PIANOFORTE
EUROPEAN PARTNERSHIP FOR RADIATION PROTECTION RESEARCH

Disclaimer: This draft represents the Strategic Research and Innovation Agenda (SRIA) for the PIANOFORTE Partnership. It is being shared to gather feedback and insights from a broad range of stakeholders, with the aim of incorporating their input into the ongoing development of the SRIA.
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Radiation Protection Strategic Research and Innovation Agenda

Chapter 1 - Advancing radiation protection research for a competitive, safe, and sustainable Europe

"We are choosing to put research and innovation, science and technology, at the heart of our economy" – Ursula von der Leyen, President of the European Commission, 5 May 2025 [1]

This clear commitment made by President von der Leyen highlights the essential role that knowledge and cutting-edge technologies play in shaping Europe's future. As the European Union (EU) is confronted with a multitude of emerging, sometimes unprecedented challenges - ranging from the Russian Invasion of Ukraine, climate change, to scepticism towards or even disengagement from internationally established scientific consensus, as well as an anticipated rise in cancer cases[2] - investing in research and innovation has never been more critical. The radiation protection field exemplifies how science and technology can drive progress by safeguarding the health of the public, workers, patients, and the environment. This protection not only enhances well-being but also pushes European industrial and medical innovation, strengthening the EU's resilience, competitiveness, and sustainability.

Today, around half of all cancer patients undergo radiotherapy, which necessitates advanced expertise in radiation protection to maximise the benefits of the therapy for patients and minimize adverse effects to healthy tissues. Furthermore, a growing proportion of public exposure to ionising radiation comes from medical applications such as X-rays and CT scans, as well as nuclear medicine imaging techniques including scintigraphy and PET scans. Optimised protection of patients, practitioners and (family) caregivers, as well as justified medical practices, are therefore key. Similarly, exposure of the environment to ionising radiation (e.g. in post-accident situations or from historically contaminated areas) and the associated consequences for ecosystems and humans, as well as human exposure to ionising radiation due to naturally occurring radioactive materials, call for robust radiation protection policies, regulations and practices, based on a scientifically sound quantification of the relevance of ionising radiation compared to other natural and anthropogenic stressors. This benefits the overall quality of life in Europe and beyond and need to continue to be rooted in state-of-the-art scientific knowledge.

The ongoing war on the European continent, fought in a nuclear energy-producing country, as well as the recent escalation of tensions in the Middle East, including the bombing of Iranian nuclear programme facilities in June 2025, further highlight the importance of radiation protection as part of comprehensive and harmonised national security strategies in times of raising geopolitical tensions that the EU is currently facing. The Chornobyl and Fukushima Daiichi nuclear power plant accidents have proven that the consequences of nuclear incidents are not limited to the country in which they occur. The ability of EU countries to prevent, detect and respond effectively to radiological and nuclear threats - whether accidental, deliberate or linked to other hazards (Chemical, Biological, Radiological, Nuclear, and Explosives (CBRN-e)) - is essential to mitigating potential impacts on people and the environment.

In this context, strengthening infrastructures, emergency response capabilities and cross-border cooperation is critical. In particular, advances in radiation monitoring, data integration and artificial intelligence (AI) can further enhance early warning systems, risk assessment and crisis management. Continuously reinforcing the radiation protection frameworks based on the latest scientific findings and maintaining high levels of expertise among emergency responders and regulatory bodies, will enable Europe to adapt to the evolving security landscape.

The COVID-19 pandemic, and more recently the spill-over of the raising geopolitical tensions onto international trade, have highlighted the importance of reliable supply chains, a robust and innovative

[1] Extract from the speech by European Commission by President von der Leyen at the 'Choose Europe for Science' event at La Sorbonne on 5 May 2025. https://ec.europa.eu/commission/presscorner/detail/en/speech_25_1130

[2] https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/european-cancer-information-system-21-increase-new-cancer-cases-2040-2022-03-16_en

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European industry and technological progress. There are a multitude of industrial applications of ionising radiation within the European competitiveness framework, ranging from non-destructive testing and medical applications to advanced material processing. These applications uphold product safety and quality and enhance Europe's position in global high-tech and high-value markets. In the energy sector, while Member States individually decide on their energy mix, radiation protection framework adjustments rooted in the latest scientific knowledge are needed to accompany progress in nuclear energy applications and innovative approaches such as Small Modular Reactors (SMRs) or novel reactor technologies, to ensure they can potentially contribute to a climate-neutral energy system safely, efficiently and securely. Additionally, the revival of international interest in space technologies - sometimes accompanied by ambitious technological programmes - are further industrial applications that require advanced radiation protection knowledge in order to be carried out safely if they are manned.

Providing cutting-edge radiological protection knowledge to European industry and technologies will enable them to compete and innovate at the highest international level. A key role of radiation safety research and international coordination is to facilitate these and other critical programmes, and to ensure that they meet societal values and needs.

The radiological protection system developed by the the International Comission on Radiological Protection (ICRP) underpins international and national safety standards. It aims to prevent tissue damage and minimize cancer risk, relying on the linear no-threshold model and the ALARA principle. But uncertainties remain large, particularly for low-dose exposures (<100 mSv), potential non-cancer effects, and variability in individual susceptibility. Basic research including biology, epidemiological investigations and improved dosimetry are essential to ensure that protection measures remain accurate, proportionate, and effective.

Technology governance in the EU depends on public support, and trust in risk management actors is key to that support. In order to foster trust, citizens must be reassured that their security is actively sustained through commitment to understanding and mitigating risks; in this case those associated with radiation. In light of the wide range of radiological protection aspects and applications that are directly relevant to EU priorities, the European partnership for radiation protection research (PIANOFORTE) was launched in 2022 as a collaborative initiative to pool and coordinate resources, identify research needs, share expertise, and foster excellence. Its aim is to carry out the necessary research to ensure the highest level of protection for the public, workers, patients, and the environment against environmental, occupational, and medical exposure to ionising radiation. PIANOFORTE's research activities, implemented through open calls for research projects, directly support European policies such as the Europe's Beating Cancer Plan[3], the SAMIRA initiative[4], including the European Radioisotopes Valley Initiative (ERVI) activities, the European Green Deal[5] and the EU Preparedness Union Strategy[6] (see Figure 1). And, with the unsettled geopolitical context, connections with the IAEA (International Atomic Energy Agency) and the European Defence Fund[7] (EDF) need to be strengthened. Ultimately, radiation protection stands as a fundamentally interdisciplinary field, which also supports United Nations Committee on the Effects of Atomic Radiation (UNSCEAR).

[3] European Commission (2020), "Europe's beating cancer plan", Communication from the Commission to the European Parliament and the Council, https://health.ec.europa.eu/system/files/2022-02/eu_cancer-plan_en_0.pdf

[4] European Commission (2021), "SAMIRA: Strategic Agenda for Medical Ionising Radiation Applications: An Action Plan for security of radioisotope supply, quality and safety, and technological development and innovation", https://energy.ec.europa.eu/system/files/2021-02/swd_strategic_agenda_for_medical_ionising_radiation_applications_samira_0.pdf

[5] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[6] https://ec.europa.eu/commission/presscorner/detail/en/ip_25_856

[7] https://defence-industry-space.ec.europa.eu/eu-defence-industry/european-defence-fund-edf-official-webpage-european-commission_en

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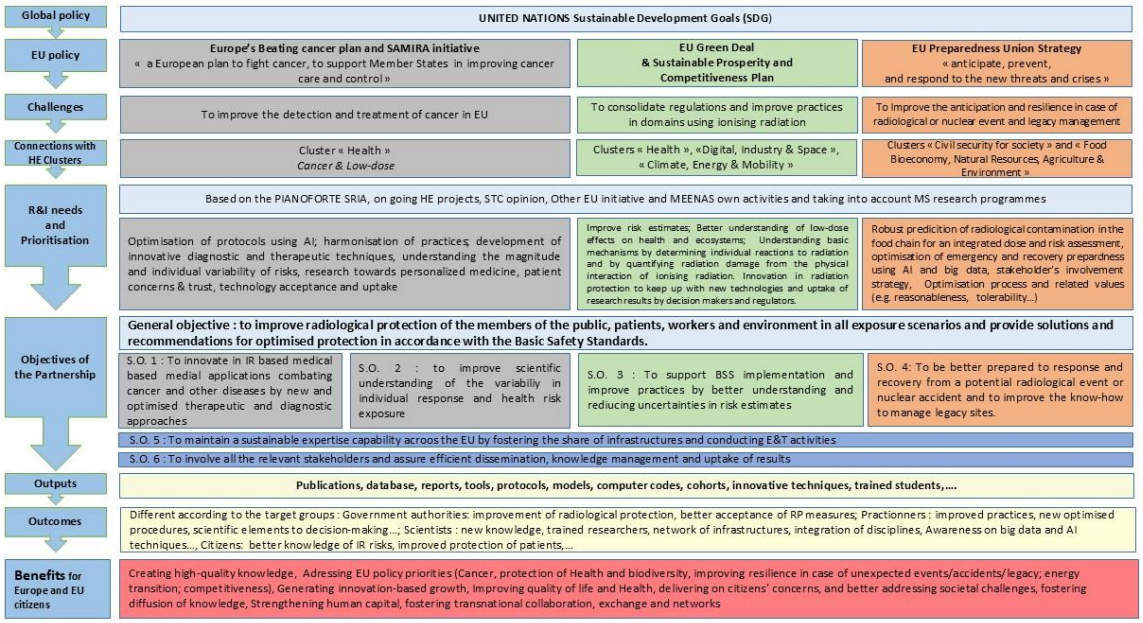

Figure 1: *Articulation of PIANOFORTE objectives with elements of the European policy context, identified challenges, relevant connections with Horizon Europe clusters and research and innovation priorities. Source: Garnier-Laplace et al. (2025), 'The PIANOFORTE partnership: Elevating European research for enhanced radiation protection', EPJ Nuclear Sci. Technol. 11 13.*

This document outlines PIANOFORTE's Strategic Research and Innovation Agenda (SRIA), which will guide its future activities and serve as a recommendation for potential future partnerships in radiation protection research or even for other funding instruments. For each of the three topics - 'Quality of Life', 'Security' and 'Competitiveness' - which are closely related to the European policy agenda - , the SRIA provides an overview of the issues at stake and recent research achievements before addressing the priority issues to be tackled in the respective field in future. It also suggests a concrete list of research topical needs. Some of these research topics have of course links to all three of the European policy priorities. Finally, it addresses some key elements of several cross-cutting topics, such as complexity reduction, use of AI, and stakeholder involvement, in short, dedicated chapters. A disclaimer: not all topics are of identical granularity, so the translation of the topics into funding systems might involve another step of breaking the topics down or combining them again due to the relevant funding programs that are available. All should demonstrate similar clarity in connecting to the overall goals of EU research funding. The crosscutting chapters don't lead to separate research topics, instead they clarify that all of the research projects contribute to the crosscutting issues. The links between the research topics and the cross cutting topics are explored and explained in an overview table in Annex I. All this shows the pivotal role of radiation protection research with links to many others areas in society, and with the agility to respond to current and future geopolitical concerns.

Chapter 2: Quality of life in Europe

Introduction

Quality of life is shaped by mutiple factors, encompassing, among others human health and well-being, eocnomic and physical safety, and environmental sustainability. Health is defined by the WHO as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" drawing in social, economic and environmental criteria. Public and occupational health, alongside the protection of natural resources and ecosystems, are thus key drivers for the quality of life for European citizens. Ionising radiation is used in several domains, not the least in medicine for diagnostic and therapeutic purposes. Increasing and ensuring individual and societal benefits of ionising radiation, while minimising deleterious effects of exposure to ionising radiation, are among the key priorities for the quality of life of the European population. In a constantly evolving world, an optimal use of ionising radiation is not possible without continuous research.

Radiation protection research is a major contributor to understanding and mitigating risks to human and ecosystem health associated with medical, occupational, and environmental radiation exposures, whether it relates to planned or emergency exposures, as well as to improving the beneficial use of ionising radiation. Radiation protection research is fully aligned with the comprehensive and integrated approach of the 'One Health' concept. For example, this research enables, the optimisation of the benefit-to-risk ratios for medical applications, as well as for industrial and energy-related uses of ionising radiation. It also enables the development and safe use of new and emerging technologies allowing to improve patient care as well as economic and social welfare. Additionally, it helps maintaining a healthy, natural environment. Ensuring sound radiation protection science, underpinned by robust evidence, therefore allows society and individuals to benefit from the uses of ionising radiation while keeping the associated risks to health and the environment at an acceptable level – supporting healthy populations and environments.

