RADIATION AND CHILDREN'S HEALTH

unicef for every child

Executive summary

Radiation (the emission of energy as electromagnetic waves or particles) can disrupt molecular structures, directly damaging people's DNA and increasing their risk of cancer and other health conditions. Children are more sensitive to radiation than adults due to several physiological, anatomical, developmental, and behavioural factors. First, children's bodies are undergoing rapid growth, which involves a higher rate of cell division. Because their cells replicate more frequently, children are more vulnerable than adults to DNA damage from ionizing radiation. If this damage overwhelms the body's natural repair mechanisms, it can lead to permanent changes in the DNA sequence, which raises the risk of developing cancer later in life. Moreover, children's smaller body size means they absorb a higher dose of radiation per unit of body mass compared to adults. Certain organs, such as the thyroid, are particularly sensitive. Additionally, children have a longer life expectancy, which increases the time for radiation-induced conditions, such as cancer, to develop. Finally, children tend to spend more time outdoors (increasing UV exposure) and may have higher exposure to digital devices emitting non-ionizing radiation. Prenatal exposure to ionizing radiation can lead to lower IQ scores and neurodevelopmental delays. The developing fetal brain is highly sensitive to radiation, particularly during the first trimester of pregnancy. Exposure to doses as low as 0.1 gray can result in cognitive impairments.

Exposure to ionizing radiation, especially from early medical imaging or fallout from nuclear incidents, increases the risk of bone marrow suppression and childhood leukaemia. Despite children's unique vulnerability to the harmful effects of ionizing radiation, many health care facilities continue to use adult-sized CT scan settings for paediatric patients, leading to unnecessarily high radiation doses. The World Health Organization (WHO) offers global guidance protocols for medical imaging, emphasizing the need to tailor these recommendations for children's heightened vulnerability. The ALARA (As Low As Reasonably Achievable) principle is critical in minimizing unnecessary medical radiation, particularly in diagnostic imaging. WHO also recommends remediation for buildings with radon levels annually on average exceeding 2.7 picocuries per litre.

There are a variety of actions to reduce radiation exposure. Communities can promote home radon testing and remediation programmes, especially in regions known for elevated radon levels, to reduce indoor ionizing radiation exposure. Parents can encourage sun-safe behaviours such as wearing protective clothing, applying broad-spectrum sunscreen, protecting the eyes, and limiting outdoor activities during peak UV hours. Families can encourage prudent use of digital devices, emphasizing limited screen time and maintaining physical distance from EMF sources, particularly for young children.

To reduce health care-based exposures, paediatric-specific imaging standards can be mandated across all medical facilities, ensuring consistent application of child-appropriate techniques and safety practices. The ALARA principle should be enforced in all diagnostic imaging involving children, minimizing unnecessary exposure while maintaining diagnostic quality. Non-ionizing alternatives, such as ultrasound and MRI, should be prioritized whenever clinically appropriate, particularly in scenarios where repeated imaging may be required. Paediatric-specific emergency protocols should be established for evacuation, sheltering, and post-exposure screening after a radiation emergency. This ensures that children receive appropriate care in an emergency and are monitored for immediate and long-term health effects. Such interventions can protect children's health from the adverse effects of exposure to radiation.

Healthy Environments for Healthy Children

Introduction

Radiation refers to the emission of energy as electromagnetic waves or particles and can be broadly categorized into ionizing and non-ionizing forms. Ionizing radiation (e.g., used in medical applications, present in radon gas, or produced in nuclear fallout) possesses enough energy to remove tightly bound electrons from atoms, creating charged ions. This disruption to molecular structures can directly damage people's DNA and increase their risk of disease malignancies and other health conditions (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2017). Non-ionizing radiation, which includes electromagnetic fields (EMFs) from wireless technologies, ultraviolet (UV) radiation from the sun, and visible light, does not carry enough energy to ionize atoms but can still alter biological function, particularly with chronic or high-intensity exposure (United Nations Environment Programme [UNEP], 2016).

Both forms of radiation are pervasive in modern environments and often are insufficiently regulated. Children are especially vulnerable to the effects of radiation due to their developing organ systems, longer expected lifetime for disease manifestation, and unique behaviours that may increase their risk of exposure. Prenatal exposures may disrupt fetal development, while radiation exposure in germ cells can carry transgenerational risks. Importantly, global disparities exist in the regulation, monitoring, and mitigation of radiation hazards. Conflict zones, and areas near nuclear facilities are often disproportionately burdened, further compounding risks for already vulnerable populations (International Atomic Energy Agency [IAEA], n.d.). This document details the general health impacts on children exposed to the most common forms of radiation. It outlines three distinct settings in which exposure occurs – in the household/community, and in health care- and emergency-related settings – and suggests strategies for interventions at the individual and policy levels to protect children's health.

