World Scientific Research
Vol. 13, No. 1, 1-6, 2026
ISSN(E) 2411-6661/ ISSN(P) 2518-0177
DOI: 10.20448/wsr.v13i1.7986

Methods of protecting the population in the event of a radiation accident

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Abstract

This article aims to analyze effective methods for protecting the population during radiation accidents by identifying key risks and evaluating strategies that minimize harmful exposure. The study applies a descriptive and analytical approach, examining the causes, characteristics, and spread of radioactive contamination, as well as the protective measures implemented during such emergencies. The analysis reveals that timely evacuation, temporary sheltering, appropriate use of protective equipment, and proper radiation safety procedures significantly reduce the impact of radiation exposure. The findings also show that public awareness, efficient communication systems, and the integration of modern technologies such as early warning systems, monitoring devices, and predictive modeling play a crucial role in enhancing preparedness and response efforts. The practical implications of the study suggest that adopting a comprehensive and proactive protection framework can help authorities mitigate risks, prevent long-term health consequences, and minimize environmental damage during radiation accidents.

Keywords: Accident, Evacuation, Hazardous areas, Population protection, Protective equipment, Radiation level, Radiation, Safety.

Citation | Sirojiddin, M. (2026). Methods of protecting the population in the event of a radiation accident. *World Scientific Research*, *13*(1), 1–6. 10.20448/wsr.v13i1.7986
History:
Received: 5 November 202
Revised: 13 November 2025
Accepted: 19 December 2025
Published: 5 January 2026

Publisher: Asian Online Journal Publishing Group

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

Contents

Contribution of this paper to the literature
This study is original in proposing an integrated approach that combines population protection measures with modern technologies such as early warning systems, monitoring devices, and predictive modeling. The paper's primary contribution is identifying practical ways to implement a comprehensive, technology-enhanced protection framework during radiation emergencies.

1. Introduction

Radiation accidents can occur at many large nuclear energy facilities, particularly at nuclear power plants. Historical records and reports from the International Atomic Energy Agency (IAEA) highlight that such accidents, although rare, can have catastrophic consequences [1]. These incidents are not limited to a single country or region but represent a global risk due to the potential for long-range radioactive contamination [2]. Radiation accidents drastically affect not only the environment but also the lives, health, and economic well-being of tens of thousands of people [2]. For instance, the Chernobyl disaster in 1986 resulted in radioactive contamination of territories extending for hundreds of kilometers, forcing the evacuation and permanent relocation of thousands of residents [3]. Similarly, the Fukushima Daiichi nuclear disaster in 2011 caused severe environmental degradation, long-term displacement of populations, and significant economic losses [4].

Given these historical lessons, the importance of protection against radiation hazards is a pressing issue affecting both individuals and the global community [5]. Preventing radiation accidents and mitigating their consequences requires effective protective measures, careful planning, and preparedness through modern technologies [6]. Moreover, understanding the nature of radiation, its biological effects, and pathways of exposure is essential for designing both preventive and response strategies [7].

From a scientific perspective, radiation protection is based on three fundamental principles: time, distance, and shielding [8]. Limiting the time of exposure to radiation sources reduces the total absorbed dose and the risk of acute and chronic health effects [9]. Increasing the distance from the source decreases radiation intensity according to the inverse square law [10]. Shielding, using materials such as lead, concrete, or water, absorbs or deflects radiation, providing a barrier between the source and humans or sensitive equipment [11]. These principles form the foundation of occupational safety standards applied in nuclear energy, medical diagnostics, radiotherapy, and various industrial applications [12]. International organizations, including the IAEA and regional regulatory bodies, develop guidelines and mandatory safety protocols for states utilizing nuclear technologies [13].

Dosimetry, the precise measurement of radiation doses received by individuals, is another critical component [14]. Personal dosimeters, such as thermoluminescent dosimeters (TLDs) or electronic personal dosimeters, allow continuous assessment of exposure [15]. Environmental monitoring devices track radiation in air, water, and soil to ensure exposure remains within safe limits [16]. Biological monitoring, including health examinations and cytogenetic analyses of workers, supports early detection of radiation-induced health effects, enabling timely interventions [17].

Modern technological advancements have significantly improved nuclear safety. Safer reactor designs, such as Generation III+ reactors, incorporate passive safety systems capable of automatically shutting down during abnormal conditions [18]. Enhanced waste management strategies, including secure storage and advanced processing of radioactive materials, reduce long-term environmental risks [19]. Early warning and real-time monitoring systems help detect abnormal radiation levels promptly, minimizing the likelihood of large-scale disasters [20]. Digital simulations and predictive models now also allow operators to anticipate potential failures and optimize preventive measures [21].