Where we stand

EU-funded projects have, in recent years, generated significant new knowledge regarding risks of ionising radiation at low levels of exposure in humans. These efforts have addressed also environmental radiation-related issues like exposure to radon and other naturally occurring radionuclides and remediation of legacy sites (e.g., NORM affected sites), as well as recovery of areas affected by nuclear or radiological accidents. These projects have contributed to advances in radiation monitoring technologies, improved environmental impact assessments and risk assessment frameworks and models for environmental and occupational exposures, notably by improving the understanding of low dose risks among affected populations. They have also played a crucial role in updating international regulatory frameworks and strengthening their implementation, fostering stakeholder engagement in decision-making processes, and strengthening radiation protection culture across industries.

In the medical field, recent EU funded projects, have made significant progress in assessing patient exposures, risk indicators and quality parameters, alongside active stakeholder engagement to ensure public awareness and patient safety. Important results on methods for optimisation of radiation therapy and medical imaging procedures were produced and steps were made to achieve standards on justification of imaging procedures throughout Europe.

The PIANOFORTE partnership has fostered and funded research through different open calls. To date these have focussed on developing a knowledge base for a better understanding of pathogenesis of ionising radiation-induced cancer to improve risk assessment, and for investigating the effects of temporal and spatial variations on the risk of health effects. The goal is to progress with personalisation and optimisation of radiation therapy and imaging procedures and to interlink radiation biology, radiation epidemiology and radiation medicine approaches to reduce detrimental effects of ionising radiation in medical applications. This includes the implementation of new and optimised radiation therapy approaches for better targeting to protect healthy tissues against detrimental effects of ionising

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radiation. Next to this an integrated approach for risk assessment and evaluation from environmental exposure to ionising radiation is being developed, including following the conflicting geopolitical context.

Collectively, all these actions are serving to enhance the quality of life for European citizens and allowing the benefits of the applications of radiation in industry, medicine and elsewhere to individuals and society to be realised.

What we have to do

New Technologies to Accelerate Research on Low-Dose Risks

Improving our understanding of the health effects of low dose ionising radiation, including both cancer and non-cancer pathogenesis, remains a high research priority. To enhance insights in this field, new technologies are opportunities to accelerate new findings. These are e.g., AI, machine learning (ML), advanced computational techniques such as causative inference, 'omics' approaches, and new advances in the 'Adverse Outcome Pathway' framework. Research on low-dose radiation is crucial for understanding disease mechanisms and developing early detection strategies. It also plays a key role in refining radiation protection guidelines. Given the widespread public health concerns linked to radiation-related diseases, advancing this research holds significant societal benefits. Furthermore, a clearer understanding of dose-response relationships is vital for establishing well-founded radiation protection strategies. This would lead to effective and efficient risk management avoiding potential overprotection and leading to a simplification of the whole radiation protection system. More knowledge on radiation exposure risks will also lead to improved diagnostic capabilities with an optimised use of ionising radiation, benefiting public health and enhancing safety of medical settings.

Radiation Technology Development and AI in the medical field:

The use of new technologies such as AI based systems could benefit patients, if implemented in a safe and secure way, attending to relevant ethical considerations. This requires supporting research covering aspects of technology, data security, data sharing and addressing the heterogeneity of data sets and their description, as well as quality assurance of data and tools. The same holds for new Ionizing Radiation sources as there is a lot of knowledge on developing and suitable use of sources for ionising radiation (ERSF, ARRONAX, DESY, ELI etc.) and corresponding developments for new therapeutic approaches (FLASH, mini beam therapy, radionuclide therapy, etc.) as well as diagnostic approaches (phase contrast imaging, X-ray fluorescence imaging etc.). The possibilities of the emerging technologies and their radiation protection aspects are not yet studied. Standardisation, mobility, and integration of patient data from therapeutic and diagnostic new technologies will be necessary for the application of modern AI techniques, and preparing data to be "AI-ready" and accessible is a critical and urgent challenge. Further developments are needed that enable the implementation of e.g., personalised radiation therapy or combining X-ray techniques with other imaging modalities. These new evolutions in the medical field require thorough research to optimize the protection of the patients and staff by reducing and avoiding unnecessary radiation and further maximizing the benefits.

Radiation biology has in the past years developed more insight into specific, individualised radiation effects related to medical exposures. There is also need for combined efforts between researchers of different disciplines and clinicians for optimised individualised treatment of patients including new radiopharmaceuticals for diagnostic, therapeutic and radio-theragnostic approaches as well as in combination with other therapeutic techniques.

Due to this broad knowledge base European research is in an excellent position to develop clinical decision support systems related to the use of ionising radiation in medicine. In terms of expected outcomes, all these opportunities would allow better and more efficient patient health care while reducing the potential detriment due to the ionising radiation. By this, it will also reduce the occupational radiation burden for clinical staff. Another aspect to address this challenge is to spread out this knowledge, for example, by supporting initiatives such as trainings which enhances the quality, safety

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and consistency interventional procedures, across Europe. Many of topics could include a specific focus on pediatric aspects because of the specific sensitivity of children to ionising radiation.

Manage Complex Environmental Radiation Risks for Protecting Human Wellbeing and Ecosystems

Environmental radiation-related issues, such as exposure to radon and naturally occurring radionuclides, the sustainable remediation of legacy sites (e.g., NORM sites, areas affected by accidents), and approaches to managing radioactive residues in a circular economy, are complex and are thus not completely understood or predictable. The impact of environmental radiation and multi-stressors on ecosystem services and, indirectly, on human health are currently poorly understood. Industries dealing with NORM require ongoing expertise in risk assessment, management and communication to address societal concerns and address legal, social, economic and transnational challenges, that may hinder the development of industries vital for new technologies. The risks are further compounded by climate change and the growing combination of exposures to radiation, hazardous physical stressors, and chemical substances. Furthermore, several countries intend to expand their nuclear energy power capacity, notably using emerging nuclear technologies and new siting configurations, which requires improved assessments for ensuring legal compliance and adequate emergency preparedness, response and recovery (EPR&R). A solution is also needed for the radioactive waste disposal issue, which is linked to many questions of classic radioecology. In addition, the consequences of potential domestic uranium production (from mining to enrichment) should not be ignored. Evidence-based risk assessments will support the sustainable development of industries that utilise ionising radiation science and technologies. Improved dosimetry and transfer modelling for non-human biota across underrepresented ecosystems (tropical, deep marine, Arctic) and life stages are needed to replace the narrow species set on which reference models still rely. Further mechanistic work linking molecular and individual-level effects to population and community outcomes, so that ecological endpoints can be incorporated into protection standards with defensible confidence. Greater understanding of public understanding of radiation risks, social and cultural aspects, and the needs for communication and stakeholder and public engagement, will facilitate effective risk management in the context of broader environmental challenges. These efforts are essential for managing radiation risks in an evolving environmental landscape and will lead to safer living conditions and better societal trust and protection for communities and ecosystems exposed to radiation.

Improving risk assessment for combined exposure situations in the environment and food chain

Currently, the chemical risk assessment in the European Food Safety Authority (EFSA) and the EU mainly relies on the assessment of individual substances or, in a few cases, groups of substances that are expected to occur together. To comprehensively assess human health, it is important to have a combined approach for the identification of all contaminant sources and assess the cumulative effects and potential risks from pollution exposure, as in everyday life humans are affected by a mixture of various contaminants (co-exposure). This is also true in terms of food safety. The combination of several pollutants, even at low concentrations, may pose a risk to human health. Additional supplementing doses/risks should be considered along with the existing exposure/doses. There is a need to develop methods and models for the assessment of potential synergic effects of mixture of contaminants (such as radioactive substances, metals, Persistent Organic Pollutants, etc.) in the environment and food chain. There is also a need to derive threshold values for a number of contaminants that are currently missing such values to be used in models.

Improving monitoring and reducing occupational exposure

A portion of the European workforce is exposed to ionising radiation in various occupational settings, including healthcare, nuclear energy, aircrew, and industrial applications. To ensure their safety while maintaining operational efficiency, new technologies, advanced detector developments, simulation and AI tools can improve radiation monitoring and dose assessment. These advancements not only help in reducing workers' radiation exposure but also simplify procedural complexities. Research in this field plays a crucial role in refining monitoring techniques, reducing uncertainties in exposure assessments,

and ensuring compliance with evolving legal and regulatory requirements. The largest collective dose at workplaces is due to geogenic radon, so strategies are also needed to decrease this.

Bulleted list of research topics

Q1. Biokinetic and internal dosimetry studies for theranostic approaches.

Q2. Biological Mechanisms and Risk Assessment of Low- and Intermediate-Dose Ionising Radiation

Q3. Enhancing Oncologic and Interventional Imaging: Addressing Training Gaps, Quality Standards, and AI Integration in CT and PET/CT Practice

Q4. Personalized Radiation Risk Assessment: Addressing Individual Variability and Susceptibility.

Q5. Understanding and Modelling Complex Radiation Dose Distributions: Temporal and Spatial Dynamics.

Q6. Integrated Risk Assessment of Combined Radiation Exposure Scenarios

Q7. Understanding of effects on ecosystems exposed to ionising radiation

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Chapter 3: Security in a changing world

Introduction

Nuclear and radiological emergencies have been and still pose complex and far-reaching challenges that demand continuous advancement in preparedness, response and recovery. Their inherent rare occurrence but far-ranging nature and potential impact necessitate robust planning, coordination, and scientific and technological advancement. Despite significant progress, critical gaps remain across all emergency phases, particularly in preparedness strategies, risk assessment methodologies based on models and monitoring, and crisis communication.

Given the transboundary nature of nuclear and radiological threats, European harmonisation of regulations, early warning systems, strategies and emergency protocols is essential. Nuclear and radiological emergencies require integrated approaches encompassing impact and risk assessment based on state-of-the-art modelling and monitoring, dosimetry, effective communication strategies, and agile decision-making frameworks.

Recent geopolitical shifts—including Russia's invasion of Ukraine, growing tensions among global powers, and instability in regions like the Middle East—have highlighted the vulnerabilities in existing nuclear and radiological emergency frameworks. The renewed focus on nuclear energy expansion, including the accelerating deployment of small modular reactors (SMRs), coupled with heightened security threats in an era of hybrid warfare (e.g., novel cybersecurity issues, vulnerabilities for installations in remote areas), underscores the urgent need for a comprehensive and adaptive research agenda to enable resilience societies.

The complexity of dealing with the preparedness for, and aftermath of, potential nuclear or radiological accidents highlights the need for transdisciplinary research approaches involving different disciplines (e.g. natural sciences, social sciences and humanities) and a wide range of societal actors (e.g. radiation protection experts, authorities, industry, citizens).

Another threat of strategic importance, particularly to the European medical sector, is the current reliance on complex and fragile radioisotope supply chains for medical applications. These supply chains are especially vulnerable to geopolitical tensions, economic pressures, or targeted sabotage, posing risks to the supply of essential medical radioisotopes for cancer therapy, imaging, and surgery (e.g. Molybdenum-99, Technetium-99m). Establishment of alternative supply chains, quality assurance for new suppliers, patient dosimetry requirements in the face of isotope use switching, all raise important radiation protection questions. Europe therefore has a security interest in establishing and maintaining reliable radioisotope supply chains, as well as achieving greater independence in key medical technologies[8]. While these challenges are of strategic importance for European autonomy, they extend beyond radiation protection research and must also be addressed through broader economic, industrial, and security policies.

To ensure Europe's readiness for an evolving security landscape, the following questions related to radiation protection research must be addressed in the next years:

- How can existing radiological emergency preparedness strategies be enhanced in an increasingly hostile geopolitical environment? This includes countering risks associated with e.g. nuclear attacks, sabotage of nuclear facilities, and threats/disruption to radiological material supply chains, including those related to medical isotopes.

[8] European Medical Agency and Heads of Medicines Agency (2025): Tackling vulnerabilities in the supply chain of radiopharmaceuticals in the EU | European Medicines Agency (EMA)

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- How can the increased reliance on nuclear technologies—ranging from power plants to medical and industrial applications—be balanced with the heightened risk of conflict? What measures ensure the resilience and safety of radiation-related infrastructure in both peacetime and crises?

Where we stand

Over the past 15 years, EU funded research initiatives have yielded significant advancements in radiation emergency preparedness. Many lessons have been learned from the Fukushima Daiichi nuclear power plant accident in relation to public engagement and communication. These efforts have improved radiological risk assessment methodologies, decision-support systems for emergency management, public health response frameworks, stakeholder engagement and communication strategies. This progress through the projects includes e.g. improved computer models and tools for decision support, improved strategies for medical and health surveillance, improved consideration and coping with uncertainties in modelling and decision making, advanced approaches to reduce uncertainty where necessary, a better understanding of social and ethical aspects of EPR&R, and improved concepts for stakeholder participation in radiation protection and decision making.

