

Eurasian
Research Bulletin



Radiological Contamination: A Modern Overview

N.T. Akhmedova

Assistant, Department of Clinical Disciplines, EMU University

L.A. Mamadalieva

Student, Cosmetology program C101AR, EMU University

ABSTRACT

Radiological contamination of the environment remains one of the most pressing contemporary challenges, arising from both natural sources of ionizing radiation and anthropogenic activities. This comprehensive review presents a systematic analysis of current scientific data on the sources of radioactive contamination, mechanisms of biological impact on the human body, epidemiology of radiation-induced diseases, and contemporary approaches to diagnosis, treatment, and prevention of radiation injuries. Based on authoritative international sources — including epidemiological studies of the Japanese atomic bombings, the Chernobyl and Fukushima accidents, as well as long-term observations of occupational and medical exposed cohorts — the review examines current concepts of stochastic and deterministic effects of ionizing radiation. Particular attention is paid to the analysis of the radiation situation in the Russian Federation in 2024, including the structure of radiation accidents, the problem of unauthorized circulation of radioactive sources, and contamination of food products. The article is intended for specialists in radiation hygiene, ecology, disaster medicine, and for a broader audience interested in radiation safety issues

Keywords:

radiological contamination, ionizing radiation, acute radiation sickness, radiation-induced carcinogenesis, Chernobyl accident, radiation safety, decontamination, radionuclides, stochastic effects, deterministic effects, radio-phobia, nuclear accidents, Fukushima

Introduction. Ionizing radiation is an integral environmental factor. Since the dawn of humanity, populations have been exposed to natural background radiation from cosmic rays and radioactive elements in the Earth’s crust. However, with the development of nuclear technology, atomic energy, and widespread use of ionizing radiation sources in medicine and industry, the problem of radiological contamination has acquired a qualitatively new dimension. Thousands of radiation incidents and accidents are registered annually worldwide, and major catastrophes — such as the Chernobyl accident (1986) and Fukushima

(2011) — lead to long-term contamination of vast territories and substantially affect public health.

Despite significant progress in understanding the biological effects of radiation, many unresolved questions remain. Risk assessment at low doses, individual radiation sensitivity, long-term health consequences, and effective treatment methods for radiation injuries continue to be subjects of active scientific research. These issues gain particular relevance in light of the ongoing threat of radiological terrorism, the possibility of new accidents at

nuclear facilities, and the need for evidence-based radiation hygiene regulation.

This review article aims to systematize current scientific knowledge on the problem of radiological contamination, covering sources and mechanisms, medical consequences, and approaches to prevention and treatment of radiation injuries.

Materials and Methods. This review is based on the analysis of scientific literature published primarily in the period 2020–2025, as well as a retrospective analysis of key epidemiological studies that laid the foundations of modern radiobiology.

Sources of information:

1. International databases: PubMed, PMC, containing results of key epidemiological studies, including long-term observations of survivors of the atomic bombings of Hiroshima and Nagasaki (Life Span Study).

2. Official data and guidelines: World Health Organization (WHO) materials, data on radiation accidents and incidents in the Russian Federation for 2024, presented by the St. Petersburg Research Institute of Radiation Hygiene named after Professor P.V. Ramzaev.

3. Clinical guidelines: Data from the MSD Manuals (professional version) on the diagnosis and treatment of radiation injuries, updated as of January 2025.

4. Educational and scientific publications: Textbooks on radiation ecology and radiobiology, scientific reviews on radioactive waste management and decontamination methods.

5. International studies: Results of comparative studies in regions with elevated natural background radiation (India, China, Indonesia).

Key search terms: ionizing radiation, radiological contamination, acute radiation sickness, radiation carcinogenesis, radiation safety, nuclear accidents.

Results and Discussion

1. Sources of Ionizing Radiation and Radiological Contamination

Ionizing radiation has both natural and artificial origins. Understanding these sources is

fundamental for risk assessment and the development of protective measures.

