personnel from various organisations and services. They were involved in the emergency response to provide support to evacuees, medical care, monitoring, and sampling.

(B 10) The severe radiological conditions associated with the accident led the authorities and the operator to adopt exceptional arrangements to ensure the protection of workers against radiation exposure on-site. During the response, the dose limit for emergency responders was temporarily increased from 100 mSv to 250 mSv. Six emergency responders received doses in excess of this level (highest dose 678 mSv), mainly due to lack of availability of adequate protective measures and lack of training (ICAFN, 2011).

B.3. Intermediate phase

(B 11) During the intermediate phase, several key issues were addressed to characterise the exposure situation in order to attain adequate knowledge of where, when, and how people are exposed and will be exposed in the future in affected areas. In May 2011, the national government established a ‘roadmap’ with successive steps to move from the emergency response to the recovery process, with the objective to return to a situation considered as ‘normal’. Characterisation of the radiological situation progressively enabled informed planning and implementation of longer-term actions, including the establishment of detailed environmental monitoring plans, long-term health surveillance, formalisation of the long-term management of radioactive waste, and establishment of long-term plans for decontamination. Application of this approach proved to be effective in the communication and preparation for long-term recovery operations (NERHQ, 2011b).

B.3.1. Emergency responders

(B 12) The increased dose criterion for emergency workers of 250 mSv was withdrawn gradually from November 2011 for newly engaged emergency workers, and since the attainment of a cold shutdown state at the plant in December 2011 for most emergency workers. However, even when this was being announced, it was obvious that there was a continued need for some TEPCO employees to be subject to less stringent dose criteria, owing to the specifics of the duties they carried out. Approximately 1 year after the accident, the increased dose criterion of 250 mSv was fully withdrawn for emergency workers.

B.3.2. Radiation monitoring

(B 13) In order to assess the impact of radioactive material released from the accident, the national government actively continued environmental monitoring. In July 2011, a monitoring co-ordination meeting was established to promote precise implementation and evaluation of monitoring based on the overall results of wide-range environmental monitoring performed by related ministries and agencies, municipalities, and the operators. The first comprehensive monitoring plan was established by the co-ordination meeting in August 2011 to move on to a new stage of radiation monitoring for the purpose of assessing the overall impact on the surrounding environment, and contributing to the review of the future protective actions to be adopted. The detailed monitoring was carried out in response to people's demands for the recovery of the environment around the plant, for children's health, and people's protection and security (NERHQ, 2011b).

B.3.3. Levels of contamination

(B 14) In May 2011, the first map of measured aerial ambient dose rate within an 80-km radius of the plant was produced jointly by the national government and the US Department of Energy. The map showed the dose rate at 1 m above the ground surface (NERHQ, 2011a). The national government has continued to conduct aerial monitoring (latest measurements taken in November 2018) in order to ascertain changes in the distribution of ambient dose rates in affected areas.

(B 15) The radionuclide analysis of soil samples collected at around 2200 locations within approximately 100 km of the plant was performed during June and July 2011; ambient dose rate measurements were also taken at the sample locations. Maps of the deposition densities of radioactive caesium and the distribution of ambient dose rates were produced in August 2011. Deposition densities of ^{137}Cs >3,000,000 Bq m^{-2} were measured in several locations close to the plant (NERHQ, 2011b).

B.3.4. Decontamination of individuals and levels of exposure

(B 16) With regard to body surface contamination of residents, screening surveys were implemented in Fukushima Prefecture, including people evacuated from the 20-km zone. Most of the 200,000 people had body surface contamination below the 100,000 counts per minute limit. Decontamination was performed for approximately 100 people who exceeded this limit, and their contamination levels fell to levels of no concern after decontamination (ICAFN, 2011; NERHQ, 2011a).

(B 17) From 26 March to 30 March 2011, a survey on thyroid exposure for infants was implemented in Iwaki City, Kawamata Town, and Iitate Village in order to understand the current exposure more precisely, particularly for infants and children who are particularly sensitive to iodine exposure. From the results for 1080 children under 15 years of age, no children exceeded the screening level of 0.2 µSv h^{-1}, which corresponds to a thyroid dose of

100 mSv for 1-year-old infants (NERHQ, 2011a). According to IAEA estimates, the geometric means of the distribution of individual equivalent thyroid doses for children up to 15 years of age derived from direct thyroid measurements are 3.2 mSv for 134 children in Iwaki City and 2.2 mSv for 647 children in Kawamata Town (IAEA, 2015c).

