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Radiation Accidents and Malicious Events – Scenarios and Scope of the Work of ICRP Task Group 120

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Abstract

The International Commission on Radiological Protection (ICRP) Task Group 120 (TG120) is developing ICRP recommendations for radiological protection for a wide range of radiation accidents and malicious events, complementing those given in ICRP *Publication 146* (2020) for large nuclear accidents. The scope includes accidents involving criticalities, operating faults, and fires and explosions in nuclear facilities, inadvertent damage to sealed radiation sources, as well as malicious events, such as sabotage of nuclear facilities or materials, use of radiological dispersal devices, the contamination of food and drinking water supplies, and the deployment of nuclear weapons. A template has been designed to collate relevant information on a wide range of case studies and hypothetical malicious scenarios to ensure that the recommendations developed are broadly applicable and comprehensive. For all scenarios, a graded approach to protection is being taken, accepting that specific guidance may be required for some distinctive aspects, for example, protection during times of armed conflict. This paper provides an overview of the scenarios and scope of the work of TG120, including some of the radiological and non-radiological impacts of radiation emergencies, along the response and recovery timeline.

In 2005, the International Commission on Radiological Protection (ICRP) Publication 96[1] set out guidelines for protecting people against radiation exposure in the event of a radiological attack involving, for example, radiological dispersal devices (RDD). Since then, in 2007, ICRP has updated its fundamental recommendations in Publication 103,[2] and in 2020, also produced Publication 146,[3] giving advice on protecting people and the environment in the event of a large nuclear accident at a nuclear power plant (NPP). This leaves an important gap in the advice offered by ICRP for radiation emergencies or events that are not large-scale nuclear accidents at NPPs and are of malevolent origin. Furthermore, some of the basic concepts/approaches described in Publication 96 have been superseded by the 2007 recommendations, so the advice currently offered by ICRP for malicious events is not as consistent or comprehensive as it should be.

A Task Group (TG120) was established by ICRP in 2021 with a mandate to develop ICRP recommendations for radiological protection for a wide range of radiation accidents and malicious events, including a nuclear detonation. These recommendations will complement those given in Publication 146 for large nuclear accidents. This short paper describes the scenarios and scope of the work of TG120.

Radiation Accidents and Malicious Events

Scenarios involving the release, or potential release, of radioactivity into the environment, as well as those resulting in over-exposure of humans without a release, can result from accidents and malicious events.

Accidents can occur at nuclear facilities, following a criticality, fault in operation, fire, or explosion at facilities where nuclear material is stored. Accidents can also arise from inadvertent theft, damage, or loss of radiation sources, as well as during transport of radioactive materials via road, rail, air, sea, or space. Other accidents involving radioactive materials can occur in wider industrial applications or where nuclear medical isotopes are used in health care. Furthermore,

Table 1. Scenarios considered by ICRP TG120*

Scenario type	What/where	Cause	Specifics
Accident	Nuclear facility	Criticality	Tokaimura, Japan (1999)
		Operating fault	Three Mile Island (1979)
		Fire/explosion	Windscale (1957)
			Kyshtym (1957)
			Hanford (1976)
		Leakage	Techa River (1961)
	Inadvertent theft, damage and loss of sources. Orphaned sources	Theft	Goiania (1987)
		Damage to sealed source	Harborview (2019)
		Orphaned	Chile (2005)
	Transport	Satellite accident	Cosmos 954 (1978)
		Plane accident	Palomares (1966)
	Nuclear medicine	Isotope spill	Birmingham hospital (2018)
Malicious event or military act during armed conflict	Sabotage	Nuclear facility or transport during armed conflict	Military attack (hypothetical)
	RDD	Explosive	Hypothetical RDD
	RED	Covert	Hypothetical RED
	Nuclear detonation	Ground-burst	Hypothetical
	Nuclear detonation	Air burst	Hiroshima (1945)
	Contaminated food and drinking water	Food and drink	Hypothetical
	Poison individuals	Food and drink	Litvinenko (2006)

*Advice on protecting people and the environment in the event of a large nuclear accident at a nuclear power plant has been provided by ICRP Publication 146; such large accidents are not specifically included in the scope of TG120.

external events such as earthquakes, tsunamis, hurricanes and flooding can lead to, or worsen the impact of radiation emergencies.

