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Long-term maintaining and expanding expertise in the field of radiation research and application in Germany – Measures

Recommendation by the German Commission on Radiological Protection

Adopted at the 327th meeting of the German Commission on Radiological Protection
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Langfristige Sicherung und Ausbau der Kompetenz auf dem Gebiet der Strahlenforschung und -anwendung in Deutschland – Maßnahmenkatalog Kompetenzerhalt

Empfehlung der Strahlenschutzkommission

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1 Introduction

1.1 BMU advisory mandate

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) issued an advisory mandate on 11 November 2020 asking the SSK to review and if necessary revise its 2006 recommendation on ensuring the long-term preservation of expertise in the area of radiation research in Germany ("Langfristige Sicherung des Kompetenzerhaltes auf dem Gebiet der Strahlenforschung in Deutschland" –SSK 2006). The BMU wanted the SSK to answer the question *"who in Germany will be capable in future of undertaking basic research in radiation protection and what measures can be taken to promote radiation research."* The objective was to assemble a package of measures *"the implementation of which will support research in the field of ionising and non-ionising radiation in Germany and ensure the preservation of expertise in the long term*." The BMU asked the SSK to focus in particular on a potential reorientation of institutional research funding and, as a first step to be concluded swiftly by early 2021, to *"identify the most important areas of expertise and actors needed to ensure the maintaining of expertise in radiation research in the long term."*

The background to the advisory mandate from the BMU was the fact that the Federal German Government (2017 to 2021) had "*highlighted the importance of maintaining expertise and specialist personnel in the field of nuclear safety, radiation protection and safe disposal into the future even after electricity generation in nuclear facilities has come to an end*" in the coalition agreement of March 2018 and its Strategy for Competence Building and the Development of Future Talent for Nuclear Safety.

In this connection, the SSK expressly emphasises that the importance of radiation research for Germany is not affected, or only barely, by the ending of the commercial use of nuclear energy in Germany in April 2023. Radiation protection (or radiological protection) – protection against ionising and non-ionising radiation – encompasses a large number of very different disciplines. The field of occupational radiation protection affects all workers who deal with or are exposed to ionising radiation or radioactive substances, and not only persons employed in nuclear facilities. These include, for example, people working in the medical sector, on the demolition of decommissioned plants or in waterworks, as well as aircrew. As far as radiation exposure of the general public is concerned, radon in indoor settings makes the largest contribution to annual radiation exposure in Germany in terms of natural radioactivity. Medical applications, too, contribute more to annual radiation exposure of the general public than was the case from the operation of nuclear power plants in Germany. Furthermore, there is little change to the importance of radiological emergency preparedness and response because Germany is surrounded by numerous countries that continue to use nuclear energy to generate electricity. The importance of protection against non-ionising radiation is apparent in the need for protection against UV radiation and heat as a central element of urban planning, for example, especially against the backdrop of climate change, or protection against electromagnetic fields (EMF), in particular in light of the expansion of 5G and 6G networks or power transmission lines and electromobility in the course of the energy transition. This field of radiation protection is by its very nature not affected by the phase-out of nuclear energy. Radiation protection is therefore a separate matter from electricity generation in nuclear facilities and is an indispensable part of services of general interest and a key element in maintaining Germany as a centre for research and technology.

In response to the advisory mandate from the BMU, an SSK working group drew up a statement (SSK 2021), which should be seen as the first step in executing the mandate. In that statement the SSK identified the most important scientific disciplines and actors in radiation research (see Section 1.3). In the recommendation published here, the SSK now identifies the need to maintain and promote expertise in the various disciplines, analyses strengths and weaknesses of radiation research in Germany and presents proposals for measures to safeguard expertise in the long term.

In this context the SSK always views radiation research in terms of its (immediate and long-term) relevance to radiation protection, which also encompasses corresponding basic research on the effects of radiation. Wherever people are exposed to elevated radiation levels or new technological developments are accompanied by the generation and use of radiation, whether ionising or non-ionising, consideration must also be given to radiation protection, and such protection must be further refined as necessary.

The SSK conducted a questionnaire survey among relevant experts, from which a broad consensus emerged that many areas of science and technology benefit from expertise in radiation research and many technological developments would be impossible without such expertise. For example, technological advances in medicine are greatly dependent on expertise in radiation research, in particular the development of radiological imaging techniques (including MRI), new forms of radiation therapy (FLASH therapy, individualised treatment, particle therapy) and developments in diagnostics and therapy in nuclear medicine. Other examples mentioned were the expansion of the 5G network, detector development, the development of artificial intelligence methods, the development and application of lasers, and techniques that make use of neutrons. In addition, many developments in the natural sciences in general were also mentioned (e.g. bioinformatics, biology, immunology, geophysics), as well as those in environmental applications, space flight, materials research and testing, nuclear waste management (dismantling, interim storage, final disposal) and energy generation (nuclear fission, nuclear fusion, transmutation). To these can be added, in the SSK's view, future technologies such as quantum and biocomputing, and technologies used in the manufacture of chips or microdevices in the fields of mobility, data transfer and the circular economy. Many of these fields of research can benefit from the return flow of data, methods and findings from radiation research. It follows from this that – as described below – many societally relevant initiatives such as the Decade against Cancer cannot manage without radiation research and radiation protection.

In this recommendation the SSK focuses on maintaining expertise in training and research, since there can be no expertise in practical application without appropriately trained young people. This is true of both ionising and non-ionising radiation (UV radiation and EMF). The SSK is aware of the fact that there are also areas of application (for instance in radiation emergency medicine) that require structural (or infrastructural) change, but these are not conclusively discussed in this recommendation.

Radiation research in Germany continues to enjoy an excellent reputation on the international stage. The main reason for this is that German researchers in the past and to this day have been able to make a major contribution to improving our understanding of the significance of radiation for human beings while also playing a substantial part in putting this knowledge into practice for the further development of international radiation protection in a wide variety of international organisations. Maintaining and expanding expertise in radiation research in Germany is essential in order to ensure that Germany can continue to participate in international bodies in the future. Without such expertise, German involvement in the development of international radiation protection will no longer be possible, with the consequence that Germany could no longer contribute to international debate.

1.2 Initiatives by various ministries

1.2.1 Strategy for nuclear safety

In August 2020 the German Federal Ministry for Economic Affairs and Energy (BMWi) published a Federal Government Strategy for Competence Building and the Development of

Future Talent for Nuclear Safety, which was prepared jointly with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (BMWi 2020). In this, nuclear safety is understood as encompassing "*reactor safety, including the security, decommissioning and dismantling of nuclear facilities, nuclear waste management, including interim and final storage, and protection against ionising radiation in these areas.*" One of the challenges for Germany is "*to preserve its vast reservoir of knowledge and experience, amassed over decades of research and practical applications in various fields of nuclear safety, for future generations and expand it appropriately as part of a state service of general interest. To safeguard German safety interests, broad and interdisciplinary expertise in these fields will remain necessary in the future*." At the same time it is pointed out that similar issues regarding the maintenance of skills and competencies arise in "*radiation protection in medical therapy and diagnostics, in the industrial sector (outside nuclear technology) and in connection with natural sources of ionising radiation*." One reason for this is that research and development of innovative processes that involve the utilisation and generation of ionising radiation produce a constant demand for oversight by radiation protection experts both in industry (e.g. in material processing) and in medicine. However, the issues regarding the maintenance of skills and competencies in radiation protection in these areas "*must be addressed in a separate process*" (BMWi 2020).

The Strategy for Competence Building and the Development of Future Talent for Nuclear Safety identifies six areas of action, between which there is some overlap:

1) Education and teaching
2) Advanced and continuing training
3) Research and development
4) Knowledge retention, committee work and networks
5) International networking and cross-border activities
6) Career prospects and recognition in society

A total of 32 recommendations are put forward for these areas of action. The strategy concludes with the following assessment: "*Within their respective fields of responsibility, the BMBF, the BMU and the BMWi will take suitable measures to retain competence and skills and implement the strategy to the extent that funds available under the individual plans and human resources permit.*" The outcomes were to undergo review within five years at the latest (BMWi 2020).

In a statement on the strategy, the German-Swiss Association for Radiation Protection (Fachverband für Strahlenschutz – FS) insists that "*the focus within 'nuclear safety' on technical issues such as reactor safety, the decommissioning and dismantling of nuclear facilities and nuclear waste management is too narrowly trained*" (FS 2020). In particular, the FS notes that no account is taken of medical emergency preparedness and response in the event of radiological accidents, including its foundations in radiation physics and radiobiology. The SSK likewise, in its statement, recently identified these three areas (radiobiology, radiation physics and medical emergency preparedness and response) as being important areas for radiation research and the use of radiation (SSK 2021). The FS statement closes with the following assessment: "*There is already a lack of future talent, for example to fill positions on national and international advisory committees. This situation should be reversed*." (FS 2020).

1.2.2 Analysis of the requirement for expertise in radiation protection

To complement the BMWi strategy mentioned above, the BMU together with the Federal Office for Radiation Protection (BfS) drew up a needs analysis for maintaining and developing expertise in radiation protection in Germany, which goes beyond radiation protection in nuclear safety and takes account of radiation protection in its entirety, including both ionising and non-ionising radiation (BMU et al. 2021a). The needs analysis states that "*Expert knowledge and capacity in radiation protection are being further scaled back and are being lost for the long term, or have already been lost*." This leads to the fact that in radiation protection there is "*already a substantial and fundamental difficulty – and one that is likely to continue to grow – in recruiting personnel with medical, scientific or engineering knowledge*."

In order to counteract these trends, required actions and recommendations in five pillars are discussed in the needs analysis for maintaining and developing expertise in radiation protection:

1) Education and teaching
2) Advanced and continuing training
3) Knowledge base
4) Committee work and networks
5) Research and development

To this end, 17 fields of competence are identified in the needs analysis, in the following order: radiation and society, radiation risk assessment, radiobiology, occupational radiation protection, nuclear medical protection, medical physics, radiological emergency preparedness and response, applied radiation protection, working in strong gamma and neutron radiation fields, laboratory measurement methods, nuclear forensics, radioecology and radiation protection, radon and NORM (naturally occurring radioactive materials), prognostic and diagnostic dose assessment, biological dosimetry, radiation epidemiology, and non-ionising radiation. This list of 17 fields of competence is not exhaustive, the analysis states, because new fields of application could be constantly added in radiation protection.

In order to understand the needs analysis, it is important that the required actions and the recommendations in the five areas are relevant for all of the identified fields of competence and are thus to be seen as spanning multiple fields of competence. Specific action required and recommendations for the respective fields of competence are listed individually in the subsequent brief explanatory texts.

For pillar 1 (education and teaching) the proposals are to improve the attractiveness of radiation protection topics, extend the thematic breadth of curricula and engage in cooperation arrangements with universities on vocational education and training.

To continue development of pillar 2 (advanced and continuing training), the proposals are to expand capacity and the range of training on offer to diversify advanced and continuing training, and to create a national institution for advanced and continuing training.

To support pillar 3 (knowledge base), the analysis calls for the strengthening of expertise in radiation protection standards and strategies, systematic, cross-institutional knowledge management and appropriate data collection and awareness-raising for the retention of knowledge.

The preservation and expansion of activities on committees and in networks are seen as being important for strengthening pillar 4 (committee work and networks).

Finally, pillar 5 (research and development) requires a systematic, forward-looking orientation, stronger infrastructure and, more generally, cutting-edge research for the issues of the future through networking and interdisciplinary approaches.

1.3 The SSK statement of June 2021

The aim of the statement published by the SSK (SSK 2021) was to identify the most important scientific disciplines and research actors in the field of radiation research and the use of radiation in Germany. To this end, the SSK evaluated roughly 370 research projects on ionising and non-ionising radiation (including UV radiation and electromagnetic fields (EMF)). These projects had received funding either since 2007 under the Competence Network for Radiation Research (Kompetenzverbund Strahlenforschung/KVSF) initiative from the Federal Ministry of Education and Research (BMBF) or since 2010 within the framework of the BMU's departmental research plan on radiation protection. In addition to the statement itself, a brief summary and a set of slides with relevant information are available on the SSK website[1].

The analysis conducted by the SSK culminated in 15 conclusions on Germany as a location for research, ionising radiation, UV radiation, electromagnetic fields, research funding and research strategy.

Germany as a location for research

- Conducting research, whether research into radiation or research that makes use of radiation, calls for interdisciplinary scientific approaches, from which other scientific disciplines also benefit. The SSK is of the opinion that this mutual interaction has a positive impact on the development of Germany as a location for research.
- The SSK stresses that German radiation researchers continue to enjoy an excellent reputation at international level, which it is important to maintain and further consolidate.

