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The Future of Radiological Protection

CRPPH Expert Group on International Recommendations

George Vardulakis, NEA Scientific Secretariat (george.vardulakis@oecd-nea.org)
Lucas Martiri, NEA Scientific Secretariat (lucas.martiri@oecd-nea.org)

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Executive summary

This Nuclear Energy Agency (NEA) working paper explores how forthcoming shifts in society, climate and nuclear science and technology may affect the System of Radiological Protection (SRP) and its primary aim. It reviews sustainability (including SRP alignment with the United Nations Sustainable Development Goals [SDGs]); emerging technologies (artificial intelligence in radiological protection and medicine; small and advanced modular reactors [SMRs/AMRs]; and fusion); new applications (space and maritime nuclear uses; expanding radioligand therapy [RLT]); and emerging hazards (armed conflict), alongside cross-cutting issues such as optimisation, stakeholder engagement and regulatory coherence. The paper concludes that the SRP's primary aim remains fit for purpose. It identifies areas for refinement: explicitly embedding sustainability within the articulation of the SRP; ensuring flexible, values-aware optimisation that integrates social, economic, and environmental factors; preparing guidance for new reactor types and complex waste streams; advancing fusion-specific dosimetry and regulatory frameworks; addressing governance gaps for space and maritime nuclear activities; harmonising practices for rapidly scaling medical RLT; and designing regulatory flexibility for wartime and multi-hazard scenarios. It encourages the International Commission on Radiological Protection (ICRP) and partners to use these insights as inputs to the next SRP review cycle and related international standards work.

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The EGIR acknowledges the following main contributors (drafting): Christina Dodkin (Canada), Caroline Schieber (France), Haruyuki Ogino (Japan), Graham Smith (United Kingdom), Stefan Mundigl (European Commission), Peter Bryant (WNTI), Anikitos Garofalakis (NEA), George Vardulakis (NEA Secretariat), and Lucas Martiri (NEA Secretariat), and the following members who provided review comments: Debora Quayle (Canada), Borja Bravo (EPRI), Mika Markkanen (Finland), Augusto Giussani (Germany), Carol Robinson (Norway), Isabel Villanueva Delgado (Spain), Odd Runevall (Sweden), Kevin Dressman (United States), Jacqueline Garnier-Laplace (former NEA Secretariat), Nina Cromnier (NEA) and Tamara Yankovich (NEA).

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List of abbreviations and acronyms

AI	Artificial intelligence
ALARA	As low as reasonably achievable
AMR	Advanced modular reactor
CPPNM	Convention on the Physical Protection of Nuclear Material and its Amendments
CRPPH	Committee on Radiological Protection and Public Health (NEA)
DDREF	Dose and Dose-Rate Effectiveness Factor
DSA	Norwegian Radiation and Nuclear Safety Authority
EC	European Commission
EGEPSMR	Expert Group on Emergency Preparedness for Small Modular Reactors (NEA)
EGIR	Expert Group on International Recommendations (NEA)
EPR	Emergency preparedness and response
EPZ	Emergency Planning Zone
FAO	Food and Agriculture Organization of the United Nations
FNPP	Floating nuclear power plant
GEP-NETs	Gastroenteropancreatic neuroendocrine tumours
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILO	International Labor Organization
ITER	International Thermonuclear Experimental Reactor
mCRPC	Metastatic castration-resistant prostate cancer
NEA	Nuclear Energy Agency
NHSI	Nuclear Harmonization and Standardization Initiative (IAEA)
NPS	Nuclear power station
PSR	Permanently Shadowed Regions
PWR	Pressurised water reactor
RLT	Radioligand therapy
RP	Radiological protection
RTG	Radioisotope thermoelectric generator
SDGs	Sustainable Development Goals (United Nations)
SMR	Small modular reactor
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SRP	System of Radiological Protection
TNPP	Transportable nuclear power plants
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization
WNA	World Nuclear Association
WNTI	World Nuclear Transport Institute
WPNEM	Working Party on Nuclear Emergency Matters (NEA)

1. Scope of study on the future of radiological protection

The focus of this study is to identify and consider how future changes in the use of nuclear science and technology could affect the System of Radiological Protection (SRP). This includes evaluating the suitability of the current primary aim (as set out below) to ensure it remains fit for purpose. The study should take into account the changes that have occurred since the primary aim was last published in 2007, but more importantly, should focus on the need to look forward in order to accommodate changes in society, climate and industry, including new technologies, and explore how the system is aligned to the United Nations Sustainable Development Goals (UN SDGs). To ensure transparency for an evolving topic, this study applies a cut-off date of 30 September 2025 for literature, events and developments considered; items after this date fall outside the scope unless explicitly noted.

Extract from ICRP *Publication 103*, paragraph 26: The primary aim of the System of Radiological Protection is: "to contribute to an appropriate level of protection for people and the environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure" (ICRP, 2007).

For People – Exposures are managed and controlled to:

- Prevent the occurrence of deterministic effects
- Reduce the risk of cancer and heritable effects to the extent reasonably achievable

For the Environment – The aim is to prevent and reduce the frequency of deleterious radiation effects to a level where they would have a negligible impact on:

- the maintenance of biological diversity
- the conservation of species
- the health and status of natural habitats, communities and ecosystems

To meet this goal, EGIR will lead on developing a vision to support and influence the review and revision of the SRP, including the primary aim. This will focus on providing an overview of the future challenges and opportunities facing nuclear science and technology. Specifically, it will cover: (i) sustainability, (ii) new technologies – e.g. use of artificial intelligence (AI) in medical applications, small modular reactors (SMRs) and fusion reactors, (iii) new applications – e.g. space-nuclear applications and radiological protection, maritime applications of nuclear power, medical applications, (iv) emerging threats and hazards – e.g. armed conflict situations, and (v) other challenges and opportunities identified by the subgroup.

2. Overview of future challenges and opportunities

2.1. Sustainability

Sustainability increasingly shapes how the System of Radiological Protection (SRP) is applied in practice. In line with the SRP's primary aim, sustainability is best understood through optimisation and justification that integrate social, economic and environmental factors across the full life cycle of activities, including design, operation, decommissioning and waste management. Recent international discussions emphasise that safety and radiological protection should be considered within a holistic all-hazards approach to decision making.

Sustainability was the subject of an NEA report published in 2007 (NEA, 2007). In summary, ICRP's development of recommendations shifted towards broad dialogue and stakeholder involvement from IRPA-10 onward, with drafts discussed widely and revised to reflect input. CRPPH and ICRP may wish to consider how this approach has improved radiation health protection since 2007 (for example, Fukushima Daiichi clean up and legacy sites), and whether current international roles (NEA, International Atomic Energy Agency [IAEA], United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], World Health Organization [WHO], Food and Agriculture Organization [FAO], International Labor Organization [ILO], European Commission [EC], International Radiation Protection Association [IRPA]) are sufficiently distinguished and co-ordinated to support efficient optimisation.

A holistic approach to risk management remains difficult. Additional international harmonisation of norms for radiological risks may be needed, though achieving such integration is challenging. These difficulties are evident in the NEA sustainability report (NEA, 2007) and in the NEA report of the Expert Group on Legacy Management (NEA, 2020).