Sources of exposure

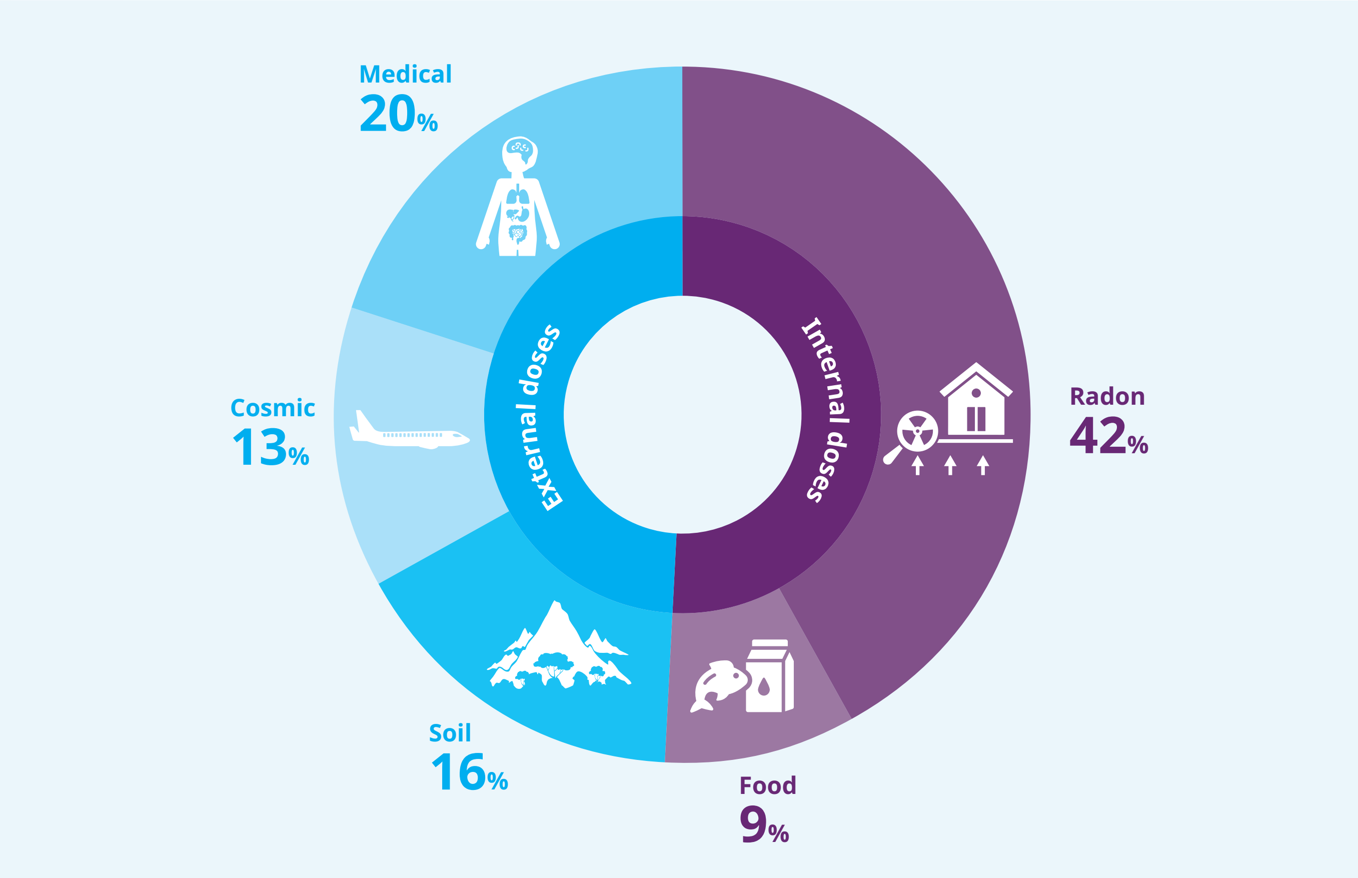
Children worldwide are increasingly exposed to a wide array of radiation sources, both medical and environmental. The use of ionizing radiation such as medical imaging in paediatric care has risen significantly over recent decades, driven by technological advancements and improved diagnostic capabilities. While many of these procedures are essential, studies show a growing reliance on modalities such as computed tomography (CT) scans and imaging-guided interventional procedures, which contribute disproportionately to cumulative ionizing radiation doses in children. Beyond clinical settings, environmental exposures also are widespread. Naturally occurring sources of ionizing radiation like radon, a radioactive gas found in some poorly ventilated homes and non-ionizing UV radiation from the sun are nearly universal and remain under-recognized contributors to the paediatric radiation burden. Other non-ionizing exposures – particularly from EMFs associated with digital devices, Wi-Fi, and cell towers – are becoming more pervasive with wireless connectivity and increased screen time, even among young children. See Table 1 for types and sources of radiation exposure and Figure 1 for the worldwide distribution of radiation exposure.

Global exposure, however, is not evenly distributed. Geographic hotspots include conflict zones, where children may be exposed to ionizing radiation from depleted uranium or radioactive remnants of warfare. Other hotspots include regions in which nuclear disasters have occurred (e.g., Chernobyl, Ukraine, in 1986; and Fukushima, Japan, in 2011); certain geographic areas in which radon enters into homes and buildings and is trapped there; and communities served by under-resourced health systems, where overuse of radiation in medical applications or the lack of imaging safety protocols can compound risk. Additionally, the intensity of non-ionizing solar UV radiation increases closer to the equator and at altitude, as thinner air absorbs less radiation. Reduced atmospheric ozone due to climate change enables greater penetration of UV radiation reaching the Earth's surface (World Health Organization [WHO], 2022) where children can be exposed. These disparities highlight the urgent need for expanded global surveillance, stronger implementation of standardized paediatric imaging guidelines, and policies that prioritize radiation protection, particularly in vulnerable populations.

Table 1. General sources of radiation exposure

	Ionizing radiation has enough energy to remove tightly bound electrons from atoms, creating ions	**Non-ionizing radiation** does not have enough energy to make changes to atoms or molecules
Natural sources	**Radon gas:** Naturally occurring radioactive gas that can accumulate in buildings **Cosmic radiation:** Radiation from space that reaches the Earth's surface **Terrestrial radiation:** Radiation from naturally occurring radioactive materials in the Earth	**Sunlight:** Inclusive of UV, visible, and infrared radiation **Earth's magnetic field:** Generates extremely low frequency radiation [<300 hertz (Hz)]
Human-made sources	**Medical devices** (X-rays, CT scans, nuclear medicine, and radiotherapy) **Industrial applications** (nuclear power plants) **Consumer products** (smoke detectors, certain types of luminous watches) **Emergencies/disasters:** Radiological incidents that disproportionately affect children due to vulnerability and displacement	**Electrical appliances:** Microwave ovens, power lines, and common household electronics that give off low levels of electromagnetic energy, including very low-frequency waves (from 3 Hz to 300 Hz) and radio waves (from 100,000 Hz to 300 billion Hz) **Telecommunications:** Mobile phones, Wi-Fi routers, and broadcasting antennas that emit radio frequency radiation **Medical devices:** LASERs and certain diagnostic equipment that emit UV, visible, and infrared radiation

Figure 1. **Worldwide distribution of radiation exposure**



Adapted from *Radiation: Effects and sources,* 2016, by UNEP, p. 27. (https://www.unep.org/resources/report/radiation-effects-and-sources)

Exposure pathways

Children may encounter radiation through multiple environmental pathways, and each of these pathways contributes to children's overall exposure burden in a unique way. This document describes in detail three broad exposure settings: the household/community, health care-related, and emergency-related settings. A comprehensive (but not exhaustive) list of exposure sources by radiation type (ionizing vs. non-ionizing) is below.

- **Inhalation** is a common route of exposure, particularly when children breathe in radon, a naturally occurring ionizing-radiation gas that can accumulate in some poorly ventilated homes, or when children inhale airborne radioactive particles released during nuclear accidents or industrial activities.
- **Dermal penetration** is typically less significant for ionizing radiation, yet it is an important route for non-ionizing UV radiation, especially in children who spend greater time in outdoor activity and have more sun exposure. Direct exposure may arise from frequent use of personal electronic devices emitting EMFs, or in residences near nuclear facilities, cell towers, or other high-intensity, EMF-emitting infrastructure.
- **Ingestion** of radiation is a less common exposure pathway, but the health impacts are equally severe. It occurs when radioactive materials enter the body through eating, drinking, or swallowing contaminated substances (i.e., breast milk) or in emergency contexts involving radioactive fallout. Documented pathways of ingestion exposure include people's drinking of groundwater contaminated with radioactive substances (He et al., 2022) and consumption of fish and seafood exposed to radioactive isotopes like caesium-137 after nuclear disasters (IAEA and Food and Agriculture Organization of the United Nations [FAO], n.d.). Once inside the body, these materials can continue to emit harmful radiation, damaging cells.