Ionising radiation

- The SSK considers the following research areas to be particularly important: radiobiology, radiation epidemiology, radiation risk assessment, medical applications of ionising radiation, radioecology, radiation metrology, dosimetry, and protection in the event of radiological or nuclear emergencies, including medical emergency preparedness and response.
- Roughly half of the evaluated research projects were carried out by about 15 research institutions, some of which are now no longer actively engaged in radiation research or to only a limited extent. The SSK points out that a minimum number of institutions is needed in order to cover the scientific topics that are relevant for radiation research.
- The SSK is missing clear signals from universities that radiation research will be granted the academic attention that is needed to conduct research at a high level.
- The SSK notes that radiation research has declined in importance within the Helmholtz community, despite its considerable relevance for society.
- In the opinion of the SSK, there are shortfalls in Germany in particular in basic radiobiological research, radiation epidemiology, radiation risk assessment, radioecology, radiation metrology and dosimetry.

UV radiation and electromagnetic fields (EMF)

- Just over half of the radiobiology projects involved in UV radiation research and funded by the BMBF were carried out by only five institutions. Of these, one no longer exists, and another has since reduced its activities. In the SSK's opinion, the critical mass of required institutions is thus no longer present.

[1] https://www.ssk.de/SharedDocs/Beratungsergebnisse/2021/2021-06-09_Stgn_Kompetenzerhalt.html.

- Although research on radiation epidemiology, radiation risks, metrology and UV treatment has an important role to play in a comprehensive UV radiation protection strategy, such research is funded either insufficiently or not at all.
- The SSK emphasises that it is important to research new hypotheses regarding the biological mechanisms underlying the effects of EMF exposure. The prerequisite for this is that technical and scientific expertise needed to conduct EMF exposure experiments and EMF metrology research remains available in the long term.

Research funding and research strategy

- Questions concerning radiation protection and radiation research and how to deal with new technologies are relevant to society and call for an active dialogue. Consequently, the SSK believes that interdisciplinary cooperation with the humanities and social sciences is a matter of great importance.
- The SSK considers the preservation and expansion of infrastructure in the field of ionising and non-ionising radiation to be a vital precondition for maintaining expertise.
- Complementary research funding through the KVSF initiative from the BMBF and the departmental research plan from the BMU has had a key role to play in the preservation of expertise in radiation research in Germany for 15 years, in the SSK's view.
- The SSK emphasises that collaboration between all actors including university and non-university research institutes and departmental research facilities is crucially important.
- The SSK recommends that radiation research should be integrated into national research strategies on a sustainable basis.

As a general point, the SSK is of the view that ionising and non-ionising radiation plays or can play a part in numerous initiatives that the Federal Government has launched to strengthen and advance the position of Germany as a location for research. This relates to many initiatives that are extremely relevant to society, such as the High-Tech Strategy 2025[2], the National Decade against Cancer[3], the National AI Strategy[4] and Federal German Government's energy transition strategy[5]. The recently announced Gigabit Strategy[6] should also be mentioned in this context. Systematic accompanying radiation research in the form of preparatory research, technology impact assessment and implementation support is an essential part of initiatives such as these.

Furthermore, it is important to develop attractive research topics, taking account of the latest technological developments including ongoing digitalisation, artificial intelligence and methods for evaluating large volumes of data. This will raise awareness of radiation research and increase its competitiveness vis-à-vis other research disciplines.

Conclusions of the statement

Ionising and non-ionising radiation from natural and artificial sources have become an integral part of everyday life. Examples of this include natural radioactivity in the environment (e.g. radon in buildings) or cosmic radiation encountered when flying, solar and artificial UV radiation, modern methods of medical diagnostics and therapy that make use of ionising radiation, and electromagnetic fields created in 5G and 6G networks and in the development of electromobility.

2 https://www.bmbf.de/bmbf/en/research/future-research-and-innovation-strategy/future-research-and-innovation-strategy.html
3 https://www.dekade-gegen-krebs.de/
4 https://www.ki-strategie-deutschland.de/home.html
5 https://www.bundesregierung.de/breg-de/themen/klimaschutz/energiewende-im-ueberblick-229564
6 https://bmdv.bund.de/SharedDocs/DE/Anlage/K/gigabitstrategie.pdf?__blob=publicationFile

Given the wide-ranging societal importance of radiation research and of applications of radiation, the SSK believes that long-term support for basic and applied radiation research in Germany is of the utmost importance.

The SSK is convinced that Germany as a location for research benefits substantially from scientific expertise in radiation research, and in the sense of a technology impact assessment this can also facilitate the societal acceptance of new technologies.

The statement by the SSK was presented on 24 June 2021 as part of a joint event with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Federal Office for Radiation Protection (BfS) and the SSK on radiation research under the title "Strahlenschutz Forum. Strahlende Zukunft in Digitalisierung und moderner Medizin – mehr Sicherheit durch Forschung" (Radiation protection forum. A radiant future in digitalisation and modern medicine – greater security through research) (BMU 2021). The aim was to raise awareness of the issue among the responsible decision-makers and in particular staff at relevant ministries and Members of the German Bundestag. A summary of the event is available here (BMU et al. 2021b).

1.4 Structure of this recommendation

Building on the statement of 2021 described in the previous section, this recommendation from the SSK analyses the need in Germany for expertise in the field of radiation research and the use of radiation to be maintained, developed and/or expanded. In a second step, it proposes suitable measures to support research relating to ionising and non-ionising radiation in Germany and to safeguard expertise in radiation protection for the long term.

The publicly funded research landscape in Germany is predominantly built on three pillars – universities and other higher education institutions, research facilities supported by institutional funding, and the Federal Government's departmental research institutions – which also participate in radiation research (Figure 1). In addition, institutions and companies in the private sector are also involved in publicly funded radiation research. Measures designed to maintain, develop and/or expand expertise in Germany are proposed in this recommendation. It was not possible to take account of research activities in industry within the scope of this document.

Section 2 outlines the viewpoints of other institutions (various specialist associations etc.) on the need for radiation research in Germany, along with international perspectives and funding initiatives. Subsequently, the need for radiation research and correspondingly trained personnel in Germany is analysed in Section 3. Following the evaluation of a questionnaire survey, the current situation on the labour market and in professional education and training in radiation protection in Germany is analysed. A SWOT analysis then examines the strengths, weaknesses, opportunities and threats applicable to radiation research and radiation protection research in Germany (SWOT stands for **s**trengths, **w**eaknesses, **o**pportunities, **t**hreats). Finally, in Section 4, measures are proposed which in the opinion of the SSK will contribute to a long-term improvement in and maintaining of expertise in radiation research in Germany.

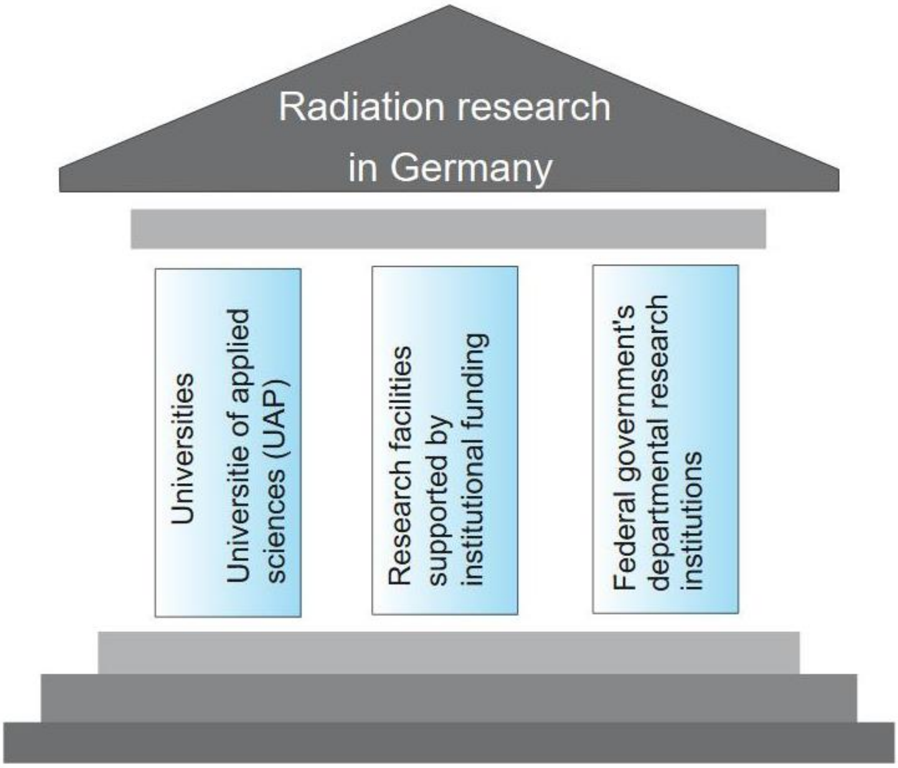

Figure 1: The essential pillars of radiation research in Germany. As categorised by the SSK, "research facilities supported by institutional funding" include, for example, the Fraunhofer-Gesellschaft, the Helmholtz Association, the Leibniz Association and the Max Planck Society. The Federal Government's departmental research institutions include, for example, the Federal Office for the Safety of Nuclear Waste Management (BASE), the Federal Office for Radiation Protection (BfS), the Federal Institute for Occupational Safety and Health (BAuA), the Bundesanstalt für Materialforschung und -prüfung (Federal Institute for Materials Research and Testing, BAM), the Physikalisch-Technische Bundesanstalt (National Metrology Institute, PTB) and the Bundeswehr Institute of Radiobiology (InstRadBioBw). In addition, institutions and companies in the private sector are also involved in publicly funded radiation research.

2 Need for expertise in radiation research – viewpoints of other institutions

2.1 Viewpoints of German political parties

In the run-up to the 2021 election for the Bundestag, the German-Swiss Association for Radiation Protection (FS) submitted six questions on societally important issues of significance for FS members to all parties represented in the Bundestag and to those parties that were represented by at least one member in the European Parliament and were standing for election for the Bundestag. One of these questions was also relevant in connection with this SSK recommendation:

"Do you see a need for greater government support for research and the preservation of expertise in areas including the use of ionising radiation and radioactive substances in medicine and business?"

The published responses from the surveyed parties can be found here: https://www.fs-ev.org/newsliste/wahlpruefsteine-des-fs-an-parteien. It is noticeable that most of the parties stress the need for expertise in radiation research, even if in some cases this is for different reasons. The areas in which the parties stated that expertise in radiation research would continue to be required in future included medical applications of ionising radiation, nuclear technology and plant safety, materials research, and the final disposal of radioactive waste, among others. Expertise in these fields is also necessary, they said, in order not to jeopardise the economic competitiveness of Germany in various fields and to ensure that it continues to have a voice in relevant international bodies. The reasons quoted can also be found in the SSK statement from 2021. Only one or two parties considered a reduction in expertise to be logical in light of the phase-out of the use of nuclear power, or saw no need for expertise in radiation expertise except in connection with medical applications.

2.2 International perspectives and funding initiatives

The development of radiation research is closely monitored outside Germany, too. Its importance is not called into question, and efforts are made to set up funding for research accordingly.

2.2.1 Europe

A relatively high degree of importance has been attached to radiation research in Europe in the past. The OPERRA project (Open Project for the European Radiation Research Area) analysed trends in research funding for projects involving ionising radiation that were relevant to radiation protection. The analysis was based on data available on the European Commission's CORDIS (Community Research and Development Information Service) website (https://cordis.europa.eu/projects/home_en.html). Information was evaluated from framework programmes FP4 (1994 to 1998), FP5 (1998 to 2002), FP6 (2002 to 2006) and FP7 (2007 to 2013). Projects in the field of nuclear waste management and disposal were not taken into consideration, nor those in reactor development. The findings are summarised in Table 1 (Cho et al. 2019). At first glance the amounts of funding appear considerable, but these are put into perspective in light of the funding periods of five to seven years in each case, and the fact that they are distributed between all member states. The annual funding amounts for individual countries thus tend to be rather small.

Table 1: Distribution of research funding provided through the European Commission's framework programmes for the various European radiation research platforms; FP4 (1994-1998), FP5 (1998-2002), FP6 (2002-2006) and FP7 (2007-2013); European Radioecology Alliance (ALLIANCE) – radioecology; EURADOS – dosimetry; MELODI – biological effects of low radiation doses; NERIS – emergency preparedness and response; E&T – education and training (after Cho et al. 2019; the rounding of the figures by (Cho et al. 2019) means that the total of the percentages shown in the table for each framework programme is not necessarily 100%).

Research platform	FP4	FP5	FP6	FP7
ALLIANCE	27.1%	12.5%	16.3%	8.4%
E&T	0.1%	0.9%	5.0%	2.0%
EURADOS	16.3%	14.7%	1.6%	3.3%
MELODI	36.1%	44.3%	48.4%	63.2%
NERIS	8.3%	15.9%	21.7%	6.6%
Medical applications	10.2%	7.6%	6.9%	16.5%
Other	1.9%	4.2%	0	0
EC contribution	EUR 56.9 million	EUR 49.6 million	EUR 61.2 million	EUR 88.2 million

Table 1 shows that projects in the fields of radioecology (ALLIANCE) and in particular dosimetry (EURADOS) received considerably less funding in later years compared with FP4 and FP5, presumably because these topics had received greater funding in FP4 and FP5 in the wake of the accident in Chornobyl. Similarly, the funding for projects on emergency preparedness and response (NERIS) in FP5 and FP6 could be linked to the Chernobyl accident. In the case of medical applications, substantial growth was registered above all in research on biological effects of low-dose radiation (MELODI). Overall, funding for projects relevant to radiation protection rose from FP4 to FP7, which underlines the importance of radiation protection research for the European Commission (Cho et al. 2019).

