Application of the Commission's Recommendations to the Protection of Individuals Living in Long Term Contaminated Territories after a Nuclear Accident or a Radiation Emergency

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PREFACE

In November 2006 the Main Commission of the International Commission on Radiological Protection (ICRP) approved the formation of a new Task Group, reporting to Committee 4, to develop guidance on the implementation of its new recommendations [ICRP 2007] to the protection of individuals living in long-term contaminated territories after a nuclear accident or a radiological event.

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

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

In developing its guidance the Task Group was encourage to coordinate with the concurrently approved Task Group in charge of elaborating recommendations on the Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations.

The present report takes account of past experience with the protection of populations living in contaminated areas, particularly in the CIS territories affected by the Chernobyl accident, and to a lesser extent to other past accidents and events that resulted in the contamination of large areas or territories. It takes also into account recent methodological and practical developments at international and national levels: the INEX programme of the Committee of Radiation Protection and Public Health of the NEA/OECD, the EURANOS Project of the European Commission, the French CODIRPA exercise, the ETHOS Project and the CORE Programme on post-Chernobyl rehabilitation in Belarus.

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

The membership of the Task Group was the following:

Jacques Lochard – France – *Chair*
Iossif Bogdevitch – Belarus
Eduardo Gallego – Spain
Per Hedemann-Jensen – Denmark
Andrew McEwan – New Zealand
Anne Nisbet – United Kingdom
André Oudiz – France (2006 - 2007)
Thierry Schneider – France
Per Strand – Norway
Augustin Janssens – European Commission (EC)
Ted Lazo – Committee on Radiation Protection and Public Health (CRPPH-NEA/OECD)
Zhanat Carr – World Health Organizations (WHO)

The Task Group met four times:

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

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

The Task Group would like also to thank those organisations and staff that made facilities and support available for its meetings. These include the Nuclear Energy Agency of the OECD (NEA/OECD) - Paris, and the World Health Organization (WHO) – Geneva.

The report was adopted by the Commission at its meeting in … on …2008.

1. INTRODUCTION

1.1 Scope

(1) In its Publication 103, the International Commission on Radiological Protection (ICRP) has described the general principles for the implementation of its system of protection in three different types of exposure situations: planned, emergencies and existing, which replace the previous distinction between practices and interventions [ICRP 2007, §176].

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

(2) The present report provides guidance on the application of the Commission's recommendations for the protection of individuals living in long-term contaminated territories resulting from either a nuclear accident or a radiological event. This "post-accident rehabilitation" situation [ICRP 2007, §240] is considered by the Commission as an *existing exposure situation*.

(3) Nuclear accidents and radiological events are generally managed according three phases: early, intermediate and late [ICRP 2008, §12, 13 and 14]. Guidance related to the management of protection strategies during the first two phases (i.e. early and intermediate phases) is provided by the report of the Task Group on the Application of the Commission's Recommendations for the Protection of People in Emergency Exposure situations. The 'rehabilitation' phase covered by this report corresponds to the late phase of a nuclear accident or radiological event.

(4) The transition from an emergency exposure situation to a following existing exposure situation takes place at the end of the intermediate phase, if any. It is characterised by a change in management, from strategies mainly driven by urgency, with potentially high levels of exposures and predominantly central decisions to more decentralised strategies aiming to achieve levels of exposures comparable to those in normal situations. These strategies must take into account the long term dimension of the situation with the direct involvement of the exposed individuals in their own protection. The Commission recommends that this transition should be undertaken in a co-ordinated and fully transparent manner and agreed and understood by all the affected parties.

(5) The change from an emergency exposure situation to an existing exposure situation will be based on a decision taken by the authorities to allow people to live permanently in the contaminated territories. This will mark the beginning of the post-accident rehabilitation phase. Implicit is the ability to provide individuals protection against the potential health consequences of the radiation and the provision of sustainable living conditions, including respectable lifestyles and livelihoods.

(6) In the case of severe accidents affecting large areas, the management of the response may need to deal simultaneously with actions relating to its different phases in different geo-

graphic areas. Thus the transition from an emergency to an existing exposure situation might occur at different times within the contaminated territories.

(7) The present recommendations have been developed for managing long-term contaminated territories from a nuclear accident or radiological event, however, many aspects may be broadly applicable to other existing exposure situations like long-lived radionuclides in human habitats resulting from past military or industrial activities.

1.2 Structure of the report

(8) The Report in Chapter 2 considers the effects of a nuclear accident or radiological event on an affected population. This includes the pathways of human exposure, the types of exposed populations, the characteristics of exposures and the experience from past events. Chapter 3 discusses the application of the Commission's Recommendations in this type of existing exposure situation, and includes consideration on justification and optimisation of protection strategies and the introduction and application of reference levels to reduce inequity in dose distributions. Chapter 4 considers practical aspects of the implementation of protection strategies, both by authorities and the affected population. Chapter 5 deals with radiation monitoring and health surveillance. Finally, chapter 6 deals more particularly with the management of contaminated foodstuffs and other commodities.

Annex A summaries past experience with contaminated areas and territories resulting from radiological events and nuclear accidents including radiological criteria followed in carrying out remediation measures. Annex B provides practical recommendations for engaging with stakeholders in the management of the radiological situation in existing exposure situations. Annex C deals with cancer risks associated with radiation exposures in contaminated territories including considerations about the statistical limitations of detecting health effects in a population exposed to low doses.

2. LIVING IN CONTAMINATED TERRITORIES

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

2.1 Exposure Pathways

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

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

2.2 Characteristics of exposures

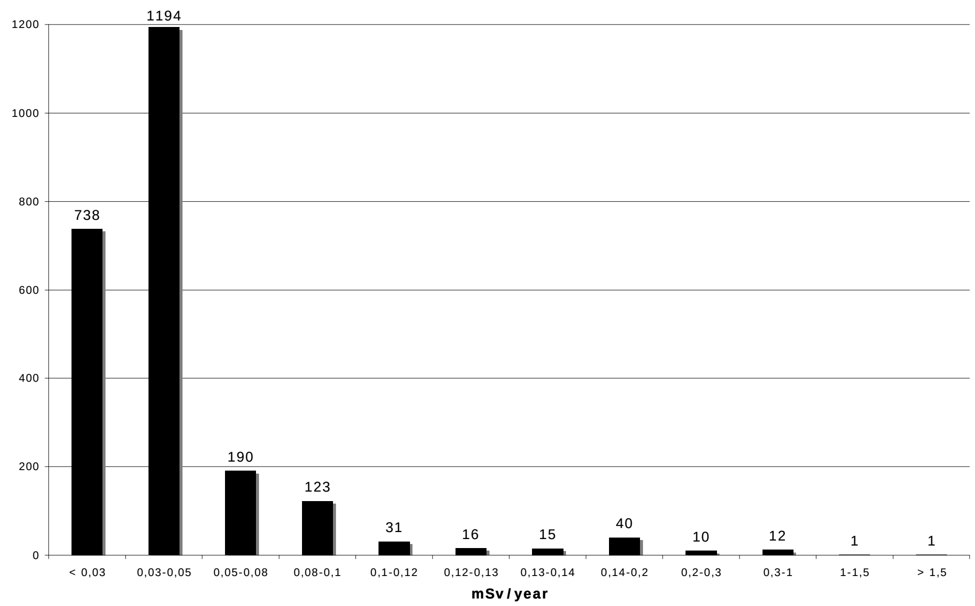
(12) In most existing exposure situations affecting the place of living of the population, the level of exposure is mainly driven by individual behaviour and is difficult to be controlled at the source. This generally results in a very heterogeneous distribution of exposures. The main

consequence from living in a contaminated territory is that it is difficult to escape from the contamination. The day-to-day life or work in such a territory inevitably leads to some exposures.

(13) The exposure situation prevailing after the termination of large scale protective actions implemented during the early or intermediate phases of a nuclear accident or a radiological event will generally show a very broad range of individual exposures, both for the doses already received and for the projected residual doses. The range of individual exposure may be affected by many individually related factors. These include:

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

Experience has shown that the use of “average individual” is not adapted for the management of exposure in a contaminated territory. Large differences may exist between neighbouring villages, within families inside the same village or even within the same family according to the diet, the living habits and the occupation. These differences generally result in a highly



skewed dose distribution among the affected population (Figure 1).

Figure 1: Typical dose distribution in the contaminated territories around Chernobyl 20 years after the accident

(14) Exposure from ingestion of contaminated foodstuffs may result from both chronic and episodic intakes according the relative importance of local produced or wild foodstuffs (berries, mushrooms, game…) in the diet. Figure 2 presents the evolution of the whole body activity associated with a daily intake of becquerels of caesium over 1000 days. The curves are provided for different age groups per daily incorporated becquerel. Figure 3 presents the evolution of the whole body activity associated with an episodic intake of 1000 Bq of caesium. *In fine*, for the same total intake, the resulting whole body activity at the end of the period is significantly different. This illustrates the intrinsic different burden between ingesting day-by-

day contaminated foodstuffs when living permanently in a contaminated territory and ingesting from time to time contaminated foodstuffs. In practice, for people living in contaminated territories, the whole body activity is resulting from a combination of daily and episodic intakes depending on the origin of foodstuffs and the dietary habits.

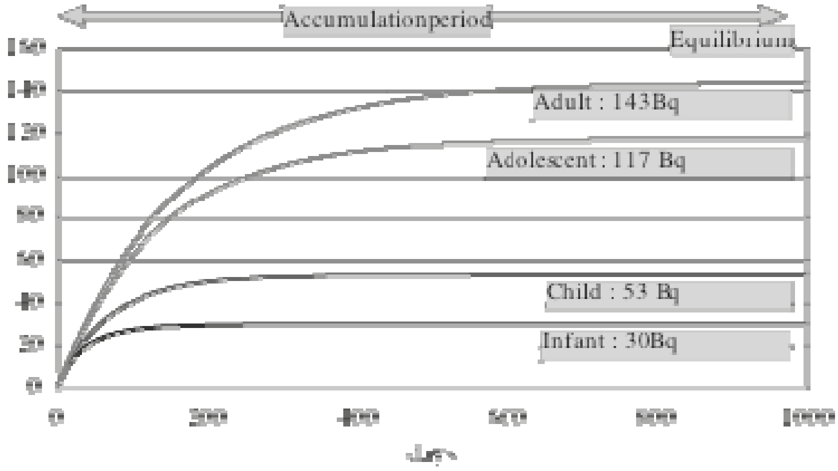


Figure 2: Evolution of the whole body activity associated with a daily intake of 1 becquerel of caesium over a pluri-annual period

