EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH
CONCERT

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* Despite the title of the deliverable this document is not a first draft joint roadmap, but it represents *the **first steps and current ideas to build a joint roadmap for radiation protection research**. In this document a set of **exposure scenarios** is proposed to identify potential radiation protection needs when faced with man-made and natural sources of ionising radiation. Secondly, a **first set of radiation protection research challenges is proposed. Both the exposure scenarios and the research challenges will serve as a basis to initiate discussions** with the wider research community and other stakeholders*. Stakeholder involvement along the course of the development of the joint roadmap is important, since *the **joint roadmap is meant to be a guide to plan research and develop radiation protection tools** for the benefit of the society.*

***A stakeholder involvement plan* will be elaborated in 2018 to involve stakeholders in each step of the Joint Roadmap development.**

Contents

Executive summary and purpose of the document

This document presents the first steps to build a joint roadmap for radiation protection research.
The Joint Roadmap for Radiation Protection Research (abbreviated as Joint Roadmap) is intended as a guide to plan radiation protection research over the next decades. The Joint Roadmap will promote long-term research to assess the effects of ionising radiation on humans and the environment, and to develop tools to improve practical radiation protection related to different situations resulting in exposure to ionising radiation, with the aim to improve the radiation protection system, to answer priority radiation protection questions and to support decision making.
The Joint Roadmap will also highlight the needs with regard to research infrastructure, education & training, and discuss some principles to determine research priorities and budgets.
Based on an overview of realistic exposure contexts and scenarios, the first list of joint R&D challenges is proposed, based on the research disciplines of European radiation protection research platforms, namely MELODI, EURADOS, NERIS, ALLIANCE and EURAMED, and also on expertise in Social Sciences and Humanities in the field of Radiation Protection (SSH). This proposal is primarily based on input from the research community and a number of radiation protection research program managers and program owners from European Member States.
The roadmap will be further developed through a broader stakeholder involvement: in 2018 a stakeholder involvement plan will be developed and implemented. A first draft joint roadmap will be ready in 2019.
It is the intention to regularly update the joint roadmap beyond CONCERT, as it is intended as a guide to plan radiation protection research over the next decades. Within this time frame, the joint roadmap for radiation protection research should take into account research progress and updated societal needs.
In parallel, Individual Roadmaps are being developed by the platforms and the SSH community dealing with radiation protection issues. While the Joint Roadmap deals with the overarching R&D challenges, the individual roadmaps intend to develop the R&D challenges within the respective radiation protection research disciplines and serve as guides for the research community.
Currently, Strategic Research Agendas (SRAs) present the challenges and priority research areas for each platform and SSH. These SRAs were developed over the last decade by the platforms and SSH, and updated taking into account scientific progress and input from relevant stakeholders. These SRAs contain valuable information presenting the state of the art and the knowledge gaps.
The proposed Joint and Individual roadmaps may serve as a guide to organise a long-term plan for open research calls covering the different areas of radiation protection research, subject to appropriate funding at the national and European scale.

I. Preamble - Depicting the framework of the need to develop a joint roadmap in radiation protection research

The Lund Declaration 2009[1] called upon Member States and European Institutions and expressed the need to address Societal Challenges (called "Grand Challenges" in the declaration) existing in Europe and beyond, by redirecting research beyond rigid thematic approaches and aligning European and national strategies and instruments. The Societal Challenges concern amongst others health, climate and other environmental challenges, as well as secure, clean and sufficient energy.

As a consequence, Joint Programming Initiatives have been set up to support these Societal Challenges.

EURATOM has defined Radiation Protection as an area of research deserving a H2020-consistent approach to address Societal Challenges by launching a call to set up a European Joint Programme for Radiation Protection Research[2]. Following this Euratom Call, the European Joint Programming CONCERT started in June 2015 and will last for five years.

The aim of EJP CONCERT is the implementation of a joint programme of activities in radiation protection research, ranging from organising open research calls to coordination and networking activities, including training, research infrastructure development and stakeholder involvement. Ultimately, radiation protection research should enable optimisation of the current RP system, by reducing uncertainties related to the effects of ionising radiation in realistic exposure scenarios.

The recommendations in the revisited Lund declaration[3] regarding research funding, organisation and implementation of research are also relevant to radiation protection research. The efforts and (partial) achievements in radiation protection research responding to these recommendations are summarised as follows:

- At the European scale, efforts have been made to establish and bring together European platforms for radiation protection research in the five key areas of low dose risks, dosimetry, emergency and preparedness, radioecology, and medical applications namely MELODI, EURADOS, NERIS, ALLIANCE, and more recently EURAMED[4] (respectively), as well as social sciences and humanities researchers. All platforms have developed Strategic Research Agendas (SRAs), listing the research priorities within their disciplines. An SRA on Social Sciences and Humanities research related to radiation protection has also been elaborated and is currently available. These SRAs are updated regularly taking into account recent scientific achievements and actual operational and societal needs. From these SRAs, Annual Statements are created as short lists of key priorities. These statements are defined by taking into account feasibility in the short term as well as urgent operational and social needs.
- At the national level, Member States attempt to increase their political commitment and try to align their national strategies and co-funding modalities compatible with the European Joint Programming Instrument used in EURATOM for Radiation Protection Research.

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[1] *The Swedish EU presidency Conference: New Worlds – New Solutions. Research and Innovation as a Basis for Developing Europe in a Global Context"* 7-8 July, *Lund, Sweden, Lund Declaration 2009 in Appendix 3.* link to the LUND Declaration 2009

[2] Link to the EURATOM Call topic NFRP7-2015 from which EJP CONCERT has been developed: https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/nfrp-07-2015.html

[3] link to the revisited Lund declaration, 2015

[4] MELODI – Multidisciplinary European Low Dose Initiative; EURADOS – European Radiation Dosimetry Group; NERIS - European Platform on preparedness for nuclear and radiological emergency response and recovery; ALLIANCE – European Radioecology Alliance, EURADOS – European Radiation Dosimetry Group; EURAMED - The European Alliance for Medical Radiation Protection Research.

- Subsequent Open Research Calls have been organised by the research community in OPERRA and COMET (FP7) as well as in CONCERT (H2020), with radiation protection research topics to support the European integration process in the disciplines concerned. Important drivers in this are (a) the need to contribute to answering overarching questions regarding the adequacy of the current system and practice of radiation protection and (b) responding to society's needs through excellent science, making use of state-of-the-art research infrastructure. The call priorities were based on a selection of key priorities from the Annual Statements of the radiation protection research platforms.
- Connections have been established with international organisations linked to radiation protection and its underlying science (e.g., UNSCEAR, ICRP, IAEA, OECD-NEA), with international networks of expertise (e.g. IRPA, MODARIA, BIOPROTA, International Union of Radioecology), and with Technical Platforms on nuclear safety or waste like SNE-TP and IGD-TP respectively[5]. These connections were also extended to broader scientific areas such as human health, environment and ecology. Initiatives towards E&T, use of and access to infrastructures (including biobanking and tools dedicated to knowledge management) and stakeholder involvement have been taken and will be continued.

A long-term research funding instrument would enable the planning of research calls in a consecutive way based on the joint roadmap and the individual roadmaps prepared by the radiation protection research platforms, to enable research to be planned in a strategic and logical manner. Such long-term instrument would avoid the limitation of duration of funded research projects, as was the case in research calls launched in DoReMi, COMET, OPERRA and CONCERT. It would allow long-term studies (e.g. epidemiological life-span studies) and an even better interlinked research between the different areas of radiation protection.

The joint roadmap is intended as a guide to plan radiation protection research over the next decades. It intends to provide the scientific basis to support a long-term funding instrument for radiation protection research. The joint roadmap also intends to provide information to research groups to align their research priorities accordingly and increase their potential for participation in radiation protection research. The roadmap might be used as a basis to setup a long-term research call plan in Europe. The joint roadmap for radiation protection research should be regularly updated taking into account research progress and updated societal needs, even beyond the end of the CONCERT project.

II. Proposed strategy to build the joint roadmap for radiation protection research

The ultimate goal of the joint roadmap will be to identify and plan the research and the development of tools that would be of assistance to further optimize the existing radiation protection system, taking into account the societal needs and concerns.

Figure 1 gives the proposed steps to build the joint roadmap.