1.1. Natural Sources. Humans are constantly exposed to natural radiation, which forms the so-called background radiation. The main components of natural exposure are:

- **Cosmic radiation:** A flux of charged particles and photons arriving from space. The level of this radiation increases with altitude and depends on geographic latitude, concentrating near the Earth's magnetic poles.

- **Terrestrial radiation:** Originates from radioactive elements contained in the Earth's crust. Key long-lived radionuclides are uranium-238, thorium-232, and potassium-40, whose half-lives are comparable to the age of the Earth (about 4.5 billion years).

- **Internal exposure:** Radioactive isotopes of carbon (C-14), potassium (K-40), and others are constantly present in the human body, entering through food, water, and air. Approximately 7,000 atomic decays occur every second in the human body.

- **Radon:** The largest contribution to the natural exposure dose (on average about 50%) comes from inhaling radioactive isotopes of the noble gas radon (Rn-222 and Rn-220), which emanate from the Earth's crust and can accumulate in enclosed spaces.

On average, a person receives an effective dose of about **3 mSv/year** from natural sources, although in some regions of the world (high mountains, areas with elevated radionuclide content in soil) this dose can exceed 50 mSv/year. Interesting data have come from studies of regions with high background radiation areas (HBRA) in Asia. Studies conducted in India, China, and Indonesia have provided unique information on the effects of long-term chronic exposure at elevated doses on public health, which is particularly valuable for refining radiation risk models.

1.2. Artificial Sources. Artificial radiation sources contribute significantly to the collective exposure dose of the population. The main ones are:

- **Medical exposure:** Currently the largest anthropogenic source. Diagnostic procedures (radiography, computed tomography,

fluorography) and therapeutic methods (radiotherapy for cancer) account for the majority of exposure from artificial sources. In the United States, for example, the dose from medical procedures is comparable to that from natural background (about 3 mSv/year per capita). CT scans and nuclear cardiology procedures make the largest contribution.

- **Nuclear fuel cycle:** Uranium ore mining and processing, nuclear fuel production, operation of nuclear power plants, spent nuclear fuel reprocessing, and radioactive waste disposal. During normal operation of NPPs, radionuclide releases to the environment are minimal and controlled. However, accidents can lead to large-scale contamination.

- **Industry and science:** Use of radionuclides in flaw detection, measurement technology, and scientific research.

- **Nuclear testing and accidents:** Atmospheric nuclear explosions in the 20th century led to global fallout of radionuclides.

A significant problem is the unauthorized circulation and improper handling of ionizing radiation sources.

1.3. Radioactive Waste: Classification and Scale

Radioactive waste management is a critically important aspect of radiation safety. Depending on activity level and half-life, radioactive waste is classified into several categories: very low-level, low-level, intermediate-level, and high-level waste. Interestingly, about 95% of all radioactive waste by volume is very low- and low-level, while high-level waste accounts for less than 1% of volume but contains the vast majority of total activity.

The main sources of radioactive waste are:

- **Nuclear power plants** (operation, fuel reprocessing, decommissioning)
 - **Nuclear fuel cycle facilities** (uranium mining and processing)
 - **Medical institutions** (radiopharmaceuticals, diagnostic and therapeutic equipment)
 - **Research centers**
 - **Processing plants** (e.g., metallurgical plants where radioactive scrap metal may be melted)
- In the Russian Federation, according to 2024 data, the most frequent cause of radiation incidents is **disposal of ionizing radiation sources at municipal solid waste landfills** — 46 cases (29.7%). In the vast majority of cases, these were personal hygiene items (diapers, sanitary pads) contaminated with medical radionuclides (I-131, Lu-177, Tc-99m). This indicates systemic deficiencies in the radioactive waste management system in medical institutions.