The PIANOFORTE partnership identified two areas that need prioritisation. Firstly, the development of risk assessment and risk management approaches and technological capabilities to cope with threats due to war or armed conflicts situations or natural disasters. Secondly, the use of AI and big data techniques to improve emergency response – covering radiological impact assessments, decision support, data collection response and integration, and recovery strategies as well as public engagement, communication, education and training.

What we have to do

Risk assessment and emergency response: CBRN-E and nuclear warfare

New and emerging nuclear technology trends require further development of risk assessment and risk management approaches as well as technological capabilities to cope with novel threats and risk scenarios.

In the case of a chemical, biological, radiological, nuclear, explosive (CBRN-E) event, the challenge lies in the simultaneous occurrence of a nuclear security event alongside other disasters and/or security events. The development of an all-hazard approach - including standard operating procedures of common processes across involved authorities – is a key point in improving the ability of authorities to respond adequately. Also, more guidance, stockpiling and research on medical protective actions for CBRN-E events are needed. Specifically, there is a need for a more holistic medical diagnostic approach, consisting of the interplay of biodosimetry, physical dosimetry and clinical outcome prediction for the medical management of radiological mass-casualty events. A closer relationship with the COUNTERACT[9] network and its actors should be set-up.

In the scenario of the deployment of a tactical nuclear weapon of smaller yield, direct effects are severe but still localised. Effects due to fallout have a much larger range and are thus critical for radiation protection. This includes better and quicker identification of the initial dimensions of the mushroom cloud directly after explosion, improved abilities to assess the fallout of the nuclear explosion up to large distances and the associated health consequences (combined injuries, acute radiation syndromes and late effect), improved strategies and technical means to quickly alert the population in such scenarios. Research on innovative medical counter measure and on improved protection of monitoring and communication devices and other critical infrastructure against the various effects of a nuclear explosion are needed.

[9] https://www.europarl.europa.eu/doceo/document/E-9-2023-003643_EN.html

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Another challenge is the ongoing change of radiological impact assessments, decision support and response and recovery strategy through the introduction of AI and big data techniques.

Making the best, most efficient and rapid use of large amounts of uncertain data in crisis situations is a joint challenge for many practitioners in emergency preparedness.

Transdisciplinarity to improve resilience

The war in Ukraine resulted in the identification of new challenges in conflict situations, e.g. the need to assess how fundamental radiation protection principles may be applied in armed conflict situations.

Even after the experiences in Ukraine, it remains unclear how to actually deal with the potential for deliberate attacks on nuclear facilities and the consequent risk of radioactive releases. Europe has to consider the challenges of radiological monitoring and alerting the population in conflict situations, how information will be communicated to the public in parallel to potential active electronic warfare and disinformation campaigns, and how the situation might alter behaviours, thereby affecting the effectiveness of any protective action strategy. The necessity to build resilience and prepare European citizens for the new security situation has to be aligned with parallel ongoing activities all over Europe in different silos of civil protection attempts and if possible also in accordance with European Defence Fund (EDF) objectives.

Finally, there is a need for better integration of resilience and sustainable development principles including the consideration of the UN Sustainable Development Goals in emergency preparedness, response and recovery strategies.

Address and reduce uncertainties

The need for further improvements of radiological impact assessment for human dose and environmental impact also includes coping with uncertainties in crisis situations, where often only limited information is available. This includes research related to impact assessments for planning, real-time impact assessments during the response phase, dose reconstruction in a later phase, uncertainty quantification of the impact assessment and visualisation, as well as the reduction of uncertainty related to specific modelling approaches.

Large uncertainties still exist in the application and efficacy of management strategies for radiological emergencies. Further research is needed on the consideration of uncertainties in the decision making and in the communication of uncertainties to all relevant stakeholders and the public.

Altogether, these three topics lead to three research areas: first, in risk assessment, emergency response, and technological resilience; second, in transdisciplinary research and strategic adaptation and third, reducing uncertainties. All three topics will have to be accompanied by major development aspects in advancing emergency preparedness beyond the current state-of-the-art: AI-driven decision-support tools must be developed to integrate vast, uncertain data streams into rapid, actionable intelligence for first responders and policymakers. Additionally, research should focus on enhancing public preparedness and bridging gaps between radiation protection and broader civil protection frameworks, integrating efforts across law enforcement, intelligence agencies, healthcare systems, and disaster response units. To do so, multidisciplinary collaboration between natural sciences, social sciences, policy experts, defense capabilities and technology developers will be required. Important is also the “zeroth area of research” which is linked to avoiding CBRN-E events.

Bulleted list of research topics

S1. Enhancing resilience to Radiological Threats to EPRR amid Geopolitical Instability and Hybrid Warfare

S2. Integrated optimisation of decision-making for emergency response, transition and long-term recovery for populations and the environment

S3. AI application in nuclear and radiological EPRR

S4. Innovative medical countermeasure

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Chapter 4: Competitiveness

Introduction

Ensuring Europe's global competitiveness, fostering a risk-informed society and making informed choices about energy sources are essential for sustainable development and climate change mitigation. A competitive Europe must strike a balance between innovation and sustainable economic growth, without compromising or even while improving the quality of life. Whatever energy choices countries make, radiation protection research plays an essential role in this context by ensuring the safe use of nuclear technologies and the appropriate knowledge and know-how for a robust comparison of both their safety and environmental impact with other technologies, taking into account the associated safe storage of nuclear waste. Only this approach can enable countries to make the best choices for their energy portfolio, mitigating risks and boosting public confidence in energy choices. Understanding and managing radiation risks through robust research can enhance public trust in scientific assessments, leading to evidence-based energy policies. This includes Europe's ability to anticipate and manage risks from ionising radiation, through sustained investment in interdisciplinary research, without unjustifiably hindering the development of new technologies and solutions.

Furthermore, radiation protection research complements Horizon Europe's objectives, particularly in the context of energy transition and the shift towards a circular economy. As new energy designs or technologies and sustainable practices emerge including the reuse of materials containing low levels of radioactive substances, it is essential to develop knowledge and methodologies to assess potential risks and ensure harmonised regulatory compliance at a European scale.

Finally, non-energy applications of ionising radiation play a crucial role in the medical sector, as well as in related and many other industrial domains. These technologies bring in high revenues, create skilled jobs focused on innovation, and help improve the quality of life for people in Europe.

Where we stand

In recent years, EU funded partnerships and research projects have significantly contributed to understanding radiation risks associated with energy production, industrial applications, and environmental exposures. These initiatives served as a foundation for PIANOFORTE research priorities and projects to pave the way to (i) improve and adapt radiation dose and risk assessment models, assumptions and data, for new nuclear technologies emerging in energy and non-energy related industries, (ii) foster stakeholder engagement and risk communication deploying modern tools to ease societal understanding of radiation risks and supporting informed decision-making, (iii) contribute to the development and deployment of sustainable practices (e.g., decommissioning of nuclear facilities, radioactive waste management, remediation of contaminated sites). Additionally, European projects have advanced radiation monitoring technologies, ensuring the safe operation of nuclear facilities and other industrial applications. The development of improved dosimetry methods has contributed to e.g., occupational safety in nuclear power plants and medical settings. For the medical area, such research has been fostering the potential for the health of European citizen in combination with the strong MedTech industry on all scales within Europe, like it is also reflected in the SAMIRA action plan. Actually, with ERVI activities which explore the possibilities for building European production capacity for metallic high-assay-low-enriched uranium (HALEU), enhancing Europe's production of enriched stable isotopes, strengthening the medical radionuclide production, expanding the European medical radionuclide (PRISMAP[10]), and developing more reliable monitoring of supply and demand. The results of the projects also allowed further potentials for market use of European MedTech products. In a nutshell, these achievements underline that Europe's progress in radiation protection has only been possible through strong research collaboration. By working together, PIANOFORTE and its predecessors have created a world-leading approach that should be actively promoted as a joint European success.

[10] https://www.prismap.eu

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What we have to do

Advancing radiation protection for sustainable energy choices

The different energy choices and implementation of solutions to mitigate the impact of climate change require informed decision-making based on the best available scientific expertise within the Member States. Radiation protection research supports this effort by facilitating the energy transition and advancing sustainable practices and circular economy. As emerging energy technologies gain prominence, including novel nuclear technologies such as small modular reactors and fusion experimental facilities, it is crucial to develop robust methodologies and related knowledge for assessing their potential risks. There is also the potential novel application of nuclear technologies as industrial heat sources, including in Europe. Improving research and simplifying radiation protection frameworks without compromising the underlying risk-proportionate approach for risk assessment and management, will enable to make these new technologies more efficient. Additionally, sustainable resource management, including the reuse of materials with low levels of radioactive substances and site remediation, requires clear regulatory frameworks and comprehensive human and environmental health impact and risk assessments to ensure both safety, environmental protection and stakeholder acceptance. The more we understand the science involved in such technologies, the more it will help to facilitate deployment for societal benefit and to improve energy security and independence.

By fostering a knowledge-based approach, radiation protection research enables the responsible deployment of new technologies fostering a risk-proportionate and trustworthy regulatory framework that encourages innovation while maintaining high safety standards, ultimately supporting Europe's leadership in sustainable energy development.

Fostering innovation in radiation protection tools and technologies

The rapid progress in nuclear science and technology, coupled with the growing influence of artificial intelligence and advanced computational tools, has created new opportunities for radiation protection research and practice. AI-driven methods, including big data analysis and predictive modelling, offer unprecedented capabilities in radiation risk assessment and communication, understanding uncertainties in both exposure, effects and risk estimates, as well as challenges related to disinformation and misinformation. New radiation measurement techniques and the use of drones for radiation protection are examples of such technology innovation taking into account AI and increased computational power which will actually change the radiation protection practices. Advances in cellular and molecular biology, provide deeper insights into radiation-induced biological effects, enabling more precise health risk evaluations, and even personalised assessment, with tailored estimates of exposure, effects and risk. These developments underscore the urgent need for modern approaches to radiation protection that integrate cutting-edge scientific advancements. By establishing interdisciplinary collaborations that bridge nuclear science and technology, AI, and all radiation protection related research disciplines, research outcomes will enable the refinement of risk assessment models and the adaptation of both standards and practices through scalable, risk-based approaches in medical, industrial, and environmental applications.

Realisation of the benefits of new technology is, almost without exception, based on data acquisition and analysis, and knowledge management. This is particularly true for the use of AI based analyses which require standardised formatting and metadata to enable aggregation, integration and algorithmic ingestion. Specifically, information on metadata and format need to be machine readable for efficient and agile distribution and use. The flow and utilisability of data is essential for competitiveness, and the EU is in a strong position to support the flow and integration of data across borders and legislatures which in turn will support technological developments as well as advances in basic science.

Radiation protection for space exploration

The expansion of space exploration and the increased presence of humans in space environments necessitate enhanced protection against cosmic radiation. Astronauts and space mission personnel are exposed to high levels of cosmic radiation, which poses significant health risks. A deeper understanding of the biological effects of different radiation particles, including protons and heavy ions, is essential for improving the safety and success of space missions, especially those into deep space such as the

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projected Mars missions. Notably, there is a movement towards much longer human residence times in more distant cis-lunar space, which will require the acquisition of new understanding of chronic exposure effects. In this context, the development of both operational and biological mitigation strategies will be a priority, as current radiation protection dose limits alone will not ensure the safety of future space travel. Research in this field not only benefits space exploration but also has applications for medical treatments on Earth, particularly in cancer therapy, where particle radiation is increasingly used for targeted treatment.

Sustainability of innovation in all sectors of radiation protection

The rapid advancement of technologies involving ionising radiation demands continuous investment in research and expertise to maintain Europe's global competitiveness. Strengthening risk assessment (also for combined factors), risk communication, and risk management ensures that technological innovations are safely implemented while fostering public trust. Without these efforts, misinformation and uncertainty could hinder the adoption of sustainable energy solutions and disrupt industrial progress. In medicine the awareness of radiation protection aspects had led to innovations which still allow the European industry an advantage compared to other competitors.

Bulleted list of research topics

C1. Radiation Protection Methodology for Novel Nuclear Facilities and Emerging Energy-Related Applications

C2. Towards improved occupational dosimetry in view of BSS regulation and practical application

C3. Sustainable management and integrated risk assessment of radioactive waste and effluents: towards circular economy solutions and holistic radiological protection

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Chapter 5: **SRIA Stakeholder Engagement**

In radiation protection research as for most research areas with applied focus, the strategic involvement of stakeholders plays a pivotal role in shaping research priorities, ensuring both societal and economical relevance, and enhancing the applicability of scientific advancements for increased impact.