(B 18) A typical contribution of short-lived radioiodines to the thyroid dose for residents of areas where the main fallout occurred on 15 March 2011, and who did not consume contaminated drinking water and foods, is estimated to be within 15% of the dose to the thyroid from ^{131}I. The contribution to the thyroid dose for residents who lived in areas where the main fallout occurred on 12 March 2011 might be as great as 30–40%. The main contributors to the thyroid dose among the short-lived radioiodines are ^{131}I and ^{132}I through intake of ^{132}Te and its radioactive decay to ^{132}I in the body (Shinkarev et al., 2015).

(B 19) The Fukushima Health Management Survey, including a basic survey for external dose assessment and four detailed surveys, was launched in June 2011. Individual external doses in the first 4 months were estimated based on information on the movement of residents after the accident as recorded in response to the questionnaire, and on the daily gamma ray dose rate maps. Ninety-four percent of residents were estimated to have received doses <2 mSv, with an average dose of 0.8 mSv and a maximum dose of 25 mSv.

(B 20) As part of the preliminary survey of the Fukushima Health Management Survey, internal exposure was measured by whole-body counting and the bioassay method using urine for residents in the restricted area and the deliberate evacuation area. The estimated internal doses due to ^{134}Cs and ^{137}Cs were reported to be <1 mSv.

B.3.5. Protective actions

(B 21) As a result of monitoring conducted beyond the restricted area and the deliberate evacuation area, specific locations were identified with projected doses to residents >20 mSv within 1 year of the accident. In June 2011, the national government began to designate these locations as specific spots recommended for evacuation, and several houses were identified as such until November 2011. The national government provided information to alert the concerned residents to the possibility of radiation exposure, and supported them if they wished to evacuate (ICAFN, 2011; NERHQ, 2011b).

(B 22) In August 2011, the national government prepared a review of evacuation areas to address: (i) safety of the damaged reactors at the nuclear power plant; (ii) the decrease in air radiation dose rate; and (iii) restoration of public services and infrastructures. Based on various monitoring activities in affected areas and recovery programmes developed by all the municipalities of the evacuation prepared areas, the national government concluded that all the conditions for termination of the evacuation prepared areas had been met. The national government exchanged opinions on termination of the evacuation prepared areas and the recovery process with the leaders of the cities, towns, and villages concerned. In September 2011, a directive was issued that the emergency evacuation preparation zones should be lifted (ICAFN, 2011; NERHQ, 2011b).

B.3.6. Waste management

(B 23) Following the accident, contaminated waste off-site was classified either as debris from the earthquake and tsunami, or as a consequence of protection and 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 responsible authority established the criteria for treatment and disposal of such waste in consultation with other relevant organisations as an ad-hoc response.

(B 24) The Act on Special Measures concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake that Occurred on March 11, 2011 was enacted in August 2011 and took full effect from January 2012. The Act became the main legal instrument to deal with all remediation activities in affected areas, as well as the management of waste materials resulting from the remediation activities. 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 (NERHQ, 2011b).

B.3.7. Decontamination programme

(B 25) As decontamination was an urgent issue, the national government established a basic policy for decontamination work in August 2011, with specific targets and working principles in implementing decontamination, before the Act took effect. The national government aimed to achieve rapid, step-by-step reduction of the area with additional radiation dose >20 mSv per year. In areas with an estimated annual radiation dose <20 mSv, the national government aimed to work with municipalities and local residents to implement decontamination works, so that the additional radiation dose would be reduced to ≤1 mSv per year as a long-term objective (NERHQ, 2011b).

(B 26) For implementing decontamination in contaminated areas, the target was to reduce the additional annual radiation dose due to the accident by approximately 50% for the general public, and by approximately 60% for children, within the next 2 years, including physical decay of radioactive material and weathering effects. The long-term target was set to reduce the additional annual dose to <1 mSv per year in accordance with the recommendations of ICRP for the protection of people living in long-term contaminated areas after a nuclear accident. Associated with this objective, the national government adopted the dose rate criterion of 0.23 $\mu Sv\ h^{-1}$, including 0.04 $\mu Sv\ h^{-1}$ due to the natural background dose rate, to guide the decontamination works (NERHQ, 2011b; IAEA, 2015d).