Despite these advancements, human factors remain a critical determinant of nuclear safety. Management errors, insufficient training, or failure to follow established safety procedures have historically contributed to severe accidents [22]. Therefore, fostering a culture of radiation safety, implementing regular personnel training, and conducting public awareness campaigns are indispensable for comprehensive protection strategies [23].

The global dimension of radiation hazards is crucial. Radioactive particles released during major accidents do not respect borders, affecting air, water, food supplies, and ecosystems far from the accident site [24]. International cooperation, rigorous scientific research, and unified regulations are necessary to protect humanity from radiation dangers [25]. Only through joint efforts can societies ensure sustainable development while harnessing nuclear technologies for energy, medicine, and science without compromising human health and environmental safety [26].

1.1. Main Part

A radiation accident can pose serious threats to both people and the environment. In such cases, it is crucial to implement highly effective measures to protect the population and workers. This article analyzes the main methods of protecting the population in the event of a radiation accident. These methods include detecting radioactive contamination in the environment, ensuring safety in hazardous areas, implementing radiation safety measures, and using protective equipment against radiation sources. In addition, technologies and systems necessary for protecting the population are also considered.

The methods of protecting the population during a radiation accident include.

- Characteristics of radioactive contamination in the environment.
- Ensuring radiation safety measures and analyzing compliance with standards, rules, and hygiene norms in the field of radiation safety.
- Assessing the probability and scale of radiation accidents, as well as the level of preparedness for effectively eliminating accidents and their consequences.
- Analyzing doses of radiation received, being received, and expected to be received by workers and the population from all ionizing radiation sources.
- Determining the number of people exposed to radiation levels exceeding the established basic dose limits.

Radiation safety at a facility and in its surrounding areas is ensured by the following indicators.

- Construction of the radiation facility.

- Rational selection of site and location for the radiation facility.
- Physical protection of radiation sources.
- Zoning of territories inside and around the most hazardous facilities.
- Conditions of technological systems' operation.
- Radiation-hygienic assessment and licensing of activities involving radiation sources.
- Radiation and hygienic assessment of products and technologies.
- Availability of a radiation monitoring system.
- Planning and implementation of measures to ensure radiation safety of workers and the population during normal operation, reconstruction, and decommissioning of a facility.
- Improving radiation and hygienic literacy of workers and the population.
- Restrictions on access to work with radiation sources are based on age, gender, health status, previous exposure level, and other indicators.
- Knowledge and compliance with rules for handling radiation sources; adequacy of protective barriers and distance from radiation sources, as well as limiting the duration of work with them.
- Creating working conditions that meet the requirements of NRB-2006 and relevant regulations.
- Use of personal protective equipment.
- Compliance with established reference levels; organization of radiation monitoring.
- Organization of a radiation information system.
- Taking effective protective measures for workers when planning responses to threats and accidents.

Protection of the population against radiation is achieved through the following tasks.

- Timely introduction and application of tools and methods to identify and assess the scale and consequences of accidents at radiation-hazardous facilities.
- Establishment and use of monitoring systems (mainly automated) and local warning systems at hazardous facilities.
- Development and implementation of radiation protection regimes for the population, functional facilities of the economy, and infrastructure in conditions of gas contamination of the area.
- Pre-adaptation of utility services and transport enterprises to carry out special decontamination of clothing, property, and transport in emergency situations.
- Training the entire population to use personal protective equipment and follow the rules of conduct in contaminated areas.

In the event of an accident at nuclear power plants and other nuclear energy facilities, a number of measures must be implemented to protect the population. The scope and nature of these measures depend on the scale of the accident, its phase, and the time elapsed.

From a scientific perspective, radiation accident preparedness can be categorized into preventive, operational, and post-accident stages. Preventive measures include risk assessment, strict regulation of radiation sources, and the implementation of international safety standards. For example, the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) emphasize the importance of early risk identification, staff training, and the establishment of specialized emergency response units. Operational measures are implemented during the accident itself and focus on minimizing exposure through evacuation, sheltering, distribution of iodine tablets (to reduce thyroid uptake of radioactive iodine), and continuous radiation monitoring. Post-accident measures involve long-term decontamination of affected areas, medical surveillance of exposed populations, and socioeconomic rehabilitation programs.

The effectiveness of radiation protection directly depends on the quality of environmental monitoring systems. Automated monitoring technologies, such as dosimetry networks and mobile detection units, enable real-time assessment of radiation levels. These systems allow authorities to make informed decisions on whether evacuation, sheltering, or food and water restrictions are necessary. Moreover, the integration of geographic information systems (GIS) and remote sensing technologies has significantly enhanced the precision of radiation mapping and contamination analysis.