[5] Links to international organisations, international networks of expertise and technological platforms: UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation; ICRP: International Commission on Radiological Protection ; IAEA: International Atomic Energy Agency; OECD-NEA: Organisation for Economic Co-operation and Development - Nuclear Energy Agency; IRPA: International Radiation Protection Association; MODARIA Modelling and Data for Radiological Impact Assessments; BIOPROTA: International collaboration in biosphere research for radioactive waste disposal; IUR: International Union of Radioecology; SNE-TP: Sustainable Nuclear Energy Technological Platform ; IGD-TP: Implementing Geological Disposal of radioactive waste Technology Platform

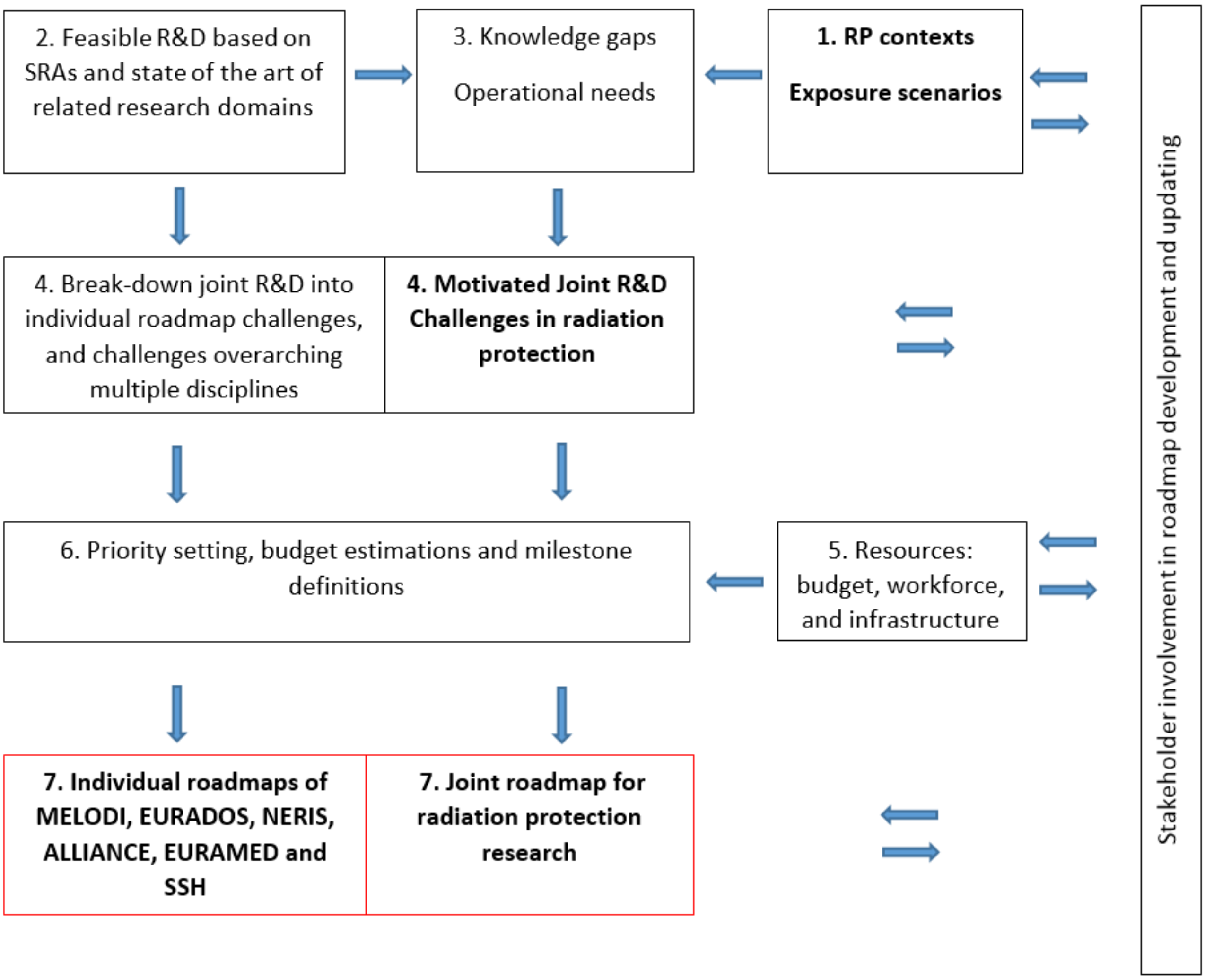

Figure 1 Proposed strategy towards the development of joint and individual roadmaps for radiation protection research.

A set of realistic exposure scenarios that may result from exposures to man-made or natural sources of ionising radiation has been identified (**Step 1**, cfr. Section III). Feasible R&D as listed in the Strategic Research Agendas (SRA) available for all areas of radiation protection research (**Step 2**), in combination with a description of realistic exposure scenarios allows to identify potential knowledge gaps and operational needs regarding radiation protection **(Step 3)**. This resulted in a first set of joint radiation protection research challenges and tools (**Step 4**, cfr. Section IV), as the current basis to initiate discussions with the wider research community and other stakeholders. In parallel to the development of the joint challenges, individual challenges focusing on the research areas of the different radiation protection platforms and SSH are being developed (Step 4).

Future steps to develop the joint roadmap, beyond this document, will include priority setting, taking into account available resources / needed resources related to budget, workforce and infrastructure (**Steps 5 and Step 6).**

All steps should be further elaborated taking into account input from relevant stakeholders. A short description how to proceed is provided in Section V.

Alongside the development of the joint roadmap, individual roadmaps will be provided by the individual radiation protection research platforms and SSH, focusing on their respective research disciplines **(Step 7)**. The development of joint and individual roadmaps should be performed in a concerted way to create a consistent set of documents guiding research for the next decades.

III. Radiation protection contexts and scenarios as a basis for radiation protection research

Section III presents the first results of step 1 of the joint roadmap development strategy as represented in Figure 1.

Mapping of potential exposures of humans and the environment has been based on a two-dimensional approach, with on one side **RP contexts** resulting from man-made or natural sources of exposures, and on the other side **exposure scenarios** that may result from planned, existing or emergency situations. A graphical representation of this two-dimensional approach is available in Table 1 on page 10

1. Radiation protection contexts

Exposures to ionising radiation for which radiation protection may be required can be grouped in the four following contexts, from which the first three result from human activities, whereas the last one is inherent to the natural environment on earth and in the atmosphere.

I. **Human activities related to medical therapy and diagnosis using radionuclides and X rays, protons or ions:** medical exposure of patients and personnel due to procedures, production and manipulation of sources/radiopharmaceuticals and related radioactive waste management.

II. **Human activities related to nuclear energy applications and other industrial applications of ionising radiation not related to medical applications**
   a. Installations from the nuclear fuel cycle: uranium mining and milling, fuel preparation, exploitations such as energy production in NPPs, spent fuel reprocessing, waste management and decommissioning, research reactors, fusion research and particle accelerators.
   b. Industrial and scientific applications of ionising radiation e.g. welding control, security screening, irradiators.
   c. Military: former nuclear bomb testing sites, weapons fallout and nuclear-powered vessels (submarines).

III. **Human activities related to the use of natural resources, containing naturally occurring radionuclides (NORM / TENORM)**
   a. Mining, processing, waste management of natural resources containing natural radionuclides (NORM) (e.g. oil and gas extraction, NOR-rich ore mining).
   b. Use, processing, recycling and waste management of technologically enhanced naturally occurring radionuclides, including decommissioning of NORM affected industrial facilities.
   c. NORM contaminated legacy sites.

IV. **Natural radiation as source of ionising radiation: terrestrial and cosmogenic radiation, natural events leading to radionuclide releases**
   a. High natural radiation background areas, potentially resulting in radon and thoron in indoor air and/ or in natural nuclides present in water/food.
   b. Exposure to cosmic radiation at high-altitude or in space.

Seven exposure scenarios related to the four contexts have been identified as shown in Table 1. The seven scenarios are grouped according to the ICRP classification in planned, existing and emergency exposure situations. These scenarios cover all the types of exposure situations potentially experienced by the public, patients, workers and the environment. The table illustrates which types of exposure situations may occur in a certain context and exposure scenario.

The contribution and or relevance of particular scenarios to the total exposure may differ for humans and the environment between countries, regions, populations and individuals, and may also change in time.

It should be noted that each of the seven scenarios represent a variety of sub-scenarios, resulting in specific exposures that may exhibit specific knowledge gaps, research needs or tools.