Malicious events involve the deliberate introduction of radioactive material with the intent to cause physical, psychological, or economic harm. Planning for response to malicious events is based mainly on hypothetical scenarios that might include transport of nuclear materials, theft of radiation sources for use in radiological dispersal devices (RDDs) and covert radiological exposure devices (REDs), as well as the poisoning of individuals and more widespread deliberate contamination of food and drinking water supplies, or military acts during armed conflict involving sabotage of nuclear facilities and nuclear detonation (either from an improvised nuclear device (IND) or a nuclear weapon). Hypothetical scenarios have been developed using best estimates from credible models or expert judgement. In terms of context, the IAEA Incident and Trafficking Database,[4] published in 2024, contains a total of 4243 confirmed incidents of either unauthorized activities or events involving nuclear and other radioactive materials out of regulatory control, since 1993. Of these, there were 350 incidents connected with trafficking or malicious use.

Table 1 summarizes key features for a range of radiation accidents and malicious events, including historical examples. They encompass a diverse range of initiating events of various scales, that have resulted in a broad range of impacts. By evaluating such diverse scenarios, ICRP hopes to ensure that the Commission's recommendations on protection are comprehensive. For all scenarios, a graded approach to protection is being taken, with the aim of making the advice as generally applicable as possible, accepting that specific guidance may be required for some distinctive aspects.

Collection and Compilation of Information

A template was designed to collate relevant information on a range of radiation accidents and malicious events considering radiological and non-radiological aspects. An indicative, non-exhaustive list of the type of information recorded for each scenario is summarized in Table 2. Most of the radiological information was found to be readily available in the published literature. For non-radiological aspects, some interpretation of papers and reports was required, particularly for those relating to whether the principles of justification and optimization had been applied; whether

Table 2. Attributes considered in the scenarios template by ICRP TG120

Radiological	Non-radiological
Radionuclides involved	Scale and land use: area, people
Duration of response and recovery phases	Mental health and psychosocial consequences
Dose criteria and other derived criteria	Societal and economic impact
Exposure pathways	Stakeholder engagement
Justification and optimization	Role of communication
Protective action(s)	Environmental impact and sustainability
Doses (responders, public, non-human biota)	
Tissue reactions and cancer	

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psychosocial and economic attributes were considered; whether there was evidence of stakeholder engagement; and what forms of communication were used. So far, some 18 case study templates have been produced, providing an important resource for the Task Group (TG) as it develops its recommendations.

Exposure Situations and Timelines

In 2007, ICRP introduced 3 different types of exposure situations: existing, planned, and emergency. All 3 types of exposure situations can occur in the course of radiation accident or malicious event. For most emergencies, an emergency exposure situation will transition into an existing exposure situation. For some small incidents an emergency exposure situation will transition into a planned exposure situation, where emergency responders will be managed as occupationally exposed workers.

The TG distinguishes between response and recovery phases. The response phase is further subdivided into early and late phases. The early phase marks the beginning of the radiation emergency. During this phase, there may be a risk of over-exposure of people due to the presence of a covert/contained source (e.g., RED) or the release of radioactive material into the environment. Releases can last from a few minutes or hours to a few weeks and can be a single release or multiple intermittent releases. Depending on the type of emergency, there may be a period of time between the declaration of the emergency and the start of the radionuclide release, while in a malicious event there is unlikely to be any warning. In all cases, however, there will be considerable uncertainty about the prognosis and little information and data available on which to base protection decisions. The late response phase (also known as the "intermediate phase" in ICRP Publication 146[3]), is when the release of radioactivity, whether that be a plume, external dose from a sealed/unsealed source, or threat of an event has been brought under control but not necessarily stopped. However, further significant releases are unlikely. The recovery phase begins when the radiological conditions in affected areas are sufficiently characterized to support decisions by the authorities about the future of these areas. Preparations for recovery begin during the late response phase, and the period between the 2 is known as the transition phase.