CRPPH and ICRP might consider whether these difficulties mean we should stop trying, or that it is even more important to address them, at least to avoid grossly disproportionate management of risks from different threats.

In November 2023, the IAEA hosted an International Conference on the Safety of Radioactive Waste Management, Decommissioning, Environmental Protection and Remediation: Ensuring Safety and Enabling Sustainability (IAEA, n.d.). The call for papers underscored that safety alone may be insufficient, and that optimisation should integrate economic, societal and environmental factors in a **holistic decision-making process.**

This echoes the messages above and extends optimisation of radiological protection to include safety as well. A significant number of relevant presentations were made, but they either pointed out challenges that have already been identified many times, or spoke to progress within a specific area but without addressing the broader integration issues.

The alignment of SRP and SDGs is, at least to a significant degree, achieved through the application of optimisation as envisaged since 1977 (ICRP, 1977). In some ways, ICRP was leading the way in international thinking in this area. However, two points need emphasis:

1. the "economic and social factors" part of ALARA needs in-depth consideration rather than being treated an add-on; and

2. optimisation in radiological protection needs to be seen as part of a wider overall optimisation process and recognised as such in regulatory activity.

Recently, ICRP published a paper elaborating the SRP and the UN SDGs (Rühm et al., 2024). The main goal of this paper is to describe how the current SRP relates to the SDGs, to examine whether SDGs can be considered as drivers for the next general recommendations of the ICRP, and to consider how the SDGs may be integrated. ICRP concludes that sustainability is already an implicit part of the current SRP. However, whether this could be more clearly articulated, for example through including sustainability as a core element of the SRP, remains to be addressed. The challenges for the system associated with the implementation of the 2030 Agenda for Sustainable Development need to be identified and discussed with the international community interested in radiological protection, to properly address the issue of sustainability in the system.

On 3 October 2024, the ICRP and World Nuclear Association (WNA) held a webinar on "Enabling Sustainable Development through the System of Protection". During the webinar both ICRP and WNA provided their views on a number of topics.

These included:

- The future of the RP profession and tripling the RP workforce capacity.
- How to make better decisions at very low dose exposures.
- Views regarding upcoming changes in the Dose and Dose-Rate Effectiveness Factor (DDREF) at low dose.
- Individual sensitivity and the nuclear industry.
- The role of the ICRP and the System of Radiological Protection in the UN SDGs, including outcomes of the recent SRP Sustainability Session.

About 250 participants attended the webinar. Its outputs informed the in-person WNA/ICRP workshop, held in Canada in September 2025, which explored these topics in greater depth (ICRP, n.d.a).

On 15 May 2024, the Society for Radiological Protection in collaboration with the WNA ran a workshop at their 2024 Annual Conference titled "Role of ICRP and the System of Protection as part of the UN SDGs". The workshop presented the current work of the ICRP on mapping the intersection of the SRP and UN SDGs, and invited five panellists (in addition to the moderator) across different sectors of the profession (both inside and outside the ICRP) to share their thoughts, followed by a general questions/comments and answer session. The outputs of this workshop are captured in a paper intended to support further reflection and deliberation (Bryant et al., 2024).

Optimisation remains a cornerstone of radiological protection and should be applied to nuclear technology applications (including decommissioning and legacy management) with at least the same vigour as to other radiation issues. Because the issues of interest vary over time and place, they must be weighed within the social and economic context of both ALARA and the SDGs. While there may be different appropriate solutions in different regions, it would be ideal to respond to the same optimisation attribute set, even if we do not respond in the same way. Using a shared definition of detriment across all kinds of health hazards would be useful.

Having social inputs to optimisation was recognised as important ab initio (Dunster and McLean, 1970), but that recognition has not always been clearly reflected in

implementation or in transparency of assessments designed to inform decisions. Recognition of a hierarchy is especially important, with principles at the top which can be internationally signed up to, supported by national and regional application and derived standards. However, more needs to be done to identify the circumstances in which it is appropriate to derogate responsibility to regional and local levels.

Application of the SDGs in practice has shown that industry recognises the need to consider the SDGs together by balancing all 17 goals rather than selecting a few when demonstrating optimisation. There is evidence in the United Kingdom of reactor designers engaging separate frameworks to enable the demonstration of the adoption of sustainability in their designs, including the Building Research Establishment Environmental Assessment Methodology (BREEAM) Infrastructure framework. Consideration on how to include sustainable development and SDGs in the SRP, through its three pillars of scientific evidence, ethics and experience, is noted in the conclusion of a recently published ICRP paper (Rühm et al., 2024).

The NEA's post-accident waste management report (2016) observes that reducing one detriment can increase another, so optimisation needs a holistic view that is meaningful both within radiological protection and to stakeholders (NEA, 2016).

There is still much to be done to better address environmental, economic, social and scientific uncertainties. In this context, it is important to clearly distinguish between **scientific** and **societal** uncertainties, both within optimisation studies and in how they are presented. Final decisions will also need to consider diverse inputs from a wide range of stakeholders.

A further challenge is how to set discount rates (the parameters that reflect the effect of time) over the very long periods during which investments committed today will yield benefits or harms. This applies just as much in the health context as in the financial world. For example, using a **1.5%** social discount rate, preventing one statistical premature death in 100 years is weighted at about **0.23** of preventing one today, illustrating how strongly results can depend on the chosen rate.

Management and regulatory oversight are increasingly well co-ordinated, though significant difficulties remain. These arise from the very complex nature of the problem, partly a necessary subdivision of labour and responsibilities, and partly an ineffective process of budgeting across different silos. In any case, there is a balance to be made between making a decision, which may be urgently needed, and delaying that decision until all the attributes of interest have been studied thoroughly and then consulted upon.

2.2. New technologies

As noted in the NEA report (NEA, 2023a), the SRP has continuously improved over time and is an effective system for radiation safety and protection of people and the environment. As new technologies are deployed and implemented, we must consider what can be learned at this moment that directly impacts and influences the ICRP's review of the SRP, including identifying specific challenges to the system and to the primary aim of protection.

2.2.1. AI in medical applications

Within the medical sector, new treatment technologies using novel radionuclides, medical procedures in an ageing and wealthier population and the use of artificial intelligence (AI) are growing rapidly. While these developments may not challenge the SRP, they do introduce new values and ethics considerations, prompting ICRP to establish a Working Party (WP) on applications of AI in medical imaging, under Committee 3. It is noted that in November 2023 ICRP Committee 4 proposed to establish a WP on "Artificial

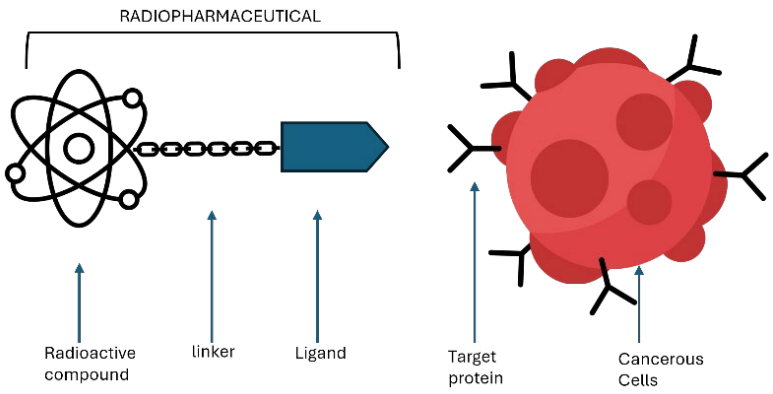
Intelligence in Radiological Protection", with aims to anticipate what the impacts of AI tools and their application could be on RP application, practice and operations (ICRP, 2024). Among the tasks of the WP is to monitor and understand the advances of AI in RP, including consideration of ethical implications. ICRP Committee 4 recognised the growing interest for AI applications in Radiological Protection also beyond medicine, and in relation with the increasing popularity of generative AI foundation models (ChatGPT, DALL-E, Gemini, BERT, LaMDA, Claude, etc.). A joint FANR-ICRP workshop on AI in radiological protection, originally planned for 28-30 January 2025, in Abu Dhabi, UAE, was postponed.

