Paper

"LIVING IN CONTAMINATED AREAS"—CONSIDERATION OF DIFFERENT PERSPECTIVES

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Abstract—**Following large-scale nuclear power plant accidents such as those that occurred at Chernobyl (Ukraine) in 1986 and Fukushima Daiichi (Japan) in 2011, large populations are living in areas containing residual amounts of radioactivity. As a key session of the ConRad conference, experts were invited from different disciplines to provide state-of-the-art information on the topic of "living in contaminated areas." These experts provided their different perspectives on a range of topics including radiation protection principles and dose criteria, environmental measurements and dose estimation, maintaining decent living and working conditions, evidence of health risks, and social impact and risk communication. A short summary of these different perspectives is provided in this paper.**

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INTRODUCTION

AFTER THE accident at the Chernobyl nuclear power plant in 1986, large parts (23.5%) of Belarus were contaminated (~48,800 km^2). Nevertheless, as a result of radioactive decay, environmental processes, and remediation efforts, around 1.5 million people are able to live there. This paper addresses different aspects relating to living in contaminated areas (Fig. 1). Section 1 describes the radiation protection principles for living in contaminated areas and the application of dose criteria for keeping exposures as low as reasonably achievable (ALARA). Section 2 describes an approach for converting environmental radiation measurements into individual dose estimates. Section 3 looks at a range of strategies for maintaining decent living and working conditions in previously contaminated areas, including protective actions to reduce transfer of radionuclides in the food chain, other actions to decontaminate inhabited areas, methods for involving local stakeholders in protection decisions, and not forgetting the need to consider the impact of low levels of radiation on biodiversity.

It is widely recognized that residual levels of radioactivity will not cause deterministic health effects in those living in contaminated areas. Section 4 focuses on epidemiological aspects of what is known about the induction of chronic health effects, using studies that looked at populations living in areas of high natural background radiation. The prerequisites for carrying out epidemiological studies to determine the exposure-effect association are also discussed.

Nuclear accidents do not only cause chronic health problems associated with the presence of radiation, but they can also significantly affect psychological health and well-being. Risk communication can make a significant contribution to long-term psychosocial support of affected populations. These topics are covered in Section 5.

RADIOLOGICAL PROTECTION PRINCIPLES AND THE APPLICATION OF DOSE CRITERIA

The ICRP system of radiological protection is a fundamental framework for dealing with any exposure situation in a systematic and coherent manner. ICRP Publication 109 (ICRP 2009a) and ICRP Publication 111 (ICRP 2009b) are focused on emergency and existing exposure situations resulting from nuclear accidents and were built on the experience of managing the Chernobyl accident in Europe in 1986, but they were published before the events at Fukushima Daiichi nuclear power plant in 2011. An ICRP Task Group (TG93) was established in 2013 to update Publications 109 and 111 in light of the lessons learned from the management of Fukushima and from the series of dialogue meetings organized by ICRP in cooperation with national and local

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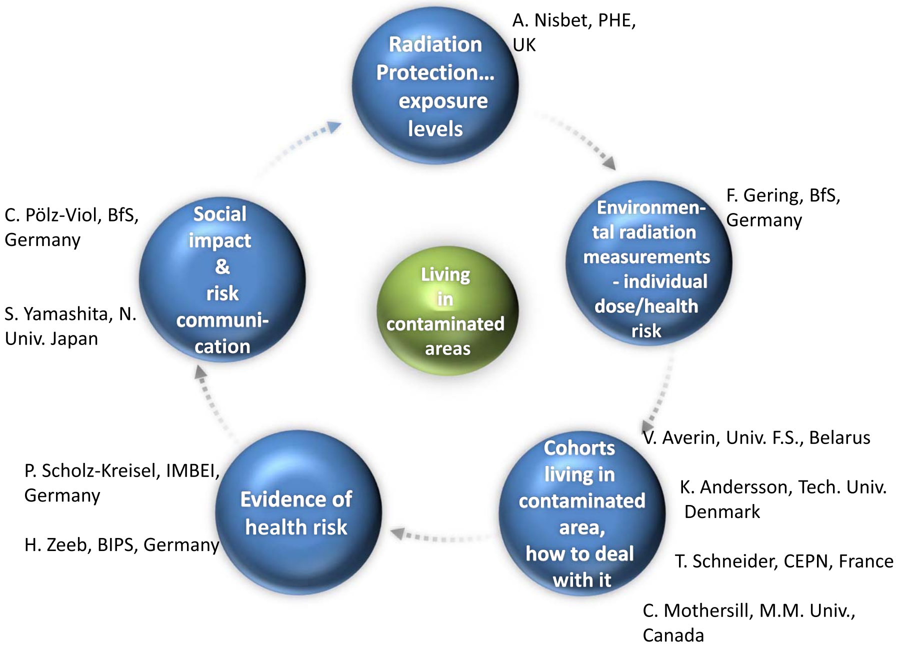