Types of stakeholders in radiation protection encompass a diverse range of entities and groups including European and national policy makers, regulatory authorities, the scientific community including the field of education and training, occupational stakeholders, various industrial sectors, medical experts, patients and finally the public as a whole. In this heterogeneity they reflect the interdisciplinary nature and wide range of questions related to radiation protection. Their engagement is crucial to facilitate a well-grounded understanding and implementation of radiation protection measures that adequately meet both professional standards and public expectations, and ensure compliance with national and European legislation, i.e. the BSS (Basic Safety Standards) directive. In radiation protection research itself, it is necessary to foster collaboration and exchange across sectors and to try to integrate different scientific domains in research activities as appropriate. In particular, inter- and transdisciplinary collaboration is essential to address complex, domain overlapping scientific challenges and shall ensure that research outcomes and recommendation meet the broader societal needs. In parallel, the stakeholder needs differ depending on the specific topic or concern being addressed and are not limited to the radiation protection science community. Diverse end-user groups and industry stakeholders for example from the medical field, the material and processing industry, the nuclear energy sector and many more need to develop, implement and use radiation and radiation-based technologies in various settings. Their perspectives, needs and expertise are crucial for ensuring that the research outcomes are relevant, actionable, and widely accepted. They cannot simply be “averaged” but have to be addressed individually according to the different dimensions of radiation protection research. Collectively, this comprehensive network of stakeholders from politics, research, and industry underscores the complexity and importance of radiation protection, as we have to work collaboratively to protect humans and the environment.

Involvement of stakeholders in radiation protection research should enable effective participation of these stakeholder groups consistently throughout the different stages of a research project's life cycle. Therefore, research activities should identify and involve stakeholders from the earliest stages of the research design and continue this engagement specifically throughout potential dissemination and exploitation phases. This includes establishing communication channels and collaboration strategies to integrate the insights and needs of each stakeholder into the research efforts effectively. By doing so, scientists and researchers can ensure that their findings are not only scientifically valid but also directly applicable to the needs of the wider community, thereby enhancing the overall value and impact of radiation protection research.

For simplicity, in the following table/graphic we try to sort stakeholders according to the three pillars of net benefit for European citizens that radiation protection research can generate: (i) quality of life, (ii) security, (iii) increased competitiveness. This provides a non-exhaustive overview of stakeholders and groups relevant for the specific fields of the SRIA.

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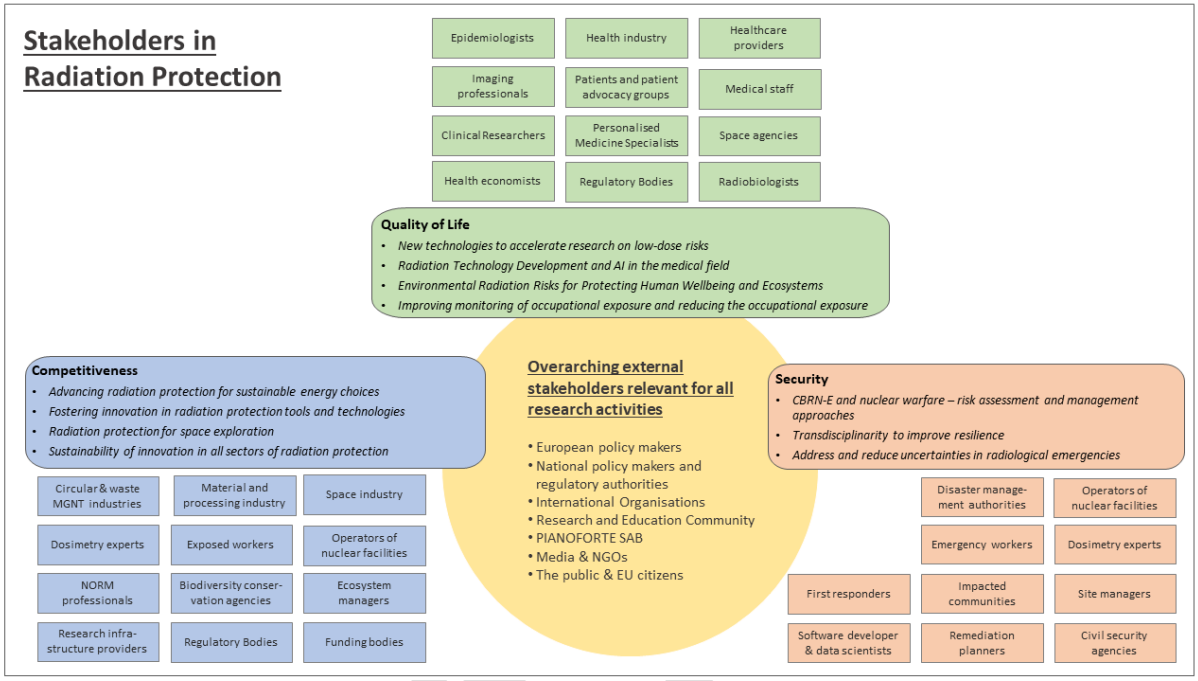
In the following, an exemplary table/graphic on stakeholders in the various domains of radiation protection is provided.



		Relevant Stakeholders (non-exhaustive)		
		SRIA chapters / Research clusters		
Stakeholder group	**Addressed by**	***Quality of Life***	***Security***	***Competitiveness***
European policy makers	PF	EC, Article 31 Group of Experts, HERCA, WENRA and others		
International organisations	PF/projects	IAEA, ICRP, UNSCEAR, IRPA, ENA, ERA and others		
National policy makers and POMs	PF/projects	Ministries and other public bodies, including those at regional and local levels; POMs of the EU memberstates		
Regulatory authorities	PF/projects	Relevant public authorities on national and European level		
PIANOFORTE SAB	PF	The PIANOFORTE Stakeholder and Advisory Board can be addressed in a coordinated manner via WP3		
Implementers & users	Projects	Medical physicists, Public Health Officials, Patients and Patient Advocacy Groups,	Emergency Response Teams/First Responders, Nuclear Power Plant Operators,	Waste managers, NORM professionals, Nuclear facility operators, exposed workers, NPP operators, space agencies
Industrial domains	Projects	medial equipment manufacturer, health industry in general	Nuclear industries, measurements and equipment provider	NORM, Mining, Non-disruptive testing, waste management, Additive manufactureing and material processing.
EU R&I Initiatives	PF/projects	European Partnership for Personalised Medicine	Projects within the European Defence Fund, GUARDIANS	European Partnership for Metrology
Research platforms	Projects	EURAMED, MELODI, EURADOS, ALLIANCE, SHARE	EURADOS, ALLIANCE, NERIS	EURADOS, ALLIANCE, NERIS, SHARE
Research & education community	Projects	Health sector, biologists, imaging professionals, clinical researchers, health economists, SSH	Meteorology, geology, SSH	Engineeering, SSH
Media & NGO	PF/projects			

Chapter 6: Infrastructure

Research infrastructures are defined by the European Commission to be facilities that provide resources and services for research communities to conduct research and foster innovation. They can be used beyond research e.g. for education or public services and they may be single-sited, distributed, or virtual.

As the general definition, research infrastructures of relevance for radiation protection research include:

• major scientific equipment or sets of instruments

• collections, archives or scientific databases

• computing systems and communication networks

• any other research and innovation infrastructure of a unique nature which is open to external users

A key, jointly agreed, action within the radiation protection research community is the sharing and mutualisation of infrastructures at the European level, with maintenance and easy access to relevant research infrastructures being one of the jointly agreed pillars of excellent radiation protection research. Critical infrastructures need to be identified and appropriately supported, and access to these infrastructures should be possible for the whole radiation protection community.

The European Commission published a revised Charter for Access to Research Infrastructures[12]. The Charter sets out non-regulatory principles and guidelines, which Research Infrastructures can use as a reference when defining their access policies. In parallel, progress on infrastructures has been made under various collaborative projects at European Level, not least the inventory of European infrastructures and future needs performed during the H2020 CONCERT EJP. This work demonstrated that most infrastructures required are already available within Member States, Associated Countries or beyond[11].

Concentrated efforts are, and will continue to need to be, focused on supporting maintenance and development of, access to and training in respect of critical infrastructures.Work will need to continue on harmonisation of quality standards, practices and protocols for the full range of different types of infrastructures, including through intercomparisons, to facilitate high quality data outputs and impact. In addition, work focused on understanding and planning to overcome the key challenges facing our infrastructures is required - not least ever decreasing funding, attraction, recruitment and retention of early career scientists to support maintenance and development of infrastructures, and the extremely fast pace of analysis and storage technologies (including those facilitated by AI). In respect of this latter point, the European radiation protection community will need to work closely together to further develop and put into practice FAIR and open science, including in relation to data sharing, management and reuse of archived data. Integration of standards and best practice with exiting ones (e.g. ELIXIR[12], European Open Science Cloud[13]) is already in place, but these need to be expended and widely implemented to support the efficient exchange and integration of data across the global community.FAIR data principles can ensure that data is not only reusable by humans across disciplines, but also machine-actionable for AI systems and beyond

In common with other aspects, stakeholder input into this work will be crucial, facilitated through the current international networks and with direct involvement in the work programmes as well as specific workshops with representatives of infrastructures, users and other relevant stakeholders (see Chapter 5) from across the full range of different types of activities currently ongoing within the community.

[11] Infrastructures | The European Partnership for Radiation Protection Research

[12] https://elixir-europe.org/

[13] https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/our-digital-future/open-science/european-open-science-cloud-eosc_en

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Overall, a mutually agreed, strategic, programme of work is needed to ensure long term sustainability of the critical radiation protection research infrastructures and their use in development of radiation protection science and operational practice.

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Chapter 7: Expertise / E&T

Education and Training (E&T) in radiation protection is a strategic enabler for ensuring the safe, effective, and innovative use of ionising radiation. It plays a pivotal role in translating scientific research into practical applications. As radiation technologies evolve rapidly—driven by advances in medicine, energy and industry, and fueled by potential game-changers such as artificial intelligence—the need for a well-trained, multidisciplinary workforce becomes increasingly urgent.

E&T actions are essential not only for empowering the next generation of researchers and professionals but also for supporting the current workforce in adapting to new scientific insights and technological developments. Moreover, E&T contributes to making research outcomes more accessible and understandable to broader audiences, complementing traditional dissemination efforts within the scientific community. In this context, building and sustaining expertise in radiation protection is not merely a support activity—it is a strategic imperative.

Europe has a strong foundation in radiation protection education, supported by academic institutions and research platforms, and also underlined in initiatives such as PIANOFORTE. The partnership has already implemented mechanisms to support education and training for students, early career researchers, and professionals. These include funding for targeted training courses, mobility grants for participation in conferences and exchange visits, support for networking activities and enabling PhD research in the various projects.

However, despite these efforts, challenges remain. There is currently no sustainable overarching European framework for managing knowledge transfer activities specifically in the radiation protection domain. This makes the current initiatives vulnerable to fragmentation and loss of expertise. The ageing workforce, limited visibility of career opportunities in radiation protection, and declining enrolment in STEM disciplines further exacerbate the issue. General interest in RP is insufficient, as a consequence shortage of competent RP workers at all levels in Europe is a fact.

To ensure a robust and future-proof radiation protection workforce, coordinated action across three strategic dimensions is required within a European context: attracting new talent, building competences, and maintaining expertise. To achieve this, a sustainable European E&T framework in radiation protection needs to be established, complemented by clear communication channels to increase the visibility and accessibility of existing initiatives. Without losing the essential link to radiation protection research, this framework will also need stakeholder involvement to bridge existing initiatives and to bring together organisations and platforms with common goals of building and maintaining competences in nuclear and radiological sciences (e.g. European Nuclear Skills Academy).

Attracting New Talent

Outreach and science communication can be intensified to highlighting actions towards radiation sciences and inspire young individuals to pursue education and careers in STEM. Role model campaigns, teacher support programs, and engaging digital content such as webinars and podcasts are just a few examples of means that further enhance interest. Such actions can highlight the societal relevance of radiation protection and the diverse RP career opportunities in research, healthcare, industry, and regulation.