2.2.2. New treatment technologies – radioligand therapy

While medical radioisotopes have been primarily utilised as diagnostic tools, the last 15 years have witnessed a revolution in their use for therapeutic applications, opening new possibilities for treating tumours more efficiently.

The therapeutic potential of radioisotopes, however, is not a recent discovery. As early as the 1940s the capacity of iodine-131 (I-131) to treat disease was recognised. Once injected, I-131 accumulates preferentially in the thyroid gland and for decades it has been routinely used to treat hyperthyroid conditions and thyroid cancer by emitting beta radiation that destroys diseased cells. However, addressing cancers in tissues that lack a natural affinity for radioisotopes required advancements in molecular biology. These breakthroughs enabled the development of ligands — molecules designed to bind specifically to proteins or receptors on cancer cells (see Figure 1). Attaching a radioisotope to a ligand makes targeted therapy possible, with the ligand acting as a "biological GPS" to deliver radiation precisely to cancer cells, potentially damaging or destroying them, while limiting damage to healthy cells.

Figure 1. Radioactive compound linked to a ligand who has affinity for cancer protein



Radioligand therapy (RLT) is therefore emerging as an innovative modality of treatment in different types of cancers. Recent regulatory approvals of ^{177}Lu -DOTATATE (Lutathera) for gastroenteropancreatic neuroendocrine tumours (GEP-NETs) and ^{177}Lu -PSMA-617 (Pluvicto) for metastatic castration-resistant prostate cancer (mCRPC) highlight the growing clinical adoption of RLT. Both pharmaceuticals employ the beta-emitter lutetium-^{177}Lu which has become a cornerstone of RLT. Efforts are also underway to develop

therapies using other beta and alpha emitters, such as actinium-225 (Ac-225), which delivers higher energy over a shorter range, making it ideal for treating micrometastases.

2.2.3. New nuclear technologies: SMRs and AMRs

Within the nuclear sector, significant changes are expected over the next two decades, including the decommissioning of existing reactors and a shift towards new nuclear technologies: small modular reactors (SMRs)[1] and advanced nuclear reactors (AMRs)[2]. Governments worldwide are looking to new nuclear technologies, including SMRs, with the intent to help meet aggressive and important climate change commitments and energy security priorities. The NEA Strategic Plan 2023-2028 further highlights SMRs as a viable option to address long-term energy security and environmental challenges for both nuclear and non-nuclear countries (NEA, 2023c). The Russian invasion of Ukraine has highlighted the potential vulnerabilities of depending on others for energy needs. However, these advances bring challenges, such as finding a permanent solution for waste. Issues with waste volumes and content from SMRs were raised in a recent Committee on Radioactive Waste Management paper (CoRWM, n.d.) including noting issues with the non-radioactive properties of waste. For example, there is currently no treatment route for large volumes of radioactively contaminated lead. With the introduction of non-water-cooled reactors and compact designs, new challenges with respect to the radiological protection of workers can also arise. In the case of public exposure, routine discharges are expected to be lower than those associated with existing reactors, but this may depend on reactor design and operating conditions.

The nuclear industry is evolving with great strides towards deployment of new reactor technologies. As highlighted, the contributions to achieving climate change commitments and energy security are of high interest. Widely deploying these technologies in time to address climate change, while considering or addressing the interests and concerns of involved or impacted individuals and groups, remains a challenge. Climate change will likely present the greatest health and environmental risks, which need to be accounted for in future decision making, along with other factors, such as sustainability, ecosystem services and increased stakeholder engagement, as these will be key issues when considering future needs. It is essential that the SRP be set up to adapt to these risks, factors and issues. Use of AI and deep learning within the nuclear sector present other challenges, particularly their use under current, strict regulatory frameworks, as discussed previously.

NEA (2023a) identified that for any nuclear technology, radiological protection is fundamental to safe deployment and operation of new reactors and facilities. The potential for innovation in the design, regulation and operation of new nuclear technologies provides an opportunity to examine the approach to radiological protection throughout the life cycle of new nuclear technologies. For example, new nuclear technologies can challenge existing waste management processes, and in some cases, result in more complicated waste streams,

[1] SMR are smaller, both in terms of power output and physical size, than conventional gigawatt-scale nuclear reactors. Typically, SMRs are nuclear reactors with power output less than 300 megawatts electric (MWe), with some as small as 1-10 MWe. SMRs are designed for modular manufacturing, factory production, portability and scalable deployment. SMRs use nuclear fission reactions to create heat that can be used directly, or to generate electricity. Some SMRs are based on currently deployed technologies, while others are based on so-called "Generation IV" and advanced reactor concept (NEA, 2023b).

[2] The term "advanced reactors" refers to reactors under consideration that are cooled by fluids other than water e.g. liquid salt (NEA, 2025).

in terms of both composition and volume. Early considerations are needed to incorporate and address these aspects to the extent practical within the design and regulatory frameworks.

Any changes under consideration by the ICRP to the SRP must be based on the state of the art in science and technology and take account of the wider social, environmental, and economic issues at stake, including consideration of non-radiological risks. With this in mind, the NEA Task Force on radiological protection challenges associated with the deployment of small modular reactors (SMRs) identified several challenges related to radiological protection from the rapid deployment of SMRs, including a lack of operating experience, source terms, public risk perception and risk communication. Notable variables include siting, emergency preparedness and response, small and compact design, and staffing and other resources (NEA, 2026). It is noted that the NEA convened a new Expert Group on Emergency Preparedness for Small Modular Reactors (EGEPSMR). The expert group's scope is to support the Working Party on Nuclear Emergency Matters (WPNEM) and the CRPPH in addressing emergency preparedness and response (EPR) applicable to SMRs, exploring how a graded approach can be applied to emergency planning, ensuring that the protection strategies are appropriately tailored to SMRs' unique characteristics and deployment scenarios. The expert group will deliver an international workshop and a report for publication as per its mandate.

In October 2024, the IAEA hosted the first International Conference on Small Modular Reactors and their Applications (IAEA, 2024). The conference provided an opportunity to review global activities related to SMRs and to discuss emerging challenges and opportunities. To advance efforts in the development and safe, secure deployment of SMRs, the Platform on SMRs and their Applications (IAEA, n.d.a) and the Nuclear Harmonization and Standardization Initiative (IAEA, n.d.b) were established.