Fig. 1. Structure of the key session "living in contaminated areas."

stakeholders starting in 2011. The widely anticipated update will be published once feedback from the public consultation, taking place in summer 2019, has been addressed. Key elements of the new publication, relating to radiological protection principles and the application of dose criteria, are described in the section below.

For managing a large-scale nuclear accident, it is convenient to distinguish between the emergency response, with the early and intermediate phases, and the recovery process corresponding to the long-term phase of the accident. For the implementation of the system of radiological protection the ICRP considers the emergency response as an emergency exposure situation and the recovery process as an existing exposure situation.

Radiological protection principles relevant to contaminated areas are justification of decisions and optimization of protection. Justification relates to the fundamental decision to allow people to remain in the affected areas and subsequently to the justification of decisions to improve the radiological situation. Optimization relates to the ALARA principle, whereby the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ICRP 2007). Restrictions are placed on individual exposures through the application of reference levels to limit inequity between individuals, taking into account the views and concerns of stakeholders. Optimization is a step-by-step process that aims at selecting the best protective actions given the characteristics of the exposure situation (under the prevailing circumstances). Reference levels are expressed in terms of individual effective dose (mSv) and are tools to help identify exposures requiring more attention. They can also be specified in measurable quantities to facilitate their application in specific circumstances, but these derived quantities must be realistic. Reference levels are not limits.

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

For protection of responders after the emergency response, the reference level should not exceed 20 mSv y^{-1}. For people living in long-term contaminated areas following an emergency response, the reference level should be selected within or below the Commission's recommended band of 1–20 mSv y^{-1} for existing exposure situations (ICRP 2007), taking into account the actual distribution of doses in the population and the tolerability of risk for the long-lasting existing exposure situations. There is generally no need for the reference level to exceed 10 mSv y^{-1}. The objective of optimization of protection is a progressive reduction in exposure to levels of the order of 1 mSv y^{-1}.

ENVIRONMENTAL RADIATION MEASUREMENTS AND INDIVIDUAL DOSE ESTIMATES

Assessing doses of individuals affected by nuclear or radiological accidents is an important issue in emergency response. It enables the individual comparison of doses with reference levels, allowing for identification of those members of the affected population who have received the highest exposure and thus might require additional medical follow-up. This approach thus allows for optimization of the protection of the public and of emergency and recovery responders. In addition, large-scale individual dose assessment can also provide a basis for epidemiological studies.

A software tool for dose reconstruction was recently developed by the German Federal Office for Radiation Protection (Folger et al. 2018). It makes use of all kinds of available environmental monitoring data, including gamma dose rate, air concentration, and ground contamination measurements. Individual doses are computed based on the time and duration of stay of the respective person within the contaminated areas. The output of the tool comprises individual values for the effective dose and for the equivalent doses to the thyroid and red bone marrow. If sufficient environmental monitoring data are available, such a dose assessment should primarily be based on the monitoring data, as the corresponding uncertainties of the estimated doses will typically be smaller than for any dose assessment based only on modeling.

The dose reconstruction tool as described above is designated to be used in emergency care centers where potentially contaminated people arrive after an emergency exposure situation. It was tested during several emergency exercises since 2017, now reaching an operational status for application in any future emergency exposure situation.