General Considerations

In considering such a wide range of radiation emergencies, the TG hopes to identify commonalities and to encompass all relevant radiological and non-radiological factors contributing to and influencing radiological protection advice and criteria. The subsections below provide an overview of some of the general considerations that have been considered. Going forward, these will be further elaborated for specific phases of the timeline, including what can be done in advance by preparedness and planning.

Radiological Aspects

Radionuclides

A wide range of radionuclides can be released to the environment from the scenarios listed in Table 1. These include both short- and long-lived radionuclides, and a range of alpha, beta and gamma hazards and, in certain scenarios and conditions (e.g., a criticality accident), neutron hazards. Radionuclides can be released singly or as a mixture, depending on the type of scenario. Typically, accidents involving criticalities, operating faults, and explosions at nuclear facilities and malicious use of nuclear weapons involve the release of a range of fission products (e.g., isotopes of cesium, iodine, and strontium), noble gases (xenon, krypton), and activation products (e.g., isotopes of iron, zinc, and manganese). Scenarios involving single radionuclides from medical or industrial settings tend to be beta/gamma emitting sources, such as ^{60}Co, ^{99}Tc, ^{131}I, ^{137}Cs, ^{192}Ir, and ^{241}Am. These sources are also the most likely to be used with malicious intent in a RDD or RED scenario. However, as the Litvinenko ^{210}Po poisoning case in the UK indicated, any available radionuclide can be used with malicious intent to contaminate food and drinking water supplies.

Duration of response and recovery phases

The duration of different phases is driven by the size and complexity of the radiation emergency. For a criticality accident, such as the one at Tokai Mura, Japan in 1999, the response phase may only last a few days. In contrast, damage to a radioactive source like what happened at Goiania, Brazil in 1987, can lead to a response phase of several months. Similarly, the recovery phase for small scale emergencies or those involving short-lived radionuclides (e.g., Windscale Fire, UK in 1957), may be of short duration, lasting a few months, while for large accidents, malicious events or military acts during armed conflict, involving long-lived isotopes, the recovery phase may extend over several years to decades (e.g., atomic bombings in Japan in 1945, Kyshtym explosion in former USSR in 1957, or Palomares accident in Spain in 1966).

Dose criteria and other derived criteria

For the protection of people in emergency and existing exposure situations, ICRP Publication 146[3] recommends using reference levels, expressed in terms of individual effective dose (mSv), to restrain inequity in the distribution of exposures and to maintain or reduce all exposures to as low as reasonably achievable. ICRP notes that the use of effective dose is primarily aimed for planning purposes and to support preventing and mitigating stochastic health effects. Whilst this can be useful for large scale releases involving whole body immersions in a plume (e.g., the Three Mile Island accident in USA in 1979), it may be less appropriate for malicious events or smaller scale accidents where the exposures may be localized to a specific area of the human body (e.g., RED, ^{210}Po poisoning of Litvinenko in the UK in 2006, and the orphaned source accident in Chile in 2005). Given the range of situations that may be encountered, the TG is also considering developing additional situation specific criteria expressed in terms of absorbed dose (including RBE-weighted absorbed dose) to protect against severe tissue effects or injuries.