Table 1 (next page): Exposure scenarios related to different exposure situations categorised according to ICRP classification (planned, existing or emergency exposure situations). The columns represent the different exposure sources (anthropogenic/natural) and contexts (medical, nuclear, NORM - TENORM and natural). The table shows that scenarios may originate from the different exposure situations. For emergency scenarios it should be noted that the first phase is classified as emergency while the recovery phase on the longer term is treated as legacy which is an existing exposure situation.

ICRP classification	n°	Radiation protection in various exposure scenarios	Sources giving rise to exposure of humans and the environment (under planned, existing or emergency exposure situations)			
			Anthropogenic sources of ionising radiation			Natural sources
	n°	4 Contexts→ 7 Scenarios ↓	Human activities related to **medical therapy and diagnosis** using radionuclides and ionising radiation	Human activities related to **nuclear applications and applications of ionising radiation** not related to medical applications	Human activities **using natural resources containing naturally occurring radionuclides (NORM/TENORM)**	**Natural background radiation**: telluric and cosmogenic, and natural events leading to radionuclide emissions
Planned	1	Patients exposure regarding medical applications of X rays, electron or particle radiation including the use of radiopharmaceuticals	Patients undergoing - diagnosis - therapy			
Planned	2	Exposure of the general public and the environment as a consequence of industrial applications of ionising radiation and the use of NORM in normal operation (full facility life cycle)		Habitants and environment near nuclear fuel cycle activities (including NPP) and other nuclear installations, including impact of non-radioactive pollutants	Members of the public and the environment exposed to liquid, gaseous and solid discharges from NORM generating industry: - oil & gas platforms - coal mines and coal combustion installations - exploitation of geothermal energy, - mines and processing facilities related to Rare Earth Elements, Phosphate, Zircon and Zirconia	
Planned	3	Planned exposure of workers in normal operation conditions	- Clinical staff - Workers in radionuclide source / radiopharmaceuticals production sites technical staff operating accelerators	Workers in nuclear fuel cycle and in industries using radioactive sources	Workers in NORM generating industries - Workers using NORM containing materials/tools (e.g. welding rods, abrasive materials) - Workers involved in NORM contaminated sites reclamation - Workers involved in NORM residues disposal/recycling/reuse	Aviation personnel and astronauts
Existing	4	Exposure of the general public and the environment with regard to legacy		- Legacy from nuclear fuel cycle including mining, processing, electricity production, reprocessing, waste and decommissioning - Legacy from other nuclear installations	NORM legacy sites such as unauthorised landfill sites, sediments created from formation water released into fresh water / marine environment and NORM in building materials	
Existing	5	Exposure of the general public and the environment with regard to the natural radiation environment				Elevated natural background: - radon / thoron - high gamma by Uranium and Radium in ground waters Cosmic radiation (aviation by public)
Emergency	6	Exposure of the general public, workers and the environment following a major nuclear or radiological accident or incident including long term consequences (referred as existing exposure situation)	Accident/incident related to - radionuclide / radiopharmaceuticals production in nuclear installations; - lost sources, - patient dosimetry accident	Accident related to nuclear fuel cycle, NPP and other nuclear installations, transport or waste repository	E.g. leakage from NORM industry installations: soil, river and/or seawater contaminations; including consequences to human health	
Emergency	7	Radiation protection of public, workers and environment as a consequence of a malevolent nuclear or radiological act including long term consequences (referred as existing exposure situation)	Malicious act to society with consequences on installations or abuse of ionising sources			

2. Exposure scenarios

Exposure scenarios cover a range of potential exposures of humans and the environment. These may originate from various human-made sources or from natural radiation and may result from planned, existing or emergency situations.

Scenario 1 – Patients exposure regarding medical applications of X-rays, electron or particle radiation including the use of radiopharmaceuticals

This scenario encompasses the medical exposure of patients to ionising radiation. These exposures result in the highest average exposures to humans related to man-made sources of ionising radiation at least in developed countries like in Europe, where the total annual average dose of X-ray and nuclear medical imaging procedures is 1.1 mSv per caput, from which about 5% is due to nuclear medicine imaging procedures[6].

The exposures to individual members of the public may vary substantially depending on their health status, the national health care system and the type of equipment technology used: For example, the average annual effective doses per caput from X-ray procedures in Europe range from 0.25 mSv in Moldova to 1.96 mSv in Belgium[7]. Each specific investigation might be performed within a large variety of parameters and settings within different countries, regions, hospitals or even departments. Many individual members of the public may not receive any medical exposure in one year at all whilst some patients may undergo some abdominal CT scan each of which with an effective dose[8] of about 10 mSv.

A slightly increasing trend of average exposure per caput related to medical applications of ionising radiation is seen during the last decades, and the awareness of adverse effects has pointed out the need for optimising imaging procedure with respect to the diagnostic outcome based on valuable description of image quality and outcome while decreasing the exposure to ionising radiation. The distribution of exposures resulting from certain procedures like interventional or fluoroscopy-guided procedures can show differences in orders of magnitude resulting in local doses in the range of a few gray. Exposure related to radiation therapy using external irradiation or radiopharmaceuticals may result in very high doses to tumours, in the order of multiple tens of grays. Surrounding healthy tissues may also receive significant doses in the range of a few gray, which may result in secondary effects such as acute inflammation, or late cancer / non-cancer diseases.

Especially young children with higher radiosensitivity undergoing repeated examinations may develop secondary effects. Like age, other individual sensitivities related to e.g. gender, age, disease-related and genetic background seem important to deal with. Unravelling individual sensitivities may ultimately refine the system of radiation protection, especially in the context of medical applications.

Besides the development of direct radiation protection optimisation in terms of medical outcome per related risk through personalization and harmonisation of practices it would be feasible to study the secondary effects of medical exposures. However, it is important that assessment of secondary effects resulting from medical exposures take into account the health status and drug intake of the patient.

Such research initiatives are only possible when regulations are adapted to support the harmonisation of medical practices and protocols, and to enable the use of relevant patient data for research, while respecting privacy.

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[6] Study on European Population Doses from Medical Exposure (Dose Datamed 2, DDM2) Project report part 1: European Population Dose, page 9. Contract ENER/2010/NUCL/SI2.581237, 2010

[7] DDM2, table 5.13, part 1, 2010

[8] The meaning of effective dose in terms of medical exposures might be questionable; it should not be used for individual risk estimates. We refer to dose concepts in Challenge 2.

The ultimate goal of research related to scenario 1 is to provide information to policy makers, national healthcare, health practitioners and patients on optimisation strategies, to allow informed decision-making, and to adjust protocols to optimise image quality/dose.

Scenario 2 – Exposure of the general public and the environment as a consequence of industrial applications of ionising radiation and the use of NORM in normal operation conditions

This scenario is covering a wide range of human activities. The operations linked with the nuclear fuel cycle (from uranium mining and milling up to final radioactive waste management and disposal and decommissioning), with industrial activities making use of ionising radiation as well as linked with the industries handling material containing natural radioactivity (NORM/TENORM), may lead to releases of radioactivity to the environment, which need to be controlled in order not to harm man nor environment.

To assess robustly the transfer and distribution of radionuclides in the environment from source to target (man and environment), fit-for-purpose models are required capable to capture the required uncertainty. Uncertainties linked with exposure assessment may be related to the physicochemical behaviour and transport of radionuclides, transfer to biota, dosimetry and dose assessment in humans and biota.

In some cases, a full understanding of the bio-physico-geochemical processes affecting radionuclide mobility in biosphere, geosphere and atmosphere is required. This requires the development of models underpinned by dedicated laboratory and field experiments and studies, the development of dedicated data bases of parameter values.

The human and environmental exposure and impact assessment, both for predictive (e.g. new built) and operational situations needs to consider not only the radiological component but also societal and ethical aspects.

Potential (health) effects to man and environment is expected to be negligible given the generally very low dose rate/annual exposure.

Scenario 3 - Exposure of workers in normal operation conditions.

The description of this scenario is based on a summary of data from the ESOREX[9] platform, which was developed to gather information on occupational exposures in Europe. The information gathered by ESOREX included how personalised monitoring, reporting & recording of dosimetric results is structured in European countries. The ESOREX platform also collects reliable and directly comparable individual and collective exposure data in all occupational sectors in which classified workers are employed, i.e. in the medical field (e.g., diagnostic radiology, interventional radiology, radiotherapy, diagnostic/ therapeutic nuclear medicine, dental radiology, veterinary medicine), in nuclear industries (nuclear fuel cycle for civil and military purposes), in industries using radioactive sources (e.g. industrial radiography, X ray fluorescence, industrial gauges, electro-beam welding, radioisotopes production and conditioning, industrial irradiation, security screening), in NORM-related industries (e.g. ore mining & processing, handling and storage of NORM, oil & gas industries, coal combustion) and in activities where employees are exposed to natural background radiation (e.g. in aviation).