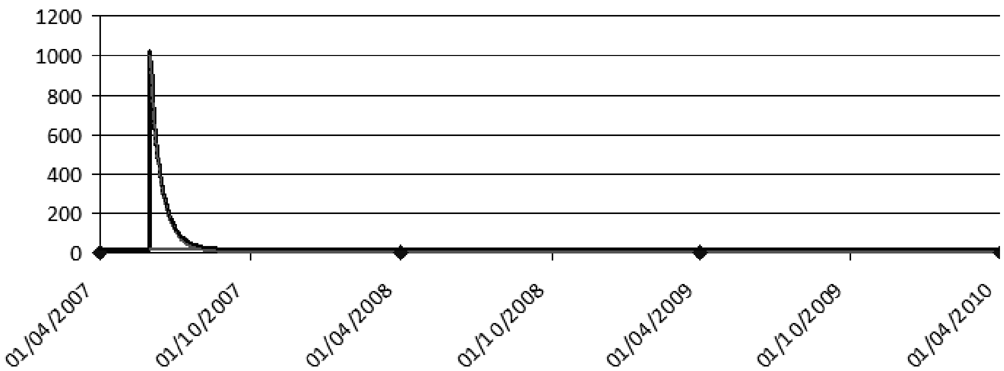


Figure 3: Evolution of the whole body activity associated with an episodic intake of becquerels of caesium over a pluri-annual period

(15) Twenty years after the accident typical average daily intake of an adult in the contaminated territories around Chernobyl due to caesium-137 is in the range of 10 to 20 Bq to which some additional higher episodic intakes in the range of a few hundreds Bq are common due to the ingestion of wild mushrooms or berries for example. This results in annual effective doses in the range of 0.1 mSv. As the annual dose is directly proportionate to the daily intake, doses in the range of 1 mSv/y and 10 mSv/y correspond respectively to a daily intake of 100-200 Bq to 1000-2000 Bq. These upper values are not compatible with “the desire from the exposed individual, as well as from the authorities, to reduce exposures to levels that are closed to or similar to situations considered as normal” that is present in many existing situations as indicated by the Commission in Publication 103 (§288). Such a consideration is important for the selection of the relevant reference level (see Chapter 3).

(16) For the sake of controlling exposures in long term contaminated territories, different exposed groups of populations may need to be considered to assess the overall dose impact in individuals. The typical groups of population generally considered are:

a) the ‘rural’ population, where farmers or families with small holdings are assumed to reside and work in the affected area, and to derive much of their food from locally grown products, and

b) the ‘urban’ population, where people inhabit houses constructed in an affected built-up area, but may derive foodstuffs from outside the affected area.

In addition, various groups of exposed workers may also need to be considered according the economic activities affected like foresters and employees of sawmills for example in the case a forest region is impacted. Members of these groups may reside in the contaminated area or just stay during working hours and reside outside the affected zone. In the later situation most of their food will come from non-contaminated territories. If the region has attraction for tourism, transient resident population may also need to be considered with its peculiarities.

2.3 Experience from past events

(17) There have unfortunately been in the past several nuclear tests (on Bikini Island in the Pacific, at Maralinga in South Australia and at Semipalatinsk in Kazakhstan) and several nuclear accidents (Windscale in United Kingdom, Kyshtym in Russia, Palomares in Spain) that have resulted in the contamination of large areas or territories. One can also mention the more recent Goiânia radiological source accident in Brazil which resulted in the contamination of a site rather than a territory. These events have provided significant experience that is of practical value in developing appropriate management approaches to address long-term post-accident radiological but also social, economic, and political issues. However, the Chernobyl accident in Ukraine and other non-radiological event that caused long-term social disruption (flooding, earth-quakes…) brought the most important lessons that have served as input for the Commission in its development of these recommendations. More details about the nuclear events can be found in Annex A.

(18) The complexity of the situations resulting from widespread and long lasting contaminations inevitably generates concerns and anxiety among the affected populations, which feel helpless in front of the contamination. Experts and professionals in charge of managing the situations generally use scientific terms, measurement units and technical procedures, which are difficult to understand by non-specialists and indirectly tend to re-enforce their feeling of loss of control of the situation.

(19) A commonly observed consequence is the progressive renouncement of individuals to involve themselves in the day-to-day management of such complex situations and their confrontation with a multitude of questions, which remain in most cases without answers. Is it possible to live further in the contaminated territory? What are the long-term effects of radioactivity on health? Is it possible to protect oneself from the contamination? As a result, inhabitants of contaminated territories are often facing difficult personal choices concerning their future and are particularly confronted to the dilemma to leave the place or to stay. Experience shows that it is difficult to answer to this dilemma relying solely on radiation protection considerations. Many personal aspects are entering into the balance and generally people living in contaminated territories are very reluctant to leave their homes and they are preferably desiring to improve their living conditions. This calls for authorities not only to develop protective actions but also favour initiatives for enhancing the quality of life of the residents of the territories.

(20) Past experience with long-term contamination after a nuclear accident has also shown that the affected populations tend to adopt a denial or fatalist attitude to face day after day the radiological situation. This is a way to support further the situations, which generally results

in neglecting basic radiation protection actions and in increasing exposures. Some individuals however, are able to face the situation and to maintain vigilance. This is only possible with a good knowledge of the situation and the possibility to act in a prudent way, which implies to be personally involved in the rehabilitation process with the objective to improve the daily life.

(21) Various projects implemented in the contaminated territories in Belarus (see Annex 1) have demonstrated that the involvement of inhabitants and local professionals in the decision making process is an effective way to improve rehabilitation process [Lochard 2007]. This requires a regular information on the successes and difficulties within the implementation of protection strategies. In this perspective, authorities must shift as soon as possible after the early phase of an emergency to decentralized approaches favouring the empowerment of the population. This must be done taking into account the local living conditions to allow individuals to understand and assess their personal situation and to protect themselves and their offspring for the future. The role for the authorities (both national and local) should be to create the best conditions so that the population can get involved in their own protection. The aim should be to help individuals to regain control of their lives, in which radiation protection against the existing contamination is a factor to add to several other factors affecting the rehabilitation of living conditions.

3. APPLICATION OF THE COMMISSION'S SYSTEM TO THE PROTECTION OF POPULATIONS LIVING IN CONTAMINATED TERRITORIES

(22) Living or working in contaminated territories is considered as an existing exposure situation. For such situations, the fundamental protection principles include the justification of implementing protection strategies, and the optimisation of the protection achieved by these strategies. Reference levels are used during optimisation to restrict individual doses. Dose limits do not apply because existing exposure situations cannot be managed in an *a priori* fashion.

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

3.1 Justification of protection strategies

(24) The principle of justification is a *source-related* principle, ensuring that any decision that alters the radiation exposure situation should do more good than harm. As far as an existing exposure situation following an emergency exposure situation is concerned, the principle of justification is intrinsically linked to the fundamental decision, taken at the end of the emergency exposure situation, to allow people to live permanently in the long term contaminated territories. Such a decision may be accompanied by the setting of a radiation protection criterion above which it is mandatory to relocate the population and below which inhabitants are allowed to stay subject to certain conditions. Several areas may be defined with relevant conditions according to a graded approach. For example, this is the approach that was adopted in the early nineties in the CIS countries affected by the Chernobyl accident (Annex A).

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

(26) Justification is concerned with the cumulative benefits and impacts of individual protective actions composing the protection strategy. A range of individually justified actions may be available but may not provide a net benefit when considered as an overall strategy because, for example, collectively they bring too much social disruption for the considered exposed population as a whole, or they are too complex to manage. Conversely, a single protective action may not be justified alone, but may contribute to an overall net benefit when included as part of a protection strategy.

(27) In existing exposure situations justification should be considered differently for two broad categories of protective actions: those implemented by authorities, experts and professionals and those directly implemented by the exposed individuals as self-help protective ac-

tions. The protection strategy defined by the authorities should take into account both categories of protective actions, and should in fact enable affected individuals to take self-help initiatives. However, as far as self-help protective actions are implemented – and thus largely decided – by the inhabitants themselves, they must be properly informed and if relevant trained (to use the means and equipments provided by the authorities) in order to take informed decisions concerning their own protection, with a net benefit. The balance to be considered by the individuals includes, on one side, their desire to improve the situation and, on the other side, the 'burden' induced by the implementation of protective actions.

(28) According to the radiological situation prevailing after the emergency, authorities may consider to maintain protective actions already implemented during the emergency exposure situation but also to introduce new ones. The decision on whether to introduce these new actions will depend on several criteria including the residual individual levels of exposures of the residing population, the feasibility of implementing new actions and the impact these actions will have on the quality and sustainability of the living conditions in the territory.

(29) The responsibility for ensuring an overall benefit to society as well as to individuals when populations are allowed to stay in contaminated territories lies with governments or national authorities. Worldwide experience following nuclear and non-nuclear accidents shows that neither nations nor individuals are willing to abandon the affected territories easily. In general, wherever possible, authorities will aim at rehabilitating these territories to allow further human activities.

3.2 Optimisation of protection strategies

(30) The principle of *optimisation* of protection is - like the principle of justification - a *source-related* principle, which should ensure the selection of the best protection strategy under the prevailing circumstances, i.e., maximising the margin of good over harm. In order to avoid severely inequitable outcomes of this optimisation procedure, there should be restrictions on the doses or risks to individuals from a particular source through the application of dose or risk reference levels. Therefore, optimisation involves keeping exposures as low as reasonably achievable, taking into account economic and societal factors as well as any inequity in the distribution of doses and benefits amongst those exposed.

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

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

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

- Consumer versus producer interest: to live in a territory supposes that an economic activity is maintained on the spot with local production and trade of goods including foodstuffs. Optimisation strategies should balance the need to protect individuals against distribution of radioactivity and the need for the local economy to exist and to be integrated in the global market;
- Local population versus national and international population: the conditions to restore a kind of "normal" life in the contaminated territories suppose solidarity in sharing some disadvantages of the situation between local and non-local populations (mainly related to the movement of goods and people). Optimisation strategies should favour equity taking into account national regulation and plans as well as international recommendations (e.g. on trade of foodstuffs);
- The multiple decisions taken by the inhabitants in their day-to-day life: in most cases, the level of exposure is driven by individual behaviour. The inhabitants should define and apply their own optimisation strategies. A positive aspect is that individuals regain control on their own situation. However, self-help protective actions may be disturbing (e.g. pay constant attention to the food one eats, the places one goes, the material one uses, the things one touches in order to avoid as much as possible internal and external exposure). This supposes that affected individuals are fully aware of the situation, well informed, properly equipped and possibly trained (for the use of equipment provided by the authorities).

As it was said previously, taking into account that the predominant pathway in contaminated territories is generally ingestion, optimisation strategies should therefore be based on controlling this pathway in relation with relevant groups of population.

(34) Unlike emergency exposure situations, for which time is a stake in terms of urgency, in case of living in a contaminated territory, what is at stake is the long term. This sounds both positive, because it is possible to spread in time the optimisation process of protection strategies aiming to achieve exposure comparable to those in normal situations, and negative, because individuals are day-to-day exposed during a long time. This process should then be considered as a step by step one.