2. Biological Effects of Ionizing Radiation.

Ionizing radiation, interacting with biological tissues, causes ionization of atoms and molecules, triggering a chain of pathophysiological reactions. The key target is DNA. DNA damage can be direct (direct impact on the DNA molecule) or indirect (through the formation of free radicals from water, which then damage DNA). Clinical manifestations depend on many factors: dose, dose rate, radiation type (alpha, beta, gamma, neutrons), irradiation area, dose distribution over time, and individual radiosensitivity.

2.1. Classification of Biological Effects

According to current understanding, all effects of ionizing radiation are divided into two main categories: **deterministic (threshold)** and **stochastic (probabilistic)** effects.

Characteristic	Deterministic Effects	Stochastic Effects
Threshold	Yes (there is a threshold dose below which the effect does not develop)	No (theoretically, any dose, even very low, can cause the effect)
Dose-effect relationship	Severity increases with dose above threshold	Probability increases with dose, but not severity

Examples	Radiation sickness, radiation burns, cataracts, radiation sterility	Cancer, leukemia, hereditary diseases
Mechanism	Death of a large number of cells in the irradiated tissue	Somatic mutations in cells (cancer) or mutations in germ cells (hereditary diseases)

2.2. Acute Radiation Sickness (ARS)

ARS is a clinical form of radiation injury that develops after short-term (seconds to 3 days) external whole-body or partial-body irradiation at a dose exceeding 1 Gy (100 rad). It is characterized by a cyclical course.

In the classic bone marrow form of ARS (at doses of 1–6 Gy), four periods are distinguished:

- 1. Prodromal period (first hours):** Nausea, vomiting, general weakness, headache, fever. Develops shortly after irradiation.
- 2. Latent period:** A period of apparent well-being. Symptoms disappear, but destructive processes continue in the bone marrow. Duration is inversely proportional to dose.
- 3. Period of illness (main clinical manifestations):** Develops against the background of deep bone marrow suppression (agranulocytosis, thrombocytopenia). Characterized by infectious complications (due to lack of white blood cells), hemorrhagic syndrome (bleeding, rash), gastrointestinal damage, hair loss.
- 4. Recovery period** (if favorable) or death (usually from infection or bleeding). At very high doses (>10 Gy), gastrointestinal, vascular, or cerebral forms of ARS develop, which are generally incompatible with life. The diagnosis of ARS is based on exposure history, characteristic cyclical symptoms, and dynamics of peripheral blood parameters (the absolute lymphocyte count in the first 48–72 hours is a key prognostic sign).

2.3. Local Radiation Injuries and Chronic Radiation Sickness

• **Local radiation injuries:** Occur with local irradiation of a body area (e.g., during

radiotherapy or careless handling of a source). Manifest as radiation dermatitis (redness, dryness, peeling, ulceration of the skin), radiation ulcers, radiation cataracts (clouding of the lens).

• **Chronic radiation sickness (CRS):** Develops after prolonged (months, years) repeated low-dose irradiation. Unlike ARS, the onset is gradual. The clinical picture is nonspecific and includes asthenic syndrome (weakness, fatigue), autonomic-vascular disorders, leukopenia, thrombocytopenia. Diagnosis of CRS is complex and requires confirmation of long-term occupational exposure. Currently, full-blown CRS is rare due to strict radiation safety standards.

2.4. Long-Term Consequences: Radiation Carcinogenesis

These are the most significant stochastic effects, determining long-term health risks. Radiation-induced cancer and leukemia develop years to decades after exposure and are indistinguishable from cancer caused by other factors. Key evidence comes from the long-term epidemiological study of survivors of the atomic bombings of Hiroshima and Nagasaki (Life Span Study). The main findings of this study:

- **Increased risk:** For survivors who received a dose >0.1 Gy, a statistically significant increase in the risk of all solid cancers and leukemias is observed.
- **Linear non-threshold model:** In the dose range of about 0.1–2 Gy, cancer risk is well described by a linear non-threshold model (i.e., risk is directly proportional to dose).
- **Latent period:** For leukemias, the latent period is 2–10 years, peaking at 5–7 years. For

solid tumors, the latent period is longer — 10–60 years or more.