MAINTAINING DECENT LIVING AND WORKING CONDITIONS IN CONTAMINATED AREAS

Economic and social development of contaminated areas is important to stop the exodus of local people and to encourage others to come and live or work in these areas. This can be achieved by providing subsidies for new housing, the creation of new jobs with competitive salaries, and the guarantee that agricultural products will have a place in the market and be competitively priced. There are also various protective actions that can be implemented to ensure exposure of the affected populations is kept as low as reasonably achievable; these include agricultural countermeasures and decontamination of inhabited areas.

Agricultural countermeasures in Belarus after the Chernobyl accident

Agricultural countermeasures in the Republic of Belarus were implemented extensively with the aim of reducing radionuclide transfer into food products (Averin 2012, 2009). Reductions in soil-to-plant transfer were achieved by ploughing, the application of lime, and increased rates of potassium fertilizers to soils. Radionuclide content in animal products was reduced by means of feed management, the application of cesium binders, and the provision of 'clean' feed. Technological processing of crops or animal products (i.e., the processing of whole milk into cream, cottage cheese, or butter) was also used for reducing the radionuclide content of the end products. Implementation of agricultural countermeasures resulted in a reduction in collective dose from ingestion of contaminated food by a factor of 4–5 (Alexakhin 1993). The highest dose reduction was recorded for countermeasures that lowered ^{137}Cs concentrations in milk. In Belarus, agricultural countermeasures were perceived positively, with clear economic advantages (increase in yields and animal productivity) as well as social and psychological benefits (Firsakova 1993; Alexakhin 1993).

Agricultural countermeasures are most effective when there is a good understanding of the exposure pathways and when they can be implemented promptly. Countermeasures implemented soon after the accident guarantee a high level of effectiveness compared to those implemented later on, when the absolute concentrations of radionuclides in foodstuffs are lower (Firsakova 1993). The reduction of radionuclide concentrations in farm products is caused by natural processes (radioactive decay, cesium fixation by clay minerals in soils) and from the application of agricultural countermeasures. Over time, the contribution of natural processes prevails over that achieved by the countermeasures. In the period 1992–2010, the effectiveness of agricultural countermeasures in Belarus declined to an average of 50–80%.

Experiences on reduction of external dose to inhabitants of contaminated areas

Prior to the Chernobyl accident in 1986, it was considered highly unlikely that any plausible incident leading to airborne dispersion of radioactive contaminants would affect inhabited areas to any significant extent. Therefore, efforts made to that time to investigate countermeasures that might be implemented in case of a large contaminating incident had almost entirely focused on rural land areas and, in particular, agriculture (Andersson 2009b). According to recent reviews (e.g., Howard et al. 2017), the long-term ingestion and external dose contributions received by inhabitants of areas contaminated by the Chernobyl accident were estimated to be about equal in magnitude, whereas the long-term external dose contribution to the public in areas contaminated by the Fukushima accident has been estimated to around 80–90% and the corresponding ingestion dose only 10–20%. This is noteworthy because Chernobyl effects on milk consumption with radioiodine became a very important exposure factor, although this exposure was received over a short time period due to the short physical half-life of ^{131}I (IAEA 1991). In preparedness for possible future nuclear power plant accidents, it is thus very important to be able to implement effective recovery strategies for contaminated inhabited areas. The international state of unpreparedness in this context at the time of the Chernobyl accident is reflected in the generally poor results of efforts in the late 1980s to reduce external dose in the affected areas (Anisimova et al. 1994). Throughout the 1990s, an experience base was formed through examination of a wide range of different countermeasures under different environmental conditions. On this basis, the first compendium describing important features of recovery countermeasures for contaminated inhabited areas in a standardized format emerged in 1995 (Roed et al. 1995) from the European Experimental Collaboration Project No. 4. Over the following decade, this work underwent a large further development and today constitutes the backbone of the European recovery handbook for contaminated inhabited areas (Andersson 2009b).