(35) The Commission has introduced the concept of constrained optimisation. In case of existing exposure situations, like for emergency exposure situations, the dose restriction is termed "reference level". Reference levels should be set according to Publication 103 recommendations (see below section 3.3).

(36) Optimisation of protection strategies is the process of developing the strategy's form, scale, and duration. The aim is to obtain not only a positive net benefit, but also a maximised net benefit, and decision-aiding techniques can be used to guide the selection of protection strategies and their various elements. The Recommendations of the Commission on how to apply these techniques have been provided earlier in publications 37 [ICRP 1983], 55 [ICRP 1989], 63 [ICRP 1991b], 101 [ICRP 2006], and these recommendations remain valid and are not repeated in detail here. In the process of selecting strategies for protecting people living in contaminated territories, the participation of relevant stakeholders is essential.

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

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

(39) The best option or strategy is always specific to the exposure situation and represents the best level of protection that can be achieved under the prevailing circumstances. Therefore it is not relevant to determine, *a priori*, a dose level below which the optimisation process should stop [ICRP 2007, §218]. According to the characteristics of the situation, with the presence of relatively long lived radionuclides in the environment affecting places of living, protective actions are expected to be implemented during a long time (several tens of years). Optimisation of protection, however, is not minimisation of dose. Optimised protection is the result of an evaluation, which carefully balances the detriment from the exposure and the resources available for the protection of individuals. Thus the best option is not necessarily the one with the lowest dose [ICRP 2007, §219].

(40) Optimisation also relates to the cycle of assessment and further practical guidance. It is the government's responsibility to provide good guidance, and to provide the means to implement it. Hence the government, or the responsible authority, will need to constantly evaluate the effectiveness of the protection strategy in place, including protective actions carried out at local or individual level, in order to provide better guidance and support on how to further improve the situation.

3.3 Reference levels to restrict individual exposures

(41) The use of reference levels for the management of both emergency and existing exposure situation is a change from Publication 103 [ICRP 2007] compared to Publication 60 [ICRP 1991a]. Some other ICRP Publications issued in between already introduced the concept of reference level as appropriate to manage prolonged exposure situations but Publication 103 clarifies the concept.

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

the situation and the optimisation process may apply to initial levels of individual doses above the reference level.

(43) The Commission recommends that reference levels, set in terms of individual annual effective residual dose (mSv in a year), should be used in conjunction with the implementation of the optimisation process for exposures in existing exposure situations. The objective is to implement optimised protection strategies, or a progressive range of such strategies, which will reduce individual doses below the reference level. Priority should be given to reduce any exposure that is above the reference level to a level where protection is optimised and hopefully the exposure is below the reference level. However, exposures below the reference level should not be ignored; they should also be assessed to ascertain whether protection is optimised or whether further protective actions are needed [ICRP 2007, §286].

(44) In case of existing exposure situation following an emergency exposure situation, the reference level is set at the end of the emergency exposure situation, i.e. during the transition between intermediate (if any) and late phases of a nuclear accident or a radiological event, when the decision is taken to allow people to live in a contaminated territory. The selected reference level represents a level of ambition, with the intention to strive to move all individual exposures below this level as low as reasonably achievable, social and economic factors being taken into account.

(45) The Commission proposed a framework presenting the factors influencing the choice of source-related dose constraints and reference levels [ICRP 2007, Table 5, p. 97]. In that framework, the Commission has introduced three bands of constraints or reference levels according to the characteristics of the exposure situation taking into account the controllability of the exposure, the benefit from the situation to individual or society and the radiological protection requirements that would need to be implemented. These requirements include the need or not to establish protection strategies as well as to provide information, training and/or monitoring to exposed individuals. It is the responsibility of regulatory authorities to decide on the legal status of the reference level set to control a given situation. In general reference levels are not mandatory.

(46) In case of an existing exposure situation following an emergency exposure situation, the radiation source is under control but the controllability of the situation may remain difficult and request a constant vigilance from the inhabitants in their day-to-day life. This constitutes a burden for the individuals living in contaminated territories and for the society as a whole. However both may find a benefit to continue to live in the affected areas. Countries generally cannot afford to lose a part of their territory, and in general most inhabitants would prefer staying in their home rather than being relocated (voluntarily or not) to non-contaminated territories. As previously said, numerous radiological protection requirements are needed to allow people to continue to live in contaminated territories. These considerations suggest that appropriate reference levels should be preferably chosen in the '1 to 20 mSv' band proposed by the Commission.

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

(48) As far as the long-term objective is to reduce exposures to a level comparable to those in normal situations and providing that the optimisation can only be implemented step-by-step, the appropriate reference level should logically be chosen in the lower range of the band

i.e. close or equal to 1 mSv/y. According to the situation, such a level may not be suitable at the beginning of the situation, e.g. after a severe accident. The national authority may then usefully take into account the timing of the strategy and set intermediate reference levels higher than 1 mSv/y but remaining inside the '1-20 mSv' band.

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

(50) The use of reference levels in an existing situation is illustrated in Fig. 4, which shows the evolution of the distribution of individual doses with time as a result of the implementation of protection strategies. The evolution of the distributions indicates that the number of people in the contaminated areas exceeding the reference level is decreasing with time as a consequence of the introduced optimisation process.

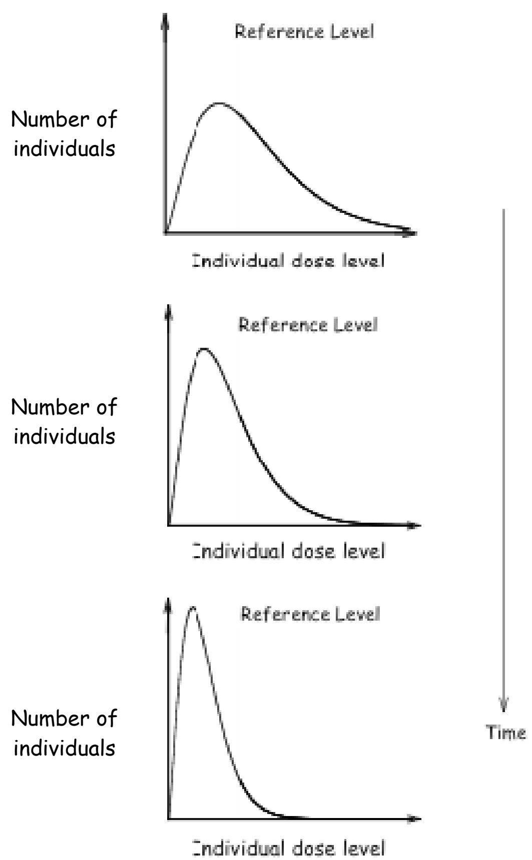


Figure 4. Use of a reference level in an existing exposure situation and evolution of the distribution of individual doses with time as a result of the process of implementation of the protection strategy.

(51) The fact that exposures have been reduced below the reference level is not a sufficient condition to discontinue protective actions as long as there is room for further reducing exposures in conformity with the optimisation process. The continuation of such actions would

probably be a prime mechanism to maintain exposures comparable to those in normal situations as recommended by the Commission.

4. IMPLEMENTATION OF PROTECTION STRATEGIES

(52) The management of an existing exposure situation relies on the implementation of a wide rehabilitation programme coping with numerous dimensions (social, economic, health, environmental…). The radiation protection part of this programme is characterised by a combination of radiation protection strategies: those driven by authorities at the national and local levels and others based on self-help protective actions implemented by the affected population. In some situations protection strategies driven by authorities may dominate, whilst in others, local initiatives and self-help actions will be of greater significance, although for these to be successful, authorities should provide the necessary infrastructure as well as practical guidance. The implementation of protection strategies will be a dynamic process and their relative components (either driven by authorities or the affected population) will change with time.

(53) It is the role of the authorities to establish the conditions, particularly at the regulatory level, and to implement the means to allow the effective engagement of the affected population in the protection strategies and more globally in the rehabilitation programme. Past experience with the management of contaminated territories has demonstrated that the involvement of local professionals and inhabitants in the implementation of protection strategies is key to the sustainability of the rehabilitation programme [Lochard 2004]. Practical recommendations for engaging with stakeholders in the management of the radiological situation in existing exposure situations are given in Annex B.

4.1 Strategies implemented by authorities

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

(55) This assessment can often most effectively be carried out through individual whole-body counting. If measurements are not feasible it is possible to estimate the dose likely to be received by the individuals based on local information. In such a situation, the concept of "representative person" as described in Publication 101 [ICRP 2006] may be used bearing in mind that this concept is most useful for the purpose of prospective assessments of continuing exposure. In case it is however used, the Commission recommends not to discarding the doses related to the 95-100 % percentile.

(56) Once the individual dose distribution is characterised, it is necessary to further investigate the main exposure pathways for the affected population (ambient dose rates, soil contamination, foodstuffs contamination…). This will help authorities, in cooperation with the affected population, to decide if they need to pursue protection strategies implemented during the early phase (decontamination works, foodstuffs restrictions…), to modify them according to the evolution of the radiological situation, or to establish new strategies.

(57) Typical strategies to be implemented by the authorities in a post-accident situation are clean up of buildings, remediation of soils and vegetation, changes in animal husbandry, monitoring of the environment and produce, provision of clean foodstuffs, managing of waste (resulting from clean up, or from unmarketable contaminated goods), provision of information, guidance, instruction as well as equipment (e.g. for measurements), health surveillance,

education of children, and information for particular exposed groups and the public at large, etc.

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

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

(60) In this perspective, authorities will have to set up infrastructures to support the dissemination of a "practical radiological protection culture" within all segments of the population, and especially within professionals in charge of public health and education. Experience has shown that the development of such a culture is based on 3 key pillars:

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

4.2 Strategies implemented by the affected population

(61) In case of a radiological accident, the affected population will be confronted to new problems and new preoccupations. Each individual will have questions regarding radioactivity and its effects: how is the environment contaminated, how is one exposed, and at which moments particularly, is one contaminated? One will also wonder how to face to this new situation, what to do concretely, by oneself, to reduce his/her exposure as low as reasonably achievable and to avoid or minimize future exposures.

(62) Typical actions to be taken by the inhabitants (self-help protective actions) will be based on the characterisation of their own radiological situation, notably their external and internal exposure. They will then mainly consist in monitoring their own exposure as well as the exposure of the people for whom they have responsibility (children, elderly…) and in adapting their way of life to reduce their exposure.

(63) As far as the evaluation of external exposure is concerned, inhabitants can manage to establish a local mapping of their living places (house, garden, working place, leisure areas...). They can then identify places where the higher ambient dose rates are registered and/or those

contributing significantly to the external dose according to the time spent. In both cases, it is then possible to try to minimize as far as possible time spent in these places.

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

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

(66) Beyond their contribution to individual exposure, self-help protective actions can also concern the management of the radioactive contamination of the environment. In that perspective, the affected population should take care to adopt protective actions that would avoid re-concentration of radioactivity in their local areas: a particular attention will have to be paid to the management of radioactive house waste as for example ashes from fireplaces in rural areas.