B.4. Long-term phase

B.4.1. Recovery responders

(B 27) Following the basic policy and guidelines on decontamination work issued in August 2011, the national government issued a notification to ensure the radiation protection of responders involved in decontamination activities. Every employer was responsible for ensuring the protection of each worker engaged in decontamination work. Basically, the requirements for occupational exposure in normal operation were applied for all workers engaged in decontamination work, restoration, and waste management. Self-employed workers, residents, and volunteers who performed decontamination works in their local area were asked to follow the applicable sections of the guidelines for workers engaged in decontamination works by the national authority.

B.4.2. Decisions of authorities

(B 28) After the re-establishment of control and the attainment of cold shutdown status at the plant in December 2011, the national government re-arranged the restricted areas and the deliberate evacuation area. These areas were divided into the following three areas on the basis of the annual effective dose criterion of 20 mSv in terms of projected dose:

- Area 1 – areas where evacuation orders were ready to be lifted (estimated annual cumulative dose ≤20 mSv per year).
- Area 2 – areas in which residents were not permitted to live (estimated annual cumulative dose >20 mSv per year).
- Area 3 – areas where it was anticipated that it would be difficult for residents to return for a long time (estimated annual cumulative dose >50 mSv, estimated annual cumulative dose expected to be >20 mSv for >5 years).

(B 29) The criteria for lifting an evacuation order were as follows: (i) confirmation that the annual cumulative dose will be ≤20 mSv; (ii) confirmation that sufficient progress has been made in the general restoration of essential infrastructures, especially with regard to children's living environments; and (iii) confirmation that extensive talks had been held between local government and residents (IAEA, 2015b).

(B 30) Based on this policy, consultations and adjustments were made with Fukushima Prefecture and relevant municipalities as well as residents. Initially, three municipalities decided to make arrangements for their areas in April 2012. The period covering publication of the 'Basic Concept and Issues to be Challenged for Rearranging the Restricted Areas and Areas to which Evacuation Orders Have Been Issued where Step 2 Has Been Completed' (ICAFN, 2012) and the first re-arrangements that followed can be considered as the end of the intermediate phase of the emergency response and the beginning of the recovery process. In other words, it corresponds to an existing exposure situation.

(B 31) As shown in Fig. B.2, arrangements for areas where evacuation orders had been issued were completed in all 11 municipalities in August 2013.

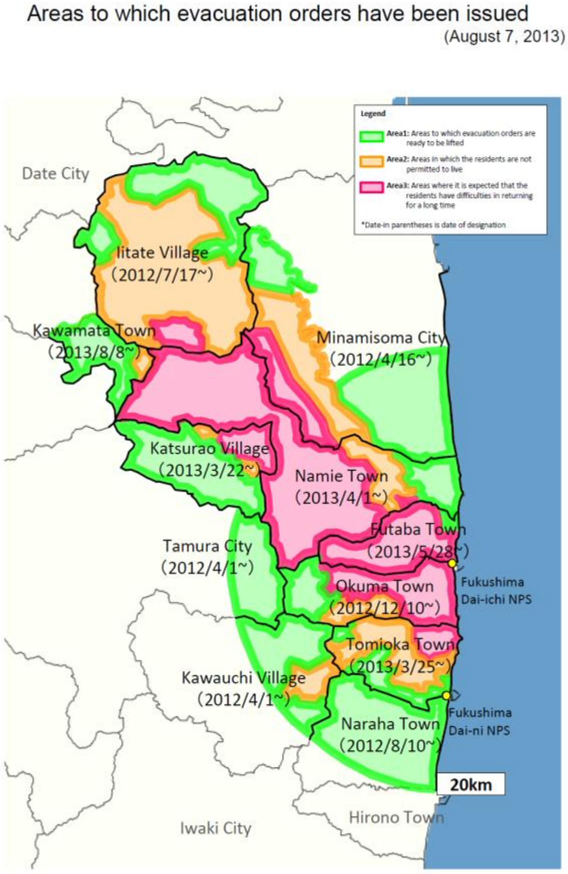

Fig. B.2. Completion of arrangements for areas where evacuation orders had been issued (as of 7 August 2013).

B.4.3. Foodstuff management

(B 32) In April 2012, the responsible authority established new standard limits for radioactive caesium in food, replacing the provisional regulatory values set in March 2011 during the emergency response. These values were designed to reduce the long-term contributions of internal dose, lowering the annual effective dose to 1 mSv. The limits took into account the 50% contribution to total consumption of food contaminated by radioactive caesium and some other radionuclides. As a consequence, these values were much lower than the provisional regulatory values they replaced (ICAFN, 2012; MHLW, 2012).