Building Competences

Education and training programs are to be developed and maintained to cover both foundational and advanced topics, enhancing knowledge and skills in RP. Whilst general education is more offered by academic institutions to students, training is seen as continued and advanced learning for both students and professionals. In both cases, involvement of RP experts from different stakeholders (industry, healthcare, governmental institutions, research centers, academia, …) brings immediate added value to the learning curve as these experts bring direct insights from their daily work and experience. Continued support from the PIANOFORTE community and associated platforms is therefore essential to optimize the education and training activities in RP, from theoretical courses to support for internships and thesis work, as well as to oversee and coordinate funding to support mobility and facilitate hands-on experience and international collaboration.

Maintaining Expertise

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Continuous professional development is essential to keep pace with scientific and technological advances. This includes for example transdisciplinary training courses, refresher sessions, webinars, and joint events showcasing ongoing research and converting theory to policy and practice. Competence-building activities could be embedded in funded research projects, with clear metrics for evaluation and impact. In line with research topics mentioned above in healthcare, industry and policy organisations, studies should also assess the needs, effectiveness, societal impact of E&T and its role in enhancing public understanding and policy uptake. Also in this phase, the support of PIANOFORTE as mentioned in the previous paragraph is essential.

By investing in a sustainable and strategic E&T infrastructure, Europe can secure its leadership in radiation protection, empower current and future workforce, and ensure that the benefits of ionising radiation are realized safely and responsibly across all sectors.

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Chapter 8: Basic Research

The system of radiological protection as developed by the International Commission on Radiological Protection (ICRP) underpins the IAEA and EURATOM Basic Safety Standards which in turn underpin national legislation in Europe and most parts of the world. The system is based on science, ethical values and practical experience. While it is true that ionizing radiation is relatively well characterized in terms of risks that exposures pose to human health and to the environment, the evidence base is incomplete and continues to evolve. Therefore, basic research into the effects of radiation exposures on human health and the environment will make an essential contribution to better protection, through informing judgements on risk and appropriate protection strategies.

In terms of health risks, the system is constructed to avoid acute tissue injury (such as burns to the skin, damage to the eyes and heart) and minimize the occurrence of stochastic effects (cancers and effects on future generations). There is good evidence of cancer risk in human populations down to around 100 mSv but protection is predicated on a linear non-threshold model of cancer risk for low doses, whereby there is no exposure with no risk and a direct proportionality between exposure dose and risk. This, in turn, has informed one of the fundamental principles of protection – that exposures should be kept As Low As Reasonably Achievable (ALARA). Therefore, a better characterization of radiation cancer risks below the 100mSv level, more in the region of exposure levels encountered in practice in industry today is necessary. Additionally, there are concerns that cancers are not the only risk of low dose exposures, with some evidence suggesting that cardiovascular diseases, cataract and effects on cognition may be present. Work in this area is essential to ensure adequate protection. Another key issue is that of the distribution of risk within the population. Currently the system assumes everyone on a population is at equal risk, with dose limits set on a population average basis rather than individual basis. Further evidence is required to investigate this area more thoroughly, to ensure everyone is adequately protected and consider if it is feasible to develop tests to assess individual risk.

Risks to the environment are controlled by the application of derived consideration reference levels (DCRLs), dose-rates that are considered to have modest and acceptable impacts on population and reproductive health. There are around 2 million described species on Earth, and this is likely an underestimate; it is therefore impossible to assess the risks to all species of non-human biota on the planet. Protection is directed by consideration of impacts on some twelve ‘reference animals and plants. From a biological and evolutionary perspective this is naïve. A deeper knowledge of the impacts of radiation exposures on a wider range of species is required to ensure protection of the environment is adequate and not over-protective. As part of this we need to consider the indirect effects of environmental radiation on human health and economic activity through the effects on other biota. An ecocentric approach to human safety, for example embracing a One Health concept or ecosystem services, encompasses a much wider-reaching and realistic set of impacts on human wellbeing than currently offered.

Both human and environmental protection are underpinned by dosimetry – the measurement of radiation exposures. Clearly it is essential that doses are accurately and reliably measured or assessed to serve as a basis for research to evaluate radiation effects on the environment and humans. Furthermore, efficient and accurate dosimetry underpins the application of radiation protection in practice.

Thus, while radiological protection is fundamentally a practical discipline, it has to be based on sound evidence of risk. It is known that there are knowledge gaps in the evidence base, and some of the key ones are mentioned above. It remains essential that basic research into these areas is maintained and further developed to ensure protective measures are proportionate to risk and applicable in practice.

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Chapter 9: Research as a Driver for Simplification in Radiation Protection

As outlined before, a robust system of radiological protection must be based on sound scientific evidence. Even though the regulatory framework for radiation protection is meant to be simple, the complexity of regulations has increased with time. New applications and new insights have led the ICRP (International Commission on Radiological Protection) to periodically update and extend the framework. While the ALARA approach has driven a reduction in exposures in the nuclear industry over the years, it does have costs associated with its application. In the process from science to protection, sometimes different layers of terminology, procedures, and administrative requirements can reduce the clarity, agility, and effectiveness of radiation protection efforts. PIANOFORTE's collaborative approach, used also in drafting the present Strategic Research and Innovation Agenda, brings together most actors of the European radiation protection community to identify strategic research needs that can play an important role in overcoming remaining barriers to regulatory simplification.

Specifically, there is a growing need to simplify the system while upholding the foundational goal of keeping exposures *as low as reasonably achievable*. Strategic, targeted research can play an important role in enabling this simplification, by reducing uncertainties and providing a more solid basis for risk-informed decision-making. Research into the socio-economic dimension of the ALARA principle appears particularly promising in this regard, notably to support holistic, inclusive and sustainable (i.e. optimised) decision-making procedures [14]. Understanding, considering and weighting involved risks and benefits can be enabled by targeted research. The concepts of tolerability and reasonableness could also be further explored in this context.

Advances in key research areas—such as atmospheric transport and radioecological modelling, emergency response analysis, biological effect characterization, epidemiology and dosimetric methodologies—can refine the scientific basis for protective actions. When risks are better quantified, unnecessary conservatism can be reduced, and regulatory measures can be tailored more precisely to actual needs. This, in turn, allows for reduced administrative burden without compromising safety.

Furthermore, emerging technologies such as artificial intelligence and real-time monitoring systems can transform how radiation protection is implemented. These innovations offer the potential to streamline procedures, automate decision-making support, and adapt protective measures dynamically to changing conditions.

To achieve meaningful simplification, strategic alignment of research with practical regulatory challenges and with a focus on reducing key uncertainties should be sought. These key uncertainties need to be identified and addressed in research projects. Policymakers should be prepared to translate scientific progress into leaner, clearer, and more proportionate regulations where possible.

A strategic agenda for radiation protection must therefore foster research that not only improves safety but also enables a more effective, efficient, and adaptable system—one that is scientifically sound, operationally practical, and resilient for the future. This is clearly a cross cutting topic, that should ideally be addressed in each research topic.

[14] https://www.oecd-nea.org/jcms/pl_103069/third-nea-stakeholder-involvement-workshop-on-optimisation-in-decision-making-summary-report?details=true

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Chapter 10: Innovation and Connection to SMEs and Start-ups

Radiation protection research has repeatedly proven to be a catalyst for innovation, stimulating the emergence of new technologies, services and enterprises across Europe. Advances in dosimetry, detector development, imaging, environmental monitoring and digital data processing have generated practical solutions that extend well beyond traditional scientific boundaries. These research achievements have fostered the creation of small and medium-sized enterprises and start-ups that translate scientific knowledge into market-ready applications. By linking cutting-edge science with industrial needs, radiation protection research not only strengthens safety and health but also contributes to technological competitiveness, skilled employment and sustainable economic growth within the European innovation ecosystem.

Strengthening the link between research and market uptake

To realise the full potential of research results, a stronger and more direct interface between the research community and the innovation ecosystem is required. Several mechanisms can accelerate this translation process:

- Early industrial engagement. Involving SMEs and start-ups already during research planning ensures that project results address real technological and market needs.
- Open innovation and shared infrastructures. Access to research facilities, testing platforms and data repositories enables industrial partners to validate, scale and certify emerging technologies.
- Innovation-friendly regulation. Continuous dialogue between researchers, industry and regulators can shorten the path from laboratory to application, ensuring that safety standards evolve in step with new technologies.
- Technology transfer and intellectual-property support. Structured frameworks for licensing, spin-offs and public–private partnerships can secure European ownership of radiation protection innovations.
- Cross-sectoral collaboration. Technologies developed for one application—such as medical imaging, environmental monitoring or space radiation detection—can often be adapted for others, creating new industrial value chains.

These actions promote a research-to-market continuum where scientific excellence and industrial innovation reinforce one another.

SMEs and start-ups as drivers of innovation

Small and medium-sized enterprises play a decisive role in bringing innovative radiation protection technologies to the market. Their agility allows rapid adaptation of research outputs to niche applications, while start-ups often serve as incubators for disruptive ideas emerging from academic or collaborative projects.

SME participation could be encouraged through dedicated funding instruments within partnership calls, simplified access to infrastructures and calibration services, innovation vouchers and pilot validation schemes, and mentoring and networking opportunities connecting entrepreneurs with research institutions and hospitals.

By integrating SMEs into research consortia, PIANOFORTE and future partnerships can foster sustainable innovation ecosystems that combine scientific expertise with entrepreneurial dynamism. Such cooperation accelerates the development of technologies for radiation monitoring, dosimetry, medical imaging, waste management and environmental protection—areas directly linked to the SRIA's three pillars of Quality of Life, Security and Competitiveness.

Towards an innovation ecosystem for radiation protection

Innovation in radiation protection encompasses not only new technologies but also novel organisational, social and regulatory approaches. Emerging business models—ranging from digital platforms for data-driven risk assessment to citizen-science initiatives and integrated environmental monitoring services—expand the boundaries of the field.

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Creating a coherent European innovation ecosystem in radiation protection will require sustained coordination among research institutions, industry and end-users; interlinking with existing EU programmes and clusters such as the European Health Data Space, the European Radioisotopes Valley Initiative (ERVI) and the European Institute of Innovation and Technology (EIT Health); ensuring open access to infrastructures, FAIR data principles and standardised quality-assurance frameworks; and promoting education and training activities that combine technical, regulatory and entrepreneurial skills. Such an integrated ecosystem will facilitate faster deployment of safe, effective and competitive radiation-related technologies while maintaining the high protection standards that underpin public trust.

Expected outcomes

- A stronger interface between science, society, policy and industry within the European radiation protection landscape.
- Increased participation of SMEs and start-ups in the development, validation and deployment of radiation protection technologies and services.
- Faster translation of research results into clinical, industrial and environmental applications.
- Consolidation of European value chains for detectors, dosimeters, radiopharmaceuticals and monitoring systems.
- Enhanced innovation capacity, competitiveness and resilience of the European radiation protection sector.
- Harnessing of novel applications of AI to accelerate research and drive organisation, coordination and efficiency.

Sustained support for innovation and entrepreneurship in radiation protection will ensure that research outcomes continue to evolve into tangible benefits for society. Encouraging agile collaboration between research organisations, SMEs and start-ups will accelerate the deployment of safer, smarter and more efficient technologies across medical, industrial and environmental domains. By fostering open innovation, facilitating access to infrastructures and aligning regulatory frameworks with technological progress, Europe can maintain its leadership in radiation protection while strengthening its industrial base. As digitalisation and Artificial Intelligence increasingly shape scientific and technological development, the next step is to harness these tools to further enhance innovation, efficiency and safety in radiation protection research and practice.

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Chapter 11: Artificial Intelligence

As in many fields AI based methods are already providing, will provide and may provide major improvements in radiation protection related topics and applications. There are already many approaches especially in the field of medical applications of ionising radiation as optimising imaging procedures to lower patient or staff exposures, enabling prediction of therapy responses to optimise therapy approaches including reduction of exposure to healthy tissues, planning of radiation therapy application and fast dose monitoring or therapy adjustments e.g. in MRI-Linac configurations etc. Also in other fields like dose monitoring of staff using camera based and calculation approaches or in dispersion calculations for radioactive releases or emergency situations AI based approaches can help dramatically to improve radiation protection of staff and the population. Especially in emergency preparedness people would benefit from faster modelling of dispersion by improved and faster prediction of exposure scenarios relevant for protection measures. The ability to conduct real time decision-making using AI tools has already been implemented in the military sphere and would be invaluable in disaster response. This SRIA cannot cover all dimensions of AI given its massive overlap with all steps from protection goals to science to regulation. We want to underline that importance, though, by including it explicitly here, because basically all research will be conducted in a period where instruments that involve aspects of AI are increasingly available and many areas will involve AI in radiation protection research explicitly even further in the future.