(67) As underlined before, authorities will have to facilitate the implementation of protection strategies by the inhabitants. They can provide with existing results of measurements, information and training to help people to understand and manage their radiological situation and monitoring equipment (for example, making the equipment available through local doctors or pharmacies who are trained to make measurements). Furthermore, they should ensure regular whole body measurements of the affected population so that people can evaluate the efficiency of changes in their diet.

(68) Authorities will also have to facilitate the setting-up of local forums involving representatives of the affected population. These forums will allow to gather and to share information and favour a common assessment of the effectiveness of both strategies driven by the populations or the authorities.

5. RADIATION MONITORING AND HEALTH SURVEILLANCE

As recommended by the Commission in the case of an existing exposure situation, individuals concerned should receive general information on the exposure situation and the means of reducing their doses. In situations where individuals life-styles are key drivers of the exposure, individual monitoring is an important requirement. Furthermore, because of the uncertainties concerning the differed potential effects of the emergency phase but also the late phase, it is the responsibility of the authorities to implement an health surveillance programme.

5.1 Radiation monitoring

(69) In a situation of long-term contamination, it is essential to benefit from a radiation monitoring system allowing the follow-up of the radiological situation and the definition of radiation protection strategies. The key objective of monitoring systems is to assess current and predict future levels of human exposures (both external and internal).

(70) In practice, this supposes to beneficiate from a radiation monitoring system dealing with measurements of whole body contamination, of concentrations of radionuclides in foodstuffs and the environment, and of ambient dose rates.

(71) The efficiency of the monitoring system will rely on its capacity to cope with specificities of the local affected territory. The more the measurements will be adapted to the local situation, the more they will allow to identify population groups receiving elevated doses in a contaminated area (inhabitants, workers, visitors and tourists) and to orientate radiation protection strategies.

(72) In this purpose, a key issue will be to beneficiate from radiological competence at the local level in combination with the national system. Furthermore, the existence of measurements from different origins - authorities, expert bodies, local and national laboratories (NGOs, private institutes, universities, nuclear installations…) – will allow a better understanding of the radiological local situation and favour confidence in the measurements among the affected population.

(73) The monitoring system should be designed to provide regularly updated information and to allow an extended coverage of the affected territory on a long-term perspective. The sustainability of such a system will require the establishment of continued maintenance and training programmes by the national and local authorities.

5.2 Health Surveillance

(74) Following a radiological event, the exposed population should have an initial medical evaluation. Beyond the identification of people who need specific medical care, this first examination may help to determine potentially susceptible or sensitive subgroups that need further health surveillance. In addition, regardless of the level of dose, the affected population should also be supplied with accurate and appropriate information regarding their level and potential type of risk.

(75) Taking into account these different individual situations, long-term health surveillance programmes will have to cover the three following objectives [WHO 2006]:

- The follow-up of persons who have received absorbed doses that have resulted (or may eventually result) in clinically significant deterministic effects (such as skin burns, cata-

racts etc.).
- The "medical monitoring" of the general population. It consists in investigating for potential adverse events (mainly incidence of radiation induced cancers). A subcategory of medical monitoring is the follow-up of potentially "sensitive subgroups" (e.g. children).
- And finally, "epidemiological" studies.

(76) The medical monitoring refers to the screening of the whole affected population in order to detect specific preclinical disease with the purpose of delaying or preventing the development of disease in those individuals. The first step will be to justify and delineate the extend of the programme based on consideration of a number of factors. For instance the following characteristics are of prime importance: the exposure of concern (e.g., its certainty, dose and temporal relationship of exposure to observation); the disease of interest (e.g., its natural history and prevalence in the population); the characteristics of available screening tests (e.g., their effectiveness, sensitivity and specificity); the potential for the tests used to cause harm themselves; the potential for action when test results are positive (e.g., the availability of and risks from follow-up evaluation); whether there is evidence that an intervention can improve the clinical outcome; the latency period between radiation exposure and the development of a clinically detectable tumor.

(77) According to WHO definitions [WHO 2006], the aims of epidemiological studies in a long-term perspective are to:

- Identify adverse health effects in an at-risk group and to determine whether the risk of such effects is greater than that for a comparable non-exposed group of individuals,
- Determine whether the increased risks that may be identified are associated statistically with the exposure,
- Determine whether the increased observed risk is related to or influenced by other factors associated with or independent of the exposure, such as tobacco smoking and radon,
- Add to the scientific knowledge base, which can then be used to derive and refine risk estimates and to develop interventions.

(78) In practice epidemiological studies will be adjusted and implemented according to the following considerations: size and composition of the study population, magnitude and distribution of radiation exposure, accuracy of the exposure measurements, disease identification and associated background rate, availability of information on other risk factors that might affect the outcome.

(79) Further considerations on cancer risk perspectives of living in contaminated areas and territories are provided in Annex C.

6. MANAGEMENT OF CONTAMINATED FOODSTUFFS AND OTHER COMMODITIES

(80) Ingestion of foodstuffs is generally the main exposure pathway for a population living in a long term contaminated territory. Long-term restrictions on the consumption of foodstuffs are difficult to maintain and are, in principle, incompatible with the sustainable development of the territory. Reducing exposure from ingestion to as low as reasonably achievable may involve the implementation of more complex protection strategies. The development and implementation of such strategies require the full involvement of relevant stakeholders. Reconciling the interests of local farmers and the local population with those of consumers and the food distribution sector from outside the contaminated territory has to be considered carefully. Determining optimal protection strategies for contaminated foodstuffs may be perceived differently for the population living inside the contaminated territory than for those living outside.

6.1 Protection of population inside the contaminated territories

(81) A fraction of the diet of the local population may include local agricultural produce, food from private gardens as well as food gathered from the wild (e.g. berries, mushrooms, game). The relative importance of local produce depends on the characteristics of the region, as well as on traditions or habits. To some extent such habits may be influenced, either by a preference for food that is less contaminated, or as a result of the availability of food from non-contaminated areas. The local population may also be in a position to control its intake of radionuclides because not all produce in the territory will be contaminated to the same extent. Furthermore, the population may choose to reserve the least contaminated food to the most sensitive groups of population or those perceived to deserve special protection (e.g. children, pregnant or breastfeeding women, people with poor health condition).

(82) In order to help the local population to control foodstuffs, authorities should provide relevant information and set derived reference levels (DRLs) from the annual dose reference level, expressed in Bq/kg or Bq/l, taking into account the proportion of locally produced food in the diet. Values have been developed by the Codex Alimentarius Commission (CAC) for use in international trade [FAO/WHO 2006]. The Guideline Levels are based on an intervention exemption level of 1 mSv in a year assuming that a maximum of 10% of the diet consists of contaminated food. The term "intervention exemption level" was introduced by ICRP in Publication 82 but is no longer used. It had the connotation that no action is warranted below this level ("non-action level"), as opposed to the concept of reference level introduced by ICRP in Publication 103 below which optimisation is required. The assumption that 10% of the diet is contaminated may not be valid for some local communities, hence the DRLs may be set below the Guideline Levels. Conversely, if the contamination affects only a few categories of foodstuffs the DRLs may be set to higher values. Higher DRLs 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. Disruption to the local economy through the placing of restrictions on the sale of contaminated foodstuffs, the loss of market share as a result of consumer preferences, or through the provision of uncontaminated, cheap food may not be warranted in terms of a benefit in dose reduction. Such decisions must be taken in close cooperation with the local stakeholders as was the case in Norway with reindeer meat produced by the Sami population after the Chernobyl accident [Skuterud *et al.* 2005].

(83) The radiological quality of foodstuffs can be managed by many protective actions aimed at reducing the transfer of radionuclides in the foodchain from farm to fork (Nisbet *et al.* 2006). These protective actions include for example, the physical and chemical treatment of soils, changes in husbandry practices, provision of feed additives to livestock, selection of alternative land uses as well as industrial scale food processing to remove contamination). The actions selected will depend on the physical and chemical properties of the radionuclides released, season of the year and the types of land use affected. Whenever possible, protective actions should be implemented so that restrictions on local produce can be avoided. There may be situations where a sustainable agricultural economy is not possible without placing contaminated food on the market. This will necessitate an effective communication strategy to overcome the negative reactions from consumers outside the contaminated territories.

6.2 Protection of population outside the contaminated territories

(84) The protection of the population living outside contaminated territories is mainly driven by the control of trade. Consumers from non-affected territories generally expect un-contaminated foodstuffs to be placed on the market. However, this situation may not always be achievable for the following three reasons. The interests of the affected population living in the contaminated territories need to be considered as it may be important to maintain some form of agricultural production there. Furthermore, foodstuffs coming from outside the contaminated territories may have some contamination present even though it is below the DRL. There is also an intrinsic difficulty in ensuring that radiological control will cover all foodstuffs everywhere and at all points in time.

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

(86) The restoration and maintenance of consumer confidence is of prime importance in the management of contaminated foodstuffs. Traceability of food is an important factor in consumer preferences. The region of origin providing an indicator which ICRP views as being sufficient for purposes of marketing, but such market mechanisms are beyond the scope of ICRP recommendations.

(87) The Commission takes the view that, despite the socio-economic complexity of the management of contaminated foodstuffs in view of the interests of different stakeholders, protection strategies should be developed to meet the established reference level and the strategy should be further optimised at all levels where it is possible to intervene: production, distribution, processing, as well as measures taken for informing consumers and allowing them to

make appropriate choices. Derived reference levels expressed in Bq/kg or Bq/l play an important role in this process, in particular for the placing of foodstuffs on the market.

(88) For the management of the radiological quality of foodstuffs in a country with a contaminated territory, the general population must be involved as a stakeholder in deciding whether their individual preferences should outweigh the need for maintaining agricultural productions, rehabilitation of rural areas and a decent living for the local community. A thorough debate at national level is necessary to achieve a certain degree of solidarity within the country.

6.3 Management of other commodities

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

(90) The Commission recommends the development of optimisation strategies, including the prevention of contamination (for example, by substitutes whenever possible and relevant, taking into account that agriculture in contaminated territories may be deliberately reoriented towards non-food products), and management of contaminated commodities. Such contaminated commodities can be traded and used with or without conditions. Relevant DRLs should be determined depending on the intended use of the commodities and the conditions for trade or use.

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

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

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ANNEX A

HISTORICAL EXPERIENCE WITH CONTAMINATED AREAS AND TERRITORIES AFTER NUCLEAR EVENTS

1. Bikini

(A.1) Between 1946 and 1958, Bikini Atoll was used for atmospheric tests of nuclear weapons. It was the site of 23 of the 66 underwater, ground-level and above-ground tests conducted in the Marshall Islands. As a result of the above-ground tests, and in particular the high-yield CASTLE series of tests, the land surfaces and the lagoon became extensively contaminated with radionuclides, of which caesium-137 subsequently proved to be the most radiologically important.