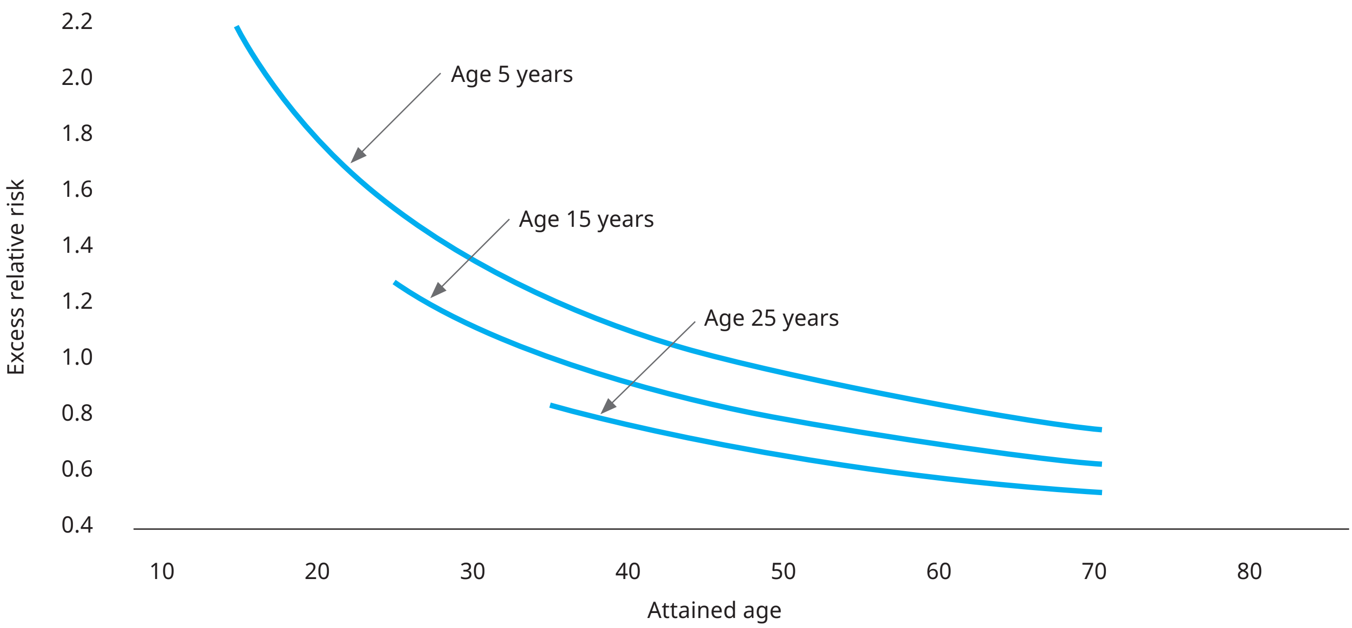
Children's unique vulnerability

Children are more radiosensitive than adults due to several physiological, anatomical, developmental, and behavioural factors. First, children's bodies are undergoing rapid growth, which involves a higher rate of cell division. Because their cells replicate more frequently, children are more vulnerable than adults to DNA damage from ionizing radiation. If this damage overwhelms the body's natural repair mechanisms, it can lead to permanent changes in the DNA sequence, which raises the risk of developing cancer later in life. Moreover, children's smaller body size means they absorb a higher dose of radiation per unit of body mass compared to adults. Certain organs, such as the thyroid, are particularly sensitive; for instance, children's thyroids absorb more radioactive iodine, increasing their risk of developing thyroid cancer (WHO, 2023).

Children also have different bodily proportions compared to adults. For example, an infant is shorter and broader at the trunk compared to an adult frame (Alzen & Benz-Bohm, 2011), therefore a greater surface area may be exposed during chest CT scans or abdominal X-rays, two common sources of ionizing radiation exposures related to health care imaging. Children with certain genetic conditions, such as retinoblastoma, neurofibromatosis type 1, and Li-Fraumeni syndrome, are at an even greater risk of developing radiation-induced cancers (Kleinerman, 2009). Additionally, children have a longer life expectancy, which increases the window of time for radiation-induced conditions, such as cancer, to develop. For example, following acute exposure to 1 sievert (Sv) of radiation, it is estimated that a child (age 5 years) will have twice the excess relative risk of developing a solid cancer compared to an adult (Figure 2).

Finally, children's behavioural patterns may magnify their exposure to risk. They tend to spend more time outdoors (increasing UV exposure), often play closer to the ground where floor-level pollutants accumulate, and may have higher exposure to digital devices emitting non-ionizing radiation. On the basis of results from various epidemiological studies, including the Life Span Study (LSS), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concluded that children are generally more sensitive than adults to radiation for 25 per cent of cancer types, including leukaemia and cancers of the thyroid, skin, breast, and brain (UNSCEAR, 2013).

Figure 2. Excess relative risk of solid cancer incidence after acute radiation exposure (1 Sv) at 5, 15, and 25 years of age



Adapted from "Ionizing radiation" by E. J. Grant and D. G. Hoel, 2024, in *Textbook of children's environmental health* (2nd ed.), edited by R. A. Etzel and P. J. Landrigan, Oxford University Press. (https://doi.org/10.1093/oso/9780197662526.003.0045)