[9] ESOREX platform: (1) Establishment of a European Platform for Occupational Radiation Exposure –Highlights of the final report Contract n° ENER/2012/NUCL/SI2.636456, Rapport PRP-HOM 2015-00010,2015; (2) website https://esorex-platform.org/

The type of occupational exposure varies and could include exposure through inhalation (e.g., of radon or radioactive dust), external whole body exposure (e.g. in various sectors and to air crew exposure to cosmic radiation), or external exposure of extremities and eyes to gamma radiation (e.g. in the medical sector), all of them potentially resulting in different health effects.

The mean values for monitored workers in 2015[10] for all categories was 0.27 mSv/year in European countries that provided data to ESOREX[11]. On the individual level, occupational exposures may be higher: From the data available for France in 2015, the annual average dose to *measurably exposed workers*[12] in NORM industry is the highest (i.e. 1.94 mSv) and originating mainly from Rn inhalation, followed by workers in industry using radiation sources (1.38 mSv), nuclear industry (1.17 mSv) and medicine (0.34 mSv), mostly as external exposures. To complete the list of occupational exposures, we include the annual average aircrew exposure in Germany in 2015 (which was not measured but calculated with suitable codes that include flight route and the field of secondary cosmic radiation in the atmosphere), which was 2 mSv, with individual aircrew exposures up to 6.5 mSv. Annual collective doses in France in 2015 in NORM industriese, industries using radiation sources, nuclear industry and medicine were 38 770, 17 990, 27 450 and 15 380 manSv, received by about 20 000, 33 000, 70 000 and 200 000 workers, respectively.

A large number of workers is covered by this scenario, and hence efforts are needed to improve the assessment of doses and optimize radiation protection.

Awareness of and integration of protection culture into industrial planning and the implementation of the new BSS plays a key role for an optimized radiological protection.

Scenario 4 - Exposure of the general public and the environment with regard to legacy.

Past development of commercial and military uses of radioactive material and material containing naturally occurring radioactive materials (NORM), led to the development of many nuclear or NORM facilities worldwide. In many countries, these facilities were built and operated before the regulatory infrastructure was in place to ensure proper emission and residue handling and end-of-life decommissioning. This has led to legacy sites worldwide, contaminated with long-lived radioactive and also other toxic residues that may pose substantial environmental and health concerns. Other type of legacy is that linked with former nuclear bomb testing sites, areas where ammunition of depleted uranium was used, areas impacted by accidents of submarine or nuclear energy-driven satellites or orphan radiological sources. Legacy sites are characterised by a large variability, complex and heterogeneous features and cover a broad range of issues. These legacy sites may cause radiological (and chemical) exposure to man and wildlife and may entail health risks and/or induce ecological damage. To robustly assess exposure to man and environment and propose remedial options fit-for-purpose, transfer and exposure models are essential. Justification and optimisation of the remediation strategy should involve a multi-criteria approach in which stakeholders are actively involved in each step.

Exposure of man and wildlife is generally higher at legacy sites than at nuclear and NORM sites under normal operation. Impact assessment for man and environment is hence generally more crucial than for scenario 2. Since public exposure is sometimes in a dose range where there are uncertainties on the effects, scientific development is essential to predict health effects at these ‘low’ dose rates and related total dose.

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[10] 2015 is the most actual year for which most countries have provided results in the ESOREX platform

[11] ESOREX data including data from France, Germany, Greece, Switzerland, Finland, Slovenia, Spain, Lithania, The Netherlands

[12] There is a difference between monitored and measurably exposed workers: compared to “*measurably exposed workers*”, “*monitored workers*” include individuals not having received a dose above the recording level, which is mostly equal to the applied method’s detection limit, or which have received doses equal or lower than the limits to the public (≤1 mSv).

Proper site characterization, human and environmental exposure and impact assessments, safety assessments and evaluation of remediation options (in terms of technical performance, associated exposure reduction and social impact), constitute the basis for decision making and need to be based on robust scientific and technological developments, as well as on the concerns of the various stakeholders. They have to integrate uncertainty estimates that would help identify the priorities for scientific research to be dedicated to the most uncertain processes/parts of the assessment, and take into account at the same time societal uncertainties and ethical implications of decision-making.

Scenario 5 - Exposure of the public and the environment to the natural radiation environment

Radiation emitted from natural terrestrial sources is largely due to primordial radionuclides, mainly ^{232}Th and ^{238}U series, and their decay products, as well as ^{40}K, which exist at trace levels in the earth's crust. Their concentrations in soil, sands, and rocks depend on the local geology of each region in the world. The average natural radiation exposure is 2.4 mSv/y (global average)[13], but may vary strongly from place to place (from < 1 mSv/year to 100 mSv/y). Indoor radon is the largest contributor to the natural radiation exposure of the general population and the link between radon exposure and development of lung cancer is well established. Dose due to inhalation of radon (and thoron) and resulting effects is subject to quite some controversy as exemplified by the discrepancy in radon dose-conversion factors (5 mSv per WLM in ICRP publication 65 and 21 mSv per WLM in the ICRP Radon Statement 2009). Worldwide consensus on dose conversion coefficients based on scientific evidence is needed to allow harmonised regulations and sound comparison of doses on a global level.

There is also a need to improve the knowledge on factors modifying the relationship between radon exposure and effects, as for example the interaction of radon with smoking habit or the radon-related risk for diseases other than lung cancer.

In recent years, several international studies have been carried out on the effects of background radiation on human health, but they are not fully conclusive on the specific radiation effect given the low dose rate, the impact of confounding factors etc. A more comprehensive dedicated international study is called upon. Another uncertainty concerns the possible relationship between background irradiation and cancer incidence, particularly in children.

High background areas might be regarded as ecosystems exposed to long-term low-dose radiation. Comparison of such ecosystems with other ecosystems in areas with much lower background radiation levels might reveal important evolutionary information on various populations.

Information on scenario 5 is important to inform public and legislators about the effects of natural radiation, and to assess the eventual needs for countermeasures to be taken to reduce the exposure of the general public and/or the environment.

Scenario 6 – Exposure of the general public, workers and the environment following a major nuclear or radiological accident or incident including long term consequences

This scenario includes all types of incidents or accidents in nuclear installations, transport of nuclear material, military installations and operations (e.g. 'broken arrow' incidents such as the incident of Palomares, Spain),

[13] UNSCEAR 2008 Annex B Table 12; it must be noted that different countries apply different dose conversion factors. Therefore the average dose should be regarded as a representation of the order of magnitude of the dose.

lost sources (such as the Goiânia accident in 1987), satellite return (such as the SNAP-A re-entry event) or other events involving uncontrolled but non-malevolent exposure or spread of radioactivity.
The impact to the affected population might range from local (e.g. a lost source) to worldwide (e.g. Fukushima and Chernobyl) and is not limited to individual health effects but may affect the environment as well as economic and social activities, e.g. all possible living conditions of a person.
Scenario 6 also **covers accidents related to the medical use of ionising radiation**. This includes among others accidental and unintended medical exposures, overexposure and wrong treatments of patients.
The timescales may range from days to decades or even longer, thus appropriate means have to be developed to deal with the related challenges as defined in Section IV. Preparedness, supporting scientific tools and engagement of all relevant stakeholders are some of the necessary scientific input to deal with the consequences and mitigate them as much as possible.

Scenario 7 – Radiation protection of the public, workers and environment as a consequence of a malevolent nuclear or radiological act including long term consequences

This scenario includes the exposure of public, workers and environment as a consequence of a **malevolent nuclear or radiological act including long term consequences**. The first threat of malicious use of radioactive matter was noted in 1995. Chechen rebels threatened the world for the first time with a new form of terrorism, which was discovered in Moscow near the Kremlin. They combined conventional explosives with radioactive material. In general the following radiological terrorist threats can be identified: (1) Improvised nuclear weapon devices; (2) radiological dispersal devices (such as dirty bomb); (3) radiological exposure devices (strong sealed source to expose an individual or group or a non-sealed source, such as the Litvinenko case) and (4) sabotage of a nuclear installation.
The expected contamination levels and as such the health and environmental consequences – except from improvised nuclear weapon devices – are generally considered to be lower, but the societal and economic impact could be comparable to a large nuclear event as described in scenario 6. Therefore, scientific means appropriate for scenario 6 can be applied but have to be adapted to meet special conditions of a malevolent nuclear or radiological act.