In the subsequent years the European Commission funded radiation protection research largely through CONCERT, the European Joint Programme for the Integration of Radiation Protection Research, which received an EU grant amount of almost EUR 20 million for five years. Further funding from the EU was provided for the MEDIRAD (Implications of Medical Low Dose Radiation Exposure) project, amounting to EUR 10 million for a term of almost five years. Other projects received EUR 7 million to complement the research agendas of the European CONCERT and MEDIRAD projects, and one project that was designed to develop recommendations for future funding of radiation protection research in Europe received EUR 0.5 million (see Cho et al. 2019).

In 2022 the EU launched the PIANOFORTE project (European Partnership for Radiation Protection Research) as a successor to CONCERT, with a volume of EUR 30 million over five years. It brings together 58 partners from 22 countries and the six relevant European research platforms: ALLIANCE, EURADOS, European Alliance for Medical Radiation Protection Research (EURAMED), MELODI, NERIS, European Platform for Social Science and Humanities Research in Ionising Radiation (SHARE). Its purpose is to consolidate European research and development in order to improve radiation protection for the population as a whole, patients, employees and the environment, in all exposure scenarios. In addition, it is intended to devise solutions and recommendations for optimised radiation protection in line with Directive 2013/59/Euratom (Euratom 2014). The budget is supplemented by national contributions from the nations participating in the projects, amounting to up to one third of the total. However, as was the case with CONCERT, too, this approach constitutes an insurmountable barrier for smaller actors and university institutes wanting to take part if they are unable to raise these additional contributions.

2.2.2 USA

During the period 1999 to 2016, the US Department of Energy (DOE) provided an average of USD 14 million per year to fund the Low-Dose Radiation Research Program, which primarily examined the molecular and cellular effects of low doses of ionising radiation (National Academies of Sciences 2022). Since 2016, the DOE has redirected its focus towards other research priorities. Recently, however, in light of the interdisciplinary nature of radiation research, a change in thinking has occurred, with the effect that in 2021 the US Congress commissioned the National Academies of Sciences, Engineering and Medicine (NAS) to develop a long-term strategy and prioritised research agenda with the aim of reorienting future research in the USA towards the effects of low radiation doses and dose rates. At the same time it serves to secure a minimum number of trained experts and an appropriate research infrastructure.

To achieve this, an NAS committee was given the following tasks: a) identify the most important scientific issues that need to be guided by an understanding of low-dose and low-dose-rate radiation health effects, b) assess the status of research in the USA and internationally, c) develop a long-term research strategy and at the same time identify specific research priorities and measures promoting public understanding of the effects of low-dose radiation, d) discuss the research needed at the research centres (National Laboratories) and universities, e) support coordination between federal agencies and with international programmes, and f) if possible, estimate the financial consequences of such a programme for the various parties involved including the relevant federal agencies, the general public, industry, the research community and other stakeholders.

The committee came to the conclusion (National Academies of Sciences 2022) that a coordinated interdisciplinary low-dose research programme can improve understanding of the adverse health effects from exposure to low-dose and low-dose-rate radiation as encountered among the population of the USA. This was necessary, it stated, in order to assess whether the rules currently applied to radiation protection are appropriate or can be tightened or relaxed.

The committee stressed the importance of epidemiological studies in improving future understanding of health effects from doses in the region of 10 mGy and the influence of genetic factors, lifestyles or environmental conditions. Radiobiological studies were important for understanding the mechanisms that determine the effects of ionising radiation. Relaunching a research programme of this nature would also leverage advances in biotechnology and research infrastructures.

Accordingly, the committee identified a total of eleven priorities for the promotion of epidemiological research (1 to 7) and the expansion of research infrastructure in the United States (8 to 11):

1. Develop cohorts of sufficient size
2. Improve estimation of risks for radiation-induced cancer and non-cancer health outcomes
3. Determine factors that can influence the effects of radiation
4. Develop suitable animal models
5. Identify biomarkers for radiation-induced health effects
6. Define dose-response curves for doses below 10 mGy and dose rates below 5 mGy/h

7. Identify factors that modify radiation-induced health risks
8. Develop techniques for identifying abnormal cell and tissue characteristics
9. Establish databases to support epidemiological and biological studies
10. Develop dosimetry for low-dose and low-dose-rate exposures
11. Construct irradiation facilities in this dose and dose-rate range

A research programme of this type would have to be maintained for several decades in order to achieve its goals, with an annual budget of around USD 100 million for the first 10 to 15 years. In the committee's opinion, providing about USD 5 million per year would not be enough even to launch an adequate research programme.

The committee found that the DOE, which had coordinated radiation research at the national research centres and universities for many years, has significantly reduced its activities in this field since 2016. Furthermore, the DOE has a credibility problem among impacted communities because of its dual role promoting nuclear technologies and at the same time managing research into low-dose and low-dose-rate health effects. The committee therefore recommended the following:

- Commit to developing and maintaining the planned research programme in a transparent way
- Arrange for the programme to be independently evaluated
- Manage the research programme in a transparent way
- Develop the necessary research agenda with input from all relevant stakeholder groups
- Select suitable research projects using a competitive procedure
- Support training for scientists
- Maintain contact with all relevant stakeholder groups
- Coordinate the entire programme with other relevant national and international organisations.

These recommendations had not been put into practice by the spring of 2023 (G. Woloschak, personal communication of 27 April 2023).

In 2015, a multidisciplinary team of experts in the USA began reviewing a selection of professional workforces in which ionising radiation plays a role in order to determine their future viability. The aim of the study was to compile information about the current status of the various workforces and their future prospects (Newhauser et al. 2022a). The professional workforces investigated in the study included general radiation protection (health physics) (Noska et al. 2022), medical physics (Newhauser et al. 2022b), medicine (Bluth et al. 2022), nuclear engineering (Townsend et al. 2022), radiation biology (Williams et al. 2022) and radiochemistry and nuclear chemistry (Tolmachev et al. 2022). The authors identified a number of factors influencing the future viability of the investigated professions, such as workforce shrinkage due to worker retirements, a decline in the capacity of higher-education pipelines and the closure of relevant training programmes. The authors concluded that a worrying decline in workforces is already apparent now in the USA, particularly in the fields of health physics, radiation biology and radiochemistry and nuclear chemistry (Newhauser et al. 2022c).

2.2.3 Global

In an overview article, Cho and colleagues examined the historical trends in international radiation research and offered an outlook for future developments. They focused particularly on the situation in Canada, the European Union, Japan, South Korea and the USA (Cho et al. 2019).

For Canada, the authors expected a further increase in financial support for radiation research. The aim there was for the radiation protection system to evolve from what is currently more of a hypothesis-based system, based on the LNT (linear-non-threshold) model, for example, to a more knowledge-based system. This would have to be done through international collaboration.

For Europe, the authors evaluated the data on research funding until 2013 given in Table 1 above, described the developments in subsequent years, likewise outlined above, and expressed the expectation that further funding for projects on radiation protection and ionising radiation applications will continue, but offered no details of the extent of such funding. They emphasised that phasing out the use of nuclear power would not change anything in terms of the need for radiation protection research, even if this was only with a view to medical radiation applications. That said, as Cho and colleagues point out, the peaceful use of nuclear power is growing rapidly worldwide anyway.

For South Korea, the authors established that policy is increasingly turning away from the peaceful use of nuclear energy, which would also have an impact on radiation research related to new nuclear reactors, for example. Consequently, the authors anticipated an increase in the relative share of funding in other areas of radiation research, such as in medical applications of radiation.

For the USA, the authors pointed to the more recent developments described in the previous section above, and anticipated in particular a revival of the research programme on the effects of low-dose radiation.

With regard to education and training, the authors assumed that the number of courses offered in Canada would continuously rise, although robust figures were not available. In contrast, they felt unable to assess the situation in the European Union because future developments were not foreseeable after the termination of the CONCERT project. In Japan the authors noted that the number of courses available on the effects of radiation was slowly rising. For South Korea, on the other hand, they found that not a single training course on radiation biology was offered any more. For the United States, they pointed to a drastic decline in the number of training programmes in radiation research, and courses in radiation biology were no longer offered at all.

In summary, the authors concluded that as a consequence of rising public concern around the health effects of low-dose radiation, a deeper understanding of the biological effects of ionising radiation will become increasingly important in future. Continued funding for radiation research is needed, they state, and education and training are also important (Cho et al. 2019).

An analysis of the expertise in radiological protection available worldwide, to which the SSK statement on the preservation of expertise (SSK 2021) contributed, motivated the International Commission on Radiological Protection (ICRP) to call for a strengthening of expertise in this field (Rühm et al. 2023). In what was then called the Vancouver Call for Action, ICRP appealed to national governments and other funding agencies to provide more financial resources in order to strengthen research into radiological protection. It encouraged national research laboratories and similar institutions to launch long-term radiation research programmes. In addition, universities should intensify their efforts to offer courses of study relevant to radiological protection. In order to explain the importance of radiation research and radiological protection for society to the general public and decision-makers, information should be presented in plain language, and particular attention should be paid to multipliers in the education system as a channel for the transfer of information. For the first time ICRP points out in the Vancouver Call for Action that radiological protection can contribute to the achievement of several of the United Nations Sustainable Development Goals (UN 2015) (Rühm et al. 2023). ICRP's Vancouver Call for Action was recently expressly welcomed by the principal authors of the studies mentioned in Section 2.2.2 on the situation of various workforces in the USA in which ionising radiation is a relevant factor (Newhauser et al. 2023).

2.3 Summary

Among international organisations there is general agreement that there is a need for long-term, sustainable efforts to promote research into the health effects of low-dose and low-dose-rate radiation, especially with reference to protecting the public. The interdisciplinary nature of radiation research is always highlighted, with contributions from disciplines oriented towards both basic and applied research, extending to the natural sciences, medicine, technology and the humanities. This is the only way that useful and responsible radiation applications and scientifically sound radiation protection strategies can be developed and implemented on the basis of current findings of radiation research.

As outlined above, numerous endeavours are made at international level to intensify the promotion of research into radiation and radiological protection. Were Germany to shut itself off from these developments, it would run the risk of falling behind scientifically within just a few years. This would make it extremely difficult to participate in international bodies engaged in the further development of radiological protection or to present the case for the country’s interests within such forums.

3 The need for expertise in Germany – SSK’s own analyses

3.1 Introduction

The SSK had previously stressed the importance of radiation research in Germany in its statement in 2021 (Section 1.3). In order to submit this assessment to independent examination, in March 2022 the SSK launched a survey among organisations that were assumed to have an interest in radiation research. Furthermore, the need for radiological protection, inasmuch as it exists, should be reflected in both the number of relevant jobs and the number of radiological protection courses on offer. The SSK therefore conducted an analysis of the state of the labour market, using job offers in the field of radiological protection in 2020 and 2021 as an example, and also investigated the number of radiological protection courses offered in the period from 2010 to 2020. In addition, a SWOT analysis was conducted in order to identify the need for radiation research in Germany and suitable measures to secure expertise in radiological protection for the long term.

3.2 Stakeholder survey

3.2.1 Introduction and methodology

In its statement in 2021, the SSK identified the areas of research that it considered to be the most important for radiation research in Germany and the institutions actively involved in the German research landscape (SSK 2021). The next step that it undertook was to devise a questionnaire, which it sent to roughly 80 organisations that were assumed to have an interest in successful radiation research in Germany. The purpose of this was to find out whether these organisations considered other areas of research to be important, in addition to those identified by the SSK, and what measures they proposed to maintain, develop and/or expand expertise in this field.

The questionnaire was drawn up on the basis of the SSK statement on the preservation of competence, and comprised ten questions. Altogether it was completed 120 times online within 28 days (from 4 March to 1 April 2022). The SSK attributes this high response rate to the fact that members of the SSK actively drew attention to the questionnaire survey through contacts with the relevant organisations in their role as mentors of the campaign, and lobbied for constructive answers.

The organisations that the SSK wrote to comprised professional societies and associations, industrial associations, research institutions, universities and other higher education institutions, agencies and departmental research institutions, expert commissions, employer's liability insurance associations, organisations and offices providing expert services and a number of commercial enterprises. The individual organisations were chosen on the basis of their fields of work and interests, but the list of organisations was not exhaustive. Moreover, the survey was conducted anonymously, so it is not impossible that in some organisations more than one questionnaire will have been completed by different members of the organisation, or also that certain individuals may have completed the questionnaire more than once because they belong to more than one of the named organisations. Consequently, the results of this survey cannot be considered representative and need to be interpreted with caution. Despite these limitations, the SSK is of the opinion that this campaign – unique in this form in Germany – provides important ideas and suggestions for the development of measures to maintain and improve expertise in radiation research and radiological protection in Germany.