• **Tissue radiosensitivity:** Not all organs are equally sensitive to radiation carcinogenesis. The most sensitive are: bone marrow (leukemia), thyroid gland (especially in children), female breast, lungs, stomach.

3. Radiological Contamination vs. Irradiation: A Key Distinction

For proper understanding of medical and counter-epidemic measures, it is crucial to distinguish between two concepts:

• **Irradiation:** This is the effect of penetrating radiation (gamma rays, X-rays) on the body. The radiation source itself is outside the body (e.g., an X-ray machine, a radioactive cloud). A person does not become radioactive after irradiation. When the source is removed, the exposure ceases.

• **Radiological contamination:** This is the deposition of radioactive substances on the skin, clothing, or inside the body. In this case, the person becomes a source of ionizing radiation themselves, because radioactive particles continue to decay on or within them. Contamination can be **external** (on skin, clothing) or **internal** (by inhalation, ingestion, or through wounds). Internal contamination poses the greatest danger because radionuclides can remain in organs for a long time, irradiating them from within. Removal of internal contamination is a complex task.

4. Major Radiological Accidents: Lessons from History

Accidents at nuclear facilities have a profound impact not only on the environment and human health but also on the formation of international radiation safety standards.

Table 3. Comparative analysis of major nuclear accidents

Characteristic	Chernobyl (1986)	Fukushima (2011)
Location	Pripyat, Ukrainian SSR (USSR)	Fukushima Prefecture, Japan
Cause	Human error + flawed reactor design	Earthquake and tsunami (natural disaster)
INES level	Level 7 (major accident)	Level 7 (major accident)
Main radionuclides released		
Total released activity	released I-131, Cs-137, Sr-90, Pu isotopes	I-131, Cs-134, Cs-137
Immediate deaths	~5.2 EBq (excluding noble gases)	~0.5–0.9 EBq
Thyroid cancer cases (children)	31 (directly from explosion/radiation)	None from radiation; ~2,300 from evacuation-related causes (elderly, hospital patients)
Evacuation zone	5,000 (in Belarus, Ukraine, Russia)	None observed
Contaminated area	200,000 km ² (Europe)	~3,000 km ² (mostly within Fukushima)
Main long-term challenge	Large-scale terrestrial contamination	Ongoing water discharge (treated ALPS water)

Key lessons:

- **Chernobyl** demonstrated the danger of massive I-131 release and the importance of rapid iodine prophylaxis (stable iodine) for children to prevent thyroid cancer.
- **Fukushima** highlighted that even with a technically better design, natural disasters can trigger severe accidents, and evacuation itself can cause health and social harm, especially among vulnerable populations.

A comprehensive analysis conducted by the St. Petersburg Research Institute of Radiation Hygiene based on 215 emergency reports from 28 constituent entities of the Russian Federation revealed the current structure of radiation accidents and incidents in Russia. A total of 155 radiation accidents were registered. The highest number of cases was noted in Moscow (47), Moscow Oblast (24), Sverdlovsk Oblast (14), and Yamalo-Nenets Autonomous Okrug (12).

5. Radiation Situation in the Russian Federation: Analysis of 2024 Data

Main causes of radiation accidents in the Russian Federation in 2024:

Table 4. Structure of radiation accidents by cause (Russian Federation, 2024)

Cause of accident	Number of cases	Share
Disposal of radiation sources at municipal solid waste landfills	46	29.7%
Violation of radioactive substance transport rules	34	21.9%
Capture/break of logging equipment in wells	22	14.2%
Detection of radiation sources in scrap metal	16	10.3%
Other (including contamination of food products)	37	23.9%

Key findings from the report:

1. The "medical" problem: The main cause is unauthorized disposal of medical radioactive waste (contaminated diapers, sanitary pads after therapy with I-131, Lu-177, Tc-99m) at ordinary garbage dumps. This indicates serious systemic deficiencies in radioactive waste management in medical institutions.