(A.2) The inhabitants of Bikini Atoll were voluntarily relocated to Kili, a small island remote from the testing, but some of them returned after a preliminary radiological survey of the atoll in 1970.

(A.3) Measurements carried out between 1975 and 1978, however, revealed that the caesium-137 body contents of the resettled people had increased by factors of about ten since their return to the atoll. The increase was attributed to high caesium uptake from the soil by coconut trees, producing high caesium concentrations in the coconut milk and flesh consumed by the Bikini islanders, so that in 1978 the population was again relocated. Scientific studies of the radiological conditions at Bikini Atoll have continued, but the population has not so far been able to return.

(A.4) It is considered that, without remedial action or restrictions on their behaviour, returnees to Bikini Atoll would on average receive an annual dose of 4 mSv from the remaining contamination. The highest plausible doses to individuals who might consume only locally grown foods rather than the more typical mix of local and imported foods are estimated to be about 15 mSv/year.

(A.5) The projected doses are largely from caesium-137 in foods and the soil. As regards the other radionuclides still present at significant levels, strontium-90 uptake in foods is low because of strong competition from high levels of (chemically similar) calcium, while plutonium and americium isotopes are largely "trapped" in lagoon sediments, uptake into fish and other forms of seafood being extremely low.

(A.6) In radiological protection terms, the contamination of Bikini Atoll represents a chronic exposure situation in which one form of intervention (evacuation of the population) has already occurred and other forms of intervention (remedial measures) are being considered in order to allow the population to return. International radiological protection guidance on intervention in a range of chronic exposure situations suggests that some form of intervention to reduce or avert exposure is normally necessary if doses to the most exposed people would otherwise exceed about 10 mSv/year.

(A.7) A possible protection strategy to allow he population to return on the island is soil removal in residential areas and potassium treatment of the existing soil in crop-growing areas. Soil removal would reduce doses from external exposure, and from inhalation and inadvertent ingestion of soil, in the areas where islanders spend most time. The potassium treatment would reduce doses from intakes of caesium in food, the main contributor to the overall projected doses.

(A.8) The Bikini soils are deficient in potassium, so that caesium - which is chemically similar - is readily taken up by plants. Experiments have shown that if potassium, in the form of fertilizer or potassium chloride, is added to soils so that there is much more potassium than caesium available to plants, the uptake of caesium can be reduced dramatically. On the basis of extensive trials, it has been estimated that a programme of potassium treatment, repeated every 4-5 years, would reduce caesium-137 concentrations in typical Bikini foods to well below the FAO/WHO Codex Alimentarius guidelines for international trade in foodstuffs. Projected doses would be reduced to about 0.4 mSv/year from the normal mix of local and imported foods, or to 1.2 mSv/year from a diet of exclusively local produce.

(A.9) An alternative option would be to remove the topsoil from the crop-growing areas as well as the residential ones. This would undoubtedly be effective in reducing exposures, perhaps more so than the potassium treatment. However, it would generate very large volumes of soil requiring safe disposal. Furthermore, replacement soil would need to be imported. The financial, environmental and social costs of this option would probably be much greater than the first option and deserve to be evaluated n a proper optimization process.

(Main reference: http://www.iaea.org/About/Policy/GC/GC40/Documents/gc40inf5ac-6.html)

2. Maralinga

(A.10) Australia established criteria in 1990 for the rehabilitation of former British nuclear test sites in Australia. At two of these sites, Emu and the Monte Bello Islands, there was little need for remediation. However, at Maralinga, several locations were contaminated with plutonium that had been dispersed locally by chemical explosions.

(A.11) Following extensive experimental studies at Maralinga, it was established that the inhalation of respirable plutonium contaminated dust by a critical group of Aborigines, living a semi-traditional life-style, was the dominant pathway for exposure in most cases. A second important pathway was the incorporation of plutonium, by way of wound contamination, at least in areas where many plutonium-contaminated fragments or particles were to be found.

(A.12) The general criterion for the clean-up was to undertake remedial measures to ensure that annual effective doses to the critical group under conditions of full-time occupancy should not exceed 5 mSv. The remediation strategy took several forms.

- Removal of soil from areas where the ^{241}Am exceeded 40 kBq m^{-2} (*i.e.* about 300 kBq m^{-2} of plutonium as the plutonium to americium ratio is about 8), with a restriction on land use which prohibits camping but allows access for hunting or transit. This figure was based on observations of the likely proportion of time to be spent in the area on allowed activities. Approximately 2 km^2 of soil has been removed from the most contaminated areas with the required end state being that after clean-up:
  - the residual americium activity should not exceed 3 kBq m^{-2}, averaged over a hectare;
  - no particles or fragments should remain with activities greater than 100 kBq of americium;
  - not more than 1 particle per m^2 should remain with activities above 20 kBq of americium.
- An outer boundary, marked by heavy-duty galvanised steel posts at 50 m intervals, warns that camping is not permitted within the area. These warning signs generally follow the

road system and contain all areas where continual occupancy would lead to doses in excess of 5 mSv a^{-1}.

- Twenty-one pits, containing unknown quantities of plutonium, but possibly with an overall content of about 2 kg, will be immobilised by *in-situ* vitrification.

(A.13) The removed soil has been buried nearby in a (200 m × 100 m × 15 m) pit with a 5 m cover of uncontaminated rock and soil.

(A.14) The actual clean-up at Maralinga began with site preparations at the beginning of 1996, and took about 4 years.

(Reference: CARE report)

3. Chernobyl/CIS countries

(A.15) The Chernobyl accident that occurred in April 1986 resulted in a widespread contamination of inhabited areas in the republics of Ukraine, Russia and Belarus of the former USSR. During the months following the emergency phase, concern raised progressively about whether or not further relocation of populations and supplementary countermeasures were needed. The long term rehabilitation issue emerged progressively during the late eighties when it became more and more evident that the protection strategies adopted after the emergency phase, basically aiming at moving away the inhabitants from the most contaminated areas and reducing and controlling the contamination in the environment whenever possible, were insufficient to durably protect the population still residing in less contaminated but large territories.

(A.16) The long lasting contamination in these territories was a permanent worry for the population as far as health was concerned because of the remaining uncertainty concerning protracted exposure, particularly due to internal contamination. It was also a very serious handicap for the long-term preservation of the quality of life of the inhabitants and the sustainable maintenance of the socio-economic infrastructures. This led the governments of Belarus, Russia and Ukraine to elaborate and adopt ambitious national laws in the early nineties in an attempt to organize radiation monitoring and health surveillance and to improve the social and economic living conditions of the population residing in the contaminated territories. The objective of these laws was mainly to address long-term issues through a series of national countermeasures and compensation mechanisms, designed mainly according to radiological protection criteria.

(A.17) In Belarus, for instance, two laws were published to define the principles governing the social protection of the population affected and the status of contaminated areas. The first law, voted in February 1991, concerns “the social protection of citizens affected by the disaster at the nuclear power plant of Chernobyl” and clarifies the status of those affected by the accident: liquidators, populations and workers in the contaminated areas, as well as the compensation allocated in each case. The second law, voted in November 1991, concerns “the legal status of the contaminated areas following the disaster at the nuclear power plant of Chernobyl” and controls the status of the affected areas, as well as living conditions and economic and scientific activities. It also stipulates the zoning organisation of the Belarus regions (Table A.1). Both laws concern about 2 million Belarus people and recognise that 20% of the Belarus territory (about 40,000 km^2) are contaminated.

Table A.1 Zoning criteria adopted in Belarus in 1991

Zoning criteria	Official designation of zones
37 < ^{137}Cs < 185kBq/m^2 Individual dose < 1mSv/yr	Periodic radiation monitoring
185 < ^{137}Cs < 555kBq/m^2 18.5 < ^{90}Sr < 74kBq/m^2 0,37 < Pu < 1.85kBq/m^2 Individual dose > 1mSv/yr	Zone with resettlement rights
555 < ^{137}Cs < 1480kBq/m^2 74 < ^{90}Sr < 111kBq/m^2 1.85 < Pu < 3.7kBq/m^2 Individual dose < 5mSv/yr	Zone of secondary resettlement
^{137}Cs > 1480kBq/m^2 ^{90}Sr > 111kBq/m^2 Pu > 3.7kBq/m^2 Individual dose > 5mSv/yr	Zone of priority resettlement
Zone of evacuation (exclusion zone)	

(A.18) Schematically, the rehabilitation programs adopted in the early nineties relied on restricting further the human presence in the contaminated territories (mandatory or voluntary relocation) and on strictly controlling the level of contamination in foodstuffs and the whole body contamination of individuals. Many countermeasures were focused on the control and improvement of the radiological quality of agricultural products in collective farms; private productions being restricted as much as possible because of the difficulty to control and monitor their qualities.

(A.19) In 2001, the law on "the social protection of citizens affected by the disaster at the nuclear power plant of Chernobyl" was amended and clarified. It was then established that in areas where conditions of life and work are not subject to any restriction, the average total exposure (external and internal) of the population should not exceed 1 mSv per year (excluding background). This low stipulated that:

- If the average exposure of the population is more than 1 mSv per year, protective measures must be implemented;
- If the average exposure of the population is between 0.1 and 1 mSv per year, actions to reduce exposures should not be deleted but adapted to the situation;
- If the average exposure of the population is less than 0.1 mSv per year, protective measures are not necessary;
- Actions should be undertaken so that the annual dose of critical groups do not exceed 0.3 mSv per year.

(A.20) As far as the control of foodstuffs is concerned authorities have adopted a pragmatic approach consisting in regularly reducing the concentration limits as he situation was favourably evolving. Table A.2 illustrates the evolution of the food concentrations limits from 1986 to 1999 in Belarus.

Table A.2. Evolution of the caesium-137 contamination limit in foodstuffs in Belarus from 1986 to 1999

	Contamination in Cs-137 (Bq/kg, Bq/L)			
Foodstuffs	1986	1993	1996	1999
Drinkable water	370	18,5	18,5	10
Milk	370	111	111	100
Butter	7400	-	185	100
Meat :				
Beef	3700	600	600	500
Lamb	3700	-	600	500
Pork, poultry	3700	370	370	180
Potatoes	3700	370	100	80
Fruits	-	-	100	40
Wild berries	-	185	185	185
Fresh mushrooms	-	-	370	370
Dried mushrooms	-	3700	3700	2500
Baby food	-	-	-	37

(A.21) It is to note that this legal framework remained with minor changes the basis of the successive rehabilitation programmes that have been implemented until the late twenties i.e more than twenty years after the accident.

(A.22) Despite the huge amount of national resources dedicated to the rehabilitation programmes in the early nineties the protection strategies failed to take properly into account the complexity of the situation created by the contamination. In particular, they did not succeeded to mobilize the local communities and the individuals who progressively felt completely powerless in the face of the radiological situation. The general loss of quality of products, commodities and assets combined with the rising concern about the presence of the contamination and its potential health consequences continued to undermine the quality of life of the families, in fact the large majority of the population, which had made the choice to stay in the affected territories. Altogether these factors contributed to generate among the inhabitants a general feeling of loss of control on daily life, exclusion and abandonment.