Biomonitoring and reference values

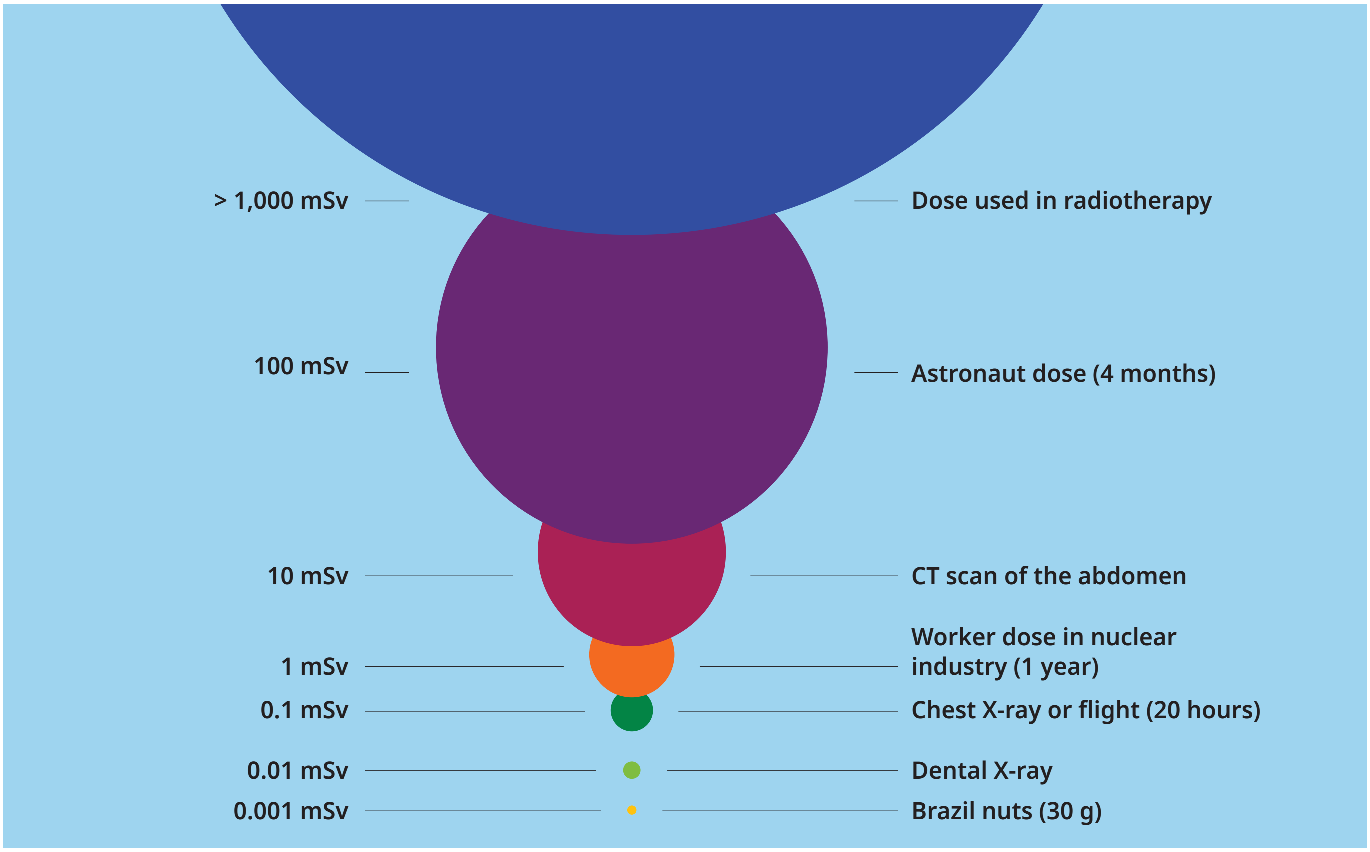
UNSCEAR evaluates scientific evidence on the health and environmental effects of radiation exposure (UNSCEAR, 2013). The impact of exposure depends on several factors, including the type of radiation (e.g., ionizing vs. non-ionizing), the duration of exposure (which may involve radioactive substances with specific half-lives), and the amount of energy deposited in body tissues. Radiation exposure is often measured using two units: the gray (Gy), which measures the amount of radiation energy absorbed by the body, and the sievert (Sv), which reflects the potential health effect of that exposure (Table 2 and Figure 3).

Table 2. Examples of radiation exposure, by dose band and range

Dose band	Dose range	Examples
High dose	More than ~1 Gy	Radiotherapy and severe radiation accidents (e.g., firemen's exposure at the Chernobyl accident)
Moderate dose	~100 mGy to ~1 Gy	Recovery operation workers after the Chernobyl accident
Low dose	~10 mGy to ~100 mGy	Multiple computer tomography (CT) scans
Very low dose	Less than ~10 mGy	Conventional radiography (i.e., without CT)

Note: 1,000 mGy is equivalent to 1 Gy. Adapted from *Radiation: Effects and sources,* 2016, by UNEP, p. 12. (https://www.unep.org/resources/report/radiation-effects-and-sources)

Figure 3. Everyday examples of radiation exposure and their effective doses



Note: 1,000 mSv is equivalent to 1 Sv. From *Radiation: Effects and sources*, 2016, by UNEP, front cover. (https://www.unep.org/resources/report/radiation-effects-and-sources)

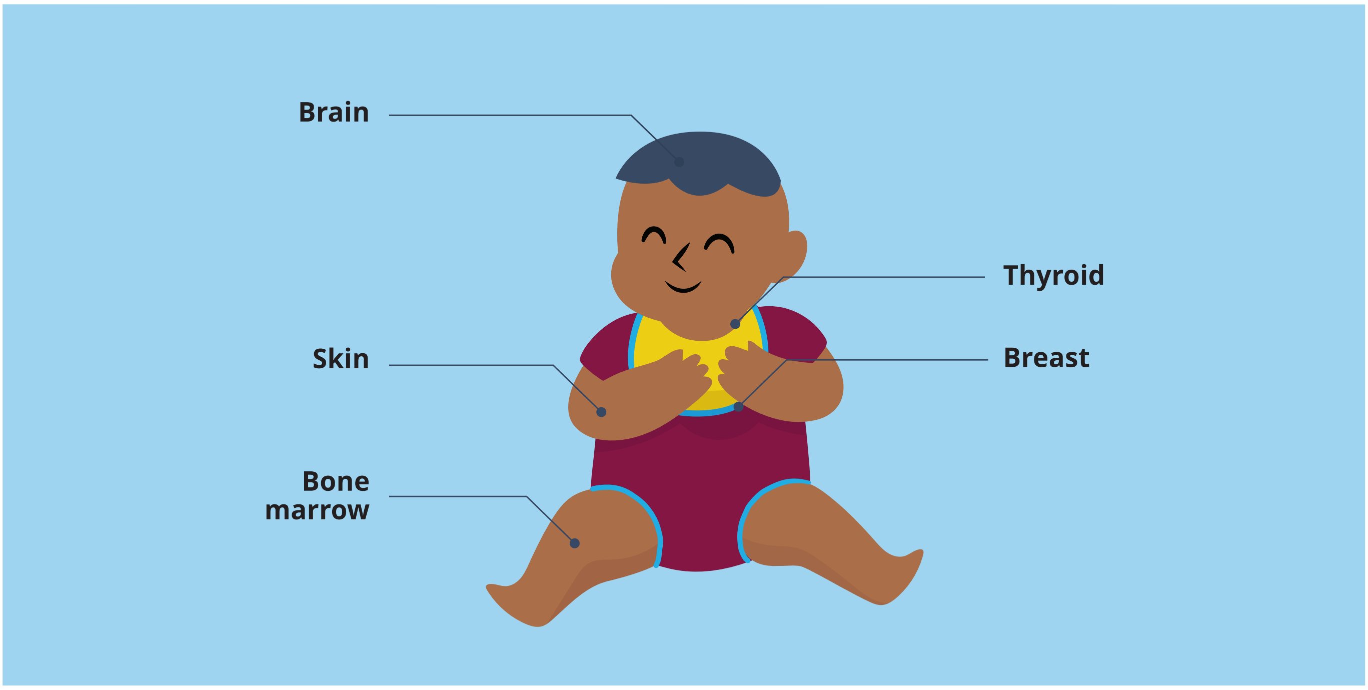
Monitoring radiation exposure in children presents unique challenges. Unlike persistent chemicals, many forms of radiation (particularly those from radionuclides) have short biological half-lives, making it difficult to capture exposures unless measurement occurs promptly after the event (UNSCEAR, 2017). Additionally, biomonitoring infrastructure specifically tailored for paediatric populations is limited, leading to gaps in exposure surveillance. In emergency settings, personal dosimeters can help track individual exposure levels, while post-exposure thyroid scans are commonly used to assess uptake of radioactive iodine (IAEA, n.d.). Urinary biomarkers can also be employed to detect specific radionuclides such as uranium or caesium (Agency for Toxic Substances and Disease Registry, 2014). To guide and standardize protective efforts, several benchmarks and principles are in place. The ALARA (As Low As Reasonably Achievable) principle is critical in minimizing unnecessary medical radiation, particularly in diagnostic imaging (Image Gently Alliance, n.d.).