IV. Proposed joint radiation protection R&D challenges

Section IV deals with step 4 of the radiation protection joint roadmap development strategy proposed in Figure 1.
In this section, a first set of joint radiation protection R&D challenges is being presented. It is based on feasible R&D as listed in the Strategic Research Agendas (SRA) available for all areas of radiation protection research, and on the set of exposure scenarios as proposed in Section III, in which associated knowledge gaps and needs are indicated.
The proposed challenges will have to be updated through consultation of the research community as well as through a broader stakeholder consultation as explained in section V.1. Within the challenge description, reference is made to the relevant research priorities as defined by ICRP in 2017[14].
The challenges presented below are ordered according to the following logics:

[14] ICRP, Areas of Research to support the System of Radiological Protection, 2017. ICRP ref 4832-9526-9446.

Challenge A, *"Understanding radiation related human health effects"*, is the challenge directly linked to the central aim of the radiation protection system, i.e. to protect humans against ionising radiation. To optimize the current radiation protection system, it is important to understand the human health effects.

Challenge B, *"Improving the concept of effective dose and other quantities"*, directly follows from Challenge A: to assess dose-effects relationships, the dose and dose rate needs to be well quantified and understood. This challenge deals with improvement of the concept of dose quantities.

Challenge C, *"Studying the biological and ecological effects on biota"*, also follows directly from Challenge A, as human health on the long term is directly related with the fitness of the ecosystem.

Challenge D, "*Optimized radiation protection in medical applications of ionising radiation*", deals with the exposure from anthropogenic origin resulting in the highest annual average dose per caput in Europe. Improvement of radiation protection in medical applications of ionising radiation would benefit a large segment of the human population.

Challenge E, "*Improving radiation protection for workers*", deals with exposure of another large segment of the human population. Although average occupational annual doses are in most cases not higher than one mSv, some individuals may receive higher doses, deserving appropriate dose assessment methods and improved protection where relevant.

Challenge F, "*Integration and optimization of environmental exposure assessment for ionising radiation and other stressors"*, deals with the fact that ionising radiation is not the only stressor affecting human health and the environment. The challenge F deals with the exposure *assessment* including ionising radiation and other stressors collectively present in the biosphere, to support the challenges estimating the combined effects on human health (Challenge A) and on the ecosystem (Challenge C).

Challenge G, "*Optimizing emergency and recovery preparedness and response"* applies the knowledge available and to be further developed in all foregoing challenges, to optimize emergency and recovery preparedness and response. This challenge also includes societal and ethical aspects related to accidents and incidents.

Challenge H, *"Enhanced integration of radiation protection science with society"*, is the last but not the least, as there is a need to bring the knowledge from all previous challenges to the society in an appropriate format and language. This challenge deals with the link to the society, and the ethical and social dimensions of radiation protection research.

Challenge A – Understanding radiation related human health effects

The central aim of radiological protection is the protection of human health. Risks to health are the prime consideration in all situations of radiation exposure that include humans, and are therefore of relevance to radiological protection in all occupational, medical and public exposure situations, be they in emergencies or under normal conditions. The ultimate goal of this challenge therefore is to have a comprehensive quantitative and mechanistic understanding of all radiogenic health effects.

Exposure limits in radiation protection are based on knowledge of radiation cancer risk derived from epidemiological studies and assumed risk of heritable effects in humans. Epidemiologically derived risk estimates are limited in power below 100 mSv; risk below this level is extrapolated using a linear non-threshold (LNT) model that is justified on the basis of a biophysical argument that relates direct damage to nuclear DNA to mutations in specific genes that drive carcinogenesis. The mutational action of radiation may be modulated by other poorly characterised processes throughout the prolonged periods over which cancers develop. In addition to cancer risks, there is a developing body of evidence of risk of non-cancer conditions, notably circulatory disease, cataracts and cognitive effects at lower doses than previously recognised.

Refinement of risk assessment for both cancers and non-cancer diseases can be improved by further large scale epidemiological studies with good exposure assessment (see challenge B) and integration of mechanistic biological understanding of radiogenic disease processes. There is a need to further characterise organ-specific sensitivity and the distribution of risk within the population (evidence points to age, gender, genetic factors, exposure to other environmental risk factors and lifestyle as risk modifying factors). Information on the effects and risks associated with internal exposures, differing radiation qualities, and inhomogeneous exposures is needed.

Research needs in this domain could be defined as:

- To improve the quantitative assessment of the association between radiation exposure and cancer and non-cancer diseases, with integration of biomarkers as noted below when feasible.
- To improve the understanding of (1) the fundamental molecular and cellular actions of ionising radiation relating to radiogenic diseases, (2) the variation of responses at the individual level due to genetic factors, environmental and lifestyle factors and the interactions between these, and thereby (3) identify and validate biomarkers of exposure, disease and susceptibility for use in prospective and retrospective protection situations.
- To develop methods to integrate mechanistic understanding of radiogenic disease pathogenesis and epidemiological estimates of disease risk to improve health risk assessment.
- To characterise the differences in quantitative and mechanistic aspects of response dependant on radiation qualities, energy spectra and dose-rates both singly and as mixed fields.

Relevant ICRP research priorities: (i) Effects of protracted exposures and low dose rates, (ii) Mechanisms of low-dose effects and dose-response models that take account of them, (iii) Organ-specific, and age and sex differences in, sensitivity to cancer induction, (iv) The role of genetic differences in determining individual sensitivity, (v) Effects other than cancer and genetic effects and their contribution to detriment.

Challenge B – Improving the concept of effective dose and other quantities

Systems for quantifying the radiation and its likely effects have been developed for radiation protection purposes. The absorbed dose, the mean deposited energy per mass, is expressed in Gray (also in J/Kg) providing a measure of the interaction between ionising radiation and exposed materials. On the other hand, ICRP has introduced a system including effective dose (expressed in Sv) that could be applied to compare all relevant exposure situations (see exposures in scenarios in Section III). Effective dose is originally meant to correlate with the risk for cancer and hereditary effects for decision-making purposes. The effective dose is calculated from the absorbed dose using radiation weighting factors accounting for the different types of radiation and tissue weighting factors representing sensitivities of specific organs/ tissues exposed. Because effective dose is not measureable, so-called operational quantities such as personal dose equivalent or ambient dose equivalent were defined by ICRU and ICRP that are supposed to provide numerically close estimates of effective dose and that allow calibration of detectors and dosemeters used in radiation protection.

Absorbed dose is not based on an adequately detailed description of the energy deposition for correlation with biological consequences, because a) the dose-response relation for a particular biological system depends on the radiation parameters (e.g., type, energy) and the stochastic pattern of energy deposition, b) different biological systems have different susceptibilities for producing radiation-induced effects, c) many biological processes are non-linear and d) biological effects may differ depending on the temporal pattern of exposure.

In the case of incorporated radioactive material, the internally deposited energy is highly heterogeneous due to the uptake, biokinetics, retention and physical characteristics of the incorporated radionuclides and the transport within the body of the radiation emitted due to their decay. This is important e.g. for radon/thoron and progeny (see Scenario 5), but also because high individual variabilities of biokinetics are observed for radiopharmaceuticals used in nuclear medicine. Therefore, averaging over certain tissues and organs as done for the calculation of effective dose might be too simple.

Since the development of effective dose, *non-cancer effects* as defined in challenge A are assigned as potential effects of ionising radiation in the low dose region, depending on dose, radiation quality (spectrum), dose rate, and tissue (sub)types affected. The tissue weighting factors and radiation weighting factors do not take into account such endpoints.

For the improvement of concepts and quantities used in radiation protection it will be necessary to advance the understanding of spatial correlations of radiation interaction events, to quantify correlations between track structure and radiation damage (early at a subcellular and late at a systemic level), to improve the understanding of the biokinetics of internal emitters, and to update operational quantities for external exposure. A decision on the role of radiation-induced non-cancer effects in radiation protection is also challenging, and further validation through epidemiological and molecular studies is needed before a decision can be made whether or not to include such effects in the system of radiological protection (see Challenge A). Finally, a fundamental debate about the concept of effective dose itself and its applicability in a wide range of exposure scenarios is needed including discussion of potential complementary quantities.