(B 33) In order to reduce internal exposure, the responsible authority restricted the distribution and consumption of food with radioactive caesium concentrations which exceed the new standard limit by extensive and comprehensive food monitoring. Based on information provided by the Ministry of Health, Labour and Welfare, the fraction of food from Fukushima exceeding the designated limit increased from 3.3% in the first year to 4.0% in the second year. However, it decreased to 1.5% in the third year and 0.6% in the final period of observation (1 April to 31 August 2014) (Merz et al., 2015). For example, the level of radioactive caesium was measured in all rice from Fukushima Prefecture, and fewer than 100 bags out of approximately 10 million were found to exceed the limit of 100 Bq kg^{-1} (Nihei et al., 2015).

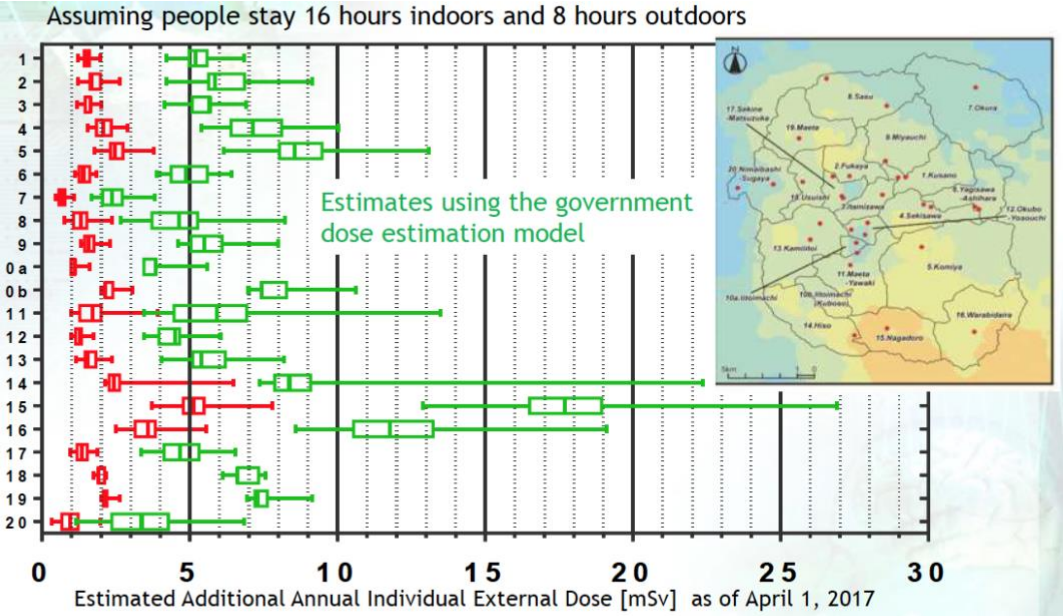

Fig. B.3. Estimates of additional annual individual external dose distribution from the Fukushima accident (Naito et al., 2017).

B.4.4. Decontamination and waste management

(B 34) Based on the Act on Special Measures Concerning the Handling of Environmental Pollution, remediation activities have been implemented extensively in affected areas since 2012 to reduce chronic exposure to external irradiation. In the case of the Fukushima accident, external exposure was the predominant exposure pathway of people in affected areas. The decontamination pilot projects were initially conducted to provide experience and tools for planning and co-ordinating efficient, safe, and cost-effective remediation programmes; evaluation of the applicability of remediation technology; and guidelines for tailoring of projects to the conditions found in different sites.

(B 35) Remediation activities were implemented in the intensive contamination survey area and the special decontamination area. The first evacuation order to be lifted was in Miyakoji District in Tamura City in March 2014. By March 2017, whole area decontamination had been completed within the special decontamination area, excluding the areas where returning is difficult. By this time, the evacuation orders had been lifted in nine of 11 municipalities. Remediation activities have generated a large amount of contaminated waste, and the national government decided to store this at temporary storage sites, then at interim storage facilities, and ultimately at a final disposal site. However, due to difficulty in obtaining agreements for the selection of temporary storage sites, some of the contaminated waste is being stored temporarily in flexible container bags near the decontamination sites.