Reference values for radiation are used to evaluate the risks of radiation exposure to people and the environment. These values have been produced for dose limits, drinking water, and air (radon gas) concentration. The International Commission on Radiological Protection (ICRP) recommends for the public a dose limit of 1 mSv per year when the exposure sources are man-made (International Commission on Radiological Protection [ICRP], 2007). The World Health Organization (WHO) has established a guideline of 0.1 mSv per year for radiation exposure from drinking water to minimize health risks (WHO, 2017a). WHO recommends remediation for buildings with radon levels equal to or exceeding 100 becquerels per cubic metre (≥100 Bq/m^3) or 2.7 picocuries per litre (2.7 pCi/L) annually on average (WHO, 2000). Finally, WHO offers global guidance on safe limits for UV exposure and protocols for medical imaging, further emphasizing the need to tailor these recommendations for children's heightened vulnerability (WHO, 2024; WHO et al., 2002).

Health impacts by organ system

The health effects of radiation exposure in children have been observed in multiple organ systems (Figure 4). The principal biological mechanism is damage to DNA (Frush, 2013), disrupting the fundamental instructions that guide how cells grow, function, and divide.

Figure 4. Particularly radiosensitive organs in children



Adapted from *Radiation: Effects and sources*, 2016, by UNEP, p. 19. (https://www.unep.org/resources/report/radiation-effects-and-sources)

Radiation can cause single-strand breaks in DNA; cells usually can repair such breaks with minimal lasting effects. However, double-strand breaks, particularly those occurring close together on the DNA helix, are more difficult to repair and can lead to mutations, cell death, or malfunctioning cells. In some cases, incorrect repairs may result in stable genetic abnormalities that initiate the multistep process of cancer development (carcinogenesis).

Fetal outcomes/teratogenesis: Evidence-based investigations of large-scale radiation disasters, studies on the effects of radiation in animals, and analysis of outcomes in pregnant women exposed to medical treatment have established thresholds for the deterministic impacts of radiation exposure on children (Sutton et al., 2023) (Table 3).

Table 3. Estimated threshold doses and their corresponding outcomes, by exposure timing

Effects	Potential outcome	Estimated threshold dose at which outcome may occur
Gestational period		
Before implantation (0–2 weeks after fertilization)	Death of embryo or no consequence	50–100 mGy
Organogenesis (2–8 weeks after fertilization)	Congenital anomalies (skeleton, eyes, and genitals)	200 mGy
	Growth restriction	200–250 mGy
Fetal period		
8–15 weeks	Severe intellectual deficit (loss of 25 IQ points)	1,000 mGy
	Microcephaly	200 mGy
16–25 weeks	Severe intellectual disability (low risk)	250–280 mGy

Note: Fetal radiation doses associated with common radiological examinations have been estimated by the American College of Obstetricians and Gynecologists. However, the authors of the estimates note that these exposure values may vary among different health care facilities and may be further influenced by individual susceptibility.

The table is adapted from "Guidelines for diagnostic imaging during pregnancy and lactation," Committee Opinion No. 723, by American College of Obstetricians and Gynecologists (2017). *Obstetrics & Gynecology, 130*(4), e210–216. (https://journals.lww.com/greenjournal/fulltext/2017/10000/committee_opinion_no__723_summary__guidelines_for.55.aspx)

Neurological: Prenatal exposure to ionizing radiation can lead to lower IQ scores and neurodevelopmental delays. The developing fetal brain is highly sensitive to radiation, particularly during the first trimester of pregnancy. Exposure doses as low as 0.1 Gy can result in cognitive impairments, with an estimated loss of 25 IQ points per 1,000 mGy at 10–17 weeks of gestation (Saada et al., 2023). In a retrospective study of children who were in utero during the Chernobyl accident, IQ loss was significant in the group of children whose mothers were most highly exposed. IQ loss was most pronounced when exposure occurred in the earlier weeks of gestation (Liutsko et al., 2024).

Carcinogenicity: Ionizing radiation in children's body systems increases the risk of childhood leukaemia, especially from early medical imaging or fallout from nuclear incidents. The haematopoietic system is highly sensitive to radiation, leading to potential bone marrow suppression and increased leukaemia incidence (Wakeford, 2013). Children and young people exposed to radiation at ages below 20 years are about twice as likely to develop brain cancer as older adults exposed to the same dose. A similar association was noticed for breast cancer when girls and young women were exposed at ages below 20 years (UNSCEAR, 2013). Thyroid cancer risk is elevated after head and neck radiation exposure, which can lead to both benign and malignant lesions (Ronckers et al., 2004).