Relevant ICRP research priorities: i) Effects other than cancer and genetic effects and their contribution to detriment, ii) reliability of dose assessments

Challenge C – Biological and ecological effects of low dose / dose rate exposure on biota

There are still key questions around low dose biological effects of ionising radiation for both human and environmental radiation protection. We need to complement the system of radiation protection to be able to address the breadth of diversity and biological responses to radiation (from molecules to ecosystems) in a credible and robust way to ensure confidence in our science.

Regarding ecological consequences of chronic exposure to ionising radiation (considering all exposure situations except those of scenario 1 and 3), the present system of radiation protection requires the development of more robust benchmarks. This requires new knowledge to confidently address the wide biodiversity for which radiosensitivity is currently thought to vary over six-orders of magnitude. We also need to understand the impact of multiple stressors exposure on radiation protection. Exploration of intra- and inter-species variation in radiosensitivity and of the mechanisms of trans-generational effects are priority topics to improve basic knowledge. Species sensitivity may often be the result of evolutionary adaptation or increased sensitivity under different environmental extremes; these processes may be genetic or epigenetic.

To support the radiation protection framework, research is required to contribute to the identification of the primary mechanisms of radiation induced effects at the molecular level and their propagation up to the individual, population and ecosystem level. To achieve this we need to improve our understanding of: (1) the fundamental molecular and cellular actions of ionising radiation relating to metabolic impairment and adverse effects on population-relevant functions (growth, reproduction and survival), (2) the variation of responses at the individual and species population levels due to genetic, environmental and behavioural factors and the interactions between them; (3) hereditary effects within populations, and the inter-population effects (including effects caused by passed exposure) in the ecosystem; (4) identify and validate biomarkers of exposure and effects for use in prospective and retrospective assessments. Fundamental to effects studies and reliable environmental assessment are robust methods for dose assessment.

Ecological consequences of ionising radiation exposure, such as after a major nuclear accident, are not fully understood and controversy still exists impacting upon the credibility of our science. Exposure-effects relationships in the field versus in the laboratory may be modified due to the combination of radiotoxicity effects on growth rate/reproduction and geographic gene diversity, competition, predation, abiotic factors including pollutants other than radionuclides, and perhaps most importantly historic exposure and effects.

Combining the “exposome” (describing the full source term of stressors to which organisms are exposed), with Adverse Outcome Pathways (the AOP approach is mechanistically based and describes the cascade of effects from molecular initiator events to subsequent responses at the cell, tissue, organ and the individual level, leading in the end to an adverse effect) has been proposed to study effects of multiple (chemical) stressors on humans and other species. This tool may also elucidate the role of ionising radiation in determining health and ecological (adverse) outcomes.

Relevant ICRP research priorities: (i) Mechanisms of low-dose effects and dose-response models that take account of them and (ii) Relating exposures, doses, and effects on population viability for non-human biota.

Challenge D – Optimizing radiation protection strategies in medicine

The exposure of patients from medical diagnostic and therapeutic procedures is the largest man-made source of exposure to ionising radiation within Europe (RP180) on average for the population, although it is not homogeneously distributed within the population. Therefore Europe faces the challenge how the exposure can be optimised and how optimization strategies can be implemented into clinical practice at the same level throughout Europe. To do so, two main sub-challenges have to be addressed:

Harmonisation of practises based on dose assessment, justification and optimisation:

Differences in population radiation doses between European countries may be partly attributed to the different criteria for justification of radiological examinations. However, a high variability in radiation doses has also been observed between sites for the same procedure. Optimisation of doses delivered during radiation therapy is a major concern due to the rapid development of radiotherapy technology and techniques. Optimization strategies are also needed for interventional procedures as well as for three-dimensional diagnostic radiological and nuclear medicine examinations. For these examinations, patient doses may be particularly high. An overall assessment of patient dose is required for estimating secondary health risks such as described in Challenge A (understanding human health effects). Major concerns in dose assessment are quantification of out-of-field dose distribution following radiotherapy and in imaging procedures as mentioned previously, with special emphasis to paediatric and young adult patients. Dose and imaging repositories need to be developed and harmonized at the European level to enable facilities to review and minimize doses and optimize protocols. The dose descriptors need to be robust, meaningful and standardized, to support future epidemiological studies as needed for Challenge A.

It is of utmost importance to perform research to find a European consensus on which procedures should be applied in which situation and how best use can be made from existing technologies for various levels of technological equipment in different environments. This “European always best use for existing technology” should allow similar exposure conditions among different patients for similar indications as well as similar diagnostic or therapeutic outcome throughout Europe. One key aspect is how to transfer the defined and agreed upon procedures into clinical practice throughout Europe.

Individualisation of medical exposures:

Individualisation of patient exposure is a very promising approach to avoid unwanted hazardous effects in applying ionising radiation in therapeutic and diagnostic procedures. This challenge should be addressed taking into consideration that the inhomogeneous spatial and temporal distributions of dynamic molecular biological processes induced in the patient needs to be understood in detail. Individualized dosimetry in this rapidly growing field is needed for accurate dose determination, e.g. dose assessment to the tumour resulting from external radiotherapy using different radiation types, or research to improve micro- or nanodosimetric dose assessment from nuclear medicine therapy and imaging techniques using different radiation types and a broad range of molecules resulting in radiopharmaceutical biokinetics which may vary substantially in different patients. Risk of radiogenic cancer or other induced diseases should also be assessed. Organs or body regions that are irradiated are typically already those affected by illnesses and might be specifically sensitive. For medical diagnostic procedures, the level of image quality performance necessary to produce images of diagnostic quality for specific clinical indications needs to be determined taking into account various parameters including patient body size, gender and, ideally, individual susceptibility. Such image quality needs to be predicted in order to optimize single procedures for individual patients. The process of stratification or individualization of procedures, diagnostic or therapeutic, has to be defined and followed upon in order to guarantee a harmonized application in clinical practice throughout Europe. Exposure data, which are derived in a standardized way, need to be documented. Specific emphasis should be placed on paediatric and young adult applications of ionising radiation.

Relevant ICRP research priority: Dosimetry and protection methods in medicine. However, there are also links to other ICRP research priorities as they are mentioned in challenge A and challenge H

Challenge E – Improving radiation protection for workers

Ionising radiation continues to be used in Europe in many industries and applications (nuclear, medical, air travel, etc.), including various and often complex exposure scenarios. Consequently radiation protection of workers is a major issue that requires continued improvement.

Internal exposures

Assessment of occupational exposure from incorporated radionuclides is still subject to major uncertainties, due to activity measurement errors, individual variability, limited biokinetic and dosimetric models, and unknown parameters of exposure. The resulting overall uncertainty on the estimated internal dose is acknowledged to be generally higher than that for external irradiation. In vivo measurements, for example, can provide actual information on radionuclide activity within the body of an individual. However, there is no standard procedure to calibrate the required detection systems (partial body counters), and anthropomorphic phantom(s) needed such as those used in order to assess the skeletal activity of bone seeking radionuclides (e.g., plutonium and americium isotopes) are scarce. Furthermore, biokinetic models for various radionuclides and individual parameters (which may also include changed body metabolism of patients, and effects of decorporation therapies) are still limited, and their predictions would benefit from the use of available databases including human autopsy cases. Thus, in a very general sense, improvements in internal dosimetry are needed to reduce the aforementioned uncertainties, with potential benefits also in radio-epidemiology (Challenge A), radiation protection of the public and diagnostic and therapeutic nuclear medicine (Challenge D).

For internal exposures the challenge is to reduce uncertainties involved in various steps of internal dose assessment. This requires major improvements in the experimental procedures used in in-vivo counting and in biokinetic modelling. In these areas, the development of individualized procedures is a particular challenge. In a very general sense, these efforts will also imply potential benefits in radio-epidemiology (Challenge A), diagnostic and therapeutic nuclear medicine (Challenge D), and radiation protection of the public in case of emergencies (Challenge G).

External exposures

The monitoring of external occupational exposure of individual workers will benefit from real-time monitoring of all limiting quantities (whole body, eye lens, extremities, brain, heart,…) including well-characterized active and passive dosimeters. In this context, neutron dosimetry includes particular problems. Some neutron applications in industry represent well-known but not yet solved problems such as the inevitable existence of photons that might interfere with the detection of neutrons. Others imply newly evolving problems due to strongly pulsed radiation or very high neutron energy ranges, i.e. radiation fields around high-energy particle accelerators and at flights at high altitudes or in space missions.