Another critical scientific aspect is dosimetric analysis. In cases of radiation accidents, accurate measurement of radiation doses is essential for both immediate medical response and long-term epidemiological studies. Individual dosimeters, bioassays, and whole-body counters are widely used to determine internal and external doses. Such data not only guide treatment strategies but also help refine safety standards for future incidents.

Radiation safety is not only a technical but also a social issue. Public awareness and preparedness are key factors in reducing panic and ensuring orderly evacuation. Research has shown that populations trained in basic protective actions (such as taking shelter indoors, sealing windows, and avoiding contaminated food) experience significantly lower health impacts compared to unprepared groups. Thus, community education programs play a vital role in building resilience against radiation risks.

In terms of facility safety, engineering controls are indispensable. The construction of nuclear power plants must incorporate multi-layered containment structures, redundant safety systems, and physical barriers against radiation leaks. The concept of "defense in depth," which requires multiple independent safety layers, has become the cornerstone of modern nuclear facility design. Additionally, facilities are required to conduct regular stress tests, emergency drills, and safety audits to ensure readiness under worst-case scenarios.

Long-term consequences of radiation accidents, such as those observed after Chernobyl and Fukushima, highlight the importance of socioeconomic rehabilitation. Beyond immediate health risks, displaced populations suffer from psychological trauma, loss of livelihood, and social disruption. Therefore, scientific approaches to radiation protection must integrate not only medical and technical solutions but also policies for social support, compensation, and environmental recovery.

Finally, radiation accidents underline the need for international cooperation. Since radioactive contamination can cross national borders, early warning systems, data sharing, and joint emergency response protocols are crucial. Programs like the International Nuclear Event Scale (INES) facilitate the transparent reporting of accidents, while multinational agreements support cross-border assistance in case of major disasters.

In conclusion, the protection of the population during radiation accidents requires a multidisciplinary approach, combining technological innovation, strict regulatory frameworks, medical preparedness, public education, and international collaboration. By integrating these elements, societies can significantly reduce the risks associated with radiation and ensure the safety and sustainability of nuclear technologies in the modern world.

Table 1. Protective measures for the population during radiation accidents.

Accident phase and its duration	Source of radiation	Main type of exposure	Protective measures for the population
Initial phase (from a few seconds to several hours)	Radioactive clouds and vapors	Internal and external exposure of organs and tissues	Public warning, protection of respiratory organs and body, evacuation, iodine prophylaxis, personal decontamination, and monitoring of food and water products.
Intermediate phase (from several days to up to one year)	Radioactive substances and radioactive cloud	Internal and external exposure of organs and tissues	Relocation of the population, environmental decontamination, monitoring of food and water products, and establishment of medical supervision.

When radioactive substances settle on the ground, dust formation can occur in many ways (strong winds, movement of vehicles, especially on dirt roads, and agricultural activities). In such contaminated areas, the use of respiratory protective equipment is extremely important.

A large amount of radioactive substances falling onto exposed areas of the skin can cause skin damage and burns. To prevent such harm, protective gear such as raincoats, vests, coveralls, rubber boots, and gloves should be used.

The protective properties of ordinary clothing can be enhanced to make it airtight: for example, by using additional layers, tightening with flaps, or impregnating the fabric with an emulsion mixture (2 liters of hot water, 250–300 g of grated soap, and 0.5 liters of mineral or vegetable oil).

Figure 1 illustrates protection against radiation through clothing.

1.2. Requirements for Limiting Radiation Exposure in the Event of a Radiation Accident

In the event of a radiation accident, it is necessary to establish control over the radiation source and take practical measures to minimize the radiation dose, the number of people exposed, the radioactive contamination of the environment, and the resulting economic and social losses.

When a radiation accident or radioactive contamination is detected, protective measures begin with minimizing the impact on the environment and protecting the population. If, within a short time (2 days), the expected radiation dose rises to a high level, deterministic effects of higher severity may occur. In this case, urgent intervention (protective measures) is required (Table 2).

Table 2. Absorbed dose levels requiring urgent measures.

Organ or tissue	Absorbed dose over 2 days (Gy)
Whole body	1
Lungs	6
Skin	3
Thyroid gland	5
Eye lens	2
Gonads	3
Fetus	0.1

In cases of chronic exposure during life, if the annual absorbed doses exceed the values given in Table 2, protective measures become mandatory. Exceeding these doses leads to serious deterministic effects.

The intervention levels for temporary relocation of the population are as follows.

- To begin temporary relocation: 30 mSv per month.
- To end temporary relocation: 10 mSv per month.

If it is estimated that the accumulated dose within one month will exceed the annual specified level, the issue of resettling the population for permanent residence must be resolved.