Additionally, in 2023, Safety Report No. 123 was published, addressing the applicability of IAEA Safety Standards to non-water-cooled reactors and SMRs (IAEA, 2024). The report identified no gaps in the safety requirements outlined in GSR Part 3, nor in the guidance provided for the protection of workers (GSG-7) and for the public and the environment (GSG-8).

While discussions directly related to the primary aims of the SRP have not been observed thus far, international dialogue on SMRs is expected to intensify in the future. Therefore, it is essential to closely monitor relevant developments moving forward.

2.2.4. Nuclear fusion

Another technology for sustainable, non-carbon emitting global energy supply that may have an impact on the future SRP is nuclear fusion. There are many research initiatives and projects around the world pursuing the development of fusion machines and reactors, with the ITER project in France being currently the largest nuclear fusion experimental device in construction, aiming to serve as a key step from fusion research machines to fusion power plants. The European Commission's *EU Scientific Seminar 2022 on Radiological protection considerations for fusion reactors* discussed radiological protection issues in future fusion reactors, based on experience from existing experimental fusion facilities, fusion reactors under construction, planning of future fusion reactors, as well as on available scientific knowledge (European Commission, 2022).

Nuclear fusion comes with specific radiological hazards in fusion reactors, such as the presence of high-energy neutrons during operation, the creation of "new" radioactive materials from the fusion reactions and processes, including tritium in different chemical forms, as wells as materials containing radionuclides from neutron activation of air, water

and structural materials. These hazards differ from those occurring in nuclear fission processes or the operation of accelerators, giving rise to new challenges for the radiological protection of workers during operation and maintenance activities in routine and accident conditions, as well as for the related dosimetry, which may still have to be developed. Furthermore, fusion processes can produce radionuclides not found naturally or in fission-based systems, some of which may currently lack established dose coefficients and data on biokinetic behaviour.

Understanding the neutron spectrum in fusion workplace environments is necessary for accurate dosimetry. In addition, the relative biological effectiveness of high-energy neutrons needs to account for the effect of scattering to lower energies in order to derive appropriate radiation weighting factors for radiological protection purposes. Further to this, the expected radioactive releases from fusion reactors will differ from those of nuclear fission reactors both in routine situations and in postulated accident scenarios, therefore requiring an assessment of the resulting radiation exposure of members of the public. Another key issue to be considered is the management of radioactive waste arising from nuclear fusion, such as materials contaminated with tritium and neutron activation products. While there is significant experience and knowledge available, further research is needed to address specific issues in view of the range of designs, technologies, materials, and scales of future fusion reactors.

The development of fusion technology also requires a clear legal framework to ensure the safety of future fusion devices. Regulatory frameworks suitable to ensure the (nuclear) safety of nuclear power plants may not be suitable to regulate fusion facilities. At present, there is no fusion-specific regulatory framework for the licensing process of a fusion device. Any such fusion-specific framework needs to take account of the specificities of fusion facilities and the differences with fission devices such as the different types of nuclear reactions, different source terms, and different potential accident and emergency scenarios and their potential consequences.

Implications for the SRP

Regulation and innovation must evolve in parallel to ensure the safety of new technologies. The SRP needs to be adaptable to this evolution through the lens of values and ethics, going beyond the science and into the broader factors behind how people make decisions every day. This highlights the importance of the SRP in considering the role and perspectives of diverse stakeholders, including the knowledge of indigenous peoples and other local communities, in decision making to help build trust and ensure the safety of new technologies.

This calls for a system that is sufficiently flexible to address and adapt to evolutions in new and advanced science and innovative technologies, potential large accidents, wide-scale decommissioning of reactors and various external factors, such as societal changes (i.e. lifestyle and population), climate change and ethical views.

2.3. New applications

2.3.1. Space-nuclear applications and radiological protection

Interest in nuclear technology for space power and propulsion is longstanding. However, the rapid growth and commercialisation of low-Earth orbit activities, combined with ambitious plans for crewed missions to the Moon within the next decade, have revitalised interest and investment in space-nuclear technologies. This renewed attention is driven not only by national and regional space agencies but also by an increasingly dynamic, well-

funded, and innovative private sector (OECD, 2023). To ensure these emerging applications are both safe and sustainable, it will be necessary to identify and analyse the radiological protection challenges and opportunities across nuclear technology, regulation and governance.

The planned exposure of humans and the space environment to ionising radiation from two applications currently seem to fall outside the scope of the ICRP system for radiological protection: (i) the use of nuclear power sources (NPS) on the surface of celestial bodies including the Moon, particularly micro-modular fission reactors, and (ii) use of nuclear technologies for propulsion.

Nuclear power sources and nuclear propulsion

To sustain human presence on the Moon for scientific exploration or commercial mining, the use of nuclear fission power sources is seen as inevitable given the lack of atmosphere and the 14-day lunar night cycle. Life support, in-situ resource utilisation, scientific research, transportation, and mining activities within and near the Permanently Shadowed Regions (PSRs) at the lunar south pole—where water ice is likely to be found—will require a significant and reliable power supply.

Nuclear fission technology can deliver continuous power levels at an energy density needed for cost-effective and practical use in these challenging environmental conditions, while meeting requirements for low maintenance and long-term power provision. For applications with lower power demands, radioisotope thermal generators (RTGs) offer another viable supplement to more traditional solar power. RTG devices convert heat from the radioactive decay of isotopes like Pu-238, to electrical energy. The advantages and disadvantages of different micro-modular fission reactor and RTG technologies need to be examined holistically by carefully optimising the potential radiological impact associated with nominal operations and those of different accident scenarios, along with the societal benefits for science and exploration, and spinoff benefits and lessons that might be drawn for terrestrial applications.

For human missions to Mars, nuclear propulsion promises to propel spacecraft to higher velocities and to significantly cut journey times, thereby reducing astronaut exposure to cosmic ionising radiation and secondary radiations from absorption in spacecraft materials. Potential exposure to radiation from a nuclear reactor onboard a spacecraft would be offset by a reduction in journey time and the total exposure to cosmic and secondary radiations—currently seen as the limiting factor for a round trip to Mars. For both power and propulsion applications, radiological protection of astronauts and the environment should be considered at the design and development stage to identify and quantify the radiological impact of different nuclear technologies and practices. Under the current SRP, regulatory bodies are national and terrestrial in their jurisdiction, so it is unclear how such assessments would be made. On the Moon or Mars, where there is no sovereignty or nuclear regulatory regime, equitable application of the principles of radiological protection, namely justification and optimisation, may prove challenging. While international agreements like the Artemis Accords represent a step in the right direction, they currently lack specific provisions to address radiological protection issues. The use of nuclear reactors on the surface of celestial bodies is also currently outside of the scope of the Nuclear Power Source (NPS) Principles outlined in the UN General Assembly Resolution 47/68 (UN, 1992).