Reproductive: Gonadal exposure to ionizing radiation can lead to long-term fertility issues. Exposure can alter sex cells, thus the health effects can be intergenerational. In adolescent males, radiation can impair spermatogenesis, leading to reduced sperm count and less motility. In females, ovarian exposure can result in premature ovarian failure and early menopause (Chougule & Joan, 2025).

Integumentary: Because skin cells are constantly proliferating, they are highly susceptible to damage from radiation exposure. Several radiation-induced skin complications have been reported in the scientific literature, including radiation dermatitis, radiation recall dermatitis, and radiation-induced skin malignancies (Bennardo et al., 2021). Most notably, UV exposure increases melanoma and non-melanoma skin cancers later in life. Childhood cancer survivors (often treated with radiation therapy) have more than a two-fold standardized incidence ratio of melanoma compared with the general population (Rotz et al., 2025). In this cohort, the development of melanoma was driven by exposures to certain drugs used to treat cancer (bleomycin and high cumulative alkylators), but not other chemotherapies.

Respiratory: Radiation exposure can significantly impact the lungs, with effects varying by age and dose. In both children and adults, high doses of ionizing radiation – such as from cancer therapy or environmental exposure – can lead to inflammation of lung tissue (radiation pneumonitis) and long-term scarring (pulmonary fibrosis), which impairs breathing and oxygen exchange. In adults who were childhood cancer survivors, abnormalities in pulmonary function testing were common. Importantly, age at treatment is associated with an increased risk of developing pulmonary dysfunction, emphasizing the critical vulnerability of children at certain stages of their development (Khan et al., 2020).

Note on units

Radiation exposure is measured using different units depending on the context (Table 4). The milligray (mGy) quantifies the absorbed dose, i.e., the amount of radiation energy deposited in a person's tissue. In contrast, the millisievert (mSv) measures the biological effect of that radiation, accounting for the type of radiation and its impact on human health.

To convert mGy to mSv, the absorbed dose is multiplied by a radiation weighting factor (wR), which varies by radiation type. For instance, 10 mGy of X-rays (wR = 1) equals 10 mSv, whereas 10 mGy of alpha radiation (wR = 20) equates to 200 mSv, indicating a significantly higher biological risk.

Table 4. Unit distinction

Category	Quantity	Definition
Physical quantity	**Activity**	The number of nuclear transformations of energy per unit of time. It is measured as decays per second and expressed in becquerels (Bq).
	Absorbed dose	The amount of energy deposited by radiation in a unit mass of material, such as a tissue or organ. It is expressed in grays (Gy), which correspond to joules per kilogram.
Calculated quantity	**Equivalent dose**	The absorbed dose multiplied by a radiation weighting factor (wR) that accounts for how different types of radiation cause biological harm. Expressed in sieverts (Sv) or joules per kilogram.
	Effective dose	The equivalent dose multiplied by organ factors (wT) that account for susceptibility to radiation harm in different tissues. Expressed in sieverts (Sv) or joules per kilogram.
	Collective effective dose	Sum of all effective doses for a population or group exposed to radiation. Expressed in man-sieverts (man-Sv).

From *Radiation: Effects and sources, 2016*, by UNEP, p. 8. (https://www.unep.org/resources/report/radiation-effects-and-sources)

Settings in which children may be exposed to radiation

Household/community exposure

Children are frequently exposed to a range of radiation sources within the home, which contributes cumulatively to their radiation burden. Unlike medical exposures (which are often episodic and regulated), residential exposures tend to be continuous, involuntary, and shaped by household infrastructure and behaviour patterns. Given children's unique physiological vulnerabilities and behavioural tendencies (e.g., floor-level breathing, hand-to-mouth activity, increased time spent close to sources), both ionizing and non-ionizing exposures warrant distinct attention. Table 5 summarizes the sources of ionizing and non-ionizing radiation exposure in the household/community setting.

Table 5. Examples of radiation sources in the household/community setting

Ionizing radiation
• Radon gas (indoor air contamination) • Indoor radionuclides in building materials • Natural background radiation (cosmic, terrestrial)
Non-ionizing radiation
• UV radiation (sunlight exposure) • EMFs from smartphones, tablets, Wi-Fi routers • RF radiation from wireless devices • LASERs used in household devices (e.g., barcode scanners)

Ionizing radiation: Ionizing radiation has sufficient energy to remove electrons from atoms and can directly damage DNA, raising long-term risks such as cancer. In the home, community, and medical setting, several important ionizing sources exist:

- **Radon gas:** Radon is a naturally occurring radioactive gas that seeps into homes through soil and rock, particularly in regions with uranium-rich geology. Some poorly ventilated spaces, especially basements, allow radon to accumulate. Its radioactive decay products (radon progeny) attach to dust particles and are inhaled into the lungs, significantly increasing the risk of lung cancer over time, especially in the presence of smoking.
- **Indoor radionuclides in building materials:** Certain construction materials (e.g., granite, bricks, concrete) may naturally contain radionuclides like uranium, thorium, and potassium-40. These materials can emit low levels of radiation that contribute to long-term exposure.
- **Natural background radiation:** Children are also exposed to cosmic radiation (from space) and terrestrial radiation (from the Earth's crust). Although these exposures are generally low-level, they contribute to total background dose and may be elevated at higher altitudes or in specific geographic regions.

Non-ionizing radiation: Non-ionizing radiation lacks the energy to ionize atoms but can still interact with biological tissues through thermal or electromagnetic mechanisms. In modern households, children encounter several key sources:

- **Ultraviolet radiation:** UV rays from sunlight are non-ionizing but biologically active, especially in the UV-A and UV-B spectrums. Children's increased outdoor activity and skin surface area relative to body mass elevate their vulnerability to sunburn, DNA damage, and increased risk of future skin cancer.
- **Electromagnetic fields:** EMFs are generated by household electronics such as smartphones, tablets, Wi-Fi routers, and power lines. While exposure levels are typically low, children's close and prolonged contact – especially during sleep or screen use – raises concerns about potential neurological, developmental, or sleep-related impacts.
- **Radio frequency (RF) radiation:** A subset of EMFs, RF radiation is emitted by wireless devices (e.g., baby monitors, smart speakers, gaming consoles). RF exposure has been the focus of growing scientific scrutiny, though evidence of harm remains inconclusive.
- **Light amplification by stimulated emission of radiation (LASER):** Household devices such as barcode scanners, CD/DVD players, and laser pointers emit concentrated beams of non-ionizing radiation. LASER devices are typically regulated and use low power. However, their misuse or prolonged exposure at close range may pose risks, particularly to developing eyes.