The findings of the survey are presented below. The order of the questions has been changed so that the replies can be discussed in a more logical context. The list of addressees, the questionnaire covering letter and the individual questions are included in the annex.

3.2.2 Participating organisations

What type of organisation are you answering on behalf of (question 9 in the questionnaire)?

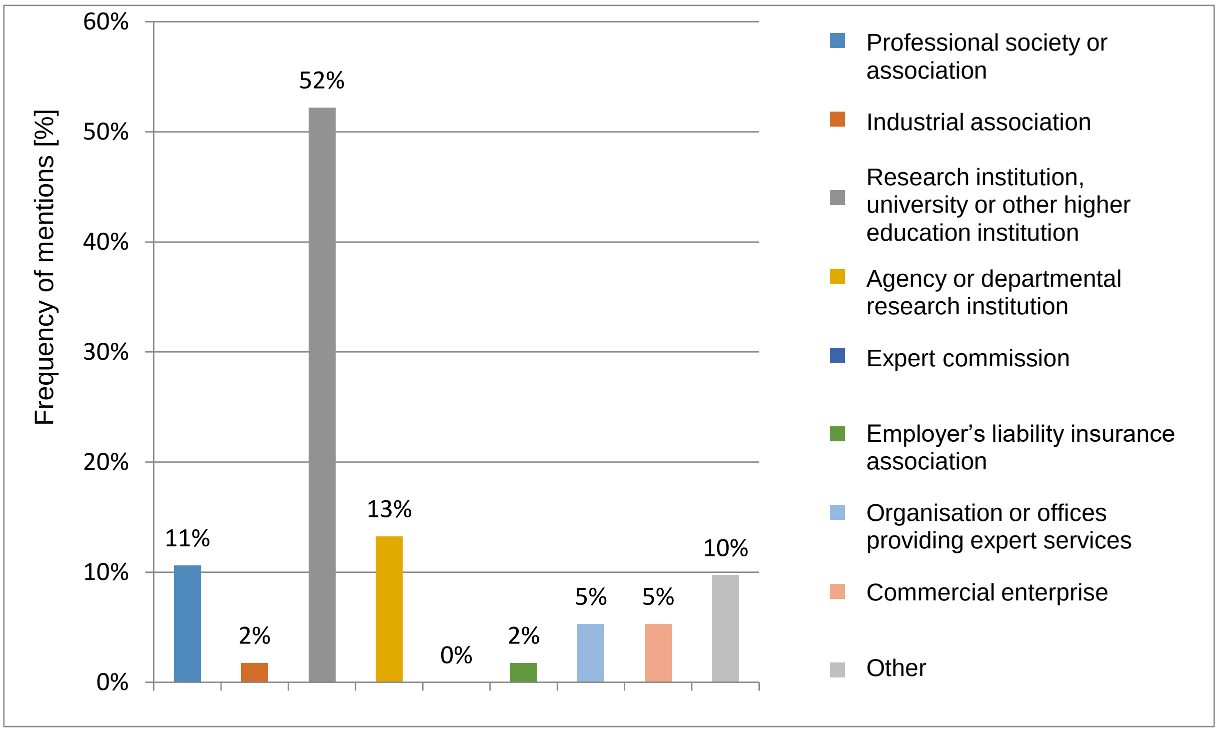

Figure 2: Organisations to which participants in the survey stated they belong (absolute figures shown in brackets; a total of 113 participants answered this question).

It is apparent from Figure 2 that by far the largest proportion (roughly half) of participants in the survey placed themselves in the category of research institution, university or other higher education institution. The second most common category was agencies and departmental research institutions, while professional societies and associations were third. The remaining categories thus play a comparatively minor role in numerical terms. In the following, therefore, the responses are often evaluated as two separate categories, namely “research institution, university or other higher education institution” and “other”.

What field do you/does your organisation work in (question 10 in the questionnaire)?

Figure 3 shows the specialist fields in which the participants were working. The majority reported being involved in the fields of radiobiology, medical applications and practical radiation protection. In contrast, the responses show that relatively few participants were working in the fields of radiation epidemiology and radioecology.

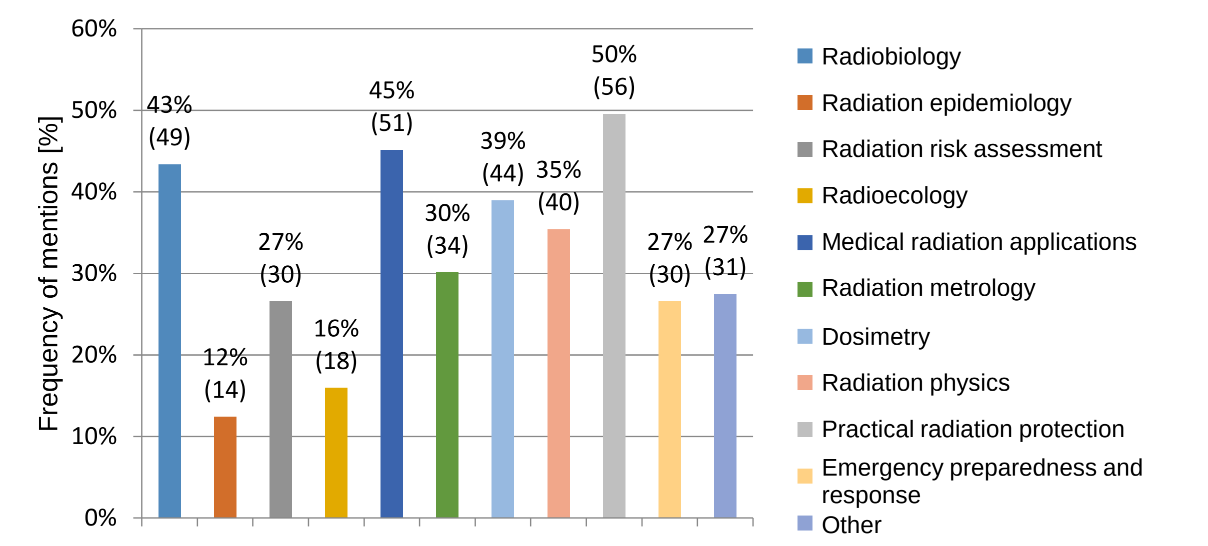

Figure 3: Fields in which participants in the survey stated they were working (question 10 in the questionnaire). Multiple answers were permitted. In total, 113 participants chose 397 answers. The absolute number of mentions is shown in brackets.

3.2.3 Relevant research areas and expertise

Modern radiation protection (ionising and non-ionising radiation) should be based on the best currently available scientific knowledge. Which of the following areas of radiation research do you/does your organisation consider to be important for Germany (question 1 in the questionnaire)?

Table 2 summarises the findings from the responses to this question, broken down according to the various organisations to which the respondents belonged. Figure 4 presents an overview in chart form of the areas of radiation research considered important.

Table 2: Areas of research stated by the participants in the survey as considered important for expertise in radiation research (question 1 in the questionnaire) by organisation (question 9 in the questionnaire; agency or departmental research institution (Agy), employer's liability insurance association (Emp), professional society or association (Pro), research institution, university or other higher education institution (R&T), industrial association (Ind), organisation or office providing expert services (Exp), commercial enterprise (Comm), other, no organisation specified (None); number of respondents in brackets). Multiple answers were permitted.

Area of research	**Agy (15)**	**Emp (2)**	**Pro (12)**	**R+T (59)**	**Ind (2)**	**Exp (6)**	**Comm (6)**	**Other (11)**	**None (2)**	**Total (115)**
Radiobiology	10	1	11	49	1	2	2	7	2	**85**
Radiation epidemiology	9	1	6	19		3	4	4		**46**
Radiation risk assessment	10	1	9	41	1	5	3	9	2	**80**
Radioecology	6	1	7	18	1	6	3	4		**46**
Med. radiation applications	10		11	46	1	3	4	6	2	**83**
Radiation metrology	11	1	8	35	2	4	4	8	1	**74**
Dosimetry	8		10	41	1	3	4	8	1	**76**
Radiation physics	8		11	36	1	1	1	8	2	**68**
Practical radiation protection	11	1	11	42	2	6	5	11	2	**91**
Emergency preparedness and response	8	1	8	29	1	3	3	6	2	**61**
Other	5	3	1	5	1	1		1		**14**

The areas of research explicitly named in Table 2 and Figure 4 had already been identified as being important in the SSK statement. This was strikingly confirmed in 115 responses in the survey: these areas were also rated as important a total of 710 times (out of 724 mentions) by the survey participants. The areas named particularly frequently were practical radiation protection, radiobiology, medical radiation applications and radiation risk assessment. It should be noted in this context, however, that a disproportionately large number of the participating organisations were working in these areas (see responses to question 10). The fact that radiation epidemiology and radioecology, for example, were considered important in comparatively few of the questionnaires can be explained at least in part by there being relatively few organisations actively engaged in these areas, according to the details given by the respondents.

As previously mentioned, roughly half of the participants in the survey were from the field of research and teaching (Figure 2). Interestingly, the pattern seen in Figure 4 (e.g. local maxima for radiobiology, radiation risk assessment, medical radiation applications, practical radiation protection; minima for radiation epidemiology and radioecology) in the "research and teaching" category is also shown in a similar, albeit weaker form in the "all other areas apart from research and teaching" category (Figure 5). It may also be a relevant factor that radiobiology, medical radiation applications and practical radiation protection appeared relatively often whereas radiation epidemiology and radioecology tended to be mentioned rather rarely.

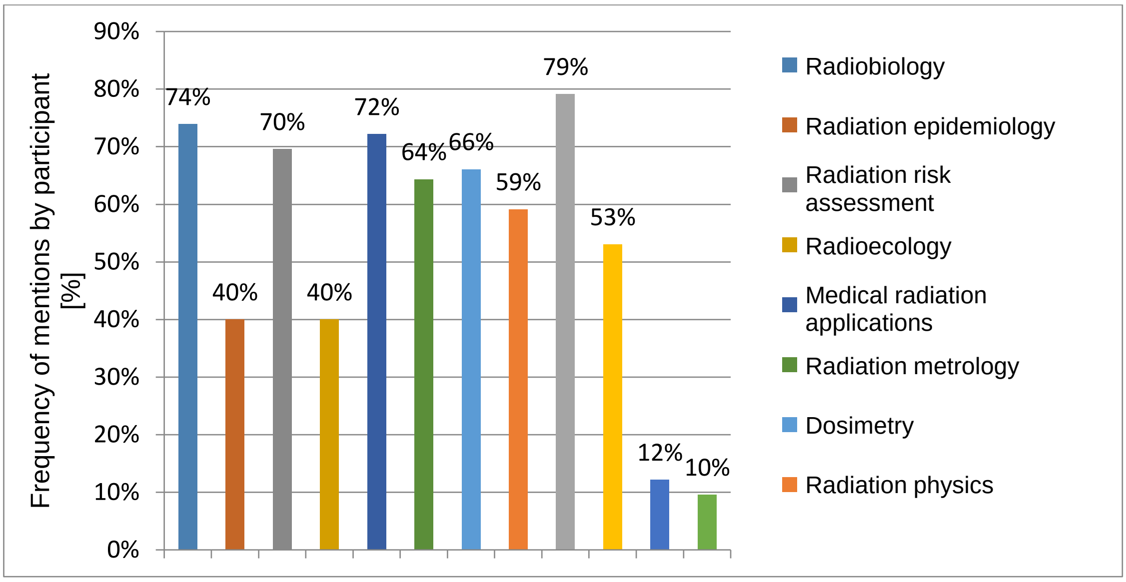

Figure 4: *Mentions of the areas of research considered important for expertise in radiation research by 115 participants in the survey (question 1 in the questionnaire). Multiple answers were permitted. In total, 115 participants chose 724 answers.*

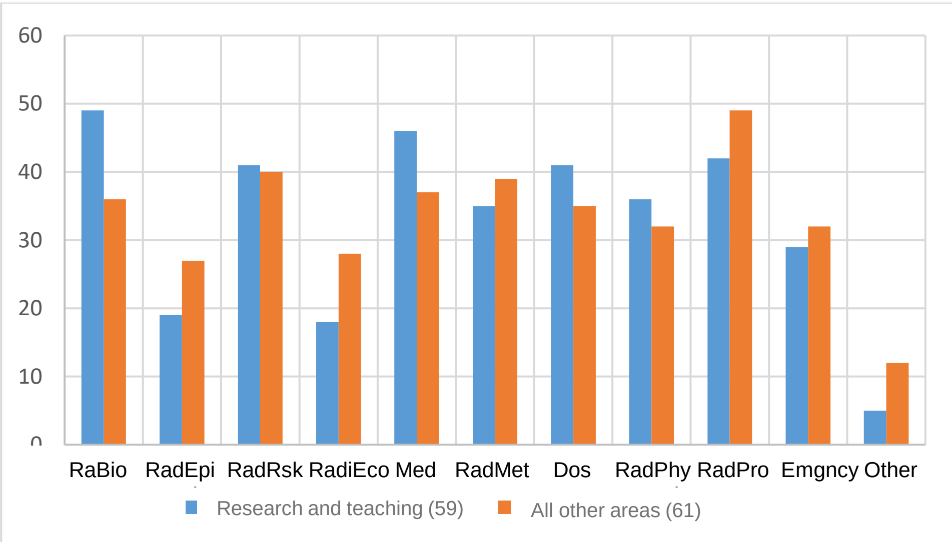

Figure 5: *Mentions of areas of research considered important categorised as belonging to the field of research and teaching or other areas (question 1 in the questionnaire).*

It is interesting that the category of "other" research areas was chosen for as many as 14 responses (Table 2). Most of the areas mentioned there were either not directly part of the "research" category (radiation protection legislation, standardisation) or overlapped to a relatively large degree with previously named research areas (e.g. nuclear medicine with medical applications, NORM with radioecology, astronauts with radiobiology, radiation physics and dosimetry, etc.). Two areas were named, however, which in the opinion of the SSK represent an addition to the areas identified in the SSK statement: risk and crisis communication, and radiochemistry.