Exposure pathways

Release of radionuclides during a radiation emergency can be to the atmosphere, to waterbodies, or to the ground. After release, radionuclides can be dispersed through the environment by wind, water flow, and other processes. Any humans present will be exposed to radiation emitted by those radionuclides via a number of exposure pathways that include inhalation of radionuclides in air; ingestion of radionuclides in dusts, water, or foods; direct deposition onto skin; and external irradiation from radionuclides present in air and soils and on surfaces of buildings, roads, and vegetation. Some types of radiation emergency, such as the Goiania accident, have the potential to involve all exposure pathways, whereas others may only affect 1 pathway. For example, deliberate emplacement of a RED leads to external exposures, whilst deliberate contamination of food and water supplies causes internal exposure following

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ingestion. In addition, scenarios such as a RDD may involve contamination of wounds with radioactive material.

Justification and optimization of protection

All decisions that aim to reduce the impact of exposure in the event of a radiation emergency inevitably introduce additional constraints on living and working in the affected areas, and these must be considered when justifying the decision and optimizing protection. Involvement of key stakeholders in these processes should be sought whenever possible, and regularly reassessed as the situation evolves. Protective actions should continue to do more good than harm in the broadest sense by balancing the level of residual exposure of the affected people against the societal, environmental, and economic effects, and mental health and psychosocial wellbeing. Protection is considered optimized when it has achieved the most reasonable outcome for all stakeholders and the magnitude of individual doses are as low as reasonably achievable.

Protective action(s)

Protective actions are taken during a radiation emergency to reduce or prevent exposures. The action can be to secure or remove the source, or to modify the location and habits of the exposed individuals. Some actions, such as sheltering in place, evacuation, and stable iodine, can be taken if there is a threat of a release (e.g., the Three Mile Island accident). In the immediate aftermath, urgent protective actions are to save life while preventing and mitigating severe tissue reactions and injuries that can result in long-term health effects, disability, and even the loss of life. Restricting access to highly contaminated areas and personal decontamination are effective in the early response phase and were implemented, for example, during the Birmingham hospital accident in the UK in 2018 and the Litvinenko poisoning in 2006.

Doses to people and effects

There are 2 broad categories of people that may be affected by radiation emergencies: members of the public and responders. Responders include for example emergency teams (e.g., firefighters, police officers, medical personnel, drivers, and crews of vehicles used for evacuation), workers who may or may not be considered as occupationally exposed, military support personnel, security services, care workers and social workers, and citizens who volunteer to help.[3] Radiation emergencies have the potential to expose responders and members of the public to a wide range of doses. Some of these doses may cause radiation-induced health effects, either by inducing tissue reactions at high levels of exposure or increasing long-term risk of cancer.

Effects: tissue reactions. Doses greater than a few Gy are likely to result in tissue/organ damage that is characterized by a threshold dose above which the severity increases with level of exposure. Threshold values vary according to the organ or tissue, to the effect considered, and to the type of radiation exposure (e.g., acute or protracted). Such damage may occur in the hours, days, or weeks after exposure (early tissue reaction), or after a much longer period of time that could extend from years to even decades (late tissue reactions). Early tissue reactions may result from high-dose external exposure or significant internal contamination. Such effects have been observed in past radiation accidents. For example, following the Tokai Mura criticality accident in 1999, 2 workers receiving absorbed doses of 16-20 Gy and 6-10 Gy (from neutrons and gamma rays) died some 83 and 194 days later, respectively, from Acute Radiation Syndrome.[5] Alexander Litvinenko, who was poisoned with ^{210}Po in 2006, died 22 days later as a result of widespread damage to the organs and tissues of the reticulo-endothelial system, including red bone marrow. The highest estimated doses to Litvinenko's liver and kidneys were 92 Gy and 140 Gy, respectively, at the time of death.[6] Early tissue reactions may also arise from military action during armed conflict, for example, a nuclear detonation. Late (delayed) tissue reactions, such as non-healing wounds, hair loss, and radiation dermatitis may occur in the months or years following external exposure or internal contamination, acute or protracted. These effects were recorded after the bombing of Hiroshima.