However, about 15 y have now gone since the latest update of the European countermeasure compendium, and new surface types have arisen—e.g., modern urban houses to a great extent have glass facades, for which countermeasures have not been described. There are also a number of new technical/methodological advances that should be described for European preparedness, and the learning points from the Fukushima accident have not been integrated. The latter would require careful expert scrutinizing. Some of the data are simply useless (e.g., reporting of a decontamination factor [DF] of 1-10 without information on what made the difference in effectiveness; JAEA 2015), but also the measurement methods behind the factors should be examined carefully.

In planning for justified intervention, estimation of factors like residual dose must be enabled. For this purpose, there are no applicable data from Fukushima on contaminant mobility on different surfaces, as the Japanese focus was generally on unshielded dose rate measurements (Kinase et al. 2017). Our European decision support systems thus rely mainly on Chernobyl-related data (Andersson 2009a).

When the Russian army in 1989 attempted to decontaminate 93 Chernobyl-contaminated settlements (Anisimova et al. 1994), they essentially selected a promising strategy involving removal of topsoil. However, the problem was that they did not measure the location of the contamination in the various surfaces, and in some cases where much of the contamination had penetrated deeply in sandy soil, a shielding topsoil layer was effectively removed, sometimes even leading to an increase in dose rate (Andersson 2009b). The work was abandoned as not worthwhile, and instead people were often permanently removed from their homes with immense personal and societal repercussions. A Danish-Russian effort in the same area in 1995 demonstrated that practically the same decontamination strategy could result in an overall external dose rate reduction by a factor of about 6 if the treatments were optimized in relation to a simple local contamination measurement strategy (Andersson 2009b). Although we have useful tools for making decisions on which countermeasure strategies to carry out, we still very much lack formulation of optimized measurement strategies to guide the practical countermeasure implementation. Although the required experience exists, there are currently no guidance recommendations available for this. The above example shows the importance of optimized practical implementation—without it, any potentially promising countermeasure may for several reasons totally fail in practice. The Fukushima accident, for instance, showed only too clearly how large amounts of waste may be generated if the surface removal is not optimized (Connor et al. 2018).

Coping with radiological exposure in daily life following a nuclear accident: lessons from the ETHOS and CORE projects in Belarus

The ETHOS project and CORE program, implemented in Belarus from 1996 to 2008, following the Chernobyl accident, highlighted the importance for the management of the recovery phase to involve local stakeholders living in contaminated territories for ensuring the effectiveness and sustainability of protective actions as well as allowing them to make informed decisions (Hériard Dubreuil et al. 1999). These projects were developed with the support of the Belarusian authorities and implemented by a European Team of experts, aiming at developing a sustainable improvement of the living conditions of the local population (Lochard 2013). Based on the direct involvement of the local populations in their own protection, four priority areas were addressed within these projects: health surveillance, economic and social development, radiological quality, culture and education, and transmission of the memory. They aimed at addressing their concerns for their daily life; i.e., management of the radiological quality of milk and meat, management of the radiological protection of children, and management of the radioactive waste.

The starting point of these projects was the observation of the human dimensions of the post-accident situation. People affected by the accident progressively lost the confidence in authorities, and experts and were generally confronted with significant evolutions of their familiar environment due to the presence of radioactivity. This situation induced a disintegration of family and social relationships for a large number of people and a strong concern about the future and particularly about potential health effects for children. There was a general feeling of helplessness and abandonment, and some people suffered from discrimination and exclusion. All these aspects contributed to a loss of control of daily life and autonomy for people affected by the accident.

In this context, the traditional approach for education in post-accidental situations was initially based on disseminating messages relying on theoretical and scientific considerations. The program was established at the national level and included of a list of restrictions and prohibitions. This approach induced difficulties for the affected populations to establish connections between this list and their current local situation. There was generally no global approach to address their living conditions.

To overcome these difficulties, the stakeholder involvement process implemented in the ETHOS and CORE projects is based on the following steps:

- Listening and learning from the villagers about their concerns, difficulties, and wishes;
- Developing a shared evaluation of the local radiological situation between experts and local professionals and the inhabitants (co-expertise);
- Implementing actions for improving the radiological situation and the living conditions of the villagers; and
- Re-establishing links between villagers, local professionals, authorities, and experts.