(A.23) During the mid nineties, the continuous degradation of the economic situation due to both the collapse of the USSR and the financial burden of the rehabilitation programs, pushed the inhabitants of the territories to restart private production and to rely ever more on wild products to ensure their daily subsistence. In the absence of individual know-how and adequate means to control the radiological quality of the foodstuff at the local level, the effect of this change was inevitably a significant increase of the level of exposures within the population and particularly among children because of the importance of dairy products in their diet. This put a strong pressure on the authorities and experts and contributed to aggravate further the loss of confidence of the population in their ability to manage the situation.

(A.24) Facing this difficult context authorities tested new approaches, as for example in the context of the ETHOS Project in the late nineties and the CORE programme in the early twenties in Belarus, with the objective to directly involve the population in the management of the radiological situation. These new approaches demonstrated that the direct involvement of the local stakeholders in the day-to-day management of the radiological situation is feasible and evidenced the potential for implementing many protective actions in the day-to-day life in complement of the collective actions taken by the authorities.

(Main references: Lochard J., 2007, Rehabilitation of Living Conditions in Territories contaminated by the Chernobyl Accident: The ETHOS Project., Health Physics, 93 (5): 522-526

Bataille, C., Croüail P., 2005, Analysis of the regulations concerning the control and the monitoring of soils, foodstuffs and commercialised products in Belarus (Analyse des dispositifs réglementaires concernant le contrôle et le suivi de la contamination des sols, des denrées alimentaires et des produits commerciaux en Biélorussie) CEPN report n°291))

4. Chernobyl/United Kingdom

(A.25) Radiocaesium originating from the accident at the Chernobyl nuclear power plant in the Ukraine was deposited across the United Kingdom on 2-4 May 1986. Highest levels of radiocaesium deposition, in the range 20-40 kBq m-2, occurred in the uplands of western Britain, where sheep farming is an important agricultural activity. A countrywide programme of sampling carried out after the accident identified sheep meat as the foodstuff of most concern. To protect consumers, a maximum limit of 1,000 becquerels per kilogramme (Bq/kg) of radiocaesium was applied to sheep meat affected by the accident. This limit was introduced in the UK in 1986, based on advice from the European Commission's Article 31 Group of experts. Under powers provided in the Food and Environment Protection Act 1985 (FEPA), Emergency Orders have been used since 1986 to impose restrictions on the movement and sale of sheep exceeding the limit in certain parts of Cumbria, North Wales, Scotland and Northern Ireland. The Emergency Orders define geographical areas, often termed 'restricted areas', within which the controls must be followed. Under the FEPA Orders, sheep with levels of contamination above the limit are not allowed to enter the food chain. Due to the particular chemical and physical properties of the peaty soil types present in the upland areas of the UK, the radiocaesium is still able to pass easily from soil to grass and hence accumulate in sheep. Consequently, more than 20 years after the accident, areas exist where restrictions are still in place. Initially these restricted areas were large, but have reduced substantially as levels of radioactivity have fallen, with all restrictions lifted in Northern Ireland in 2000. The table A.3 below gives a breakdown of the number of sheep and farms under restrictions for 1986, 1990, 2000 and 2007. The restrictions which were implemented as a response to an emergency exposure situation have become part of a protective strategy for what is now considered as an existing exposure situation.

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

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

(A.26) There were no practicable protective measures that could be implemented in the restricted areas to reduce levels of radiocaesium in vegetation due to the physical limitations of the terrain and the environmentally sensitive nature of these areas. Nevertheless, the development of a very well designed monitoring programme following the Chernobyl accident did enable lamb production to be sustained and the livelihoods of sheep farmers to be protected. Furthermore, consumer confidence in lamb was maintained. The monitoring programme known as the 'Mark and Release' scheme has operated in the restricted areas since 1986. Under this scheme, a farmer wishing to move sheep out of a restricted area can have the animals monitored to determine their level of radiocaesium. A live monitoring technique is used, which to allow for inherent variability in live monitoring results, applies a working action level of 645 Bq/kg (rather than 1,000 Bq/kg), Any sheep which exceeds the working action level are marked with a dye and are not released from restrictions. Those which pass are allowed to enter the food chain.

(A.27) Since 1986, sheep farmers in the restricted areas started to become aware that their lambs could pass the ‘Mark and Release’ test if they were brought down from the upland unimproved pastures to improved lowland pasture for a period of fattening prior to slaughter. Subsequently, these sheep farmers have adapted their husbandry practices to either make use of their own improved land or rented land, to fatten their lambs prior to slaughter. Live monitoring has become part of this routine and is generally accepted by farming communities as the new normality. The restrictions will remain in place for several years to come.

(Key reference: AF Nisbet and RFM Woodman, 2000, Journal of Environmental Radioactivity 51: 239-254 Options for the management of Chernobyl-restricted areas in England and Wales)

ANNEX B

PRACTICAL RECOMMENDATIONS FOR ENGAGING WITH STAKEHOLDERS IN THE MANAGEMENT OF THE RADIOLOGICAL SITUATION IN EXISTING EXPOSURE SITUATIONS

(B.1) In recent years, stakeholder issues have moved steadily to the forefront of policy decisions and are key to the development and implementation of radiological protection strategies. As experience in stakeholder engagement has grown, it has been possible to use many of the lessons learned as a basis for the development of best practice among the radiological protection community. Processes and tools are becoming established that can be generally applied to situations where the input and views of stakeholders are required. The process of engaging with stakeholders involves five distinct steps which follow a logical sequence: preparation, planning, engagement, evaluation and application.

(B.2) *Preparation*. Opportunities for proactive engagement need to be identified by developing a good understanding of the issues at stake. The method of engagement should be proportionate to these issues and their context, bearing in mind that there will be resource if not time constraints. The appointment of a leader who is well respected and a good communicator is important. The leader and his/her team can be independent, or selected from central Government departments and agencies, or from local authorities. They should aim to seek out and involve a wide range of stakeholders as all aspects of life need to be considered when undertaking the sustainable management of long-term contaminated territories.

(B.3) *Planning.* The engagement should be initiated as early as possible and requires the development of a sustainable plan. The engagement could be a one-off process but is more likely to be implemented over an extended period in contaminated territories to build a common understanding and shared vision of how to manage the area. Planning involves establishing the objectives, scope, format and mode of engagement, the identification of potential stakeholders and the design of the engagement i.e. agendas and meeting logistics including any rules to be applied. A non exhaustive list of the most commonly used modes of engagement, their key features, benefits and limitations is given in Table B1.

(B.4) *Engagement*. At the start of the engagement, the roles, responsibilities and accountabilities of all participants should be established. Openness, inclusiveness and transparency, which are interrelated, should constitute the essence of a successful engagement and should be present throughout the process. It is important to share the relevant information needed to build a collective understanding of the issues. The information should be presented in a simple non-scientific language. It should be concise, clear to all and honest. Each stakeholder needs to recognise their own and each others' uniqueness and to be aware that other participants may view issues from different perspectives and to respect this. The acceptance of diverse perspectives, thinking and values has the potential to enrich the process, providing that the process is controlled such that any entrenched views and ideologies, if present, are managed by agreed mechanisms.

(B.5) ***Evaluation.*** When engaging with stakeholders an opportunity should be provided for both the stakeholders and those responsible for the process to give mutual feedback on the approaches and tools used and on eventual outcomes. This serves to inform and improve ongoing processes as well as influencing how future ventures should be conducted. The following types of criteria can be evaluated: appropriateness of the terms and timing of engagement, the quality and appropriateness of the information provided; comprehensiveness of the issues that were addressed; inclusivity of the stakeholders involved; practicability/feasibility of the eventual outcomes.

(B.6) *Application.* When a stakeholder engagement process comes to an end, it is important that those responsible for the process make the results known to all those who participated. If these results do not reflect the recommendations/findings from the stakeholders, those responsible must offer an explanation to the stakeholders for any deviation from what was agreed. In this way, the feedback of results and decisions will help to maintain confidence in the process.

Table B.1. Modes of stakeholder engagement (non exhaustive)

Method	***Participants***	***Duration***	***Benefits***	***Limitations***
Citizens' jury	Approx 12 lay people.	One-off event	Ideally, the jury themselves identify the information they require and the sources they wish to cross question. The organisers then produce the appropriate 'witnesses'.	Less flexible than the citizens' panel, and therefore is less open to reformulation.
Citizens' panel	Around 12-25 lay people	3-5 days.	Highly flexible. Can be used to link to other methods. Can be customised for a wide range of topics or questions.	
Consensus conference	Around 16 lay people make up a panel: Experts are selected by the panel members for the 'public session'.	Several weeks/months	Information is more comprehensively provided in this method than in any other lay public method. The technique of asking participants to identify information needs and sources gives it more openness.	
Focus groups	Invited participants who are screened against certain criteria (e.g. social, cultural) to make up a sub-group, comprising 6-10 members.	1 day	Excellent method for getting detailed responses to a few specific questions. Simple, low-cost method.	The results can be affected by the method of questioning and how representative the target group is.
Public meeting	Open to any interested member of the public or a particular community. There is also usually a 'top table' providing information and responding to points raised from the floor.	1 day	Allow a 2-way information flow where everyone is entitled o express an opinion and share perspectives and concerns.	
Round table	Could be particular groups or a range of groups. Generally limited to 8-12 participants.	Can meet over a few hours or several days, or repeatedly over several months.	Informality and simplicity make them more accessible to a range of groups.	Limited flexibility given the commitment to small group, equal status discussion.
Stakeholder dialogue	Groups; ranging from small local groups to large national players. Individuals are generally excluded	Ongoing, ideally until all participants feel there is nothing left to discuss. In practice, it is limited by funding provided.	Controlled by the participants. Open and inclusive.	Can sometimes lack transparency.
Stakeholder forum	Representatives of key stakeholder groups	Depends on the issue being discussed. Can run for one or more days.		Numbers are limited to enable effective discussion; this can lead to accusations of exclusivity.
Standing panel/working group	Approximately 20 members by invitation. Good balance between governmental and non-governmental organisations.	The lifetime of a project (can be many years). Determined by the remit of the panel	Better than convening a fresh panel for each issue because the learning is greater and the need for time to be spent on introductory sessions is reduced.	Long-term commitments in funding and organisational support are key to the success. 'Professionalisation' of lay participants. Limited numbers.
Stakeholder workshop	Membership is invited in line with the task	As long as is appropriate to the task.	Participants have the opportunity to learn.	