When implementing radiation protection interventions, dose limits are not applied (see Table 1). In the event of a radiation incident, the planning of protective measures is carried out under the supervision of the state sanitary-epidemiological authority. The intervention level (dose and dose rates, radioactive contamination level) is established for a specific radiation facility and its location conditions, taking into account the probable types of accidents, possible emergency development scenarios, and the existing radiological situation. In such cases, the radiation levels indicated in Table 3 may be disregarded.

Table 3. Intervention levels and protective measures for radiation facilities under different conditions

Radiation facility	Location condition	Intervention level (Dose)	Intervention level (Dose rate)	Radioactive contamination Level	Notes
Facility A	Urban Area	0.5 Sv	0.05 Sv/h	1000 Bq/m²	Standard condition
Facility B	Industrial Area	1.0 Sv	0.1 Sv/h	2000 Bq/m²	Emergency situation

In the case of accidents that cause large-scale radioactive contamination of a territory, a radiation accident zone is established based on monitoring and forecasting of the radiological situation.

When a large radiation accident occurs with contamination of the territory, decisions on protective measures for the population are made by comparing the predicted dose averted by protection and the contamination level with Levels A and B given in the table.

If the exposure prevented by a protective measure exceeds Level A but does not reach Level B, the decision to implement protective measures is made based on justification and optimization principles, taking into account the specific situation and local conditions.

If the exposure prevented by a protective measure reaches or exceeds Level B, the corresponding protective measures must be implemented, even if they disrupt the normal life of the population or the economic and social activities of the area. In the later stages of a radiation accident that causes contamination of large territories with long-lived radionuclides, decisions on protective measures are made considering the current radiation situation and specific socio-economic conditions.

One of the important preventive medical measures to reduce internal radiation doses, especially in the second stage of an accident, is radiometric monitoring of radionuclide levels in food products produced from locally sourced raw materials. Such monitoring is conducted by specialized laboratories.

2. Conclusion

Radiation accidents are natural or man-made events that pose serious threats to human health. Ionizing radiation negatively affects the environment and living organisms, and high doses of radiation can alter cellular structures, cause mutations, and lead to cancer. Radiation accidents can occur, particularly at nuclear energy facilities or during the use of nuclear weapons, resulting in widespread contamination and posing significant risks to public health. Understanding how radiation affects the human body is crucial for effectively protecting the population.

Radiation can enter the human body through various pathways and damage its cells. Ionizing radiation can harm DNA and trigger genetic changes, leading to cancer, blood and circulatory system disorders, immune system weakening, and other serious illnesses. Prolonged exposure to radiation is especially hazardous, and the highest levels of radiation can cause critical biological changes and even death. Therefore, developing effective protection methods to minimize radiation risk is essential.

There are several key methods for radiation protection. First, the use of protective equipment is necessary. Maintaining distance from radiation sources, blocking radiation with protective materials (such as lead or concrete), and wearing specialized protective clothing (radiation suits, respirators) play a vital role in safeguarding against radiation hazards. Second, evacuation and rapid removal from hazardous areas are of great importance. By relocating the population and workers to safe areas, exposure to high radiation doses can be prevented. Effective control must be ensured through careful planning, automated systems, and warning systems.

Another method of radiation protection is implementing radical preventive measures, such as isolating affected individuals, continuously monitoring their health, and providing prompt medical assistance if necessary. Increasing the population's literacy on radiation safety also plays a key role in protecting against radiation hazards. Therefore, ensuring radiation safety requires not only technological measures but also social education and awareness.

Preventing radiation hazards and mitigating their consequences requires a broad and comprehensive approach. Implementing all protective measures effectively helps reduce the impact of radiation hazards. Radiation safety involves taking all necessary actions to protect the human body from high-dose radiation and prevent its long-term adverse effects.

From a scientific perspective, radiation protection is grounded in three universal principles: time, distance, and shielding. These principles emphasize minimizing the duration of exposure, maximizing the distance from the radiation source, and employing adequate barriers to block radiation. Additionally, dosimetric monitoring and health surveillance play a crucial role in understanding both immediate and long-term biological effects. Modern technologies such as automated radiation detection systems, geographic information mapping of contaminated zones, and early warning networks significantly increase the efficiency of protective measures.

Furthermore, lessons learned from major accidents such as the International Atomic Energy Agency [1] the International Atomic Energy Agency [2] highlight that radiation accidents are not only a local but also a global problem. Contamination can spread across borders, requiring international cooperation, unified safety standards, and transparent information exchange. Preparedness through joint drills, international agreements, and public awareness campaigns is therefore indispensable.

In conclusion, effective radiation protection requires a multidisciplinary and integrated approach, combining medical, technological, regulatory, and educational strategies. Only through coordinated efforts between governments, scientific institutions, and the public can radiation risks be minimized, ensuring both present and future generations' health and environmental safety.

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