This process relies largely on the development of a practical radiological protection culture, with the aim to provide capabilities to the local stakeholders for identifying and coping with the presence of radioactivity in daily life and to allow them to understand and put into perspective the measurements produced at the local and/or regional level (Beresford et al. 2001; Bataille et al. 2008). It also contributes to the development of informed decision-aiding processes and favors the evaluation and dissemination of the results and sustainability of the protective actions implemented at the local level (Hériard Dubreuil and Schneider 2001).

These projects developed in Belarus emphasize the key role of the direct engagement of the local inhabitants who are living in the affected areas to break the vicious circle of their loss of control and exclusion. For this purpose, it is essential to set up places of dialogue and to encourage the experts to be at the service of local inhabitants. The development of a "practical radiological protection culture" has to be associated with the development of a radiation monitoring system and a health surveillance system (Ayrault et al. 2006; Lepicard and Hériard Dubreuil 2001). Finally, there is a key role of authorities and radiological protection experts to ensure the implementation and sustainability of these systems and the stakeholder involvement process (Jones et al. 2006).

Toward a holistic approach to protection of inhabitants of contaminated environments: the role of non-targeted effects

Recent moves within ICRP to develop an integrated approach to radiation protection of both humans and non-human biota are focused on regulating dose to exposed populations based on behavior, size, lifestyle, and "radiosensitivity." Currently human and 12 reference organisms are used covering various taxonomic groups, behaviors, and exposure scenarios; e.g., marine, terrestrial, sediment, or airborne. However, most biologists agree that, particularly in low dose exposure legacy sites, the factors determining effects and outcomes are far more complex than this simple framework suggests. The issue is developing reliable predictors of system or ecosystem health rather than relying on biomarkers that give information about effects on individual cells, organs, or organisms. Approaches to this include the Adverse Outcome Pathway (AOP) developed as part of the CERAD project in Norway, which looks at multiple levels of organization from gene to ecosystem, building a comprehensive picture of effects at multiple levels of organization in multiple species, including humans. Various camera drone-based ecosystem evaluation techniques have been developed in other areas of environmental management. These could be applied at legacy sites where damage to, for example, tree canopies or river flow patterns can be used to assess ecosystem health much like a CAT or MRI scan reveals structural changes in individual organisms.

Another more focused approach is to look at the role of non-targeted effects such as genomic instability (GI) and bystander effects (BE). These mechanisms involve transmission of information between different levels of organization. In the case of BE, signals from exposed to unexposed cells or organisms coordinate response at higher levels of organization, permitting population responses to radiation to be optimized. GI is more complex as it involves not only signaling but also trans-generational transmission of genetic or epigenetic changes and may lead to long-term adaptive evolution. GI may also be involved in memory or legacy effects, which contribute a further component to the dose effect measured in legacy sites. Recent analysis of the contributions of memory and legacy effects to the total effect using data sets from Chernobyl and Fukushima (voles, birds, and butterflies) suggest this type of analysis may help reduce uncertainties over laboratory to field extrapolations. Given the clear discrepancy between actual data measured in the field and dose effects generated using databases populated mainly with acute laboratory-based experimental data (Garnier-Laplace et al. 2013), it is imperative that meaningful holistic systems be developed for protection of those living in contaminated ecosystems (Table 1).

EVIDENCE OF HEALTH RISK

High natural background radiation and health: an overview of current evidence

Next to medical radiation, natural radiation is a major contributor to radiation exposure of the general population. Due to the specific regional geology, there are several areas in the world that are characterized by a comparatively high natural level of natural ionizing background radiation (HNBR). These regions can be characterized according to the annual effective dose from natural background radiation: around 5 mSv as low, 5–20 mSv as medium level, 20–50 mSv as high level, and levels above 50 mSv as very high (Sohrabi 1998). In the context of understanding low-dose radiation risks for

Table 1. A comparison of possible holistic approaches versus the current approach.

Holistic
• Considers response of the system
• Allows for organization and emergent properties
• Prioritises communication and signaling
• Needs system level biomarkers of effect
• Very complicated!
Current
• Uses data from individuals and reference organisms
• Extrapolates to other groups and organisms
• Relies heavily on data in databases and on animal models
• Simple system but large uncertainties

humans, these areas have raised substantial interest among researchers as the populations living in these regions are constantly exposed to these elevated radiation levels.