Effects: stochastic. Cancer and heritable effects are characterized by an increase in the probability of occurrence proportional to the dose, while their severity is independent of the dose received. The risk of health effects associated with low-dose and low-dose-rate radiation exposure is very low, with some uncertainty about the exact risk to an individual. Based on the results of epidemiological studies, it is estimated that a dose of 100 mSv above the natural background level adds approximately 0.5% to the 25% lifetime risk of fatal cancer typically seen in populations worldwide.[2] In addition to the early and late tissue reactions, the bombing of Hiroshima in 1945 also caused a surge in childhood leukaemia cases into the 1950s, and elevated rates of other types of cancer in the exposed population.

Doses to non-human biota and effects

Flora and fauna may be exposed to radiation in a similar way to humans, leading to DNA damage. Although there are broad similarities in radiation responses of different organisms, there are wide differences in their radiation sensitivity. As such, radiological induced effects to non-human biota have no universal "value" for causing tissue reactions. As an example, the lethal absorbed dose for different flora and fauna can vary by factors of 1000 to 10 000, with mammals being the most sensitive and viruses being among the most radiation resistant.

Non-radiological Aspects

Scale and land use affected

The scale of radiation emergencies may range from an isolated occupational over-exposure of a single person (e.g., the Chile accident in 2005), to contamination of a single building (e.g., Harborview in 2019), to contamination of many buildings (e.g., the Goiania accident in 1987; the Litvinenko case in 2006), to contamination of large areas of agricultural land (the Windscale Fire in 1957; the Kyshtym accident in 1957), or extend to a major catastrophe with global dimensions (nuclear detonation). All types of land use may be affected, resulting in widescale food and drinking water restrictions, and destruction of critical infrastructure. The scale of contamination affects the resources required for remediation and decontamination and ultimately the management of large volumes of waste.

Psychosocial consequences

Lessons learned from previous nuclear accidents have demonstrated that the long-term mental health and psychosocial consequences can outweigh the more immediate and direct physical health impacts of radiation exposure and can persist for years if not adequately addressed.[7] Fear and uncertainty about radiation risks, negative perceptions about protective actions, social stigma towards affected people, and misinformation can exacerbate people's distress. This can result in substance abuse, domestic violence, anxiety, and post-traumatic stress disorder. Following

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the Goiania accident in 1987, thousands of people were impacted psychologically, especially as it happened a year after the Chernobyl accident. Some residents of Goiania were not allowed to register in hotels, to fly on planes, or to travel on buses. The mental health consequences of a malicious event are more severe than from a radiation accident, primarily due to the deliberate intent to cause harm, instill fear, and disrupt societal norms. Radiological terrorism creates a heightened sense of ongoing security threats and the potential for additional attacks. This sustained state of fear and uncertainty (in terms nature of the source and location) can contribute to chronic stress and anxiety among affected individuals and communities, made worse if there has been little or no emergency preparedness for such an event.

Societal and economic impacts

The sudden presence of radioactive contamination in the environment may upset the quality of life of affected communities. Some people will choose to stay in the affected area, when this is allowed, and others will leave. This can seriously affect community life and may impact economic activities in the affected area over the short and long terms. This can lead to the long-term depopulation of previously thriving regions due to a negative feedback loop of poor economic conditions and lack of infrastructure, especially medical care.[8] Residents of Goiania, for example, suffered significant economic and social stigma that lasted for an extended period. The impact on food production and manufactured goods was felt beyond the contaminated area.

Stakeholder engagement and risk communication

By engaging with all the relevant stakeholders, protection decisions should be more holistic, inclusive, and sustainable, provided that the process adopted is transparent and fair. Furthermore, early engagement, even prior to a radiation emergency, is key for building and shaping the subsequent communication strategy.[9] Different engagement processes are required according to circumstance, and different stakeholder groups can be reached through different channels to ensure that accessibility of the process is optimized (e.g., face to face meetings or online, social media or printed newsletters, technical or plain language). The level of engagement should be proportionate to the nature of the radiation protection issues and their context,[10] and to the level of perceived risk. Throughout the response to the Palomares accident and subsequent remediation, affected stakeholders (regional and local authorities, citizens, environmental groups, media etc.) were closely involved in decisions on the protective actions taken, and this was a fundamental to optimizing the strategy. This maintained confidence in the expert's assessments and authorities' recommendations.