It is important to emphasise once again that the findings shown in Figures 4 and 5 are largely determined by which organisations were contacted for the survey. As already mentioned, the selection of participants by the working group was not representative.

Is expertise in radiological protection and/or radiation research in Germany in danger of being lost? If so, in which areas (these may also be outside your own specialist area) and what are the possible reasons for this (question 2 in the questionnaire)?

Table 3 summarises the answers received in response to this question.

Table 3: Areas which 105 participants in the survey stated were at risk (question 2 in the questionnaire). R+T: research and teaching; number of responses in brackets. Multiple answers were permitted.

Area	R+T (53)	All apart from R+T (51)
Radiobiology	13	10
Radiation epidemiology	3	3
Radiation risk assessment	1	2
Radioecology	1	2
Medical radiation applications	8	7
Radiation metrology	2	2
Dosimetry	1	2
Radiation physics	5	4
Practical radiation protection	7	11
Emergency preparedness and response	5	6
Other		
Nuclear chemistry	1	0
Final disposal		2
Nuclear engineering		3
General or all	20	15
No danger seen	5	6

The participants in the survey classified the following areas as being particularly in danger: radiobiology, medical radiation applications, practical radiation protection and emergency preparedness and response. In this, they were largely in agreement with the assessment set out in the SSK statement. Looking at the responses to question 2 in relation to those to question 1, it is striking that radiation risk assessment, radioecology, radiation metrology and dosimetry were identified as relatively important areas in the responses to question 1 but plainly the prevailing impression was that these areas were less at risk (Table 3). This does not match the assessment by the SSK (SSK 2021). Interestingly, in eleven of the 105 answers given to this question the respondents' view was that there is no general threat of loss of expertise in radiation research and radiological protection in Germany – a view that, likewise, is not shared by the SSK.

As to the reasons given for the observed loss of expertise in radiation research and radiological protection in Germany, a relatively clear picture emerges in Table 4, in which a distinction is drawn once again between participants from the research and teaching category and those from other categories: in most of the 96 answers stating reasons for the loss of expertise in radiation research and radiological protection, those mentioned were a lack of available courses (17%), the phasing out of the use of nuclear energy in Germany (14%) and the closure of research institutions (13%). Other reasons given were a lack of specialist personnel (8%), a lack of career prospects (6%) and a lack of recognition of the societal relevance of the topic (6%).

Table 4: Reasons stated for the loss of expertise in radiation research and radiological protection in Germany mentioned by 105 participants in the survey (question 2 in the questionnaire). R+T: research and teaching. The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets). Multiple answers were permitted.

Reasons stated for loss of expertise	**R+T (53)**		**All apart from R+T (51)**	
Lack of available courses	11	21%	5	10%
Phase-out of nuclear energy	6	11%	7	14%
Closure of research institutions	6	11%	6	12%
Lack of specialist personnel	2	4%	6	12%
Lack of career prospects	3	6%	3	6%
Lack of recognition of societal relevance	3	6%	3	6%
Negative image	2	4%	3	6%
Lack of scientific foundations	1	2%	4	8%
Changes to research funding	4	7%	1	2%
Ignorance/lack of knowledge	4	7%		
Lack of financial resources, high costs	3	6%	1	2%
Lack of training facilities	3	6%		
Lack of visibility	2	4%	1	2%
Lack of research	1	2%	1	2%
Too much bureaucracy, overly restrictive regulations	1	2%	1	2%
Closure of commercial nuclear fission reactors	1	2%		
Absence of industry			1	2%
No danger of loss of expertise seen	5	9%	6	12%
None specified	6	11%	7	14%

In which of the areas listed under point 1 is it necessary to build additional expertise in order to further improve radiation research and radiological protection in Germany (question 3 in the questionnaire)?

The answers to this question essentially reflect the answers to questions 1 and 2 in the questionnaire (Table 5). Whereas 13 participants actually considered additional expertise to be needed in all areas, in the other cases radiobiology, medical radiation applications, practical radiation protection and emergency preparedness and response were the areas mentioned most prominently. The participants also saw need for greater expertise in the more physics-oriented areas (grouped together here under dosimetry, radiation metrology and radiation physics). In contrast, radiation epidemiology and radioecology were two areas mentioned rather rarely – on average 4%.

Table 5: Mentions of areas in which 102 participants in the survey stated that expertise should be built up (question 3 in the questionnaire); R+T: research and teaching. The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets). Multiple answers were permitted.

Areas mentioned	**R+T (50)**		**All apart from R+T (51)**	
All	4	8%	9	18%
Radiobiology	15	30%	9	18%
Medical radiation applications	10	20%	12	24%
Practical radiation protection	8	16%	9	15%
Emergency preparedness and response	5	10%	10	20%
Radiation metrology	6	12%	6	12%
Radiation risk assessment	4	8%	5	10%
Dosimetry	7	14%	3	6%
Radiation physics	4	8%	4	8%
Radiation epidemiology	2	4%	3	6%
Radioecology	1	2%	3	6%
Other:	5	10%	12	24%
Waste management/Final disposal			2	4%
Astronauts			2	4%
Nuclear energy			1	2%
Modelling and simulation	1	2%		
NORM			1	2%
Standardisation			1	2%
Radionuclide production, medical applications	1	2%		
Radiation protection legislation			1	2%
Non-ionising radiation	2	4%	3	6%
Artificial intelligence	1	2%	1	2%

Are there other areas of research that could be further developed through the use of radiation or radiation research (question 4 in the questionnaire)?

The aim of this question was to find out which areas of fundamental and applied research outside this field could benefit from expertise in radiation research. The responses reveal once again that radiation research is considered useful for a broad range of research areas (Table 6). Communicating this fact will be one of the most important tasks in future if society and political decision-makers are to be made aware of the fundamental significance of radiation research.

Table 6: Areas of research that according to 78 participants in the survey could be further developed through the use of radiation or radiation research (question 4 in the questionnaire); R+T: research and teaching. Multiple answers were permitted.

Areas of research that could be developed through the use of radiation or radiation research	**Responses**		
	Total (78)	**R+T (42)**	**Other (36)**
Aerospace	4	1	3
Energy generation, energy security, structural engineering, urban planning	6		6
Risk communication	3	1	2
Safety research	1	0	1
Environmental monitoring	1	0	1
Medicine (general, diagnostics, imaging, oncology, radioligand therapy, therapy stratification, nanomedicine, nuclear medical protection)	21	8	13
Biology (general, tumour biology, systems biology, immunology)	9	3	6
Chemistry	1	0	1
Biochemistry	2	1	1
Bioinformatics	3	1	2
Pharmacology	2	1	1
Neurology	1	0	1
Genetics, epigenetics	1	1	0
Epidemiology	1	1	0
Artificial intelligence	2	0	2
Materials research (general, materials testing)	5	3	2
Information technology	1	1	0
Communications technology	1	0	1
Genetic engineering	1	0	1
Nanotechnology	2	1	1
Radiation sterilisation	3	2	1
Particle acceleration	1	1	0
Pulsed radiation	1	1	0
Sensor and detector research	1	0	1
Sound, light and magnetic fields	1	0	1
Imaging techniques for waste and fuel element containers	1	0	1
Semiconductor technology	1	0	1
Art technology	1	0	1
NORM	1	0	1
Final disposal	1	0	1
Total research areas mentioned	**81**	**27**	**54**

The participants in the survey saw medicine as the main beneficiary of a high level of expertise in radiation research, by a large margin, but they also thought that such research can contribute substantially to biology, in particular tumour biology, systems biology and immunology. Other areas mentioned included research into energy generation, materials research and aerospace-related research. It is also interesting that some participants were of the opinion that findings from radiation research could be important for risk communication (which goes beyond the obvious interpretation that radiological protection benefits from research in risk communication).

What new technological developments could benefit from expertise in radiation research or radiological protection (question 5 in the questionnaire)?

Complementing question 4, this question explicitly addressed technological developments rather than research fields.

There was broad consensus among the participants in the survey that technological advances in medicine are greatly dependent on expertise in radiation research and radiological protection, in particular the development of radiological imaging techniques (including MRI), new forms of radiation therapy (FLASH therapy, individualised treatment, particle therapy) and developments in diagnostics and therapy in nuclear medicine (Table 7). Examples of technological advances in general – to mention just a few, but those mentioned relatively frequently – included the expansion of the 5G network and detector development, the development of artificial intelligence methods, the development and application of lasers, and techniques that make use of neutrons. In addition, many developments in the natural sciences in general were also mentioned (e.g. bioinformatics, biology, immunology, geophysics), as well as those in environmental applications (e.g. environmental monitoring, deep-sea research), space flight (e.g. colonisation of the moon, space tourism, development of radiation-hardened electronic components), materials research and testing, nuclear waste management (dismantling, interim storage, final disposal) and energy generation (nuclear fission, nuclear fusion, transmutation).

Table 7: New technological developments that could benefit from expertise in radiation research or radiological protection according to 85 participants in the survey (question 5 in the questionnaire); R+T: research and teaching. The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets). Multiple answers were permitted.

New technological developments that could benefit from expertise in radiation research or radiological protection	**R+T (46)**		**All others (39)**	
Medicine	44	96%	23	59%
Technical developments	23	50%	18	46%
Energy generation	9	20%	8	21%
Natural sciences	11	24%	4	10%
Materials research	8	17%	3	8%
Aerospace	6	13%	5	13%
Environment	2	4%	5	13%
Nuclear disposal	3	7%	2	5%
Other	1	2%	1	3%

From what new technological developments could radiation research or radiological protection benefit (question 6 in the questionnaire)?

Question 6 comprised a reversal of question 5, with the aim of finding out which technological developments should be given particular attention in radiation research and radiological protection in future so that the latest trends would not be overlooked.

The categorisation of the responses that were received revealed a clear picture (Table 8). The lead group of technologies that should be watched in future according to the participants in the survey consisted of metrology (20%), artificial intelligence (17%), biological technologies (16%), technological developments in medicine including medical imaging (12%), digitalisation (12%) and nuclear engineering (11%).

Table 8: Technological developments from which radiation research or radiological protection could benefit according to 78 participants in the survey (question 6 in the questionnaire); R+T: research and teaching (number of answers given in brackets). The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets). Multiple answers were permitted.

Technological developments from which radiation research or radiological protection could benefit	**R+T (41)**		**All others (36)**	
Metrology (detector development, automation, dosimetry)	12	29%	9	25%
Artificial intelligence	7	17%	11	31%
Biology (systems biology, molecular biology)	12	29%	4	11%
Medicine incl. imaging	6	14%	6	17%
IT and digitalisation	5	12%	7	19%
Nuclear engineering (incl. accelerators, neutrons)	7	17%	4	11%
Modelling, simulations	1	2%	4	11%
Nanotechnology	1	2%	3	8%
Materials research	2	5%	1	3%
Disposal	1	2%	1	3%

Has your organisation already taken steps of its own to maintain or improve expertise in radiation research or radiological protection (question 8 in the questionnaire)?

The responses to this question indicate that many of the respondents are aware of the problem of the loss of expertise. Steps in education and training that have already been introduced were mentioned in a total of 52 of 95 responses provided (Table 9). These included arranging relevant courses, in-service training sessions or workshops, for example, with most of them relating to operational radiation protection. A few respondents reported on efforts made in the academic field, for instance the establishment of master's degree courses (radiobiology, medical radiation sciences) and attempts to procure additional third-party funding. The promotion of individual school projects was also mentioned. Furthermore, several participants reported of assistance being provided for networking between young scientists, the relevant scientific disciplines and international institutions in order to support radiation research and radiological protection in Germany.