Protection of the space environment

The ongoing revision of the SRP outlined by the ICRP presents a timely opportunity to address the radiological protection of the space environment. The revision seeks to place greater emphasis on "protection of the environment", a concept currently understood within the ICRP framework as referring to terrestrial environments inhabited by animals and plants — ecosystems that could be harmed by exposure to ionising radiation (ICRP, 2014). Under this definition, lunar or space environments fall outside the scope of the SRP, as there are presently no known biological receptors in outer space (vacuum) or on the surfaces of the Moon or Mars. However, these locations will one day be inhabited by astronauts, and on the Moon, are likely to evolve into habitats and bases for human exploration, scientific research, mining, and other commercial activities. Therefore, the protection of future habitats — beyond those with existing ecosystems — could be incorporated into a revised radiological protection system. The anticipated increase in space traffic, orbital debris and the use of radioisotope thermal generators (RTGs) will significantly elevate the risk of collisions, accidents and harmful contamination in space, with potential repercussions for Earth and future generations. All environments, present and future, affected by human activity, whether under regulatory control or not, should be protected within a universal radiological protection framework.

Nominal operations and emergencies

The need for radiological protection and assessment in space and on lunar and martian environments, is crucial — not only during the nominal deployment and operation of micro-modular fission reactors, encompassing launch, transit, landing, deployment, operation and decommissioning, but also in the design and implementation of frameworks for the siting of reactors and for waste transport, processing, storage and final disposal. Practices across all these phases should be justified and optimised in co-operation with other space users. Additionally, robust systems must be established to address potential emergency situations and radiological risks to humans in outer space beyond the scope of the Safety Framework for Nuclear Power Source Applications in Outer Space (IAEA and UN COPUOS, 2009). Response and recovery plans for various accident scenarios — likely to differ significantly from those encountered on Earth — should be developed, tested and refined. Scenarios may present risks to Earth, such as during launch or unintended re-entry of a space reactor as seen with Cosmos 954 (Health Canada, 2019) or involve risks to space or lunar environments and users of such environments.

Frameworks for radiological protection

Many regulatory and technological challenges for space-nuclear applications remain unresolved at this stage, requiring further research, development and international collaboration. Given the rapid pace of technological advancements, commercial incentives for first movers, and the potential risks involved, these issues could be prioritised for identification and analysis before they are outpaced by events.

The European Space Agency has stated that new international agreements must be developed to govern operations on the Moon, not just those related to nuclear technologies (ESA, 2024). In outer space, a holistic approach to the application of radiological protection principles is essential, just as it is on Earth. The fundamental principles of justification and optimisation should be key components of any new agreements or frameworks to ensure the equitable, safe and sustainable use of nuclear technology in all space applications. In this context, radiological protection in the space environment should be communicated as an enabling framework to a broad range of stakeholders. Specifically, through identifying and resolving radiological protection challenges early on, such a framework can drive

sustainable economic growth and industry investment, support space exploration and scientific research, while enhancing public perceptions of nuclear technology (both in space and on Earth), thereby leveraging the inherent "space appeal".

2.3.2. Maritime applications of nuclear power

Nuclear technology has, for many years, been successfully used for maritime applications, most notably as propulsion for military and government-operated vessels such as nuclear-powered naval surface vessels and the submarines of several nations, and the nuclear-powered ice-breaker fleet operated by the Russian Federation.

The use of nuclear propulsion in commercial/merchant vessels was first explored in the late 1950s, initially with the launch of the US NS Savannah in 1959. The Savannah was commissioned to demonstrate that nuclear power could be adopted for civilian shipping in the same way that it was being adopted for military vessels. Other nuclear-powered merchant ships were also built in Japan, West Germany and the Soviet Union.

All of these nuclear applications used pressurised water-cooled reactors (PWRs). The use of these reactors came with significant challenges, most notably the requirements to have a suitable Emergency Planning Zone (EPZ) around the vessel. As the reactors in these vessels were pressurised, the EPZ needed would often extend into areas that would be difficult to manage, such as areas beyond the port, waterway or dockyard boundaries. This made it difficult to put the necessary liability insurance in place.

Floating platforms, equipped with nuclear reactors, have also been deployed to provide energy (in the form of electricity and heat) as an alternative to land-based power stations.

The first of these was the USS Sturgis, a converted 'Liberty Ship' that provided electricity to the Panama Canal between 1968 and 1975. More recently, Russia has operated the FNPP Akademik Lomonosov in the Chukotka region in the Russian Arctic to supply both electricity and district heating.

In recent years, more vendors have begun to revisit the possibility of using nuclear reactors to provide vessel propulsion and for floating power barges. Non-PWR technologies, such as Molten Chloride Reactors, Heat Pipe Reactors and other reactors that operate at low pressure or at atmospheric pressure, are being commercialised as a way to bring nuclear power into ports and waterways without the liability barriers previously encountered.

There will, however, be a new set of challenges to address.

Domestic and transboundary regulation

A vessel equipped with a nuclear reactor will need to be regulated by the state in which the vessel is registered (the Flag State). This will be easier to achieve for those States that have both a (mature) Nuclear Regulator and a Maritime Regulator. In recent decades, ship owners have often registered their vessels in "flag of Convenience" countries that have offered commercial incentives (tax, survey, manning regulations, etc.). These flag of convenience countries mostly do not have developed nuclear industries.

The Flag State rules will apply to the vessel at all times, including when the vessel is in the Territorial Seas of another State, and when on the high seas (International Waters). A possibly 'grey area' will be the application of the Convention on the Physical Protection of Nuclear Material and its Amendments (CPPNM) while in the Territorial Seas of a Coastal State, or when making a visit to a foreign port.

The United Nations Convention on the Law of the Seas will apply to nuclear-powered vessels, in the same way that it applies to all other commercial vessels, but a Coastal State may demand additional assurances that the relevant Articles are being complied with.

It is likely that, initially, the introduction of nuclear-powered merchant ships and floating nuclear power plants will require bilateral agreements between States to address the challenges with regulatory compliance.

From a RP perspective, these arrangements must ensure the consistent, mutually recognised application of dose limits, optimisation, monitoring of workers, the public and the environment, and emergency preparedness across Flag, Coastal and Port-State authorities.

Skills development

Along with training the next generation of operators for these new vessels, building a robust and secure supply chain will be essential. Shipyards are well versed with serial construction and employ modular construction methods with often large parts of a vessel being constructed off site by external contractors. All of these contractors and component suppliers will need to be conversant with the construction and regulatory requirements applied to the nuclear industry. It will be crucial to embed dose management, contamination control, monitoring and emergency preparedness into workforce training, contractor qualification and quality assurance across the supply chain.

Implications for the SRP

The majority of the radiological protection challenges faced by the Maritime Sector will draw parallels with those described in Section 2.3.1 in relation to Space. This includes the need for ICRP and Regulatory bodies to consider protection of the marine environment, changes to emergency planning and response requirements, management of nuclear liabilities, and an enabling framework which balances the benefits of deploying low carbon transport and electricity generation with radiological protection requirements.

New types of nuclear fuel may also present technical challenges such as the need for new designs of packages and containment, and this may require revisions to transport safety regulations. Additionally, careful consideration must be given to how a fuelled nuclear reactor — such as those used in floating nuclear power plants (FNPPs) and transportable nuclear power plants (TNPPs) — will comply with nuclear safety and security requirements during transportation across all stages of the facility's lifecycle.