Recommendations for intervention and mitigation

Individual actions

- **Radon testing and remediation:** Promote home radon testing and remediation programmes, especially in regions known for elevated radon levels, to reduce indoor ionizing radiation exposure. This helps families address potential radon risks and prevent long-term health issues.
- **Sun-safe behaviours:** Encourage sun-safe behaviours such as wearing protective clothing, applying broad-spectrum sunscreen, protecting the eyes, and limiting outdoor activities during peak UV hours. This reduces the risk of UV radiation exposure, especially in children.
- **Prudent use of digital devices:** Educate families on the prudent use of digital devices, emphasizing limited screen time and maintaining physical distance from EMF sources, particularly for young children. This minimizes the potential impact of EMF exposure on health.

Community actions

- **Housing ventilation and building standards:** Improve housing ventilation and building standards to reduce the accumulation of radon and other indoor pollutants. This helps ensure safer indoor air quality, particularly in homes located in radon-prone areas.
- **Environmental exposure assessments in paediatric health visits:** Integrate environmental exposure assessments into child health visits to identify and counsel families on modifiable risks in the home environment. Taking a paediatric environmental history helps raise awareness about household hazards and provides families with actionable steps to reduce risks.

Policy actions

- **Radon mitigation policies:** Advocate for government initiatives to provide incentives for radon testing and mitigation, ensuring homes are protected from high radon levels. This can be especially important in regions where radon exposure is a significant public health concern.
- **Climate change-related policies:** Advocate for policies that address and regulate the urban heat island effect, which increases the intensity of UV radiation in cities and accelerates climate change. This could include increasing green spaces, promoting reflective roofing, and developing shade structures in urban planning to reduce residents' exposure to harmful UV rays.

Case study:
Protecting children from UV exposure in Australia

Australia has one of the highest rates of skin cancer globally, accounting for excess morbidity and health care expenditure. UV exposure poses significant health risks to children. Australia has implemented widespread sun safety campaigns like the Slip, Slop, Slap campaign, which encourages sun protection behaviours such as wearing protective clothing, sunscreen, and hats (Walker et al., 2022). Schools have also adopted sun-safe policies, including mandatory hat-wearing during outdoor activities, to mitigate UV exposure and protect children's health.

Health care-related exposure

Medical imaging procedures – such as X-rays, CT scans, and nuclear medicine (e.g., PET scans) – are a major source of ionizing radiation in children. Children's developing tissues are more radiosensitive than adults', and their longer expected lifespan increases the window of time for radiation-related effects to manifest. Table 6 summarizes the sources of radiation exposure in health care-related settings.

Table 6. Examples of radiation sources in the health care setting

Ionizing radiation
• CT scans • Fluoroscopy [e.g., gastrointestinal (GI) studies, catheterization procedures] • Interventional procedures (e.g., angiographic studies, therapeutic procedures such as embolization and stenting) • Nuclear medicine [e.g., bone scans, positron emission tomography (PET) scans, thyroid scans, multiple-gated acquisition (MUGA) scans] • Plain radiographs (X-rays) • Dual-energy X-ray absorptiometry (DEXA) scans, used for bone density
Non-ionizing radiation
• Magnetic resonance imaging (MRI) • Ultrasound • LASERs (used in dermatology, ophthalmology, surgical procedures) • Radio frequency ablation (used in some cardiac or cancer treatments) • Therapeutic diathermy (rare; used in some rehabilitation or physical therapy settings)

While many imaging procedures, such as chest or skeletal X-rays, involve low individual doses, repeated imaging, especially in children with chronic illnesses or complex medical conditions, can lead to significant cumulative exposure over time. The type and frequency of imaging procedures is important. For instance, in young children undergoing surgery for heart disease, X-rays accounted for over 90 per cent of imaging exams but contributed less than 10 per cent of their total radiation exposure (Johnson et al., 2014). In contrast, more specialized procedures like interventional radiology, including CT guided procedures, and angiography and therapeutic procedures such as chemoembolization, though performed far less often, were responsible for more than 80 per cent of the cumulative dose. Children requiring complex medical management (arguably those most vulnerable to begin with) often have increased exposure. For example, cumulative effective radiation dose in the neonatal intensive care unit (NICU) is highest among infants with small gestational age, lower birth weight, and increased clinical adverse events (Donadieu et al., 2006).

Radiation is a common therapy for children diagnosed with cancer. As survival rates continue to improve, emerging research is increasingly focused on the long-term effects of radiation treatment in childhood cancer survivors. For example, total body irradiation (TBI) is an important component of haematopoietic stem cell transplant (SCT) for paediatric malignancies. Findings from a retrospective cohort based in the United States suggest that TBI in patients below 3 years of age will likely result in multi-organ dysfunction, including endocrine, metabolic, renal, eye, and neurocognitive abnormalities (Brody et al., 2007). Such observational findings highlight the need to balance clinical necessity with long-term safety by optimizing imaging strategies, using non-ionizing alternatives when appropriate, and minimizing exposure without compromising diagnostic quality (Alzen & Benz-Bohm, 2011).

In medical settings, high doses of radiation from procedures like CT scans or radiotherapy (1,000 times higher than from X-rays) can result in cataracts in children, particularly when the eye is directly exposed. For example, children with brain tumours exposed to craniospinal irradiation (CSI) are at significant risk of cataract development (Whelan et al., 2011). Special attention needs to be given to protect the eyes during diagnostic and therapeutic exposures.

Recommendations for intervention and mitigation

Individual actions

- **Paediatric-specific radiation protocols:** Implement paediatric-specific radiation protocols to ensure dose calibration based on a child's size, age, and clinical indication. This ensures children receive the lowest effective dose for their specific needs.
- **Risks and benefits of imaging:** Train health care providers to carefully weigh the risks and benefits of imaging procedures, promoting judicious use of diagnostic studies in children. This ensures that only necessary imaging is performed, minimizing unnecessary radiation exposure.
- **Environmental exposure histories:** Integrate environmental exposure histories into routine paediatric health assessments to identify cumulative risks from both medical and non-medical radiation sources. This helps health care providers assess overall radiation exposure risk for each child.

Health sector actions

- **Paediatric-specific imaging standards:** Mandate paediatric-specific imaging standards across all medical facilities, ensuring consistent application of child-appropriate techniques and safety practices. This ensures that imaging is always tailored to children's unique needs.
- **ALARA principle:** Enforce the ALARA (As Low As Reasonably Achievable) principle in all diagnostic imaging involving children, minimizing unnecessary exposure while maintaining diagnostic quality. This reduces radiation risk while ensuring high-quality diagnostic outcomes.
- **Non-ionizing alternatives:** Prioritize non-ionizing alternatives, such as ultrasound and MRI, whenever clinically appropriate, particularly in scenarios where repeated imaging may be required. This reduces the cumulative radiation exposure children might face over time.