For external exposures the challenge is to assess relevant dose quantities in real-time. This should include all radiation qualities and in particular photons and neutrons, static and pulsed fields, and a vast range of radiation energies up to GeV. Appropriate neutron reference fields will need to be developed. These efforts together with improvements in procedures for dose optimization and improved protection measures will significantly contribute to a safer use of ionising radiation.

Furthermore, a key aspect across all applications and domains involving workers' exposures to ionising radiation is the development of radiation protection cultures in support of improved decision-making processes regarding the management of exposure situations and the involvement of the relevant stakeholders in the identification and implementation of radiological protection actions.
Relevant ICRP research priorities: (i) Reliability of dose assessments dosimetry, (ii) protection measures in medicine and (iii) ethical and social dimensions of the system of radiological protection

Challenge F - Integration and optimization of environmental exposure assessment for ionising radiation and other stressors

Faced with environmental exposure situations (all scenarios except scenario 1 and 3) where various environmental and human-population related factors strongly interfere, holistic approaches to risk assessment seem more and more justified to ensure sustainable and safe use of radioactive substances and to protect both human and ecosystem health. Integration of scientific, societal and economic considerations is needed, if more integrated dose and risk assessment approaches are to be developed to meet societal expectations, better inform decision making and improve risk communication among stakeholders, with special attention to vulnerable groups and ecosystems.
As a basis for more robust exposure assessment we need to improve the understanding and associated modelling of radionuclide dispersion and transfer processes in the geosphere, biosphere and atmosphere. This should include the dispersion and transfer assessment in (a) marine, brackish, estuarine and freshwater ecosystems, covering the watershed continuum from the source to the ocean and further afield at the global circulation level, and (b) terrestrial ecosystems (agricultural, forestry, natural and urban). The goal is to produce advanced environmental modelling to serve individual human dosimetric assessment. This goal could be reached more efficiently by collaborating with wider environmental sciences. Models should be improved, or developed, to allow for the interaction at the various biosphere interfaces at the local, regional and global scales. Detailed and personalised dose assessment will require more detailed environmental/biological transfer models for radionuclides including foodwebs and biokinetics modelling. Specific emphasis may need to be placed on integrated vulnerability analyses, by considering the interactions between natural hazards and radiologically contaminated areas (e.g., wildfires or hydro-meteorological events leading to redistribution of radionuclides) since the magnitude and occurrence of such processes is expected to increase in the context of climate change. To cope with the large amount of data resulting from elaborated and comprehensive transfer assessment, environmental monitoring and improved dose assessment, more advanced methods for data treatment need to be developed. There is a need for the improvement/development of innovative methods to characterise the source terms to delineate the multiple-hazard footprint (*e.g.,* geostatistical interpretation of environmental, radiological, chemical data) of a site in space and time and innovative modelling approaches for improved system understanding and to support decision making at various stages of remediation. Advanced system understanding is required to identify the most significant sources of uncertainty related to the impact on human and environmental health, which may be achieved by applying an integrated holistic modelling approach. Improved risk communication and stakeholder involvement, and the development of multi-criteria decision support approaches are required for optimized remediation and management, taking into account both radiological and non-radiological aspects.

For application of these research needs, specific emphasis should go to legacy sites which generally correspond to the higher exposure scenarios. They often represent complex "objects" to be managed *via* a multistage process comprising amongst other site characterization, definition of objectives for remediation, impact and risk assessment, and evaluation and selection of remedial options. Each steps comprises an associated uncertainty analysis, which is of both technical and social nature. Science is needed to support the development of improved international guidance on legacy management.
This challenge is in part connected to the following research priorities defined by ICRP: (i) Reliability of dose assessments, (ii) Ethical and social dimensions of the system of radiological protection, (iii) Mechanisms for interaction with stakeholder.

Challenge G – Optimizing emergency and recovery preparedness and response

In nuclear or radiological emergency management including accidental and unintended medical exposures, overexposure and wrong treatments of patients and in long term recovery, radiological impact assessment is of prime importance and calls for the improvement / development / customisation of atmospheric, aquatic, terrestrial and urban dispersion models, food chain models and dose assessment models, internal and external dosimetry and dose reconstruction and monitoring of the different environmental compartments, food and goods.
One of the future challenges is to develop and combine different modelling and monitoring techniques (including data assimilation techniques) to improve the predictions on the impact of an accident. Besides advancements in operational monitoring of dose rates values, nuclide-specific information and data on ground and air contamination levels an emerging challenge is to integrate measurements or assessments made by the public. The medical aspects of this challenge focus on internal and external dosimetry and dose reconstruction and optimised measures to reduce contamination and health effects.
To manage the radiological situation, there is a need for improved understanding of countermeasures to better build and implement countermeasure strategies at different time frames (preparedness, response, recovery). This includes the development of countermeasures and countermeasure strategies as well as their lifting in time. Important issues to be addressed are among others development of Operational Intervention Levels (OIL), effective decontamination (human & environmental), and waste handling from an accident. Improved mechanistic (process based) models will aid in better predicting where countermeasures will be required, the effect of some countermeasures in different geographical areas and also the likely length of time countermeasures will be required. It is also evident that countermeasure strategies have to deal with societal and ethical aspects including the environmental characteristics.
An inclusive evaluation of countermeasure strategies requires the involvement of all actors, including the public in all steps of preparedness for and recovery from accidents; especially those with off-site consequences. However, the stakeholder engagement process as such is a challenge and further developments on the participatory processes in emergency and recovery situations are required. Further to this, nuclear or radiological emergency response and recovery requires decisions under high uncertainty. This needs advanced decision science, disaster informatics and the use of big data.
Effective communication strategies during the emergency and in the post-accident phases -even under uncertainty- are a key challenge for success of any measure as they contribute to develop and keep trust between experts, authorities and the population, helping to better implement countermeasures and manage the recovery.

Many of these topics are region-dependent. Therefore preparedness should take into account local, accurate, environmental descriptions of potential sites of nuclear or radiological emergency. Models of the surrounding environment describing e.g. the population density, biosphere, geosphere and weather conditions should be readily available as for real-time dose reconstruction and impact assessment needed at the time of the event. Harmonisation of models across Europe, guidance and preparedness, especially in certain areas of environmental and health impact assessment, emergency response and recovery would decrease the threat when accidents or incidents occur.

Relevant ICRP research priorities: (i) Reliability of dose assessments, (ii) Ethical and social dimensions of the system of radiological protection, (iii) Mechanisms for interaction with stakeholders

Challenge H – Enhanced integration of radiation protection science with society

Despite the recognized need for multidisciplinary approaches to research and innovation including social sciences and humanities (European Commission, 2014), radiation protection research is still, to a large extent, characterized by a divide between the technical content and the social context. Research and innovation in radiation protection needs to be better aligned with the values, needs and expectations of society. This situation can be observed across numerous fields and application domains: nuclear medicine, naturally occurring radioactive materials, nuclear waste management, environmental remediation, emergency management, and decommissioning. The challenges faced by radiation protection R&D are substantial and attention to the societal dimensions is insufficient.

Communication, collaboration and engagement in the radiation protection field

Research on communication, collaboration and engagement is needed to advance our understanding of how people are included and excluded in radiation protection decision-making, and how processes of communication and collaboration foster novel forms of identity, sense making and belonging. The aim is to empower citizens to take informed decisions considering risks and benefits of exposures to ionising radiation. Communication about ionising radiation has to become citizen-centered, based on participatory approaches. This requires a good understanding of stakeholders' sense-making of ionising radiation concepts, risks and uncertainties, and their information needs, enhanced interaction and mutual understanding among the radiation protection stakeholders.

Whereas most results of radiation protection research are published in scientific journals or communicated using institution-centered expert language, there is a need to provide information in the right format and language to non-specialists, including the public, patients, policy makers, and victims of accidents, legacy sites or other exposure situations. Communication has to be developed as a multi-directional learning process between the stakeholders, and adapted to their concerns, needs and values. Moreover, participation of stakeholders in the decision-making process is essential for improving the efficiency and social robustness of decisions related to radiological protection. The main challenges associated with stakeholder participation are creating opportunities and venues for stakeholder engagement in radiation protection decision-making, and improving the understanding of the factors and criteria for successful stakeholder engagement in different exposure situations.