ANNEX C

CANCER RISK PERSPECTIVES OF LIVING IN CONTAMINATED AREAS AND TERRITORIES

1. Risk of radiation induced cancer death

(C.1) Prolonged exposure of the public can be defined as adventitious exposures to radiation, which persists for long time periods. Except for the exposure to the external component of the cosmic radiation, all sources of prolonged exposure involve long-lived radionuclides. Some of these radionuclides are naturally occurring while others are man-made. They can be present in the surrounding environment and their radiation can expose people externally or they can also be taken into the body and expose people internally. Examples of prolonged exposure are radon in dwellings, residues from past uranium mining and milling operations, residues from nuclear weapons testing and residual contamination following accidental releases of long-lived radionuclides to the environment.

(C.2) Living and working in areas contaminated with long-lived radioactive materials that have originated from nuclear or radiological accidents or being of natural occurrence will expose the population and consequently give rise to an increased risk of stochastic health effects. The exposure will cause a risk commitment, *i.e.* a commitment of an increased cancer death probability rate in the future. Any change in the age-specific death probability rate would occur later in life when the risk of death from other causes also is higher. The risk committed by a radiation exposure at a given age can therefore be added to the background risk at the same age.

(C.3) All parts of the body are exposed to natural sources of radiation. Small doses from man-made long-lived radionuclides in the environment will be additions to the natural background dose. For moderate dose increments above the naturally occurring background doses, a linear relationship between the incremental dose and the incremental probability of a deleterious health effect is assumed by the Commission to be an adequate approximation of the dose-response relationship for radiation protection purposes. However, there is no direct evidence, from either epidemiological or experimental carcinogenesis studies, that radiation exposure at very low incremental doses is carcinogenic, nor would any be expected. The atomic bomb Life Span Study (LSS) provides good evidence of radiation cancer risk down to doses of 100 - 150 mGy with an approximately linear dose-response relationship.

(C.4) The annual (unconditional) cancer death probability rate has been calculated for a Swedish (sex-averaged) population (1996 WHO) for three different prolonged exposures of 1, 5 and 10 mSv/a and shown in Fig. C.1. A multiplicative risk model and a dose/dose rate reduction factor (DDREF) of 2 were used in the calculations (ASQRAD95: **A**ssessment **S**ystem for **Q**uantification of **Ra**diological **D**etriment. NRPB and CEPN, June 1995). A linear dose-response relationship down to very low doses has been used, although the actual dose-response at such low doses is unknown or even non-existent. The uncertainties on the existence of a low-dose threshold for cancer risk of a few mGy of low-LET radiation may never be resolved. The calculated cancer death probability rates shown in Fig. C.1 are therefore purely theoretical and should be treated with caution. The Commission has judged that it is not appropriate, for the formal purposes of public health, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small radiation doses received by large numbers of people over very long periods of time (ICRP103, para 66).

(C.5) The results shown in Fig. C.1 represent the normalised probability density of the age at death from radiation-induced cancer. Therefore, the areas under the curves represent the lifetime probability of dying from cancer caused by the irradiation. These probability values are indicated in Fig. C.1 as 'lifetime risk'.

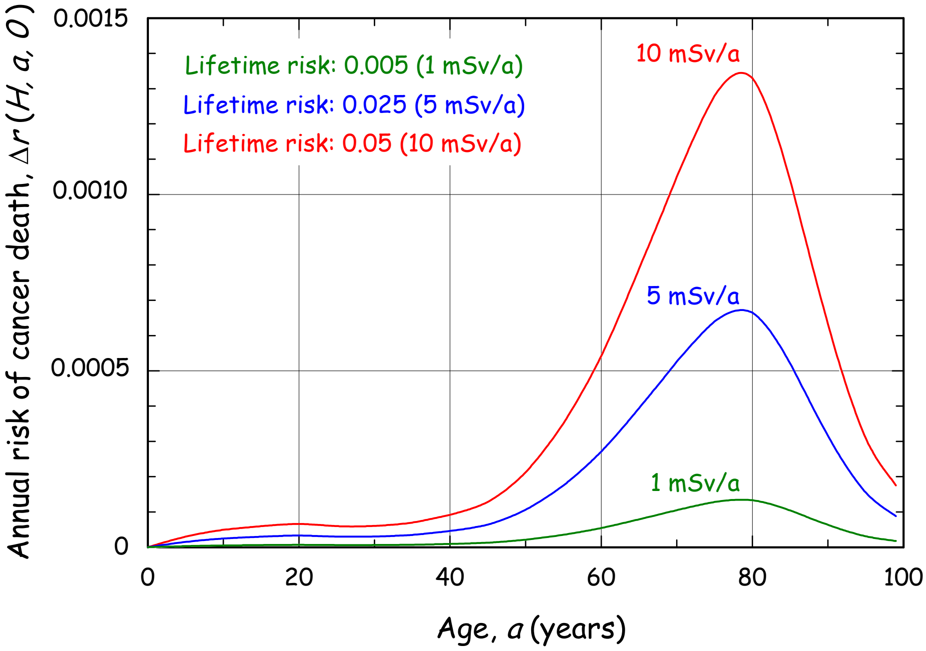

Figure C.1. Annual unconditional cancer death probability rate at various ages for a Swedish (sex-averaged) population being exposed to an additional annual equivalent whole body dose of 1, 5 and 10 mSv from birth over lifetime, assuming a relative risk projection model and a dose/dose rate reduction factor DDREF of 2.

(C.6) The models used to produce the graphs in Fig. C.1 can be applied also to calculate the lifetime risk of dying from cancer caused by the irradiation if the exposure to an additional annual equivalent whole body dose of 1, 5 and 10 mSv starts at age *a*. These age-specific lifetime risks are shown in Fig. C.2.

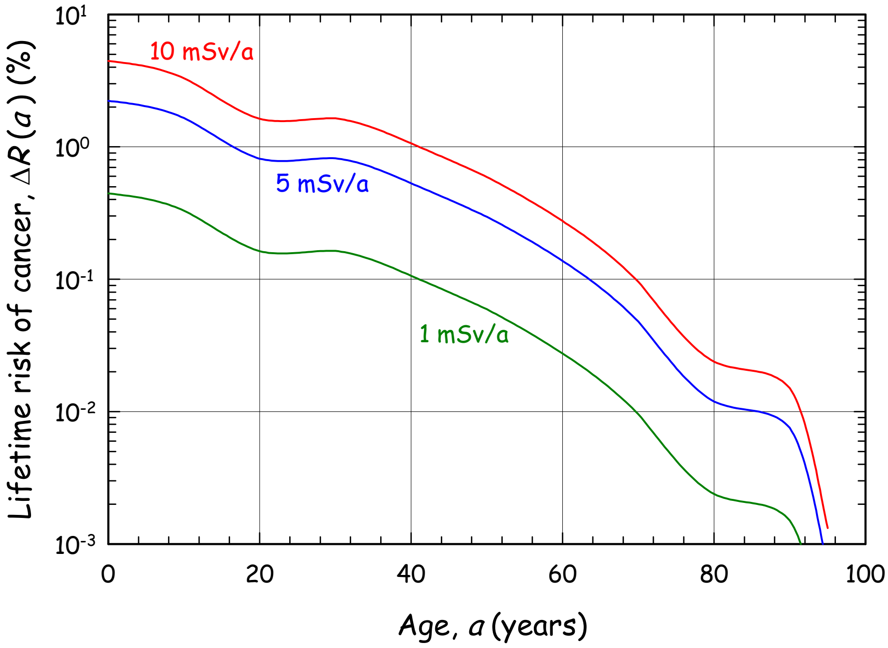

Figure C.2. Lifetime risk of cancer death for a Swedish (sex-averaged) population being exposed to an additional annual equivalent whole body dose of 1, 5 and 10 mSv starting at age a. A relative risk projection model and a dose/dose rate reduction factor DDREF of 2 have been used in the calculations.

2. Detecting cancers in irradiated populations

(C.7) Radiation risks at low doses are such that stochastic radiation effects (cancer and hereditary effects) can be unnoticeable In epidemiology, there is a statistical limitation to detect stochastic effects, which depends on the number of persons exposed and the level of exposure. The epidemiological data need considerable interpretation and studies cannot provide reliable information on the effects of very low doses. This is because cancer and hereditary disorders are naturally common in human populations. The sensitivity of studies of the effects of low radiation doses to humans is thus very limited. There are two main limitations, one of *statistical nature* and one of *demographic nature*. For carcinogenesis, these limitations are as follows.

(C.8) The *statistical limitation* is due to the fact that cancer is a common disease. The normal probability that death will be due to cancer of any origin, including cancers due to radiation from natural sources, is about 20 - 25%. Thus there is a statistical limitation to radio-epidemiological studies that requires very large numbers in both the study group and the control group for any statistical effects of small doses to be observed. The probability of spontaneously occurring cancers follows the Poisson probability model. To be able to detect an excess number of cancer cases as a result of an accumulated individual radiation exposure, the excess cancer incidence rate due to radiation should be larger than, say, at least two standard deviations of the spontaneously occurring cancer incidence rate. This would require a population size being inverse proportional to the square of the average individual dose to that population and inverse proportional to the square of the radiation risk per unit dose. This can be described mathematically in the following way.

(C.9) In a group of people, *P*, being exposed to an annual effective dose, $\dot{E}$ (Sv/a), over a time period, *Y* (years) (in excess of the effective dose from the natural background radiation), the total number of spontaneous and radiation-induced cancers would be:

$$P \cdot \dot{E} \cdot Y \cdot r + P \cdot \dot{M} \cdot Y$$

where the risk of radiation induced cancer per unit dose is *r* (per Sv) and the probability of spontaneously occurring cancers is $\dot{M}$ (per year).

(C.10) The probability of spontaneously occurring cancers follows the Poisson probability model. The expected number of cancers can be calculated from this model as $P \cdot \dot{M} \cdot Y$, and the standard deviation as the square root of this number, $\sqrt{P \cdot \dot{M} \cdot Y}$. To be able to confirm an excess number of cancer cases as a result of the accumulated individual radiation exposure, $\dot{E} \cdot Y$, the excess cancer incidence rate due to radiation should be larger than at least two standard deviations of the spontaneously occurring cancer incidence rate:

$$P \cdot \dot{E} \cdot Y \cdot r > 2 \cdot \sqrt{P \cdot \dot{M} \cdot Y}$$

which can be re-written as:

$$P \cdot Y > \frac{4 \cdot \dot{M}}{r^2 \cdot \dot{E}^2}$$

If the exposure is given as a single dose, *E*, the expression would be:

$$P > \frac{4 \cdot M}{r^2 \cdot E^2}$$

where *M* is the relative number of cancers in a lifetime.

(C.11) For estimates of the probability of incurring cancer attributable to radiation, the study and the control groups would each have to contain about the number of people indicated in the abscissa of the graph in Fig. C.3 in order to be able to detect with confidence the effects of the excess dose indicated in the ordinate of Fig. C.3.