Case study:
Paediatric medical imaging

Despite children's unique vulnerability to the harmful effects of ionizing radiation, many health care facilities continue to use adult-sized CT scan settings for paediatric patients, leading to unnecessarily high radiation doses. For example, a large analysis using data from the U.S. National Hospital Ambulatory Medical Care Survey, which sampled an average of 7,370 visits per year between 1995 and 2008, found that nearly 90 per cent of paediatric CT scans performed in emergency departments took place in hospitals primarily serving adults (Larson et al., 2011). Enhancing radiation safety through paediatric-specific imaging guidelines, staff training, and transparent communication with families is essential to minimize risks while ensuring accurate diagnosis. Initiatives like the Image Gently campaigns exemplify efforts to promote safer imaging practices for children globally.

Emergency-related exposure

Radiation exposure during emergencies – such as nuclear power plant accidents, radiological terrorism, or military conflict involving radioactive materials – can result in acute, high-dose exposure that is often unanticipated and difficult to mitigate (UNSCEAR, 2021). These scenarios can introduce multiple exposure pathways for children, including inhalation of airborne radioactive particles (e.g., caesium-137, iodine-131); ingestion of contaminated food, water, or breast milk; dermal absorption in the case of beta-emitters or radioactive dust; and direct external exposure from fallout or contaminated environments (Centers for Disease Control and Prevention, n.d.). Table 7 summarizes the sources of radiation exposure in emergency-related settings.

Unlike household/community and medical exposures, emergency radiation is often intense, geographically concentrated, and complicated by delayed detection or inadequate public health infrastructure. For instance, radioactive iodine released into the air can be inhaled or ingested, accumulating in the thyroid – a particular concern for children, whose thyroid glands are more active and susceptible than adults' (WHO, 2017b). Radioactive caesium may contaminate soil, food crops, and water sources for extended periods, especially in agricultural regions, compounding long-term exposure risks (Linet et al., 2018).

Residential proximity to nuclear facilities or uranium mines, displacement to unsafe areas, and systemic barriers to rapid response (e.g., lack of access to potassium iodide tablets, protective shelter, or uncontaminated supplies) create disproportionate risk in under-resourced and conflict-affected regions. Emergency preparedness plans that fail to include paediatric-specific protections – such as child-sized dosimetry, age-appropriate thyroid screening, or targeted evacuation protocols – can leave children highly exposed and unprotected during critical stages in their development.

Table 7. Examples of radiation sources in emergency settings

Ionizing radiation
• Radioactive fallout from nuclear explosions or reactor accidents • Airborne radioactive isotopes (e.g., iodine-131, caesium-137, strontium-90) • Contaminated water, soil, or food supplies • External exposure during nuclear emergency response
Non-ionizing radiation
• LASERs used in military or industrial-grade devices • Strong electromagnetic pulses (EMPs) in conflict zones • Emergency lighting or scanning equipment (limited use)

Recommendations for intervention and mitigation

Individual actions

- **Personal dosimeters for monitoring exposure:** Ensure emergency responders and families, particularly infants, pregnant women, and children, wear personal dosimeters to monitor real-time radiation exposure. This allows for immediate assessment of whether exposure levels reach dangerous thresholds and ensures appropriate protective actions (e.g., evacuate or seek shelter).

- **Potassium iodide (KI) use:** In the event of a radiation release, individuals living near nuclear facilities or in areas at risk for fallout should take KI tablets to protect the thyroid from radioactive iodine exposure. Newborns should avoid repeat doses due to the risk of hypothyroidism, and thyroid function should be monitored in infants and young children.
- **Evacuation and sheltering:** In the event of a radiation emergency, individuals should follow established protocols for evacuation or sheltering to minimize exposure to radioactive material, especially if near the radiation source.

Community actions

- **Early-warning systems and public education campaigns:** Implement early-warning systems and public education campaigns in radiation-prone regions to rapidly alert the public about a radiation emergency. This will ensure that communities take timely protective actions such as evacuating, sheltering, and using KI tablets.
- **Mobile scanning and treatment units:** Deploy mobile units equipped for thyroid monitoring and decontamination to affected areas, providing immediate health care services and reducing long-term health risks, especially for vulnerable populations like children.
- **Paediatric-specific emergency protocols:** Establish paediatric-specific emergency protocols for evacuation, sheltering, and post-exposure screening. This ensures that children receive appropriate care in a radiation emergency and are monitored for immediate and long-term health effects.

Policy actions

- **International protection and long-term monitoring:** Advocate for international protection of children affected by radiation exposure in conflict zones or nuclear disaster areas. Ensure long-term health monitoring and psychosocial support to mitigate the physical and mental health impacts of radiation.
- **Public health guidelines and support:** Implement public health guidelines and provide long-term mental health and developmental support for those exposed to radiation, particularly children, to address the cognitive, emotional, and physical effects of radiation exposure.

Case study:
Chernobyl nuclear disaster (1986)

The 1986 Chernobyl nuclear disaster in Ukraine released massive amounts of ionizing radiation, severely affecting children's health in surrounding regions (WHO, 2006). Among the most documented outcomes was a dramatic increase in childhood thyroid cancer, especially in Belarus, the Russian Federation, and Ukraine due to exposure to radioactive iodine (I-131). Thousands of cases emerged in children exposed under the age of 5 years. Prenatal exposure also led to low birth weight, developmental delays, and neurocognitive impairments. Many children faced long-term psychological stress from evacuation and social stigma. Chernobyl remains a critical example of the vulnerability of children and fetuses to radiation, highlighting the need for swift public health responses, protective measures, and transparent risk of communication in nuclear emergencies.

Case study:
Fukushima Daiichi nuclear power plant (2011)

Following the 2011 earthquake and tsunami in Japan, the Fukushima Daiichi nuclear power plant suffered core meltdowns and released radioactive material into the environment. While radiation exposure levels were generally lower than those seen at Chernobyl, concerns about child health prompted widespread public health monitoring (WHO, 2013). Over 300,000 children in the Fukushima prefecture underwent thyroid screenings. Although increased thyroid cancer rates were detected, ongoing studies suggest this may be due in part to overdiagnosis from intensive screening, rather than a direct radiation effect. The disaster caused deep psychological stress among children and parents, with increased reports of anxiety and long-term displacement from homes and schools (Miura et al., 2017). The Fukushima case highlights not only physical but also mental health risks for children in nuclear incidents, and the importance of coordinated long-term care and community support.

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