Crisis communication for radiation emergencies should respond to the publics' concerns and address potential uncertainties without triggering panic. The information provided should help affected individuals assess their own risks and motivate them to take appropriate protective actions. Prompt, clear, and accurate communication enhances trust in the responsible authorities. This can be strengthened by following the key principle of 1 message, many voices.[11] The communication strategy at the time of the Litvinenko poisoning was open and transparent. The government agencies responsible for managing the response held regular press conferences, issued daily press statements, set up help lines for anyone affected, responded to thousands of media calls, and regularly updated their websites.[12] In contrast, the accident at Three Mile Island was heavily criticized due to communication failures that ultimately contributed to the public's fears, confusion, and distrust, as indicated in the Report of the President's Commission on the Accident at Three Mile Island (October 30, 1979).

The rapidly evolving social media landscape over the last few decades provides new challenges to public communication. It has the potential to provide benefits to radiation protection authorities by rapidly disseminating critical information to much larger audiences. In so doing, it can help establish trustworthiness of authorities and experts.[13] However, social media can also give rise to an increase in mis- and disinformation available online, resulting not only in uncertainty and an undermining of trust, but also in the adoption of incorrect protective actions.[14] The TG is currently developing recommendations on how best to use social media for a range of radiation scenarios, as no single message fits all. Clearly, a small-scale accident involving a known radionuclide at a nuclear facility would require a very different communication strategy from that for a large scale malicious event such as a dirty bomb or nuclear detonation in an urban area, where the radionuclides may initially be unknown.

Environmental Impact and Sustainability

Since ICRP Publication 103[2] and ICRP Publication 108,[15] there has been an increasing international focus on environmental protection, including the United Nations Sustainable Development Goals (SDGs). There is an increasing need to look at emergency preparedness and response more holistically, due to the interdependence between humans and the environment. Protection is not as human centric as it used to be. As such, all protective actions, with the exception of those concerned with lifesaving, should deliver a net benefit and be informed by the short- and long-term impacts on safety and the environment, society and the economy, natural resources, and climate change. As a minimum this should include not preventing future resource or land uses that are deemed desirable by local stakeholders and wider society, such as agricultural use, commercial activities, or social and cultural activities. For example, certain remediation actions may produce adverse impacts on ecological receptors, including habitat disruption by removal of soil, or inappropriate disposal of waste. Following the Windscale Fire in 1957, some 3 million liters of contaminated milk were diluted with water and poured down drains and into rivers and the sea. Strict environmental legislation in recent years would not permit such an activity.

Next Steps

Due to the broad range of scenarios and scope of TG120, a flow chart is being developed to help navigation along the response and recovery timeline. Current focus is on prioritzying activities and actions that need to be carried out in the pre-release, early, and late phases of the emergency response, and how this may be affected by situations of armed conflict. In particular, the TG is developing guidance and recommendations on topics such as emergency dosimetry, monitoring (people and environment), modelling and dose assessment, rescue and lifesaving, triage, and protective actions. In parallel, the TG is critically evaluating how past radiation emergencies were communicated, both in terms of the media that were used and the messaging. The aim is to provide guidelines and best practices on when, how, and what to communicate; including how to counter misinformation. To aid authorities in communicating with the public early, the TG is developing social media templates to be used in emergency preparedness and response. Finally, the TG is working closely with other relevant ICRP Task Groups to ensure consistency in its recommendations, for example with TG112 on emergency dosimetry, TG114 on reasonableness and tolerability, TG124 on application of the principle of justification, and TG127 on exposure situations and categories of exposure.

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