Integration, impact and reflexivity of radiation protection research

The need for multi- and transdisciplinary research and broader societal involvement in radiation protection is increasingly recommended at national and supra-national levels for all aspects of exposures to ionising

radiation. Radiation protection should enhance integration of social and ethical concerns into the system and the practice of radiological protection. It has to consider the social and ethical justification of exposures to ionising radiation and develop radiation protection culture where appropriate. Recognizing the intertwined character of social and technical resonates with the idea that science and technology are open to individual creativity, collective ingenuity, economic priorities, cultural values, institutional interests, stakeholder negotiation, and the exercise of power. It is thus important to reflect on how this shapes the organization of radiation protection research and the formulation of its policies. The impact of research activities on the values and choices made by radiation protection researchers in their communities should be examined. This includes giving due consideration to societal and ethical implications of research agendas, processes, and outputs, in line with the European-wide calls for Responsible Research and Innovation.
Radiation protection research should support reflexive, inclusive, anticipatory and socially engaged attitudes among the science, technology and innovation communities in the radiation protection field, and should strive towards multi- and trans-disciplinary research approaches.
Relevant ICRP research priorities: (i) Ethical and social dimensions of the system of radiological protection, (ii) Mechanisms for interaction with stakeholders

V. Future steps towards development of the joint roadmap

The strategy to develop the joint roadmap as defined in Section II and Figure 1 includes the ambition to involve stakeholders in each step of the process. This is needed to ensure that the joint roadmap will be a realistic and widely accepted guide to plan research for the next decades.
The joint roadmap should also be accompanied by a realistic budget, agreed upon with relevant stakeholders, as it intends to provide the scientific basis to propose the establishment of a long-term funding instrument including a long-term research call planning.
The joint roadmap for radiation protection research should be regularly updated taking into account research progress and updated societal needs.
Prior to further elaborate the joint roadmap, the authors consider that stakeholder consultation should take place to discuss the proposed exposure scenarios including needs and research gaps (**Step 1 and 3**) and the proposed research challenges (**Step 4**).
In this section we briefly describe how a stakeholder consultation plan will be elaborated, and how **Step 5**, defining the available resources and **Step 6**, priority setting will be further elaborated.
Regardless the end of the CONCERT project in 2020, it is the purpose to further develop and updated the joint roadmap for radiation protection research beyond 2020, as it is intended as a guide to plan radiation protection research over the next decades.

1. Stakeholder involvement

The social basis of the joint and individual roadmaps for radiation protection research could be maximized through appropriate stakeholder involvement in all steps of the joint roadmap development.

A common approach for stakeholder involvement in the development of the joint and individual roadmaps will be elaborated in the near future, in collaboration with a stakeholder group that has been setup in CONCERT WP5[15].

This "CONCERT stakeholder group" includes stakeholders exposed or affected/impacted in an occupational, medical or environmental context; stakeholders coming from civil society (NGO, consumer associations, environmental associations); stakeholders with responsibilities for ensuring adequate radiation protection of those exposed (policy makers, those involved in international standard development, national authorities and public expert bodies such as technical support organizations) and stakeholders with an interest or duty of care in the system of radiation protection of humans and the environment (e.g. industrial, operational radiation protection specialists, public health workers and health physics). Members of this group have been proposed by the radiation protection research platforms, by the social science and humanities experts and by the WP5 partners.

The CONCERT Stakeholder Group was setup, amongst other goals, to organize exchange between the stakeholder group and the CONCERT WP2-WP3 group, the latter mainly representing the radiation protection research platforms MELODI, EURADOS, NERIS, ALLIANCE and EURAMED as well as experts in social sciences and humanities related to radiation protection, responsible for the development of the joint and individual roadmaps.

The first meeting of the CONCERT Stakeholder Group was organized on 27-28 September 2017. During this meeting, the WP3 leader (Nathalie Impens) introduced the aims of the roadmap, and initiated a discussion on how to involve stakeholders in the development of the Joint roadmap.

It has been proposed that the WP5 stakeholder group will provide inputs for the different scenarios, will be involved in the setup of a stakeholder involvement plan and that members of the WP5 stakeholder group will support the implementation of the plan by providing contacts, each in their own field of interest or duty, to enlarge the stakeholder consultation to a wider stakeholder community.

Stakeholders with different perspectives, skills, and decision power will be invited to contribute to the different steps in the roadmap development strategy (Figure 1), but limited to the contexts and scenarios of their interest to limit the workload and maximize the quality of the stakeholder consultation outcome in an efficient way.

Some stakeholders, including decision-makers at national level such as the CONCERT Management Board, and decision-makers at European level and other potential sponsors for radiation protection research will be invited to assist to explicitly discuss priority setting, budgets and budget allocation mechanisms, next to the other steps in the roadmap development.

A stakeholder involvement plan will be elaborated in 2018. The plan will be implemented and result in a first draft joint roadmap for radiation protection research in 2019.

2. Priority setting, budget estimations and milestone definitions

Criteria will need to be defined in order to prioritise research.

A first set of criteria was discussed with the CONCERT Stakeholder Group. The proposed criteria were:

- Dose-related: contexts/exposure scenarios/ exposure situations within certain scenarios delivering the highest exposure ranges (doses and dose-rate), the highest number of exposed, or resulting in certain adverse outcomes could be regarded as a criterion to prioritisation.

[15] The CONCERT WP5 Stakeholder Group is set up by Sylvie Charron (IRSN) with the support of Caroline Schieber and Mélanie Maître (CEPN)

- Budgets available: including that budgets might be different for different contexts or exposure scenarios.
- Feasibility: Priority respecting logical sequence of research steps.
- Relevance for society: which may be valued differently by different stakeholders; as such a weighting on these values should be elaborated.

These criteria are remarkably similar to the most important research prioritisation criteria developed by researchers and stakeholders in the FP7 COMET project for ALLIANCE-related research.
These criteria need to be further discussed in the course of the development of the joint roadmap, and weighting criteria should be setup to determine how to take into account the different prioritisation criteria.
Budget estimations and milestones will have to be defined in a later stage, as this will depend on the future elaboration of the scenarios and the research challenges and tools.

3. Available resources: budget, workforce and infrastructure

Available Budget

The ultimate goal of the joint roadmap for radiation protection research is to be a guide for research for the next decades. In order to be a realistic guide, the roadmap should be accompanied by a budget needed to fulfil the research to provide the knowledge and tools supporting improved radiation protection in areas of concern and to provide answers to the society's questions related to radiation protection.
Resources in terms of budget will have to be discussed with stakeholders responsible for national research budgets, European resources as well as with other sponsors that might be interested to contribute to the implementation of the joint roadmap for radiation protection research.

Maintaining and developing the knowledge and skills resource in the research community

It is now recognised that an essential component of any medium-long term research plan is the maintenance and development of the knowledge base and expertise of the research community through a strategic programme of education and training. This is particularly true for research into the risks from ionising radiation, both because the core subjects of radiation physics and radiobiology are not attracting new students in the numbers they used to, and because new disciplines such as systems radiation biology and bioinformatics need to be embraced so that researchers can take advantage of new technologies.
Currently, CONCERT promotes a number of E&T initiatives as integrative activities. Included in these is a requirement that any research project funded by CONCERT has an "E&T Plan" that details how the project work will involve student activities. This roadmap recommends that future research must take the same approach, and that both planning and resources must be committed to the inclusion of E&T in radiation protection research projects.

World-class research infrastructure

Research infrastructures are committed to provide access to the most advanced, unique, and large-scale resources, instruments and expertise in Europe. These services enable European scientists to conduct competitive and cutting edge research. The necessity to focus on research infrastructures in Radiation protection has been highlighted in the HLEG re-port in 2009. Since then, large EURATOM projects such as DoReMi, OPERRA, STAR and COMET include specific WPs and tasks dedicated to infrastructures as well as SRAs that present dedicated chapters.

Inventory of European infrastructures and future needs having revealed that most necessary infrastructures are already available. We need make better use of existing competences and research infrastructures in Europe. The current challenge is to facilitate their access by increasing their visibility.

In important aspect of developing infrastructure at the European level is to correct an apparent north-south bias in respect to resources and access to research financing, designing financial instruments that positively address the situation, avoiding the concentration of resources in a few well-established research centres and opening the research networks to further participation in the most transparent way possible.

Next steps will rely into further harmonisation of quality standards, practices and protocols in relation to the use of infrastructure. Huge efforts will be dedicated to sample/data acquisition and sample/data storage with the aims to re-use of archived materials. We will propose trans-national agreement on a strategic work plan for maintenance, updating, mutual use and new needs of suitable infrastructures. Meanwhile, education and training actions will promote the use of European research infrastructures the advantage of using newer, larger, faster, more powerful infrastructures although not at the bench of each user.