Some participants mentioned that it had proved possible to fill relevant vacant posts again and, in that way, at least safeguard staffing levels, and in isolated cases there were also reports of additional posts being established. In a number of cases it was also mentioned that authorities or agencies were giving thought to making structural changes to research funding in Germany – which could be important for the future.

Under the heading "Negative action", respondents repeatedly lamented the fact that in recent years the Helmholtz Association in particular had stood out by actively reducing its activities in the field of radiation research and radiological protection at some of its centres. The SSK previously described this problem in detail in its statement (SSK 2021).

Table 9: Steps already taken to maintain or improve expertise in radiation research or radiological protection as mentioned by 95 participants in the survey (question 8 in the questionnaire). R+T: research and teaching (number of answers received in brackets). The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets). Multiple answers were permitted.

Steps taken in this field	**R+T (47)**		**All others (48)**	
Education and training	25	53%	27	56%
Job recruitment	5	11%	1	2%
Networks	2	4%	3	6%
Expansion of infrastructure	3	6%	1	2%
Reorganisation	1	2%	2	4%
Research funding			3	6%
Support for young professionals			2	4%
Maintenance of staffing levels	1	2%	1	2%
Procurement of third-party funding	1	2%		
Cooperation arrangements	1	2%		
Details unclear	2	4%	2	4%
Negative action	8	17%	4	8%

3.2.4 Measures discussed and proposed

What scientific measures to improve radiation research and/or radiological protection would you propose, and what specific benefits do you hope will be obtained from them (question 7a in the questionnaire)?

Six answers that were given in response to question 7b (see below) were included in the following evaluation because they fitted question 7a better. The proposed measures are summarised in 19 categories in Table 10. The majority (45) of the 87 proposed measures related to research activities in radiobiology, including research into the mechanisms underlying the effects of (ionising and non-ionising) radiation and damage repair. The other 16 proposed categories of measures were shared relatively evenly, although there was a clear emphasis on medical applications (11 measures).

One noteworthy point is that radiobiology research (including research into mechanisms of action and repair mechanisms) was considered important by six of the eight agencies that responded to the question and by 22 of the 35 research institutions, universities and other higher education institutions (R+T) (Table 10).

Table 10: Scientific measures that were proposed in order to improve radiation research and radiological protection, grouped in 19 categories (question 7a in the questionnaire). R+T: research and teaching (number of answers received in brackets). The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets).

Proposed areas for scientific measures	R+T (35)		All others (25)	
Radiobiology research	11	31%	10	40%
Studies of mechanisms of action	7	20%	16	64%
Studies of medical applications	7	20%	4	16%
Studies of repair mechanisms	4	11%	1	4%
Applications of artificial intelligence	2	6%	1	4%
Studies of individual radiation sensitivity	2	6%	1	4%
New communication models			3	12%
Uncertainty analyses	1	3%	2	8%
Dosimetry	1	3%	1	4%
Development of decorporation measures			2	8%
Radiation physics research	1	3%	1	4%
Final disposal	1	3%	1	4%
Laser applications	2	6%		4 %
Quality assurance			1	4%
Research in the pharmaceutical sector			1	4%
Radiation metrology	1	3%		
Fusion research			1	4%
Radiation epidemiology	1	3%		40%

What technical measures to improve radiation research and/or radiological protection would you propose, and what specific benefits do you hope will be obtained from them (question 7b in the questionnaire)?

The technical measures proposed by the participants (Table 11) related first and foremost to metrology, in particular the development of radiation monitors and dosimeters (23 responses) and support for medical diagnostics and therapy (nine responses). The responses categorised as practical radiation protection equipment, for example, included technical developments regarding shielding, automation, robotics and the optimisation of procedures for the purposes of dose reduction. Similar issues are included in the materials research and use of AI techniques categories, while developments in reactor and accelerator technology are grouped under the category of nuclear engineering (Table 11).

Table 11: Technical measures that were proposed in order to improve radiation research and radiological protection (question 7b in the questionnaire). R+T: research and teaching (number of answers received in brackets). The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets).

Proposed areas for technical measures	**R+T (23)**		**All others (20)**	
Metrology	8	35%	6	30%
Medical radiation applications	7	30%	2	10%
Dosimetry	5	22%	4	20%
Practical radiation protection equipment	3	13%	3	15%
Use of artificial intelligence techniques	1	4%	4	20%
Materials research	1	4%	4	20%
Nuclear engineering	2	9%	1	5%

What organisational measures to improve radiation research and/or radiological protection would you propose, and what specific benefits do you hope will be obtained from them (question 7c in the questionnaire)?

The following evaluation also include 16 answers that were given in response to question 7a and three answers given in response to question 7b that were more suited to question 7c. The answers received were divided into nine different categories (Table 12). The largest share by far of these answers (82 out of a total of 137) pointed to measures aimed at improving education and training in radiation research and radiological protection, including the not infrequent suggestion that this should even start at school. Improving professional and vocational training in general, including that of journalists and teachers, was another suggestion, with the idea that the recognition of relevant courses could be helpful in some professional groups (for instance in medicine). For universities, respondents called for support for radiation research to be targeted at interested students, next-generation scientists, medical specialists and professors, while also appealing for better career prospects through unlimited-term contracts for mid-level academic positions in radiation research. Other suggestions were to create relevant professorships (such as in medical physics or radiochemistry) and graduate schools. In addition, a range of further research policy measures were proposed (29 entries). These included in particular the establishment of a dual training system in radiation research and radiological protection, the networking of relevant specialist disciplines, a clear commitment of programme-oriented funding to radiation research within the Helmholtz Association, the simplification of pertinent rules and regulations, the release of knowledge to facilitate technical developments, and simplified tendering procedures for research projects. Calls for emergency preparedness and response in Germany to be organised systematically were also seen relatively often. Time and again the participants emphasised that better education and training and an attractive research climate are mutually dependent, hence efforts must be made in both directions to an equal extent.

Table 12: Organisational measures that were proposed in order to improve radiation research and radiological protection (question 7c in the questionnaire). R+T: research and teaching (number of answers received in brackets). The percentages shown relate to the number of answers as a proportion of the respondents from the respective areas (in brackets).

Proposed organisational measures	**R+T (60)**		**All others (51)**	
Education and training, knowledge transfer	44	73%	39	76%
Research policy	16	27%	13	25%
Organisation of emergency preparedness and response	6	10%	5	10%
Improved communication	1	2%	2	4%
Reduction of bureaucracy	2	3%	1	2%
Removal of ideology from policy			3	6%
Better equipment and support for agencies	1	2%	1	2%
Organisation of radiation protection	1	2%	1	2%
Adaptation of rules and regulations			2	4%

What economic measures to improve radiation research and/or radiological protection would you propose, and what specific benefits do you hope will be obtained from them (question 7d in the questionnaire)?

As might be expected, research funding was the economic measure proposed by far the most frequently (Table 13). This is indicative in particular of the desire to be able to open up longer-term prospects for young up-and-coming scientists and among mid-level scientific staff. Closely linked to that, the participants also pointed out a need for systematic institutional funding for radiation research and radiological protection, in this case often calling for support for the major research centres in Germany. Explicit funding for transfer technologies and industrial start-ups was something else that respondents called for, in order to support cooperation among private and public institutions and the development of market-ready products. The stated measures were also meant to support networking between the institutions and among the stakeholders, as the participants stressed. Support measures of this type are naturally linked to funding for the next generation of scientific academics in the university environment, but also professional and vocational education and training. Radiological emergency preparedness and response was mentioned repeatedly as a specific area in which there is urgent need for education and training and support for young professionals, and where both expertise and infrastructure must be kept in place.

Table 13: Economic measures that were proposed in order to improve radiation research and radiological protection (question 7d in the questionnaire). R+T: research and teaching. The percentages shown relate to the number of answers (in brackets) as a proportion of the respondents from the respective areas.

Areas of interest for economic measures	**R+T (32)**		**All others (24)**	
Research funding	13	41%	10	42%
Institutional support	12	38%	5	21%
Support for education and training	5	16%	8	33%
Emergency preparedness and response	5	16%	2	8%
Networking	4	13%	3	13%
Support for young professionals	3	9%	2	8%
Transfer support	2	6%	2	8%
Start-up support	1	3%	1	4%
Public-private partnerships	2	6%	0	
Disposal	0		2	8%
Promotion of industry	0		1	4%

What other measures to improve radiation research and/or radiological protection would you propose, and what specific benefits do you hope will be obtained from them (question 7e in the questionnaire)?

Among the action that respondents proposed taking under "other measures" (Table 14), the category mentioned most frequently (10 out of 23 measures advocated) was better public relations. The purpose of this is to explain to a broader audience the attractiveness of radiation research, but at the same time it should facilitate fact-based evaluation of the benefits and harms of radiation applications and convey the importance of radiation research for numerous societally relevant areas (such as health, security, technical progress etc.). Public relations could also help improve the often negative image of radiation research and radiological protection. Agencies, in particular, also called for training materials on the use of both non-ionising and ionising radiation to be created.

Table 14: Other measures that were proposed in order to improve radiation research and radiological protection (question 7e in the questionnaire). R+T: research and teaching. The percentages shown relate to the number of answers (in brackets) as a proportion of the respondents from the respective areas.

Measures mentioned in this category	**R+T (10)**		**All others (13)**	
Public relations	6	60%	4	31%
Instruction, including practical exercises			4	31%
Support for young professionals	2	20%	1	8%
Image enhancement measures			2	15%
Multidisciplinary research environment	1	10%		
Changes to the legal framework	1	19%		
Cooperation between civil and military radiation protection			1	8%

3.2.5 Conclusions

In an unparalleled initiative, the SSK asked roughly 80 organisations in Germany that were assumed to have an interest in successful radiation research in the country whether other areas were important for the preservation, development and expansion of expertise in addition to those identified by the SSK in its statement of 2021, and what measures would be useful in achieving this. The unusually high response rate, with large numbers of questionnaires completed in great detail and returned, underlines the great importance that these organisations attached to this issue. About half of the organisations belonged to the research and teaching sector. The assessment by the SSK in 2021 regarding which areas of research should be considered important for radiation research was confirmed by the survey participants to a striking extent. In addition, research in two other areas, risk and crisis communication and radiochemistry, was also rated as important. The apparent underestimation of the importance of epidemiology and radioecology as manifested in the survey, an opinion not shared by the SSK in its statement, could be attributable to the lack of visibility of these specialist disciplines.

The overwhelming majority of participants saw deficiencies in expertise in the identified research areas to a greater or lesser degree. In contrast, about 10% of the respondents were of the view that there is no general threat of loss of expertise in radiation research and radiological protection in Germany – a view that, likewise, was not shared by the SSK.

Like the SSK, the participants were of the opinion that a broad spectrum of fundamental research, applied research and technological development can benefit from expertise in radiation research. Conversely, the current technological developments listed by the participants as being important or potentially important for radiation research and radiological protection should be exploited in order to enable radiation research and radiological protection to continue to meet the demands made of a modern scientific discipline into the future. The scientific, technical, organisational, economic and other measures proposed by the participants are extremely helpful for the future development of radiation research and radiological protection. In the SSK's view the next step should be to analyse them more closely, examine their suitability and, given a positive outcome, implement them if at all possible. This is one of the key tasks that ought to be performed as part of the progress initiative proposed by the SSK.

3.3 Labour market situation in Germany – job advertisements in 2020 and 2021

3.3.1 Introduction and methodology

The SSK had already pointed out in its statement of 2021 that expertise in the field of radiation research and radiological protection has been lost in Germany in recent years (SSK 2021). These circumstances could lead to a critical state of affairs if demand for such expertise remains stable or possibly even rises. Consequently, in order to examine the demand for human resources in the field of radiation research and radiological protection, the SSK carried out research into the number and type of jobs on offer on the labour market in Germany in 2020 and 2021 in which a need for expertise of this type was explicitly declared.

To do this, the SSK conducted targeted searches for appropriate advertisements on relevant job portals in both 2020 and 2021. For 2020, in a pilot project, job advertisements were evaluated on five job portals (German Federal Employment Agency, Stepstone, Stellenonline, indeed, and Jobs24) using the German search terms "Strahl" and "Strahlen" (for "radiation"). The date of the search was 22 August 2020, with the search stretching back as far as the beginning of 2020 in some cases, i.e. approximately eight months.

For 2021 the search was broadened to include additional portals, covering the following sources altogether: German Federal Employment Agency, German Society for Medical Physics (DGMP), Stepstone, indeed, jobvector, LinkedIn, Frankfurter Allgemeine Zeitung (FAZ), Zeit, and the German Federal Administration portal (service.bund.de). The search terms used were "Strahlentherapie" (radiotherapy), "Medizinphysiker" (medical physicist), "Strahlenschutzbeauftragter" (radiation protection officer), "Strahlenschutzfachkraft" (radiation protection expert) and "Strahlenschutzingenieur" (radiation protection engineer), supplemented by the terms "Radio" (radio) and "Dosimetrie" (dosimetry). The date of the search was 12 October 2021.