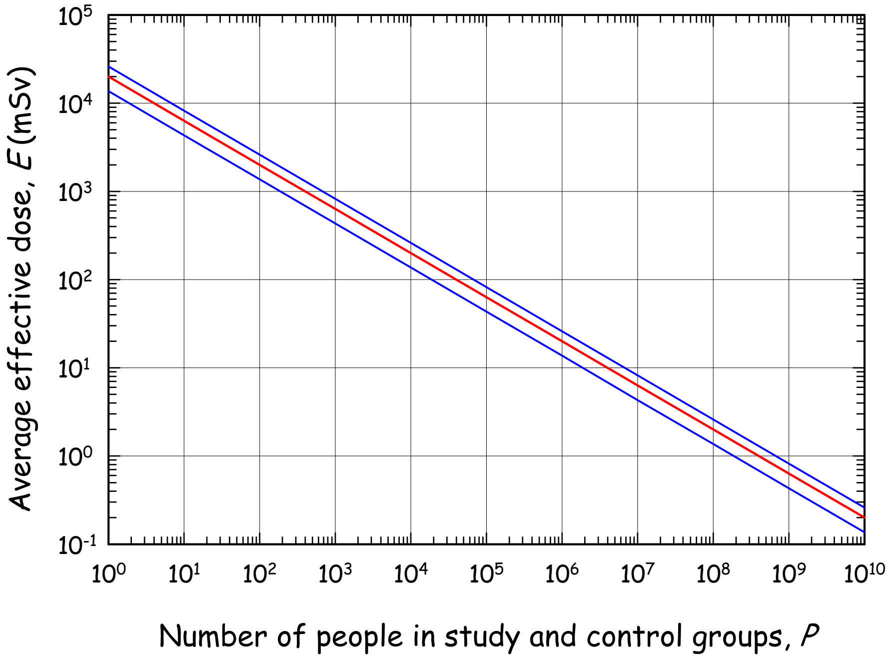

Figure C.3. Relationship between the average individual effective dose in a population and the necessary size of that population to be able to detect, epidemiologically, the carcinogenic effects (all cancers) with statistical reliability. The blue lines represent 5% - 95% confidence levels[1].

(C.12) It appears from Fig. C.3 that for a population size of tens to hundreds of thousands the average individual doses should be of the order of 100 mSv before the detection of excess cancers in well-designed epidemiological studies would be possible.

(C.13) It should be emphasized, however, that there are specific types of carcinogenesis in specific population groups, where the detectability is much easier due to the fact that the normal probability for such specific cancer is low (the inverse proportionality to the square of the radiation risk per unit dose as mentioned above). A notable case is that of carcinogenesis of thyroid in children.

(C.14) For hereditary effects, the detectability is much more difficult due to the high incidence of those effects in a population and a smaller radiation risk per unit dose of these effects compared to the risk per unit dose for cancer. Not surprisingly, radiation induced hereditary effects in man could not be detected to date.

(C.15) In summary, for stochastic health effects the possibility of detection could be remote because of demographic and statistical limitations. Causation can only be established collectively either by epidemiological detection or by theoretical presumption, although the statistical limitations do not allow any epidemiological association to be demonstrated between low doses and increased number of cancers. Therefore, the magnitude of any risk from low doses can not be established from epidemiological studies of populations being exposed to low doses. Even with enormous population sizes, risk estimates would be untrustworthy because we do not understand, and therefore cannot control or adjust for, all of the sources of variation in baseline levels of risk. Causation can be quantified on an individual basis by using probability of causation (see section C.3).

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[1] The confidence levels have been calculated with the assumptions that the range of M is 0.18 - 0.26 per year and the range of risk of radiation induced cancer per unit dose r is 0.035 - 0.07 per Sv.

3. Probability of causation of radiation induced cancer death

(C.16) The concept of Probability of Causation, PC, has been developed to answer the question: "If a person has been exposed to ionizing radiation and subsequently develops cancer, what is the probability that this cancer was due to an earlier radiation exposure?"

(C.17) The Probability of Causation, $PC(\dot{H}, a, e, k)$, of an observed cancer death of a person of sex, *k*, at age, *a*, exposed to an annual equivalent organ dose, $\dot{H}$, starting at age, *e*, was defined by the United States National Institutes of Health (NIH) as:

$$PC(\dot{H}, a, e, k) = \frac{\Delta r(\dot{H}, a, e, k)}{r_0(a, k) + \Delta r(\dot{H}, a, e, k)}$$

where $\Delta r(\dot{H}, a, e, k)$ is the probability rate of death at age *a* from the given cancer type from an annual dose, $\dot{H}$, starting at age, *e*, and $r_0(a, k)$ is the mortality rate at age *a* from all other causes for the same cancer type. The mortality rate, $r_0(a, k)$, for both sexes can be found in national cancer statistics for different cancer types, normally in five-year intervals (see Fig. C.3).

(C.18) The age and sex specific cancer rates are average values applicable to groups of a population. It is well known that the individual risk of cancer depends not only on the age and sex of a person but also on other individual characteristics such as dietary habits and genetic background. Such factors are presently not quantifiable and cancer rates are usually available from demographic data tabulated only by age and sex. This implies that in calculating the *PC* relating to a particular occurrence the individual characteristics (other than age and sex) of a person are ignored. However, for lung cancer the dependence of the spontaneous rates on smoking habits of an individual need to be considered since this is the principal cause for this cancer. However, despite of the overwhelming influence of smoking habits on lung cancer, quantitative scientific information on the possible synergism between smoking and radiation is scarce.

(C.19) Cancer mortality rates are usually collated nationally and by regions for a given calendar period. The age specific mortality rate, $r_0(a, k)$, for all cancer types except skin cancer is shown in Fig. C.4 for the Danish population in the period 1996 - 2000.

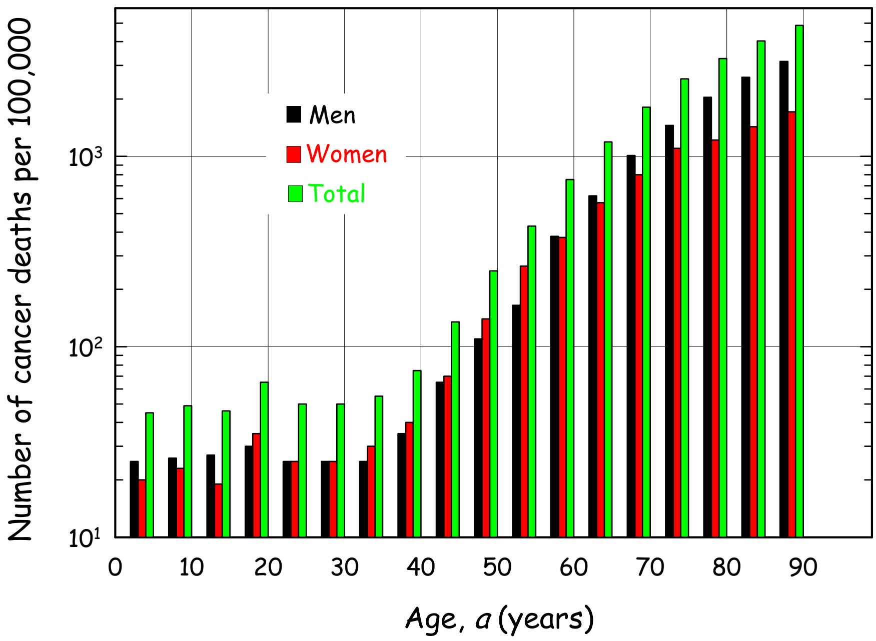

Figure C.4. Age specific cancer death rate per 100,000 in Denmark in 5-year age groups for all cancers except skin cancer. The data are representative for the period 1996 - 2000.

(C.20) PC-calculations require demographic data on cancer incidence. While reliable mortality data exists in most countries, this is not the case for cancer incidence. Existing incidence data from a given country cannot be automatically transferred or applied to other countries since there are significant differences in cancer incidence rates between countries and even within countries for a number of cancer sites. The use of cancer mortality instead of cancer incidence data is justifiable for sites with high lethality such as cancers of the stomach or lung. The method is more questionable for cancer types where therapy methods are successful.

(C.21) PC-calculations have been made for a Danish/Swedish (sex-averaged) population being exposed to an additional (over background exposure) annual effective dose of 1, 5 and 10 mSv from birth over lifetime. The results of these calculations are shown in Fig. C.5. Again, it should be strongly emphasized that the assumption used in these PC-calculations is a linear non-threshold dose-response down to doses.

(C.22) For a prolonged exposure at 10 mSv/a, the maximum *PC* occurs at age 15 - 30 with a value of about 10% as can be seen in Fig. C.5. The interpretation of this result is that cancer deaths in that age group in 10 out of 100 cases are estimated to be associated with radiation exposure. At prolonged annual exposures of 5 mSv and 1 mSv the corresponding results for the same age group of 15 - 30 are that 5 and 1 out of 100 cancer deaths are considered to be associated with radiation, respectively.

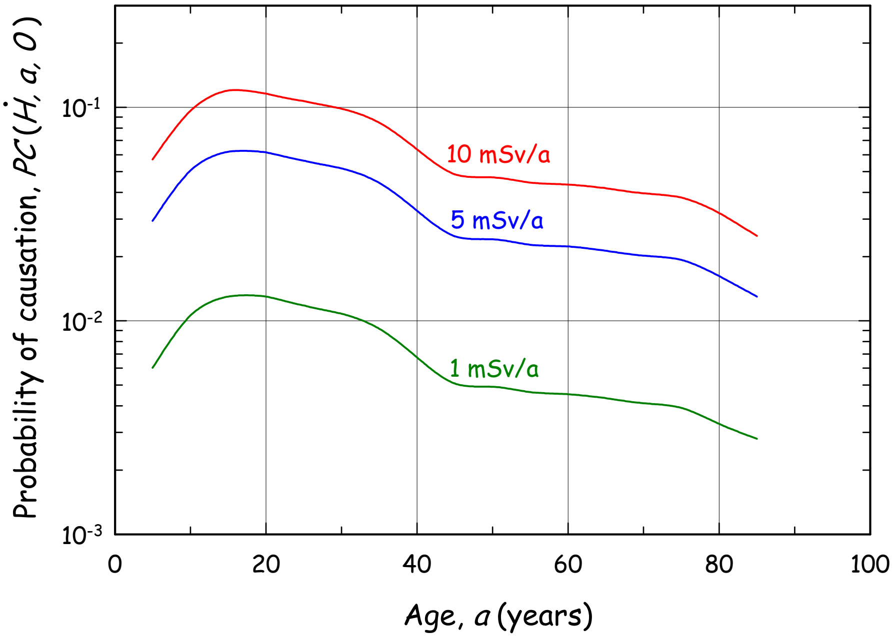

Figure C.5. Probability of causation for radiation induced cancer death at various ages for a Dansih/Swedish (sex-averaged) population being exposed to an additional annual equivalent whole body dose of 1, 5 and 10 mSv from birth over lifetime, assuming a relative risk projection model and a dose and dose rate reduction factor DDREF of 2.