Reliable and efficient AI based approaches are needed to implement AI in radiation protection research and radiation-related applications, since it could have a high impact on patient and worker safety, accurate diagnosis, effectivity of medical treatments and radiation exposure of the European population. To achieve that there is a number of prerequisites which will have to be elaborated for the different application fields in radiation protection. We need to ensure:

- Sufficient amount of independent data
- Data deposition, accessibility, mobility and protection
- Access to independently-derived datasets for training, validation and testing of models
- Quality assurance of such data in the sense that the way data are generated are well described; data curation.
- Data formats, semantic and metadata standards for aggregation and interoperability, and use by AI algorithms.
- Development of suitable models and appropriate domain-dependent guardrails.
- Characterisation of out of distribution effects
- Developments of suitable methods for quality assessment and assurance.
- Consideration of ethical guidelines in data handling and processing.
- Explicability and Interpretability – required for implementation particularly in the engineering and medical fields to enable clinicians and regulators to verify the causal or technical rationale behind an AI-generated outcome.
- Uncertainty Quantification (UQ) – essential for risk-informed decision-making; AI outputs must be accompanied by reliable estimates of their confidence and potential error margins.
- Regulatory Alignment – compliance with the European AI Act and relevant data governance frameworks, especially for "high-risk" applications in medical imaging, radiotherapy, and security-critical monitoring.
- Model Robustness and Cybersecurity – ensuring the integrity of AI systems against adversarial threats or data manipulation, particularly for systems integrated into critical safety infrastructure.

As AI systems are increasingly integrated into decision-support frameworks, defining the governance of the human-AI interface becomes a priority. Research must establish the respective roles of algorithmic outputs and professional judgment, particularly in high-stakes ethical and medical contexts. This includes developing tools that provide not just answers, but 'human-interpretable' justifications that support, rather than replace, the expertise of radiation protection professionals.

Based on these requirements and related issues, well-founded research approaches should be developed within radiation protection research areas. If these requirements are met, the potential benefit for the European population as a whole, patients and staff can be tremendous and radiation protection can be made more comprehensive, less expensive and more efficient. This might impact healthy living in Europe enhance security in the context of threads of nuclear emergencies and armed conflicts and encourage European industry to provide safer equipment e.g. in health settings, with the aim of maintaining or even strengthening economic performance.

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Conclusions

Radiation protection is a dynamic and multifaceted field with considerable implications for European policy priorities, including quality of life, security, and competitiveness. By fostering continuous and coordinated action at the European level, radiation protection research can serve as a catalyst for innovation, safety, and sustainable development across Europe. This document identifies key priority research topics, aligning them with European Commission's strategic objectives and the needs of the radiation protection community. These priorities will inform the 4th open call for research projects under PIANOFORTE and provide guidance for future joint activities within the Euratom framework.

In addition to addressing three core policy areas, this document emphasizes the importance of cross-cutting objectives, such as stakeholder involvement, infrastructure development, education and training, basic research, and the integration of cutting-edge technologies like AI. Achieving these cross-cutting objectives will amplify the impact of radiation protection research, ensuring that advancements are both inclusive, meaningful and applicable.

As PIANOFORTE prepares to apply for a funded extension of the partnership, it is essential to build on the successes of the first three open calls and further strengthen collaboration within the European radiation protection community. The SRIA will need to be regularly reviewed and updated to reflect the latest scientific advancements and evolving priorities. This iterative process will ensure that the research agenda remains relevant, flexible, and aligned with the community's needs.

Ultimately, the topics proposed in this document must be carefully tailored to and aligned with the priorities of the European radiation protection research community. By focusing on areas perceived as delivering the highest societal benefits, PIANOFORTE can drive meaningful progress, reinforcing Europe's leadership in radiation protection and contributing to a safer, more competitive, and sustainable future.

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Annex: I Overview Table

Annex: Cross-cutting topic mapping – AI, simplification, basic research and lead platforms

The following table maps all thirteen SRIA research topics both to three cross-cutting dimensions (AI relevance, contribution to simplification, basic research requirement) and to the lead European radiation protection research platform(s) whose existing strategic agenda most directly covers each topic. AI relevance is marked as 'Direct' where AI methodology is central to the topic and 'Indirect' where AI is an important enabling tool. Simplification and basic research relevance are assessed as High, Medium or Low.

ID	Topic	AI relevance	Simplification contribution	Basic research relevance
Q1	Biokinetic and internal dosimetry for theranostic approaches	Indirect – treatment planning optimisation, PK modelling	High – accurate dosimetry enables proportionate BSS compliance margins	High – biokinetics, cellular uptake, radiobiology, radionuclide physics
Q2	Biological mechanisms and risk assessment of low- and intermediate-dose ionising radiation	Indirect – omics data analysis, ML dose-response modelling	High – resolving LNT uncertainty enables risk-proportionate simplification	High – molecular radiobiology, epidemiology, AOP framework
Q3	Oncologic and interventional imaging: training gaps, quality standards, AI integration in CT and PET-CT	Direct – AI for protocol optimisation, image interpretation, dose reduction	Medium – harmonised AI tools enable streamlined QA and justification procedures	Low – primarily translational and applied
Q4	Personalised radiation risk assessment: individual variability and susceptibility	Indirect – ML for biomarker identification, genomic data integration	Medium – individual risk stratification supports move beyond uniform population limits	High – genomics, radiobiology, individual susceptibility research
Q5	Modelling complex dose distributions: temporal and spatial dynamics	Indirect – computational modelling, ML for dose reconstruction	Medium – better models reduce conservatism in protection constraints	High – dosimetry physics, radiobiological modelling, biokinetic modelling and digital twins
Q6	Integrated risk assessment of combined radiation exposure scenarios	Indirect – multi-stressor data fusion, predictive risk modelling	Low – inherently complex framework; simplification effect indirect	High – mixture toxicology, radioecology, co-exposure epidemiology
Q7	Effects on ecosystems exposed to ionising radiation	Indirect – species modelling, environmental monitoring networks	Medium – stronger species data enables streamlined DCRL framework	High – ecotoxicology, species-specific radiobiology, One Health
S1	Radiological threats to EPRR amid geopolitical instability and hybrid warfare	Indirect – threat detection, monitoring network integration	Low – new security context adds complexity rather than reducing it	Low – primarily applied and operational; SSH dimension relevant
S2	Integrated optimisation of decision-making for EPRR and long-term recovery	Indirect – decision support systems, uncertainty visualisation	High – clearer decision frameworks enable consistent, proportionate protective actions	Medium – social sciences, operational research, uncertainty quantification
S3	AI application in nuclear and radiological EPRR	Direct – AI-driven dispersion modelling, real-time data integration, near-field modelling, crisis communication	Medium – automated decision support streamlines crisis management procedures	Low – applied AI development; data infrastructure
C1	Radiation protection methodology for novel nuclear facilities and	Indirect – dose modelling for new	High – new methodology enables harmonised, proportionate	Medium – source term characterisation, new nuclide inventories

	emerging energy-related applications	reactor geometries, safety assessments	regulation for novel designs (SMR, fusion)	
C2	Improved occupational dosimetry in view of BSS regulation and practical application	Indirect – AI-enhanced monitoring devices, camera-based dose tracking	High – directly enables BSS simplification; clearer worker classification criteria	Medium – detector physics, biokinetics for internal exposure, uncertainty methods
C3	Sustainable management and risk assessment of radioactive waste and effluents towards circular economy solutions	Indirect – monitoring data integration, predictive long-term safety case modelling	Medium – harmonised risk frameworks clarify regulatory pathways for NORM and waste	Medium – radionuclide migration, long-term environmental behaviour, speciation

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Annex II: Detailed description of research topics

Quality of Life

Q1	**Biokinetic and internal dosimetry studies for theranostic approaches**
Challenge description	New therapeutic and theranostic approaches are going to play an important role for patient-specific treatment, especially in cancer patients but potentially also for other diseases. The biokinetic of emerging radiopharmaceuticals is not yet fully known and different from that of currently used radiopharmaceuticals. Currently treatments are not optimised due to a lack of understanding the fundamental mechanisms of tumor control, lack of clinically based dose-effect relationship and lack of appropriate dosimetry. Thus, investigations on the biokinetics and the corresponding dosimetric aspects are required to ensure a safe and optimized use of such radionuclides for the benefit of the patients. Furthermore, radiobiological models from external beam radiotherapy cannot be directly applied for radiopharmaceuticals due to the different spatial and temporal behaviour. Micro- or nano-dosimetry might thus help in better understanding the radiobiological effects. The new types of radionuclides used in nuclear medicine also pose new challenges for the radiation protection of workers in the hospitals, caregivers and even the public, as radiation emitted by patients as well as by waste will be different from the scenarios for radionuclides used today.
Objectives	- Improving knowledge about biokinetics and dosimetry for (new) radionuclides and radiopharmaceuticals in therapeutic and theranostic medicine - To develop population-based biokinetic models to supplement missing individual data and assess the influence on dose assessment - To provide guidance on implementation of individualized dosimetry for targeted radionuclide therapy - To advance small-scale dosimetry for short range emitters by combining advanced imaging, Monte Carlo simulations, and biokinetic modelling. - To carry out dose estimation and bioeffect modelling through micro- nano-dosimetry. - To improve assessment of exposure from nuclear medicine patients and to contribute to the harmonization on patient release criteria in Europe. - Fostering implementation of practical radiation protection measures for staff and public from emerging radiophamaceuticals
Expected outcome	- Better individualised and personalised medical care - Better radiation protection for patients, staff and the population
Addressed stakeholders	Patients, nuclear physician, medical physicists, pharmacologists, medical staff, general public, policy makers especially those involved in radiation protection.

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Q2	**Biological Mechanisms and Risk Assessment of Low- and Intermediate-Dose Ionising Radiation**
Challenge description	The past two decades have seen rapid progress in medical imaging and radiotherapy. These innovations deliver higher precision and improved outcomes but introduce new challenges for radiobiology and patient protection. Healthy tissues often receive doses leading to complex biological responses that current models cannot adequately capture. Traditional risk assessment is largely based on the linear no-threshold (LNT) model, assuming direct DNA damage as the primary driver of health effects. However, evidence shows that low-dose and intermediate-dose exposures may also trigger non-targeted and systemic responses , including bystander signalling, genomic instability, inflammation and changes in immune regulation. These responses may contribute to both cancer and non-cancer outcomes, such as cardiovascular, cerebrovascular, neurocognitive, metabolic, and immune disorders. A key research need is to distinguish short-term responses from persistent changes that are linked to health detriment. Better mechanistic understanding and epidemiological investigations are needed to refine risk estimates and support evidence-based radiation protection frameworks for Europe. Priority should be given to mechanisms that are relevant for radioprotection (e.g. realistic doses) and translatable to protection of people and and amelioration of risks (e.g., modifiable biological responses, including immune responses, inflammation, metabolic reprograming) ,. At the same time, the expansion of medical applications of ionising radiation and its innovation raises social sustainability questions: ensuring equitable access, patient rights, transparency, trust in healthcare systems, and the well-being of healthcare professionals. Safe and effective innovation must also be socially responsible, ethically sound, and aligned with public health goals. Ethical considerations on patient groups that may benefit or not benefit from innovations and corresponding treament decisions have to be addressed.
Objectives	• Investigate biological mechanisms of radiation-induced cancer and non-cancer effects at low and intermediate doses, including targeted and non-targeted systemic effects • Characterise tissue-specific radiosensitivity, near-field and out-of-field effects, systemic responses, and their contribution to cancer initiation and progression. • Apply advanced methodologies (e.g. omics, cell tracking/imaging, mechanistic radiobiology, molecular epidemiology, AI-based modelling) to map pathways from exposure to disease. • Develop Adverse Outcome Pathways (AOPs) linking molecular and cellular events to clinically relevant endpoints. • Identify and validate biomarkers relevant for radiation protection, including biomarkers of disease susceptibility, early tissue injury, persistent inflammation, immune dysregulation and long-term health detriment.