B.4.5. The ICRP Dialogue Initiative in Fukushima

(B 36) Despite all the protective actions implemented by local and national authorities, the negative effects arising from consequences of the earthquake and the tsunami, the daily difficulties encountered by evacuees who are unable to return to their homes, and continuing concerns about radiation exposure had a large detrimental effect on the well-being of individuals and the quality of living of affected communities. It is in this difficult context that ICRP took the initiative in November 2011 to initiate a dialogue between representatives of the national authorities; local authorities in Fukushima Prefecture; local professionals; communities; media; and representatives of Belarusian, Norwegian, French, and international organisations with direct experience in managing the long-term consequences of the Chernobyl accident. The objective was to facilitate discussions between stakeholders, and to transfer experience from communities affected by the Chernobyl accident to Japan, in order to find ways to respond to the challenges of long-term rehabilitation of living conditions in affected areas. For ICRP, it was also an opportunity to learn directly from those affected in order to improve future ICRP recommendations.

(B 37) Since its inception, more than 20 main dialogue meetings have been held in Fukushima Prefecture, as well as smaller dialogue meetings in the region, and exchanges bringing a few citizens of Fukushima to areas of Norway affected by the Chernobyl accident and vice versa to share experiences first-hand. The dialogue meetings have tackled difficult problems, including dealing with contaminated foodstuffs, education of children, the question of whether to remain in or return to affected areas, and rehabilitation of living conditions. Tangible results have been achieved, such as bringing teachers together to look at educational methods and tools, changing purchasing and marketing policies of a major national food distributor, and developing a practical radiological protection culture in several communities and the implementation of self-help protective actions by many local residents.

B.4.6. The co-expertise process and self-help protective actions

(B 38) In addition to protective actions by authorities, a number of initiatives were taken by local residents in co-operation with voluntary experts to better understand the radiological situation and to improve their living conditions. Two of these, which have been well documented, are particularly rich in lessons for management of the recovery process.

(B 39) Since 2012, the residents of Suetsugi, a small community located approximately 30 km south of Fukushima Daiichi nuclear power plant, have been using personal dosimeters, made village-wide trips for whole-body counter tests, and measured food contamination throughout the village. The results have been shared openly between the residents. Obtaining and discussing their own data were crucial for residents to gain understanding of various results, and to practice radiological protection in their daily routine (Ando, 2016).

(B 40) Another interesting initiative revealed the usefulness of individual dose measurements, as they responded to the need of residents to be aware of their own dose in order to adopt adequate self-help protective actions, and the need of authorities to obtain necessary data for designing radiation protective actions for the community (Miyazaki, 2017).

B.4.7. Health surveillance

(B 41) The Fukushima Health Management Survey conducted a detailed survey of children aged ≤18 years, pregnant women, and others for whom additional surveillance is deemed necessary, as well as a basic survey of all prefectural residents. The detailed survey includes four distinct parts: (i) a thyroid examination for children aged ≤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.

(B 42) The first and second rounds of the thyroid ultrasound examinations were completed in March 2014 and 2016, respectively. Children will continue to have ultrasound examinations biennially until they reach 20 years of age, and every 5 years thereafter. Childhood thyroid cancer cases found in Fukushima Prefecture are unlikely to be the result of radiation exposure after the accident. The comprehensive medical check-ups started in July 2011. The survey of pregnant women and nursing mothers involved a questionnaire, sent out to all mothers who were given a maternal and child health handbook between 1 August 2010 and 31 July 2011. This survey is updated every year to take account of new data, particularly on pregnancy and births. The mental health and lifestyle survey was conducted twice, in January 2012 and January 2013, with questionnaires covering physiological and mental conditions, lifestyle changes, experiences of the earthquake and tsunami, and radiation-related issues to provide adequate mental care and lifestyle support for evacuees (FMU, 2016).

B.5. Timeline

(B 43) Timing of the phases in the Fukushima accident are described retrospectively in Table B.1. As described in Section 2.1, transition from an emergency exposure situation to an existing exposure situation does not necessarily take place at the same time for all areas.

Table B.1. Timing of the phases in Fukushima.

Phase		
Off-site	Early phase	11 March–May 2011 (announcement by the authorities of the roadmap for immediate actions for verification of and restoration after the accident)
	Intermediate phase	May 2011–April 2012 (first re-arrangement of the contaminated area by three municipalities)
	Long-term phase	April 2012 onwards
On-site	Early phase	11 March–April 2011 (announcement by TEPCO of the roadmap towards restoration after the accident)
	Intermediate phase	April 2011–December 2011 (announcement by the authorities that the reactors are stabilised)
	Long-term phase	December 2011 onwards

TEPCO, Tokyo Electric Power Company.