Double counting can be ruled out to a high degree of certainty in both years because the company and location were recorded in all the job advertisements and duplications would have been immediately obvious.

Since different methodologies were used for the job analyses in the two years in question, it is not possible to produce a quantitative comparison of the results. They do, however, allow qualitative conclusions to be drawn as to whether expertise in radiation research and radiological protection was in demand at all on the labour market in Germany.

3.3.2 Relevant vacancies

The results of the two job searches are summarised in Table 15. Even if the results from the two years are not directly comparable (see above), it is apparent that between 200 and 300 positions in which relevant expertise was requested were on offer in these two years. In both years the biggest demand appears to be for medical-technical radiology assistants, which is plausible, since both medical diagnostics and therapy are important areas of application for ionising radiation. This is also reflected in the large number of vacancies advertised for medical specialists in radiology, radiotherapy and nuclear medicine and for consultants in radiotherapy and radiology, and in the number of vacancies advertised for medical specialists and residents who will undergo training to obtain further qualifications in radiology and radiotherapy. There is also high demand for experts in medical physics, not least because in accordance with Directive 2013/59/Euratom the member states of the European Union have to ensure that medical physics experts are appropriately involved in medical radiological practices. Accordingly, in 2017 the SSK had already recommended that "a medical physics expert in the field of computed tomography, interventional fluoroscopy procedures and nuclear medicine diagnostics should deal with the establishment and use of meaningful and optimised examination protocols in cooperation and consultation with the expert physicians and the personnel involved in technical implementation" (SSK 2017). This recommendation has since been put into practice.

Apart from the medical sector, employers were also looking for engineers, advisers, radiation protection experts, radiation protection assistants and experts with academic qualifications and expertise in radiation protection in other areas.

Table 15 makes it plain that there is considerable demand in Germany for well trained staff with knowledge of radiation protection and radiation research and the application of such research in the broader sense. As is to be expected, the medical sector has a particularly major role to play as a potential employer in this context. This confirms the belief already expressed in the SSK statement in 2021 that medicine is an area in which there is a particular need for expertise in radiation research, radiation protection and the application of radiation, alongside a number of other areas. No job advertisements were identified in which expertise in the field of non-ionising radiation (UV radiation or EMF) was explicitly required. No results were returned for either search term. It is possible that on-the-job training has an important part to play in connection with non-ionising radiation.

Table 15: Job offers identified in Germany in which expertise was required in radiation research and/or radiation protection, or in which ionising radiation had an important role to play.

Reference date	22/08/2020	12/10/2021
Total job advertisements	175	317
Medical specialists in radiology, radiotherapy	19	18
Medical specialists in nuclear medicine		8
Consultants in radiology, radiotherapy		10
Residents and medical specialists in radiology/radiotherapy training		12
Medical physics experts	8	60
Medical-technical radiology assistants	71	104
Engineers, advisers, experts etc. with academic qualifications or senior position in radiation protection	15	39
Radiation protection officers, intermediate service	6	9
Experts, assistants in radiation protection	17	41
Radiation protection workers	7	2
Classification unclear or not relevant	7	14

3.3.3 Conclusions

The analysis conducted by the SSK of job advertisements relating to radiation research and radiation protection published in 2020 and 2021 included several selected relevant job portals. It was not possible to explore a trend over time, firstly because only two years could be included in the analysis and secondly because the nature of the search differed in the two rounds of analysis. Nevertheless, in the SSK's view the results demonstrate that there is annual demand for several hundred skilled personnel with expertise in radiation research or radiation protection in Germany. In all likelihood this demand will persist over the coming years, especially as the baby-boom generation reaches pension age.

3.4 Situation of professional development in Germany

In order to further investigate the demand for expertise in radiation protection in Germany, the SSK took a closer look at the trends over time of the numbers of participants in and providers of courses in occupational radiation protection as an additional indicator. At this juncture it should be pointed out, however, that other professional qualification opportunities in radiation protection are also available, such as in-service training courses on crisis communication and certain analytical and measurement techniques, etc. Other training opportunities of this type, as well as requirements for training that is not offered at present, are explained in more detail in (BMU et al. 2021a, especially Annex 2).

3.4.1 Radiation protection course providers in Germany

The Federal Office for Radiation Protection (BfS) provides comprehensive information about occupational radiation protection on its website, including details of education and training in radiation protection. Lists of the courses in radiation protection and the corresponding course providers in the individual German federal states are available on the BfS website (in German)[7]. At the request of the SSK, the BfS used this information to draw up a list of organisations that

[7] https://www.bfs.de/DE/themen/ion/strahlenschutz/beruf/fachkunde/aus-und-weiterbildung_node.html

had offered radiation protection courses in Germany between 2010 and 2020 (up to and including October 2020) (Figure 6).

Since the five guidelines on running radiation protection courses (guideline on radiation protection in veterinary medicine, guideline under the Radiation Protection Ordinance (StrlSchV) in medicine, under StrlSchV in engineering, under the X-Ray Ordinance (RöV) in medicine and under RöV in engineering) had not yet been adapted to the new legal situation following the publication of the Radiation Protection Act in 2018 (StrlSchG 2017), the figures obtained are still structured according to the previous legal situation, i.e. in accordance with the X-Ray Ordinance and the old Radiation Protection Ordinance.

According to the BfS, when interpreting Figure 6 it should be borne in mind "*that the calculated total of all individual values, shown as the overall total, does not represent the actual total number of course providers. Many course providers offer courses under more than one guideline, which may thus occur redundantly in different categories. Similarly, some of the larger course providers occur redundantly in more than one federal state because they had been accredited in different states. The figures are adjusted only in the sense of different course providers within a particular federal state and the corresponding guideline.*" (U. Häusler, personal communication, December 2020).

Figure 6 makes it clear that the total number of registered providers remained relatively stable over the period 2010 to 2020, with a mean value of 968 and a standard deviation of 62. It therefore remains the case that there is clear demand in Germany for radiation protection courses, and hence also for appropriately qualified course instructors and professional staff with expertise in radiation protection. Furthermore, it is notable that by far the largest number of courses offered relate to radiation protection in medicine (under both the Radiation Protection Ordinance and the X-Ray Ordinance). This reflects the situation previously described in the SSK statement (SSK 2021) that medical applications of ionising radiation are important drivers of the demand for expertise in radiation protection.

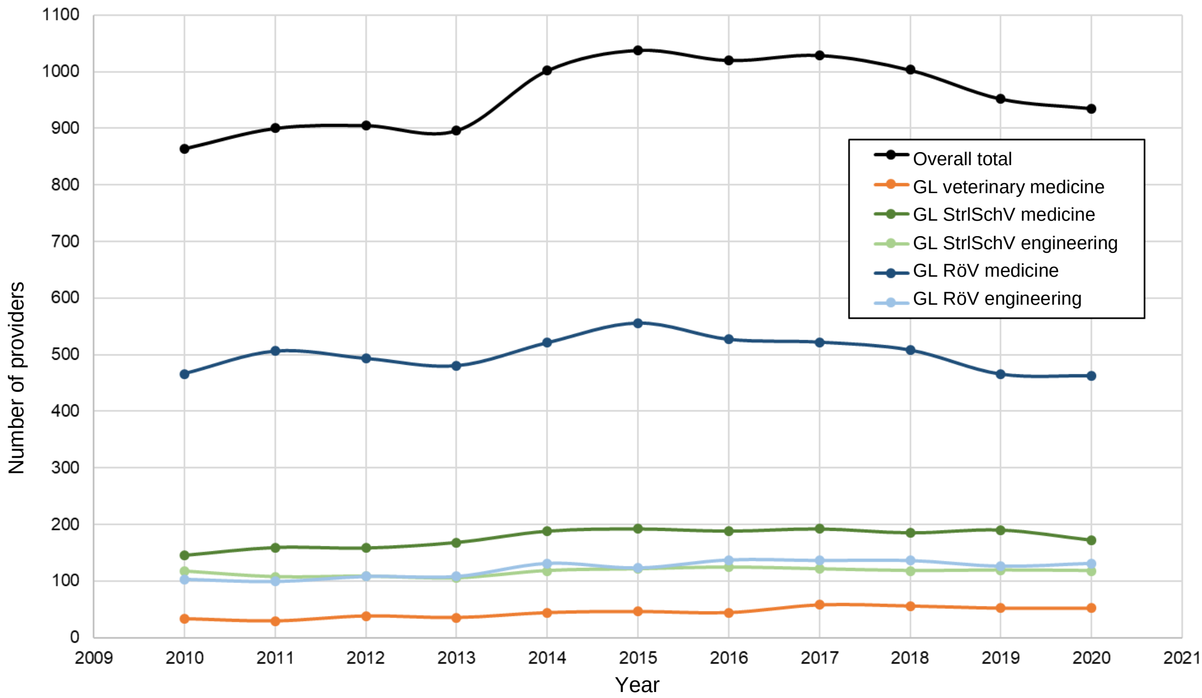

Figure 6: Number of providers of specialised courses in Germany from early 2010 to October 2020. Source: U. Häusler, BfS. GL – guideline; StrlSchV – Radiation Protection Ordnance; RöV – X-Ray Ordinance. For details, see text.

3.4.2 Radiation protection courses

In order to gain an overview of the trend in demand for radiation protection courses over time, a survey was conducted among members of the Education and Training Working Group (AKA) of the German-Swiss Association for Radiation Protection (FS). Replies were received from 14 training centres of very different sizes and orientations. The number of course participants per year ranged from 30 to about 5,000. Some providers cover a broad spectrum of expert guidelines, while others have a specialised profile. In line with the wishes of the majority, the data here is anonymised and reproduced only in summary. This selection is not representative of all providers of radiation protection courses, but it does paint a very good picture of recent developments.

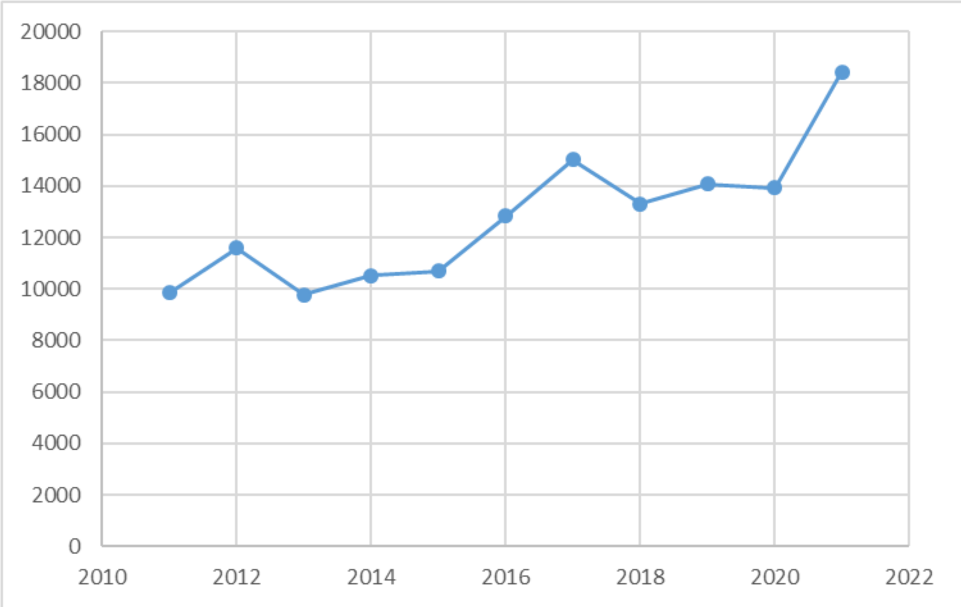

Figure 7: Total number of participants in radiation protection courses (new acquisitions and updates) in both engineering and medicine at 14 training centres in the period 2011 to 2021.

Figure 7 shows the total number of participants in events at the 14 mentioned training centres from 2011 to 2021. The chart includes both new acquisitions and updates in the specialist areas, in both the engineering and medical sectors. A marked rise is apparent since 2015. In 2021 a total of 18,400 participants completed either a new acquisition or update course at one of the 14 training centres. This should be seen against the background of there being approximately 125,000 radiation protection officers in Germany and an update period of five years.

In the engineering sector demand is at a largely constant level, with a slight dip in 2020 due to the pandemic (Figure 8).