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	• Quantify the modifying role of dose, dose-rate and tissue type on health outcomes. • Integrate mechanistic, experimental, and epidemiological data to refine risk estimation models for cancer and non-cancer outcomes, particularly at low doses. • Assess implications for radiation protection and risk communication across healthcare. • Improve patient–clinician communication and shared decision-making by providing tools based on individualised risk–benefit profiles. • Investigate the relationship between radiation protection practices and social sustainability, with focus on equity, ethics, healthcare professionals' well-being, and community trust. • Develop approaches and policies that ensure innovations in all fields of medical applications of ionising radiation are implemented in a safe, equitable, and socially responsible way.
Expected outcome	• Improved mechanistic understanding of radiation-induced health effects at low and intermediate doses. • Evidence-based refinement of radiation risk models that incorporate both targeted and non-targeted effects. • More accurate and protective regulatory thresholds for low- and intermediate-dose exposures. • New biomarkers and mechanistic insights supporting radiation risk assessment, individual susceptibility assessment and protection and therapy optimization decisions.. • Better communication of benefits and risks to patients, professionals, and the public, supporting trust in radiation-based technologies. • Reinforced European leadership in radiobiology, epidemiology and medical technology innovation, with benefits for healthcare, society, and industry. • Stronger integration of social sustainability into medical radiation practices, leading to more equitable, ethical, and trusted healthcare. • Empowered patients and healthcare professionals through improved communication, transparency, and risk–benefit decision-making.
Addressed stakeholders	Radiobiologists; medical practitioners (oncologists, imaging professionals, nuclear medicine specialists); epidemiologists; environmental and occupational health researchers; radiation safety regulators; space agencies; industry and technology developers; patients and the general public; and policymakers, radiation physicists.

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Q3	**Enhancing Oncologic and Interventional Imaging: Addressing Training Gaps, Quality Standards, and AI Integration in CT and PET/CT Practice**
Challenge description	CT and PET–CT are medical imaging modalities widely used for cancer detection, staging, treatment planning, and follow-up. However, both modalities face persistent challenges related to radiation exposure to patients, image quality variability, and inconsistencies in procedure protocols across institutions. These issues can compromise diagnostic and therapeutic accuracy, patient safety, and the reproducibility of clinical studies. As CT technology evolves, incorporating advanced reconstruction algorithms, dose-reduction techniques, and AI-based tools, the demands on healthcare professionals to maintain high standards of image quality, safety, and consistency have increased significantly. Despite advances in CT and PET–CT technology, there is a critical need to optimise imaging protocols to balance diagnostic performance with radiation safety. Furthermore, image interpretation is time-consuming, and prone to human error. The integration of Artificial Intelligence (AI) offers a transformative opportunity to address these challenges by enabling personalised imaging based on clinical indications, real-time image interpretation, standardisation across clinical settings and adequate image quality to respond to clinical questions. Research is required to analyse the current practices and to build up and optimise training and education programs throughout Europe.
Objectives	• Develop AI-based tools to optimise CT and PET–CT imaging protocols for oncology patients • Implement automated image interpretation systems for CT and PET–CT • Enhance diagnostic accuracy and reduce radiation exposure through personalised protocols • Ensure reproducibility and standardisation of CT and PET–CT imaging across clinical sites • To design, implement, and evaluate a comprehensive, evidence-based training framework that enhances the quality, safety, and consistency of CT and PET–CT in oncological and interventional procedures across Europe • To develop and integrate AI and digital literacy into clinical training
Expected outcome	• Development of AI tools that personalise CT and PET–CT acquisition parameters based on patient characteristics and clinical indications • Demonstrated reduction in radiation dose without compromising diagnostic quality • Integration of AI tools into existing CT and PET–CT scanners software and PACS systems, contributing to improve patient workflow • Structured and harmonised training programs across Europe
Addressed stakeholders	Patients, health professionals and industry

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Q4	**Personalized Radiation Risk Assessment: Addressing Individual Variability and Susceptibility**
Challenge description	Current radiation protection standards are primarily population-based and fail to adequately consider individual differences in radiosensitivity. Factors such as genetics, sex, age, comorbidities, immune status, environmental exposures, and lifestyle significantly influence individual responses to radiation. As a result, vulnerable subgroups - including children, the elderly, patients undergoing concurrent treatments, or individuals with genetic predispositions - may be either under- or over-protected by existing frameworks. This poses serious implications for both safety and therapeutic efficacy.
Objectives	• Identify and validate biomarkers of radiosensitivity and/or radiosusceptibility using cellular, molecular, systems biology approaches and epidemiological investigations. • Taking use of in vitro, in vivo and in silico studies as well as epidemiological data develop personalized dose-response models. • Assess risk profiles of vulnerable populations, including those with pre-existing conditions or undergoing co-exposures (e.g., radiation combined with chemotherapy). • Examine sex-based and genetic differences in radiation response to refine population subgroup-specific protection guidelines. • Develop tools for long-term follow-up and outcome tracking in vulnerable populations. • Integrate mechanistic models of radiation-induced tissue damage to better understand age-dependent sensitivity and latency of late effects. • Apply AI to identify markers of increased risk in existing data sets
Expected outcome	• Implementation of precision-based radiation protection strategies that tailor exposure limits and treatment protocols to individual biological profiles. • Enhanced safety for sensitive subpopulations, reducing the risks in occupational, and environmental contexts and avoiding radiation overexposure or under-treatment in clinical exposures (patient stratification). • Evidence-based policy development for occupational and therapeutic settings that accounts for personal health status and demographic variability. • Acceleration of personalized medicine adoption, improving equity and effectiveness in radiation-based diagnostics and therapies.
Addressed stakeholders	Healthcare providers, personalized medicine specialists, radiation protection policymakers, occupational health agencies, patient advocacy organizations, ethicists, and insurance and regulatory bodies.

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Q5	**Understanding and Modelling Complex Radiation Dose Distributions: Temporal and Spatial Dynamics**
Challenge description	Radiation exposures in real-world and therapeutic contexts often deviate from the idealized, homogeneous dose distributions assumed by current protection models. In scenarios such as internal contamination, space travel, radiotherapy, radionuclide therapy, and occupational or environmental exposures, radiation is delivered in chronic, fractionated, or inhomogeneous patterns across time, volume of exposed tissue and space. These variations can produce unique biological responses - distinct from those triggered by acute, uniform exposures - introducing major uncertainties into current risk assessment frameworks.
Objectives	• Characterize cancer and non-cancer risks associated with variable dose patterns, including chronic vs. acute exposures and internal vs. external irradiation using epidemiological or modelling approaches. • Advance microdosimetric and nanodosimetric tools to measure and model radiation energy deposition at the organ, tissue, and cellular levels. Couple micro/nano-dosimetric tools with advanced biological methodologies (such as next generation sequencing) in order to selectively identify and analyse hit versus non-hit cells, as well as for the statistical power to determine the frequency with which such events result in persistent effects, repair or elimination within the organism. • Use organotypic tissue models and advanced imaging to study intra-organ dose heterogeneity and biological effects of spatially localized exposures. • Refine radiation risk assessment models to incorporate real-world dose variability, enabling their application in clinical, occupational, environmental, and extra-terrestrial settings.
Expected outcome	• Improved accuracy of radiation protection guidelines for complex dose scenarios including partial-body, chronic, and internal exposures. • Optimized diagnostic and therapeutic protocols, enhancing both efficacy and safety and reducing adverse effects. • Better emergency preparedness and public health responses for accidents involving internal emitters or prolonged exposures. • Robust risk models applicable across healthcare, industry, and space exploration, supporting safer design, monitoring, and regulatory decision-making.
Addressed stakeholders	Medical practitioners (oncologists, radiologists), clinical researchers, dosimetry experts, regulatory bodies, occupational and environmental health assessors, space agencies, and industrial radiation safety regulators

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Q6	**Integrated Risk Assessment of Combined Radiation Exposure Scenarios**
Challenge description	Modern environmental and public health risk assessments face growing complexity due to the multifactorial nature of real-world exposure scenarios. Populations and ecosystems are frequently exposed to multiple, interacting stressors - including radioactive contaminants (both chronic and acute exposures; internal and external emitters), chemical pollutants (e.g., heavy metals), climate-induced environmental changes, and physical habitat disruptions. These co-exposures often result in non-uniform, heterogeneous dose distributions and biological effects that current models fail to accurately capture. The interplay between radiological and non-radiological stressors can be additive, synergistic, or antagonistic, further complicating risk characterization. Current frameworks remain largely compartmentalised between human and environmental health assessments, and the lack of harmonized methodologies and interoperable tools, hinder the development of coherent cross-sectoral responses. Evidence of variability in biological responses - including resilience or adaptation in certain populations - underscores the need for integrated, dynamic, and systems-level approaches to risk assessment and management.
Objectives	• Design and implement integrative methodologies that combine radiological, chemical and environmental stressor assessments into unified risk frameworks. • Model complex, real-world contamination scenarios, accounting for temporal and spatial dose heterogeneity, internal versus external exposures, and co-occurring stressors. • Advance understanding of low-dose radiation effects on critical biological endpoints, especially under multi-stressor and exposome-related conditions. Priority endpoints should include carcinogenesis, circulatory and cognitive function, and systemic mechanisms such as chronic inflammation and immune dysregulation • Apply AI and machine learning to create predictive tools that reflect the evolving nature of exposure patterns and adaptive biological responses. • Align protection goals and assessment endpoints across sectors to support comprehensive risk governance.
Expected outcome	• Harmonized, multi-stressor risk assessment frameworks that bridge human and environmental health considerations. • Predictive models and decision-support tools capable of accommodating the complexity and dynamics of real-world exposure scenarios. • Improved coherence across sectors and stronger scientific support for cross-sectoral regulatory, clinical, and environmental decision-making. • Enhanced capacity to anticipate and mitigate long-term impacts of combined exposures on vulnerable populations and ecosystems.
Addressed stakeholders	Environmental and health regulators, public health agencies, radiation and chemical risk assessors, ecologists, dosimetry and medical physics experts, policymakers, industrial operators, clinical researchers, safety authorities, and social scientists.

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Q7	**Understanding of effects on ecosystems exposed to ionising radiation**
Challenge description	The ecological consequences of ionising radiation exposure remain insufficiently understood, particularly under chronic or spatially heterogeneous exposure conditions. This lack of mechanistic knowledge limits the integration of ecosystem-level processes in radiation protection frameworks and hinders the development of ecologically realistic risk assessments.
Objectives	• To investigate the mechanistic effects of ionising radiation at different levels of biological organisation in ecosystems. • To identify key ecological functions and species traits that are most at risk under chronic or spatially heterogeneous exposures. • To improve the scientific basis for ecological risk assessment and support integration of environmental protection into One Health strategies. • To critically evaluate the ICRP Reference Animal and Plants
Expected outcome	• Improved ecological realism in radiation protection; • Identification of key ecosystem vulnerabilities; • Enhanced tools for environmental risk assessment; • Stronger alignment between environmental and human health protection.
Addressed stakeholders	Environmental regulators, ecosystem managers, radiation protection authorities, ecotoxicologists, biodiversity conservation agencies.

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Security

S1	**Enhancing resilience to Radiological Threats to Emergency Preparedness Response and Recovery (EPRR) amid Geopolitical Instability and Hybrid Warfare**
Challenge description	Russia's war on Ukraine as well as other political tensions are raising increasing attention on the impact of geopolitical instability and hybrid warfare on the management of radiological threats. These concerns are often linked to national security and resilience and have been increasingly studied from strategic and policy perspectives; however, more research is needed on the implications for radiation protection. The Emergency Preparedness Response and Recovery (EPRR) systems as well as the technological capabilities typically used for emergencies were not necessarily intended for war or armed conflict situations originally. The evolving nature of hybrid warfare, which blends conventional military tactics with cyber-attacks and disinformation campaigns, requires adaptive radiation protection strategies. Broader impacts - particularly concerning misinformation and public perception - still require significant consideration. When geopolitical tensions introduce new stakeholders or disrupt existing protocols, the ways in which potential radiological risks are perceived and managed become critically important. Potential rapid changes in behaviour of people in such conditions could occur, so there is the potential in applying novel techniques to understand the location, density and behaviours of affected populations in real-time to optimise protective actions strategies and communications. How do professionals and broader stakeholder groups perceive the threats posed by radiological materials in the context of geopolitical instability? How can we support resilience of communities in such situations? How do these perceptions influence the acceptance and implementation of radiation safety measures? How does the spread of misinformation and disinformation impact public trust and compliance with radiation protection guidelines?
Objectives	• Analyze the effects of geopolitical instability and hybrid warfare on radiological threat management, focusing on public perception, misinformation, and adaptive radiation protection strategies. • Co-create effective but also acceptable and feasible strategies to deal with geopolitical instability and hybrid warfare with involvement of interdisciplinary experts, major stakeholders and citizens. • Review of EPRR systems for geopolitical challenges with the aim of improved resilience. • Once potential novel techniques have been identified, these could be used to test existing decision-support systems but also to consider dynamic optimisation of strategies during response.
Expected outcome	• Evolution of the EPRR framework to improve resilience for conflict situations • Development of resilient radiation protection frameworks that address the challenges posed by misinformation and geopolitical tensions, enhancing safety measures and public trust.
Addressed stakeholders	Professionals in various research fields related to radiation protection. The general public. Policymakers and authorities.