B.6. References

Ando, R., 2016. Measuring, discussing, and living together: lessons from 4 years in Suetsugi, *Annals of the ICRP 45*, 75.

FMU, 2016. Report of the Fukushima Health Management Survey, Fukushima Medical University, revised version (April 25, 2016), http://fmu-global.jp/wp-content/uploads/bnr_report_h26_e1.png.

IAEA, 2015a. The Fukushima Daiichi Accident, Report by the IAEA Director General. International Atomic Energy Agency, Vienna.

IAEA, 2015b. The Fukushima Daiichi Accident, Technical Volume 3/5 Emergency Preparedness and Response. International Atomic Energy Agency, Vienna.

IAEA, 2015c. The Fukushima Daiichi Accident, Technical Volume 4/5 Radiological Consequences. International Atomic Energy Agency, Vienna.

IAEA, 2015d. The Fukushima Daiichi Accident, Technical Volume 5/5 Post-accident Recovery. International Atomic Energy Agency, Vienna.

ICAFN, 2012. Final Report of Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company, Cabinet Secretariat of the National Government of Japan, Tokyo.

ICAFN, 2011. Interim Report, of Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company, Cabinet Secretariat of the National Government of Japan, Tokyo.

Merz, S., Shozugawa, K. and Steinhauser, G., 2015. Analysis of Japanese radionuclide monitoring data of food before and after the Fukushima Nuclear Accident, *Environ. Sci.* 49, 2875.

MHLW, 2012. New Standard Limits for Radionuclides in Foods, Ministry of Health, Labour and Welfare, http://www.mhlw.go.jp/english/topics/2011eq/dl/new_standard.pdf.

Miyazaki, M., 2017. Using and explaining individual dosimetry data: Case study of four municipalities in Fukushima, Asia Pacific Journal of Public Health 29, 110S.

NAIIC, 2012. The Official Report of The Fukushima Nuclear Accident Independent Investigation Commission, The National Diet of Japan, Tokyo.

Naito, W., Uesaka, M., Kurosawa, T., et al., 2017. Measuring and assessing individual external doses during the rehabilitation phase in Iitate village after the Fukushima Daiichi nuclear power plant accident. J Radiol Prot. 37; 606-22.

NERHQ, 2011a. Report of the Japanese national government to the IAEA Ministerial Conference on Nuclear Safety – The Accident at TEPCO’s Fukushima Nuclear Power Stations, GOVERNMENT OF JAPAN, NUCLEAR EMERGENCY RESPONSE HEADQUARTERS, Tokyo.

NERHQ, 2011b. Additional Report of the Japanese national government to the IAEA — The Accident at TEPCO's Fukushima Nuclear Power Stations — Second Report, GOVERNMENT OF JAPAN, NUCLEAR EMERGENCY RESPONSE HEADQUARTERS, Tokyo.

Nihei, N., Tanoi, K. and Nakanishi, T.M., 2015. Inspections of radiocesium concentration levels in rice from Fukushima Prefecture after the Fukushima Dai-ichi Nuclear Power Plant accident, SCIENTIFIC REPORTS | 5: 8653.

Shinkarev, S.M., Kotenko, K.V., Granovskaya, E.O., et al., 2015. Estimation of the contribution of short-lived radioiodines to the thyroid dose for the public in case of inhalation intake following the Fukushima accident. Radiat Prot Dosimetry 164:51-6.

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.

Deterministic effect

Injury in populations of cells, characterised by a threshold dose and an increase in the severity of the reaction as the dose is increased further. Also termed ‘tissue reaction’. In some cases, deterministic effects are modifiable by post-irradiation procedures, including health care and biological response modifiers.

Dose 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.

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

An exposure situation resulting from a source that already exists, with no intention to use the source for its radioactive properties, before a decision to control the resulting exposure is taken. Decisions on the need to control the exposure may be necessary but not urgent.

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.

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 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.

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.

Recovery

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

Reference level

The dose criterion used to drive the optimisation process in existing and emergency exposure situations. It is the level above which it is not appropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented. The value of a reference level will be selected within the bands recommended by the Commission according to the prevailing circumstances. This selection should consider the individual dose distribution, with the objective of identifying those exposures that warrant specific attention.

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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