2.3.3. Medical applications

As mentioned earlier, RLT employing novel radioisotopes such as ^{177}Lu has greatly advanced in the last few years and is now used to offer novel and efficient therapies for gastroenteropancreatic neuroendocrine tumors (GEP-NETs) and metastatic castration-resistant prostate cancer (mCRPC). ^{177}Lu based radiopharmaceuticals, such as Lutathera® and Pluvicto® have changed the approach to oncology, allowing for highly precise tumour irradiation with minimal impact on normal tissues. Other novel isotopes are also under development for RLT — including alpha emitters such as actinium-225 and lead-212. These differ significantly from ^{177}Lu in terms of radiation type (e.g. alpha vs. beta emission), logistical requirements, and radiological protection measures, thereby increasing the complexity of ensuring adequate protection in centres that handle multiple types of radionuclides. The current focus on ^{177}Lu reflects the fact that, to date, the only approved RLT drugs for widespread clinical use are based on this isotope. However, even for these therapies, radiological protection remains a key challenge for broader adoption and integration into healthcare systems.

The adoption of this approach is expected to grow further as healthcare systems develop dedicated services and more drugs will eventually be approved by the regulatory bodies. More specifically, the approval of these new drugs has highlighted the importance of investing in infrastructure and training of the workforce. As the number of eligible patients for treatment is significant due to the high prevalence of prostate cancer, healthcare systems are now in the process of adapting and expanding therapeutic services to meet these demands. Furthermore, the RLT field continues to develop, with numerous ongoing clinical trials targeting a variety of cancers. Some of these tested therapies will eventually receive regulatory approval and provide major clinical benefits to patients.

However, while these treatments offer significant medical advantages, they also raise radiological protection challenges at all stages of the medicine lifecycle, including production, transport, administration, patient care and waste management.

Production and handling of radiopharmaceuticals

The production of ^{177}Lu based radiopharmaceuticals often involves the use of specialised nuclear reactors or accelerator-based production systems. In many cases non-carrier-added ^{177}Lu is produced by neutron activation of 176Lu from research reactors then processed into radiopharmaceuticals. These materials can only be handled with strict radiological protection protocols in synthesis, quality control and packaging facilities in order that occupational exposure of workers is minimal. External radiation risk, contamination and handling of radioactive liquids demand dedicated infrastructure and monitoring for compliance with radiation safety standards especially with the emergence of novel radioisotopes.

Transport and logistical challenges

Once produced, radiopharmaceuticals must be transported under controlled conditions to ensure both radiological protection and product integrity. Given the short half-life of ^{177}Lu (6.7 days), efficiency in logistics is critical since any form of delay in the delivery of the product can lead to reduction in its effectiveness. The co-ordination between suppliers and treatment centres requires careful scheduling to maximise the utilisation of each batch before significant radioactive decay occurs. It should also be taken into consideration that ^{177}Lu is a beta emitter with low-energy gamma emissions, requiring moderate shielding, which has positive impact on transportation costs and flexibility.

Administration and safety measures in clinical settings

RLT radiopharmaceuticals, when administered in the context of clinical settings, raise another level of concern with respect to radiological protection, especially for the healthcare professionals who are likely to handle and inject them. All staff members need to be trained on the correct handling of the equipment to avoid exposing themselves to high levels of radiation. The use of dedicated treatment rooms, lead shielding, and personal protective equipment also minimises the amount of exposure. At the same time, it is important to consider the occupational health impacts of such protective measures — for example, the prolonged use of heavy lead aprons can contribute to musculoskeletal strain and may result in work-related absences. Furthermore, outpatient hospitals that are adopting RLT treatment protocols need to have very strict post-treatment policies for patients to prevent exposing caregivers and the public to secondary radiation.

Patient excretion and public exposure risks

A radiological protection issue arises after RLT as patients excrete radioactive material. Studies show that 40–60 % of the injected ^{177}Lu is excreted within the first 24 hours through urine. This poses a contamination risk to hospital environments, home settings and wastewater facilities. To reduce these risks, patients receiving RLT are usually given safety information on hygiene measures, avoiding close contact with vulnerable people and using separate bathrooms if possible. This is due to differing regulatory frameworks among countries. For example, in the United States, patients receiving 177Lu-based therapies are usually treated as outpatients and are allowed to go home the same day with thorough safety information. In Germany, because of more stringent radiation safety rules, patients may have to stay in a special ward for as long as 48 hours for monitoring and allowing for radiation decay. While these differences reflect national regulatory choices, they can also impact the scalability and equity of RLT deployment by limiting patient throughput and delaying broader clinical adoption in certain countries.

Waste management and environmental impact

The management of radioactive waste from RLT poses environmental and public safety risks and protection challenges. The major type of waste is excreta of patients, which are discharged to the wastewater systems and require evaluation of their long-term potential radiological impact. Hospitals using RLT also generate contaminated medical waste such as syringes, gloves and protective garments. The decontamination procedures in the treatment areas should be applied in line with standard regulatory requirements. Studies on ^{177}Lu discharge to wastewater have shown that the radiation levels are within the allowed limits; however, with the increase in this type of therapy, appropriate protection measures will be needed to ensure safety.

The need for harmonised regulations and safety protocols

As RLT continues to expand, ensuring a harmonised and well-regulated radiological protection framework will be crucial. This includes establishing standardised international guidelines for outpatient RLT, refining protocols for radiopharmaceutical waste disposal, and implementing personalised dosimetry approaches to optimise patient care while minimising unnecessary radiation exposure. Given the rapid adoption of ^{177}Lu based therapies, it is important that regulatory bodies, healthcare institutions and nuclear medicine stakeholders work together to guarantee that radiological protection measures keep up with the medical advancements.

2.3.4. Emerging threats and hazards

The key emerging threat and hazard addressed here is the ability to control radiation exposures during and in the aftermath of armed conflict.

Armed conflict poses a very serious threat to radiation safety within a country itself, within neighbouring countries and beyond. Ukraine requires extensive assistance in bolstering its resilience to this threat during the conflict and this need is likely to continue for an extended period post-war.

The scope for development of similar situations in other locations is easily recognised. From a radiological protection perspective, the challenge for any country in an armed conflict situation is twofold:

1. to maintain and enhance the capability and capacity to effectively monitor, analyse and manage radiological protection and public health; and

2. to continuously anticipate consequences that such conflicts will have on the implementation of radiological protection regulation and practices.

These challenges apply before, during and after situations of armed conflict.

A key question is whether the SRP and regulatory frameworks that countries rely upon to ensure safety, which have evolved over many decades but were not designed to be applied in wartime, have the resilience and flexibility to be applied to situations of armed conflict. If these frameworks cannot adapt to such situations – whether before, during or after armed conflict – then what are the gaps in the existing arrangements and what measures need to be applied?

These were the key questions discussed at an international workshop on Radiological Protection During Armed Conflict: Improving Regulatory and Operational Resilience, held 22-24 November 2023 in Oslo, Norway and jointly organised by the NEA and the Norwegian Radiation and Nuclear Safety Authority (DSA) (NEA, 2024a).