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S2	**Optimisation of Decision-making for Emergency Response, Transition and Long-term Recovery for Populations and the Environment**
Challenge description	Situations of accidental exposure or historical contamination require decisions that evolve from emergency response to long-term recovery, anticipating impacts of decisions taken during the former on the latter. Authorities must interpret diverse monitoring data, address radiological, environmental and societal challenges and maintain public trust. Existing Handbooks, Decision Support Systems (DSS) and datasets support decision-making but remain insufficient to integrate population protection, their broader well-being, socio-economic and environmental impacts, uncertainties, as well as stakeholder expectations and needs. At the same time, existing tools struggle to process and integrate the growing volume and complexity of environmental monitoring and modelling data, particularly under crisis conditions. A clear gap persists between available data and their translation into operational and socially accepted decisions. Closing this gap is essential for effective and sustainable management of affected areas in both post-accidental and legacy contexts.
Objectives	• To develop integrated and adaptive decision-support approaches, linking human and environmental protection across the emergency, transition and recovery phases. • To improve existing Handbooks and DSS by incorporating recent experience, new threats and environmental dimensions, and by enhancing monitoring, modelling and data-assimilation methods to better address uncertainties. • To co-develop AI-based systems capable of synthesising diverse data streams - monitoring, modelling, expert input - into decision-ready outputs for routine and emergency use. To delineate the respective roles of AI and human expertise in high-stakes radioecological decisions. • To embed principles of transparency, explainability, and stakeholder engagement into these systems, ensuring they are trusted and usable.
Expected outcome	The work will deliver next-generation decision-support systems integrating population and environmental protection from emergency response to long-term recovery. Expected results include operational frameworks capable of transforming diverse monitoring data into optimised strategies for protective actions, remediation and land-use planning, as well as improved preparedness through advanced analytical tools. It should also improve the governance of AI tools in this context, including ethical and procedural safeguards. The topic is also expected to enhance public trust through transparent and participatory processes and to support sustainable management of contaminated environments in both post-accidental and legacy contexts, including decision-making support for lifting protective actions.
Addressed stakeholders	Decision-makers, emergency managers, first responder and health sectors, environmental authorities, site and remediation managers, local governments, affected communities, technical support organisations and public health and environmental protection agencies.

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S3	**AI application in nuclear and radiological Emergency Preparedness Response and Recovery**
Challenge description	Nuclear emergencies are inherently complex and require prompt coordinated actions from different organisations, considering large amounts of data, diverse information, contradictory constraints, while also considering public perceptions and reactions. AI has the potential to enhance nuclear crisis and routine response by accelerating predictive capabilities, improving situation awareness, including thorough dosimetry, and decision-making and efficiently managing complex, high-consequence events. There are areas such as modelling (direct and inverse), monitoring strategies such as UAVs or citizen science and data assimilation or AI that can all be combined to improve awareness. However, it's also important to explore what novel challenges related to the perception and management of potential risks AI introduces, how it would intervene in decision-making and be employed in communication and engagement, and what uncertainties are related to this.
Objectives	To develop, apply and test AI-based tools related to EPRR, and to ensure the widest range of available situational information is applied to improve decision making. • Fast, and potentially more accurate, forecasting of radioactive plume dispersion (especially under complex conditions, e.g., in cities) and inverse localisation and quantification of unknown emissions of radionuclides, including also uncertainties, which is crucial for evacuation planning and public safety warnings • Enhanced situational awareness, synthesising large amounts of potentially heterogeneous data from official radiation monitoring networks, mobile monitoring (ground and aerial), citizens' measurements, textual information, etc. to provide a comprehensive, real-time view of the situation • Improved decision making through optimisation of protective action strategies taking into account complex information and constraints; providing response teams with data-driven insights to make faster, more informed decisions under pressure; optimising resource allocations, like emergency personnel and equipment, based on real-time needs and potential impact zones • Contribute to combating misinformation and disinformation through providing guidance and access to reliable information from trustworthy sources and experts • To further develop emergency dosimetry capabilities, by improving the use of anthropomorphic, personalised and computational phantoms, and to further develop existing fast or real time dosimetry methodologies for large number of individuals • To develop methods to ensure trustworthy AI and Quality Assurance of AI in all fields of radiation protection • To explore the multifaceted roles of artificial intelligence in emergency preparedness, examining its applications, challenges, stakeholder perceptions, and broader impacts.
Expected Outcome	Faster and enhanced nuclear and radiological emergency response capabilities
Addressed stakeholders	Operators, regulators, decision-makers, first responder and health sectors, public, workers

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Competitiveness C1	**Radiation Protection Methodology for Novel Nuclear Facilities and Emerging Energy-Related Applications**
Challenge description	The development and deployment of new nuclear technologies, such as Small Modular Reactors (SMRs) and fusion experimental facilities, are gaining momentum. As SMRs and other technologies advance, they create differences in design, operational environments, and potential radiological release scenarios, and it is crucial to examine what challenges they pose for radiological protection. What are their implications for normal operations and occupational exposures? How should they be considered in the emergency preparedness, response and recovery frameworks? What would be their long-term environmental impacts? What are realistic source-terms and what are design-related challenges in this context? What are siting-related challenges from a radiological protection perspective in view of the envisaged use cases? What kind of RP knowledge and staff is needed for the deployment and operation of SMRs? How to factor the lack of operational experience? Which monitoring and dosimetric devices should be used in case of emergency and in the recovery phase? By understanding how the development of new nuclear technologies could impact on radiation safety measures, environment, community perceptions, and stakeholder trust, policies can be crafted to promote long-term radiation protection strategies.
Objectives	• Ensure that emergency response planning and systems are ready to meet the needs of wider deployment of new nuclear energy technologies, such as SMRs. • Ensure that current monitoring and dosimetric strategies and devices are appropriate in case of emergency. • Harmonize procedures for passive area dosimetry by elaborating recommendations on a common ground of requirements. • In the emergency and recovery phase ensure that uncertainties on exposure are controlled and properly communicated to the public. • Assess the potential environmental pathways, transfer mechanisms, and long-term environmental impacts associated with routine and accidental releases from new nuclear technologies, to support the development of sound protection strategies. • Develop approaches to compensate for the limited operating experience of many SMR technologies.
Expected outcome	• Establishment of comprehensive frameworks that enable the safe, equitable, and ethical deployment of nuclear technologies. • Improved understanding of new nuclear technologies and practical implementation of radiation protection measures within emergency preparedness and response frameworks. • Enabling the identification of potential long-term environmental impacts from routine operations or accidental releases and fostering the development of resilient radiation protection strategies. • Improved information for citizens and decision makers. • Platforms for exposure visualization. • Validated methods of dose and uncertainty estimation to support routine dose assessment, radiation emergency response, and long-term studies of health risk. • Implementation of new technologies, including AI. • Enhanced capabilities for monitoring, modelling, and communicating risks to both human populations and the environment, reinforcing public trust

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	and informed stakeholder engagement in the deployment of new nuclear technologies. • A clearer framework for minimum radiological-protection staffing requirements and competencies for different SMR models. • Improved methodologies and datasets for SMR-specific source-term characterisation and uncertainty quantification.
Addressed stakeholders	Operators, regulators, decision-makers, experts, public, new stakeholders whose core business is not radiation protection

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C2	**Towards improved occupational dosimetry in view of BSS regulation and practical application**
Challenge description	Radiation application in all fields requires a reliable assessment of the possible exposure under various conditions. For this, additional tools are needed, including sophisticated computational models and AI application. This includes also computational phantoms, which have reached such a level of complexity that details such as skin or cell layers can be included in the phantoms. These phantoms can also be varied in shape and posture to better represent specific individuals. Coupled with Monte Carlo codes such phantoms can be used to assess exposure more precisely than reference phantoms. This is relevant for the operator working in complex irradiation scenarios characterized by partial shielding, sources varying their position/intensity/energy during the practice, or in case of contamination during the preparation and handling of unsealed sources. Applications go from emergency situations, over medical nuclear worker occupational exposures, to dose reconstruction in epidemiology.
Objectives	• To develop measurement devices with spectrometric capability including unfolding techniques. • To explore and exploit potential developments in online dosimetry including development of new AI driven calculation methods. • To develop and test different and updated approaches based on measurements, simulations, with the aim of providing more reliable and fast dose estimation for a better dose management and planning • To investigate the practical implementation of the new ICRU 95 quantities, e.g. modification of instrumentation, guidelines and procedures in medical fields with low photon energies • To improve neutron personal dosimetry, measurement uncertainty and dosemeters • To foster further development of more personalized phantoms, also by AI-application in phantom generation from images for application in internal and external dosimetry. • To explore AI techniques applied to biological dosimetry, e.g. to improve detection of chromosomal aberrations. • To develop methods to ensure trustworthy AI and Quality Assurance of AI in all fields of radiation protection
Expected outcome	Fast, robust and validated measurement devices, computational tools, trustworthy AI driven algorithms. Recommendation of best practice, particularly for implementation of ICRU recommendations. Realistic, personalized and trustworthy models of exposure situations
Addressed stakeholders	General public, patients, exposed workers, legislator & regulators, radiation protection experts, dosimetry service

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C3	**Sustainable management and integrated risk assessment of radioactive waste and effluents: towards circular economy solutions and holistic radiological protection**
Challenge description	The use of both established and emerging technologies involving ionising radiation in medical and industrial sectors leads to the generation of various types and forms of waste, including also various effluents. It is often unclear how these wastes need to be handled – at sites of waste production, storage and disposal. Key challenges also relate to the commercial production and distribution of newly developed tracer radionuclides, which are closely tied to economic development and medical progress and its equal usability throughout Europe. Additionally, sustainable management practices such as the reuse and recycling of construction material from dismantled industrial sites and industrial residues (e.g., naturally occurring radioactive material (NORM)) and the minimization of waste are vital components of a circular economy. Furthermore, the generated waste often contains not only artificial and naturally occurring radionuclides, but also non-radioactive hazardous substances. Research is needed on: **Risk assessment and management tools:** The assessment of radioactive waste and effluents with multiple contaminants requires harmonised frameworks and interoperable tools to characterise and manage risks in a coherent and efficient manner. This is especially true also for evaluating risks of newly developed radiotracers in medicine (e.g. to define optimal hospitalization times for patients). **Waste handling and monitoring:** Knowledge should be improved on the handling of specific wastes and related exposure situations, including characterisation, treatment and monitoring. This includes defining safe storage conditions (e.g., duration and environmental requirements for storing waste in hospitals and industrial settings), developing appropriate monitoring systems, and addressing the management of radioactive excreta from patients following diagnostic or therapeutic procedures. Special attention is needed for effluents - particularly from hospital settings - that may be discharged into sewage systems. **Radioactive waste and circular economy:** There is a need to define and optimise conditions for safe waste disposal, including requirements for waste conditioning, safety assessments, radiological and environmental protection measures, and long-term monitoring. Equally important are the conditions under which materials can be reused or recycled, depending on factors such as material availability, radionuclide activity concentrations, intended use, and available infrastructure. In particular, societal considerations of circular economy approaches in radioactive waste management should be further explored. Research is needed into how circular economy practices affect and involve new stakeholders, how risks are perceived and managed, and whether/how adoption of these practices can be supported.
Objectives	• Design and implement integrative methodologies that combine radiological and chemical stressor assessments into unified risk frameworks for radioactive waste and effluents • Advanced dynamic and process-based modelling tools capable of reflecting real exposure conditions and their temporal evolution • Alignment of protection goals and endpoints across human and environmental health domains • Improved knowledge for sustainable waste management, with a focus on currently not regularly used radionuclides in medicine and industrial residues foreseen for future reuse and recycling • Foster European industry in the field of nuclear medicine, especially focusing on radionuclide and radiotracers development and commercialisation • Support and improve work on waste minimisation and circular economy practices and principles

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	• Identify and understand stakeholders‘ perceptions and behaviors regarding circular economy practices in the field of waste management, with a particular focus on radiation protection
Expected outcome	• Improved alignment of circular economy practices with radiation protection principles • Better and harmonized radiation protection throughout Europe • Successful industrial and commercial development of radionuclides for medical care, and generally reduced costs for healthcare systems • Better management of radioactive effluents, including liquid discharges from healthcare and industrial facilities, through improved technologies, regulatory frameworks and public dialogue. • Harmonised risk assessment frameworks; improved coherence between sectors; predictive tools adapted to complex contamination scenarios; stronger scientific support for cross-sectoral policy and decision-making.
Addressed stakeholders	Radiation protection, public health and environmental authorities and policy makers, industrial and waste operators, general public and patients, researchers, policymakers, industrial operators involved in risk governance.

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