2. The scrap metal problem: Detection of radiation sources in scrap metal (16 cases). In 63% of such cases, the ambient dose equivalent rate exceeded 1 µSv/h, requiring intervention by specialized organizations. Although a positive trend was noted — the average annual rate of decrease in such incidents since 2010 has been 14%.

3. Food product contamination: Five cases of significant exceedance of hygienic standards for Cs-137 in food products sold through large online platforms were identified. For example, the Cs-137 content in dried blueberries reached 4454 Bq/kg compared to the standard (presumably 200–400 Bq/kg). This indicates insufficient radiation control in the supply chain of wild-harvested products.

4. Information problems: For nearly a third of incidents (31%), final reports with investigation results are missing, making full analysis and development of preventive measures difficult.

Conclusion

The problem of radiological contamination remains multifaceted: from controlling medical

radioactive waste to managing the long-term consequences of global catastrophes. Modern epidemiological research, primarily the study of atomic bomb survivors and analysis of accident consequences, has provided the foundation for current radiation safety systems. These data have made it possible to establish quantitative dose-effect relationships for various pathologies and form the basis of international recommendations (ICRP, WHO).

Comparative analysis of the Chernobyl and Fukushima accidents shows that each major event reveals new vulnerabilities — from reactor design flaws to the cascading effects of natural disasters — and reinforces the need for continuous improvement in safety culture, emergency preparedness, and long-term environmental monitoring.

At the national level, as shown by data from the Russian Federation, priority tasks remain:

1. Improving the radioactive waste management system, especially in medical institutions, to prevent its entry into ordinary landfills.

2. Strengthening radiation control over food products and consumer goods, including those sold via the Internet.

3. Increasing radiation literacy of the population and specialists working with potentially radioactive materials (scrap metal, construction materials).

4. Improving the data collection and analysis system for radiation incidents to promptly identify threats and adjust preventive measures.

Thus, the problem of radiological contamination requires constant attention, multi-level control, and active scientific research.

References

- Little MP, et al. A historical survey of key epidemiological studies of ionizing radiation exposure. *Radiation Research*. 2024;202(2):432-487. doi:10.1667/RADE-24-00021.1.
- Kim D.Ch., Levit D.I., Gasparyan G.D. *Radiation Ecology: A Textbook*. 3rd ed. St. Petersburg: Lan; 2022. (In Russian)
- Kryshev I.I., Sazykina T.G. Radiation safety of the environment. A review. *Radiation and Risk*. 2018. (In Russian)
- Life Safety. *Disaster Medicine: Textbook*. Section "Toxicology and Medical Protection". (In Russian)
- Kosarlukova E.A. (St. Petersburg Research Institute of Radiation Hygiene). Publications in the journal *Radiation Hygiene* (2025). (In Russian)
- Bushberg JT, Brant WE. Radiation injury and contamination. *MSD Manual Professional Version*. Reviewed/revised Jan 2025; Modified Sep 2025.
- Kranrod C, et al. What can we learn from high background radiation area (HBRA) studies in three Asian countries: India, China and Indonesia? *Journal of Radiation Research*. 2024;65(Supplement_1):i32-i41. doi:10.1093/jrr/rrae032.
- Adebiyi FM, et al. Advances in the management of radioactive wastes and radionuclide contamination in environmental compartments: a review. *Environmental Geochemistry and Health*. 2023;45:2663–2689. doi:10.1007/s10653-022-01378-7.
- Chapter 28. Diseases caused by exposure to ionizing radiation. In: *Guidelines on Radiation Medicine*. (In Russian)
- Gromov A.V., Kosarlukova E.A. Analysis of radiation accidents and incidents in the Russian Federation for 2024: structure, trends, and problematic issues of radiation safety. In: *Proceedings of the scientific-practical conference*. St. Petersburg Research Institute of Radiation Hygiene, 2025. (In Russian) World Health Organization. Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami, based on a preliminary dose estimation. WHO; 2013.
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation. Report to the General Assembly. UN; various years.