The specific objectives of the workshop were:

1. To share the knowledge and experience of Ukrainian and other participating national regulators, as well as relevant international organisations and associations, on the operational management and regulation of radiological protection and public health during and after armed conflict.
2. To identify the challenges of maintaining or restoring radiation safety, including the involvement of different stakeholders **and the consideration of all hazards**, as well as the application of standard emergency preparedness, response actions during wartime, and post conflict recovery strategies.
3. To **develop proposals for further international collaboration in this area**, including how to adapt the regulatory framework and practice for the radiological protection of workers, the public and the environment during wartime, taking into account the challenges and risks associated with armed conflict.

Key take-away messages from the workshop include:

- International and bilateral co-operation is vital to address radiation and nuclear challenges within Ukraine, and this is likely to continue. At the same time, such international co-operation is necessary to enhance preparedness and response in friendly neighbouring countries. The ICRP may have a role.
- Upgrading or updating regulations takes time within a normal regulatory process. However, in a conflict situation, there is a need to act quickly. There is therefore a need to consider how regulatory processes can be improved by building more flexibility into regulatory frameworks that permits adaptive decision making to address urgent and severe priorities rather than by the (normal and appropriately cautious but slow) process of regulatory change.
- It should be asked if greater resilience could be generated by allowing adaptations outside of the normal radiological protection framework during exceptional circumstances such as armed conflict, then allow for return to the normal framework as conditions allow. This is equivalent to recognising the end of an emergency – but how to do that in a military scenario?
- There is a need to share experience of taking radiological protection decisions during conflicts and other urgent situations. Military authorities are experienced at command control and communication under difficult operations and provision of civil protection when infrastructure has been damaged and are skilled at looking at

and anticipating what opponents might be planning and how they may react to mitigation actions. Military authorities may therefore be an additional stakeholder to be engaged.

- A holistic view should be taken so that the focus is not solely on radiological protection, but also security and other threats (i.e. an all-hazards approach that addresses mines, unexploded ordnances). This includes threats associated with the un-availability of reliable information and making decisions in the absence of data, as well as establishing reliable and direct contact points for trustworthy exchange of information and ensuring security of communication channels.
- Justification and optimisation are key principles in the ICRP framework for radiological protection, but there may be need for guidance around justification to be revisited to recognise the additional threats during armed conflict (e.g. incoming missiles and mines left after de-occupation) that would affect safety priorities and require decisions to be made on a case-specific basis.
- Lessons from the Chernobyl accident suggest that regulations do not need to change, but there needs to be flexibility in their application and this is particularly important in times of war. This is likely to mean discussion between different regulatory bodies with different areas of responsibility, different safety issues but also health and welfare services. It can also mean being able to discuss with the military how risks near major facilities can best be managed.
- Analysis of release scenarios should include war scenarios for nuclear installations but also for high-risk radiation installations, e.g. waste storage facilities, industrial irradiators, hospitals. It could be beneficial to have recommendations on scenarios that should be considered to help identify critical points and initiating events and, from that, consider building defence and mitigation capacities and capabilities. A first step could be sharing of scenarios already available within national EPR programmes.
- The different scenarios could also be useful for the ICRP in their ongoing activities to consider the application of reference levels and what justification means in terms of their application by helping evaluate whether ICRP advice fits within these different scenarios. Consideration has been given to scenarios such as radiation dispersion devices and poisoning incidents, but a country at war has not yet been considered.
- Under armed conflict situations (and others) there could, often would, be concurrent emergencies and protection principles may be altered as a result to balance between the different hazards and risks (e.g. advice to shelter from contamination may counter advice to evacuate a conflict zone). The application of reference levels guides optimisation for radiation exposure, but other factors should also be taken into account within an all-hazards approach.
- There is lack of international guidance on the application of systems of safety and security during armed conflict, but there are many other national challenges during a war so, somehow, radiological protection must be integrated within the overall resilience system. Relevant international organisations might be encouraged to prepare joint guidance.
- In preparing such guidance, it is necessary to find a good balance between the need for greater flexibility to address very unusual circumstances and the need to keep within the safety fundamentals.

During the discussions, there was interesting constructive tension between those who would look for a high-level recognition of the need for greater flexibility in extreme conditions, i.e. based on changes to high-level documents, and those who felt that the existing frameworks were adequate, if applied with greater flexibility. STUK (Radiation and Nuclear Safety Authority in Finland) recently issued updated protective actions in a nuclear or radiological emergency (STUK, 2022).

Following the workshop, the CRPPH established a Task Group on radiological protection during armed conflict (NEA, 2024b). The Task Group's initial objective will be to draft a roadmap outlining priorities for the development of radiological protection during and after armed conflict, with an emphasis on regulatory flexibility. This will be based on actionable recommendations from the DSA-NEA workshop and close interactions with the DSA, State Nuclear Regulatory Inspectorate of Ukraine (SNRIU), other NEA Committees, and international groups. The Task Group plans to analyse hypothetical scenarios, as well as draw lessons and experience from other conflicts. The work of the Task Group will be conducted within the framework of the OECD country programme in Ukraine, and a report on considerations for ensuring radiological protection in a conflict zone is expected in the coming years. Outcomes of this Task Group will inform decisions on future CRPPH activities in this area.

2.4. Other challenges and opportunities

Towards holistic, inclusive and sustainable decision making

Optimisation has consistently stood as a foundational principle in decision making across all sectors of society; however, the methodology for making decisions has undergone transformation in recent times. There has been a shift in societal attitudes towards activities associated with nuclear energy, emphasising a more holistic, inclusive and sustainable approach to decision making. Embracing these perspectives acknowledges the imperative to integrate diverse elements and stakeholder opinions, especially those from civil society, to arrive at decisions that are more equitable and optimised. As nations strive to fulfil the United Nations SDGs, this necessity is expanding and must also consider national and cultural contexts, along with the intricate interplay among economic, environmental, health and societal aspects. Aligned with its pioneering efforts in fostering these advancements through diverse workshops, the NEA conducted its Third Stakeholder Involvement Workshop in September 2023 (NEA, 2024c). Centred on the theme of "Optimisation in Decision Making," this workshop marked a crucial stride towards proposing a shared, tangible approach to decision-making processes within the nuclear domain and among NEA member countries (and beyond). Some key points highlighted and elements of conclusions, collected during the workshop, include the following:

- It is recognised that stakeholder involvement in nuclear decision making is needed. However, its role and importance are not shared by all countries.
- NGOs pointed out that stakeholder involvement should not be seen solely as a means of achieving “acceptance” of projects. The issue is to reach better and safer decisions for the benefit of society at large.
- In some countries and/or specific regions, stakeholder involvement can be legally binding. However, limits of regulatory requirements have been identified, as these requirements cannot include the whole complexity of a stakeholder involvement process.

- Although the main principles are shared, the practical implementation of stakeholder involvement remains complex. Any general framework will have to be adapted to suit institutional organisations, political context, leadership, culture, etc.
- Some new forms of stakeholder engagement could be explored. Participatory science / citizen science could be notably developed in complex situations.
- The role of science in informing decision making (particularly on the effects of low doses) remains to be studied. Notably the way to address uncertainties still needs some development.
- There is a need to develop further ways of assessing decisions, in partnership with stakeholders.

In addition, the need to establish a sustainable, holistic, and inclusive decision-making process that harmonises the wide range of factors and risks based on prevailing circumstances was highlighting, to pinpoint the optimal solutions for all stakeholders and society at large.