Studies to assess potentially associated health risks have been conducted in many areas, including Brazil, Iran, China, and India. With a view to the quality of available epidemiologic studies, a recent UNSCEAR report (2017) focused on investigations conducted in Kerala (India) and Yangjiang (China) (Nair et al. 2009; Tao et al. 2012). In both regions, large-scale population-based studies have been performed. The cohort in Kerala (Nair et al. 2009) included 69,958 persons, with radiation measurements taken in each household and follow-up of cohort members for cancer incidence and mortality. More extensive assessments to support dosimetry were also undertaken in a smaller random sample of households. The mean cumulative individual dose was estimated to be 161 mSv. For overall cancer incidence (excluding leukemia), an excess relative risk (ERR) of −0.013 per 100 mGy (95%CI −0.058 to 0.046) was estimated, and the ERR for specific cancers ranged from 0.01 to 0.6 per 100 mGy, all non-significant. The somewhat smaller Chinese study among 31,604 adults (Tao et al. 2012) used similar approaches; however, in the absence of cancer registry information, only mortality data were collected. The mean cumulative dose in the high radiation areas was estimated to be 84.8 mGy, compared to 21.6 mSv in the control areas. Here an ERR of −0.101 per 100 mGy (95% CI −0.253 to 0.095) was found, and when leukemia and liver cancer were excluded, the ERR per 100 mGy was 0.019 (95%CI −0.187 to 0.304). Thus, the main results of published analyses overall do not indicate elevated cancer mortality or cancer incidence associated with high natural background radiation exposure. However, both studies have limitations that need to be considered when interpreting the data, including the potential for confounding and exposure misclassification as well as the limited statistical power.

Overall, HNBR present a useful but challenging opportunity to assess low-dose-rate ionizing radiation exposure to humans. In particular, difficulties exist to obtain relevant and updated exposure, as well as confounder and outcome information. Some of the difficulties can be overcome by focusing on specific population samples such as in a cytogenetic study of newborns in the Kerala area (Ramachandran et al. 2013) and in the future potentially by conducting nested case-control studies. Overall, these studies augment investigations on occupational groups, medically or environmentally exposed persons, and notably the life-span study among survivors of the atomic bombings.

How dangerous is living in contaminated areas? Epidemiological thoughts on risks and further studies

Assessing the health effects of living in long-term contaminated areas requires very careful analysis of both the area and the affected population. For setting up epidemiological cohort studies in such areas, emigration is creating a major problem for conducting the follow-up and can lead to severe selection effects and thus bias.

Increased incidence of thyroid cancer or leukemia as well as elevated risk of cardiovascular and endocrinal diseases are considered to be dose-associated (Hatch and Cardis 2017; Tronko et al. 2012), but evidence regarding the effect of low doses as seen in Fukushima is still incomplete. After a catastrophic event, a collapse in medical and sanitary infrastructure promotes diseases and impedes prevention efforts or early detection of cancer. Furthermore, psychological and socioeconomic issues like fear, isolation, and poverty are risk factors for medical problems like psychiatric or cardiovascular diseases (Maeda et al. 2018; Bromet and Havenaar 2007). These effects are not dose related and can also be found in successfully decontaminated and resettled areas. Due to the clear association between, for example, poverty, substance abuse, and cardiovascular diseases, these effects can lead to biased estimation of the association of radiation and cardiovascular diseases; thus, epidemiologic data are sparse.

A possible further consequence of prolonged radiation exposure in a population could be the long-term risk of genetic alterations. Chromosomal aberrations or micronuclei can be found not only in inhabitants or former inhabitants of contaminated areas but also in children of former inhabitants, who never lived in such an area themselves (Fucic et al. 2016). Thus, to get a complete picture of genetic late effects, it might be necessary to also investigate non-exposed children.