The NEA High-Level Group on Stakeholder Engagement, Trust, Transparency and Social Sciences (HLG-SET) was established in March 2023 to cultivate a deeper understanding of how the nuclear sector interfaces with society and how to develop effective mechanisms for advancing the prerequisite of public involvement and trust.

To deliver its mandate, the HLG-SET has established three subgroups:

- Data collection and analysis: To provide high-level guidance and oversight in developing approaches and a tool or suite of tools to systematically collect, analyse and monitor data on stakeholder perceptions, knowledge, attitudes, expectations and trust relating to nuclear energy.
- Best practices and lessons learnt: To develop a set of guiding principles, policy-level recommendations and a supporting toolkit for use in the development of effective stakeholder engagement practices within the nuclear sector.
- Assisting NEA with strategic planning: To provide strategic advice to the NEA in ensuring their Strategic Plan (2023-2028) is well integrated in the areas of stakeholder engagement, trust and transparency. The outcomes will ensure the efforts of other working groups are optimally leveraged.

It would be valuable to explore how the CRPPH could support the work of the HLG-SET, particularly in the area of decision-making processes related to radiological protection for workers, the public, and the environment across various exposure scenarios — whether planned, existing or emergency situations. The HLG-SET subgroup on best practices and lessons learnt could notably benefit from insights into stakeholder engagement in decision-making processes concerning radiological protection assessments. This could include examples of both successful and unsuccessful applications of such approaches.

The Expert Group on Holistic Process for Decision Making on Decommissioning and Management of Complex Sites (HDCS), established in 2020, is preparing a technical report. The report will provide advice on the preparation of a reliable, effective and efficient process for identifying, assessing, controlling and managing risks related to the decommissioning and legacy management of complex sites. It will also include guidelines and identify key decisions required to implement such a process.

Development of the 2026 long-term structure and plan for IAEA Safety Standards

The CRPPH should monitor another development related to the IAEA, which involves the creation of a draft concept paper for the formulation of the 2026 long-term structure and plan for IAEA Safety Standards (IAEA, n.d.d). Given that the most recent long-term plan for these standards was finalised in 2008, the IAEA has initiated discussions to establish a new long-term structure and plan. This process involves consultations with IAEA Member States from 2023 to 2025, aiming to implement the new structure and plan in 2026. The concept paper outlines sample questionnaires addressing various topics, such as the impact of climate change on facilities and activities, implications of COVID-19, the influence of AI and deep learning on the responsibilities and decision making of licensees, adoption of new technologies, and the management of radiation risk to humans and non-human species from an all-hazards perspective. It also covers aspects like communication, stakeholder involvement, and the measurement of the regulatory body's effectiveness. The IAEA Radiation Safety Standards Committee (RASSC) contributed inputs for the long-term strategy, which was approved during the 53rd RASSC meeting in November 2022 (IAEA, 2022). The document underscores that while the fundamental principles and safety requirements generally remain pertinent today, the emergence of new technologies and scientific foundations may necessitate updates, especially in areas related to new technologies, advanced reactors, and novel scientific principles. This long-term plan was approved by the IAEA Commission on Safety Standards (CSS) in May 2025 and is publicly available on the CSS website and in the approved Long-term plan (IAEA, n.d.c).

Nuclear liability

The Nuclear Law Bulletin No. 111 focuses on a range of legal issues in the nuclear energy sector, with specific attention to the evolving landscape of nuclear liability, international treaties, and regulatory frameworks. Key themes in this edition include nuclear liability, with a particular focus on challenges faced in conflict zones like Ukraine, where Russian military actions have raised concerns about the safety and security of nuclear facilities. The bulletin explores the legal complexities surrounding the management of nuclear installations in such areas and the difficulties in enforcing existing nuclear liability regimes (NEA, 2024d).

Additionally, the report examines the evolving definitions of "environmental damage" under modern nuclear liability laws. It provides an in-depth analysis of legal frameworks and how national and international laws are adapting to address environmental concerns, especially in the context of nuclear accidents or incidents. The report also highlights significant developments in nuclear energy policy and law, offering perspectives from various nations such as Japan, the Slovak Republic and Slovenia, where domestic nuclear law and regulation continue to evolve in response to technological advancements and safety concerns.

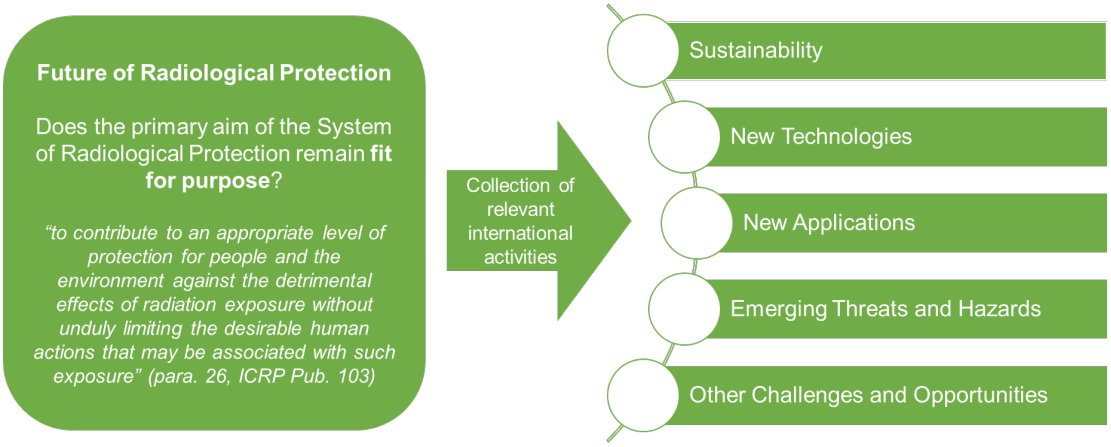
Lastly, the Nuclear Law Bulletin includes insights into legal challenges related to nuclear fusion and the international co-operation required for this emerging energy source. The bulletin also reviews updates from various international legal bodies, including the IAEA and the European Atomic Energy Community (EURATOM). These updates provide valuable context for how global institutions are shaping the future of nuclear law and policy, with particular emphasis on nuclear liability frameworks, nuclear safety, and the regulation of emerging nuclear technologies.

3. Conclusions

This study identifies how future changes in the use of nuclear science and technology could affect the System of Radiological Protection (SRP) and assesses whether the current primary aim remains fit for purpose.

It considers developments since 2007 (when the primary aim was published) and anticipates future changes in society, climate, and industry, including new technologies. It also examines how the SRP aligns with the United Nations Sustainable Development Goals (UN SDGs), to help ensure that the primary aim and supporting objectives remain resilient for the next cycle of the fundamental recommendations and beyond.

Figure 2. Forward-looking study by the EGIR



EGIR concludes that the current primary aim remains fit for purpose, based on evidence across five areas:

- sustainability;
- new technologies;
- new applications;
- emerging threats and hazards;
- other challenges and opportunities.

As ICRP embarks on the review of the SRP, EGIR recommends articulating sustainability as an explicit element of the system alongside justification and optimisation, clarifying that optimisation integrates social, economic and environmental factors over long-time horizons, and setting clear expectations for emerging technologies and applications while preserving the strengths of the existing system.

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