Planning new epidemiological studies to assess health effects for people living in contaminated areas should not only focus on radiation-related outcomes but also assess psychological and lifestyle-related factors to investigate indirect effects. To achieve this, it is necessary to develop epidemiological studies using qualitative and quantitative methods to get a deeper insight into living behavior and resulting health issues. An important possible outcome of discriminating between direct and indirect effects could be the further development and use of biomarkers for radiation injury and confounding factors like nicotine or alcohol abuse. This could be realized in combination with molecular-epidemiological studies on genetic alterations in inhabitants and their siblings. The use of new comparison groups like people living in areas contaminated with non-radiation substances such as heavy metals could help to distinguish between contamination-related and radiation-stigma-related health effects.

SOCIAL IMPACT AND RISK COMMUNICATION

Social and medical preparedness and response for a nuclear accident in Japan; lessons learned from Fukushima thyroid examinations

Immediately after the Fukushima Daiichi Nuclear Power Plant accident in March 2011, the fear of thyroid cancer prevailed throughout Japan. To overcome the difficulties of appropriate (well-balanced) radiation risk perception and to promote the population's future health and well-being, a large-scale sophisticated thyroid ultrasound examination with strict diagnostic protocols was launched promptly in October 2011 in Fukushima Prefecture as part of the Fukushima Health Management Survey (Yasumura et al. 2012).

Results from the first 5 y demonstrated a high detection rate of thyroid cancer in young individuals revealing 116 and 71 cases in the first and second screening rounds, respectively, in the same cohort of approximately 300,000 subjects, aged at the time of accident from 0 to 18 y (Yamashita et al. 2018). The postoperative pathological diagnosis revealed a high prevalence of typical papillary thyroid carcinomas with cervical lymph node metastasis that are commonly observed in children.

The high detection rate of thyroid cancer raised concerns among residents and the public that it might be due to putative exposure to radiation from the accident, although it is now apparent that estimates of effective doses to the whole body in the general population after the accident were less than several mSv for the majority of people, including infants and children (Ishikawa et al. 2015). Of note, in the case of low-dose and low-dose rate exposures, relevance to confounding and other factors need to be given particular attention. Furthermore, the so-called "existing exposure situation" (when both the exposure dose remains higher than public dose limit of 1 mSv y^{-1} during normal conditions and extended periods of time are required to reduce the dose) have manifested as changes in individual actions caused by a difference in recognition and understanding of these problems. The situation is much more complex during the current recovery phase in Fukushima, extending far beyond the spell of 1 mSv y^{-1} for radiation protection. Since a high detection rate of thyroid cancer in Fukushima by the repeated thyroid ultrasound examinations causes a negative impact by promoting fear and anxiety in the affected population, efforts to avoid misunderstanding or misinterpretation of naturally occurring thyroid cancer in the young population of Fukushima are essentially needed among the tools of risk communication.

One of the lessons from the Fukushima accident clearly demonstrates the importance of a sound understanding of radiation risk for thyroid cancers and of the differences between exposures after Chernobyl (Yamashita and Thomas 2017) in order to improve socio-psychological and ethical aspects in terms of "resilience" and "logical thinking." The stakeholders should also learn the necessity of specific interpretation of population-based screening effects and the possibility of overdiagnosis of thyroid cancer in children as well as in adults following the long-term strategies for social and medical preparedness and response, especially for thyroid health monitoring after nuclear accidents in the future (Togawa et al. 2018).

Risk communication—a significant contribution to long-term psychosocial support of affected populations

Effects on mental health and social life (e.g., depression, sleep disturbances, elevated level of suicide) have been identified as among the most severe consequences of previous radiological emergencies (Maeda and Oe 2017). Surveys show a significant correlation between higher risk perception and poor mental health of respondents. There is broad consensus that crisis communication is an important factor to support affected populations in dealing with the consequences of radiological emergencies, to reduce uncertainty, and to strengthen self-help strategies (Carr et al. 2018). However, there is still a need to foster ongoing communication about radiological risks in the post-emergency and recovery phase. There are examples of good practice. For example, after the Fukushima Daiichi Nuclear Power Plant accident, risk communication and stakeholder involvement were seen as effective means to strengthen relevant knowledge, to improve self-help abilities, to provide a sense of control for the affected population, and to overcome stigma as well as self-stigmatization. In particular, the option to have exchanges with local facilitators was found to be helpful by various stakeholders.

Though numerous guidelines have been developed that provide recommendations for good crisis and risk communication, there are still a lot of challenges. On the practical level, risk communication has to deal with the disparity in understanding between the general public and the experts (Perko 2014). Transparency, (loss of) trust, diverse personal experiences, emotions, media reporting, and different languages of lay persons and experts increase communication complexity (Bromet 2014). On the practical level, risk

Table 2. Summary on key messages per presentation.

Chapter	Presenter	Key messages
Radiation protection and exposure levels		
	A. Nisbet	1. A large scale nuclear accident creates an unprecedented and complex situation
		2. Protection strategy should prevent deterministic effects and reduce cancer risk
		3. Optimization of protection is facilitated by the application of Reference Levels (RLs)
		4. RL of 100 mSv or lower (public) – Emergency Response
		5. RL of 10 mSv/y or lower (public) – Recovery Process
		6. Optimization should take into account radiological, socio-economic and environmental factors AND the concerns of the affected people
		7. Co-expertise process facilitates emergence of a radiation protection culture
Environmental radiation measurements and individual dose/health risk estimates		
	F. Gering	1. Optimization of protection of the public and of emergency workers can be facilitated by individual dose assessment 2. This enables an individual comparison of doses with e.g. reference levels 3. It also allows for identifying those members of the affected population who received the highest exposure 4. If sufficient data is available, such an dose assessment should primarily based on monitoring data 5. Software tools for such an individual dose assessment have been developed recently
Cohorts living in contaminated areas and how to deal with it		
	V. Averin	Countermeasures can be only effective when there is a preliminary awareness of all possible pathways of human exposure, and when there is a high level of preventing preparedness to their implementation before the major part of the absorbed dose is formed.
	K. Andersson	Efforts have been made over decades to develop a good decision base for recovery of radioactively contaminated land areas, but as demonstrated after the Fukushima accident, there are still great needs for improving preparedness, e.g., in ensuring that selected countermeasures are implemented in the best possible way in practice.
	T. Schneider	1. direct engagement of the local inhabitants necessary
		2. break the vicious circle of loss of control and exclusion
		3. Importance of places of dialogue and experts at the service of local inhabitants
		4. Implementing:
		• A radiation monitoring system
		• A health surveillance system
	C. Mothersill	Given the clear discrepancy between actual data measured in the field and dose effects generated using databases populated mainly with acute lab based experimental data, it is imperative that we strive to develop meaningful holistic systems for protection of those living in contaminated ecosystems.
Evidence of health risk		
	H. Zeeb	There are several areas worldwide with high levels of natural background radiation (HNBR). Epidemiological research among exposed populations living in HNBR areas particularly in India and China has generally not shown radiation-related risk elevations, but there are many limitations that need to be considered in the interpretation of these results.
	P. Scholz-Kreisel	1. Living in contaminated areas can lead to a number of physical and mental issues
		2. Not all issues are dose / dose rate related
		3. Confounding lifestyle changes effects can bias radiation related health issues
		4. Biomarkers or molecular genetic studies could help to distinguish between direct and indirect effects
Social impact and risk communication		
	S. Yamashita	Since psychosocial well-being of individuals and communities is the core element of resilience, local individuals, health professionals and authorities in Fukushima are uniquely positioned to identify and provide insight into what would provide the best resolution for their specific needs beyond the spell of 1 mSv/year under the LNT model.
	C. Pölz-Viol	The need for communication with the public does not stop with the acute emergency phase. Ongoing risk communication has to be established in the post-emergency phase as part of long-term health surveillance in order to reduce uncertainty and support affected populations in dealing with the consequences of radiological emergencies.

communication has to be integrated as part of a multi-disciplinary and multi-layered long-term health surveillance. The necessary attention, appropriate structures, expertise, personal resources and training opportunities still have to be strengthened at all levels and in all phases of emergency response and recovery. Long-term research on public perception and mental health following a nuclear accident has to be implemented, and risk communication activities need to be monitored and evaluated continuously in order to be improved and adapted.

A summary of the key messages per chapter is provided in Table 2.

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