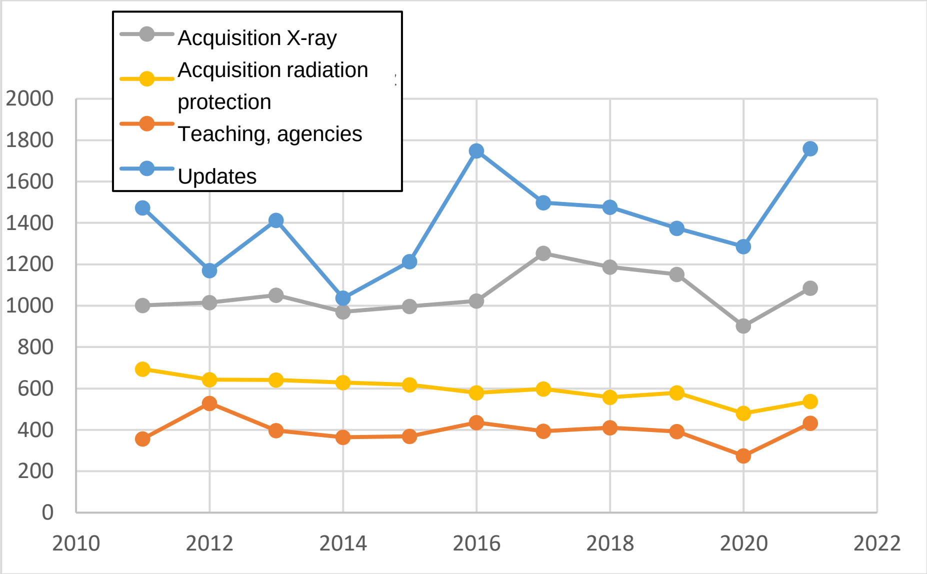

Figure 8: *Trend over time in the number of participants in radiation protection courses in the engineering sector, broken down according to the type of course/specialist area and updates.*

The number of participants in courses aimed at acquiring specialist knowledge under StrlSchV, for instance on handling unsealed or sealed radioactive material, exhibits a slight downward trend, while the number of participants in courses under RöV remains at a constantly high level. The number of updates fluctuates more than these two sets of figures, but overall tends to rise. The constant level of demand for courses for teaching staff and employees of agencies is also worthy of mention.

Growth was registered in all areas in the medical sector (Figure 9), with this being particularly marked in basic courses and the special courses for the X-ray field. Demand for update courses rises even more sharply. As it proved possible to offer a large proportion of the courses online at short notice during the period of the COVID-19 pandemic, and in contrast with the engineering sector there is no limitation on the number of participants per course, there is either no discernible dip in 2020 or only a slight fall.

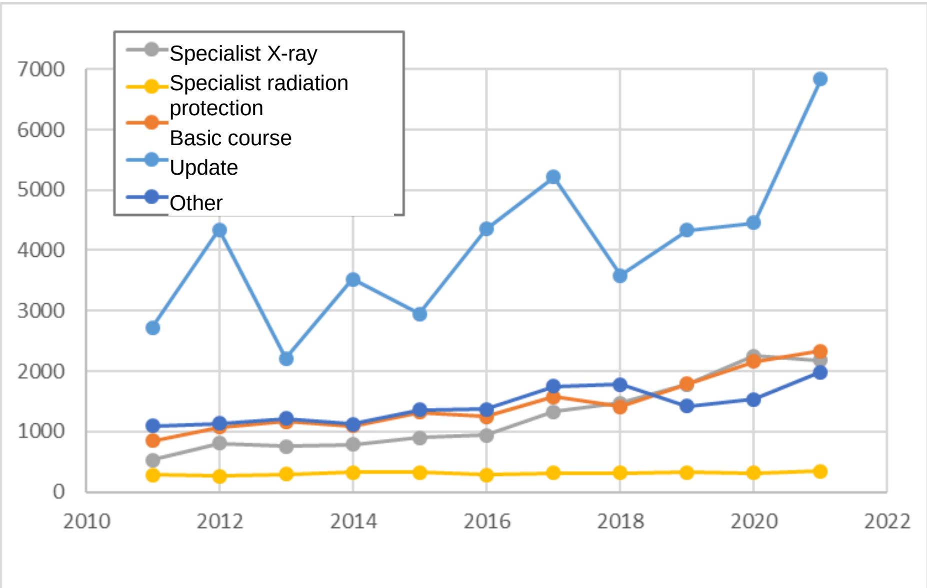

Figure 9: *Trend over time in the number of participants in radiation protection courses in the medical sector, broken down according to the type of course/specialist area and updates.*

3.4.3 Conclusions

The information on professional education and training in radiation protection that was available to the SSK confirms that there was a relatively stable number of providers of relevant radiation protection courses in Germany over the last ten years. Furthermore, the numbers of participants at 14 training centres investigated by the SSK, taken as examples, showed a rising trend over those same ten years. In the SSK's view, this suggests that ionising radiation continues to be used on a large scale in everyday professional life despite the decision to phase out the use of nuclear energy. A loss of expertise in radiation research and radiation protection would therefore be disadvantageous for Germany as a location for science and technology.

3.5 SWOT analysis by the SSK

3.5.1 Introduction and methodology

A SWOT analysis is a tool that is often used in business to analyse a company's situation in the context of its (national and/or international) market. The acronym stands for **s**trengths, **w**eaknesses, **o**pportunities and **t**hreats. From among the various available models, the SSK chose the commonly used method published by Mintzberg et al. (for reference, see https://en.wikipedia.org/wiki/SWOT-analysis), which in effect looks at the situation from the perspective of companies and distinguishes between internal factors (that can be influenced by the company itself) and external factors (that the company cannot influence). The first step is to identify both the internal factors, i.e. the characteristics of the business (strengths and weaknesses), and the external factors, which determine the position of the business in the market environment (opportunities and threats). In a second step, the internal and external factors are then correlated with each other in order to be able to devise action that can be taken to improve the company's situation. This involves, for example, examining the extent to which a company's opportunities can be enhanced or threats reduced by exploiting the identified strengths and rectifying the identified weaknesses.

The SSK made use of this tool when drawing up this recommendation in order to deduce measures that can improve the situation of radiation research and radiation protection in Germany over the long term. The members of the working group responsible for drafting this recommendation made their assessment of the areas in which radiation research and radiation protection in Germany is well positioned (strengths) and those in which they are less well positioned (weaknesses) while also being aware of the findings of other analyses. In addition, they investigated the importance of preserving and expanding expertise in radiation research and radiation protection for society (opportunities) and what the societal consequences would be if further expertise were to be lost (threats).

Finally, as described above, the correlation was established between internal and external factors, in other words the strengths and opportunities, strengths and threats, weaknesses and threats and weaknesses and opportunities were viewed in combination in order to develop measures to improve radiation research and radiation protection in Germany. The particular focus in this context was to:

- pursue opportunities and identify new opportunities that are a good match for existing strengths ("adaptation strategy S-O"),
- exploit new opportunities through the targeted rectification of existing weaknesses ("conversion strategy W-O"),
- mitigate threats by utilising strengths ("neutralisation strategy S-T"), and
- identify and avoid threats that arise from existing weaknesses ("avoidance strategy W-T").

3.5.2 Internal factors – strengths

The SSK identified the traditionally high quality of radiation research in Germany as a strength. Despite the reduction in opportunities, there is still a relatively active research landscape at universities, research centres, departmental research institutions and in industry, and the necessary infrastructure is still in place in most cases. This assessment by the SSK is backed by the high international reputation enjoyed by German scientists, which is also reflected in the strength of their international networking and their presence on national and international committees.

The high degree of interdisciplinarity of radiation research in Germany is seen as another strength, in which the research areas previously listed by the SSK in its statement of 2021 also have an important role to play, such as radiobiology, dosimetry, metrology, epidemiology, emergency response management and communication. In that statement the SSK stressed that in many areas research on ionising and non-ionising radiation including UV was working on similar issues with the aim of gaining insights into fundamental radiation-induced mechanisms. As a general rule, whatever exposure-related question arises in Germany, very good expertise can be obtained.

Another strength of radiation research is closely linked to the above observations, namely the ability of radiation researchers to cooperate with colleagues in many different disciplines and fields. Examples that could be mentioned in this context are research into tumour and cell biology, but also materials sciences, metrology and ecology. This enables radiation researchers to respond swiftly to current trends and to include new technologies in their activities, as well as taking account of any social changes in their work.

In the analysis of the strengths it also seems important that radiation protection research constitutes work of societal relevance. Radiation researchers have gained experience that extends well beyond their own particular field for many years, for example. Their experience has long taken account of age-specific and gender-specific differences, and in some cases has been incorporated into societally relevant areas such the regulation of radiation applications or risk communication. The essential foundation for all of this is on the one hand knowledge of radiation-induced health effects and on the other ensuring that risk groups are properly addressed.

Just three examples are listed here as being representative of interdisciplinary research in Germany and of the technical implementation of such research through to the commercial application of new sources of radiation:

a) The development of a high-power extreme ultraviolet (EUV) radiation source (wavelength 13.5 nm or photon energy 92 eV, over 200 W output). This enables the exposure of semiconductor structures measuring under 7 nm, a development that is the only one of its kind in the world and constitutes a significant competitive advantage for Germany as a technological leader.

b) The development of ultrashort pulse lasers for material processing and general surface processing, which is being accelerated in Germany both in industry and in public research institutions and will pave the way for new types of applications.

c) Developments relating to particle acceleration on a chip; one of the potential uses that will need to be explored is as a small-dimensioned source of ionising radiation, for instance for outpatient radiotherapy in medical practices.

3.5.3 Internal factors – weaknesses

The SSK identifies the lack of visibility of radiation research in Germany as a fundamental weakness. Presumably the problem of not being able to convey the relevance of and ongoing need for radiation research and radiation protection is partly a consequence of a certain scepticism of technology in society and inadequate communication. In the media, for example, there are often negative connotations whenever the term “radiation” is used. Another reason could be a low level of self-confidence among radiation researchers in their role as basic researchers, which makes it difficult for them to assert their own interests to a sufficient extent vis-à-vis other branches of science.

With regard to support for young professionals, a lack of structured training can be added to the above factors. Furthermore, specialising in radiation research appears to hold little attraction for next-generation scientists at the current time: there is almost no appropriately specialised training available at the universities, there are no relevant curricula, and – at least in the public perception – there does not appear to be an adequate link between radiation protection and scientific research. In addition, junior scientists do not see many career opportunities in the world of radiation research, and there are few secure positions for them in that sphere. In many cases, this state of affairs means that graduates do not come into contact with radiation protection until after they have embarked on their working life (on-the-job training). Over the coming years there will be an increasing need for a generational change in radiation protection; all of these issues put this in jeopardy.

Finally, certain research areas (e.g. radioecology and radiation epidemiology – see Section 3.2.3) that are important for radiation research and radiation protection are being neglected because of structural shortcomings. Germany does not have enough adequately equipped research institutes for many of the important scientific subdisciplines in radiation research. The financial resources available for radiation research are often insufficient and not provided on a stable, permanent basis, leading to a lack of infrastructure in some areas. There is a shortage of radiation reference fields in Germany, for example (as in Europe as a whole), and likewise a lack of exposure laboratories that can be used for multiple flexible purposes.

Another closely related feature is the fact that some areas of radiation research and procedures within it are incompatible with current science management practices, with the interdisciplinary nature of the research liable to have a detrimental effect when it comes to the appraisal of research proposals. What this also means is that existing appraisal systems are predominantly based on indicators such as the impact factor, which in comparison with medical journals tends to be rather low in the case of the journals that are of worldwide relevance to radiation research. Furthermore, assessments of scientific excellence currently take little or no account of participation in national and international committees, even though this is very important in light of the great relevance of radiation research and radiation protection within society. It should also be borne in mind that scientific priorities change at relatively short notice in science management in order not to miss out on the latest scientific trends. The strategies and goals of radiation research tend to be set up more for the long term, so as a result it is more difficult for radiation researchers to make their voice heard and add their weight within the scientific community to an appropriate extent.

With regard to the examples listed as being representative of the sector as a whole in Section 3.5.2, one disadvantageous aspect for the standing of radiation research per se is that development and research funding in these fields have been and still are promoted under headings such as “EUV lithography”, “material processing” or “acceleration on a chip”. This, however, primarily emphasises the application orientation of these examples, whereas the overarching term “radiation research” is mentioned only incidentally, if at all.

3.5.4 External factors – opportunities

The SSK sees it as an opportunity that radiation research and radiation protection can underpin and support societally relevant developments by performing the role of accompanying research.

This also includes supporting societal risk assessment for new technologies such as the expansion of the 5G network. Furthermore, findings obtained in radiation research can also be transferred to other fields. For example, an understanding of how radiation interacts with matter paves the way for an overarching view of molecular mechanisms and the principles of how biological processes work. This equips radiation research with a sound basic canon of scientific and medical training. Radiation research could also play a part in helping society to deal with risks in an informed, knowledge-based manner.

In its role as a location for technology and science, Germany is particularly reliant on basic research in a wide variety of fields. In this connection, radiation research – which all too often is merely seen as a branch of applied research – should be viewed as a branch of basic research. Studies into the interaction between radiation and living and inanimate matter provide fundamental scientific insights that are of relevance to many other areas, such as cosmology, astrophysics, particle and nuclear physics, geology, hydrology, biology, medicine and archaeology.

Further development of the health sector also has an important role to play in the advancement of Germany's position. Radiation research and radiation protection make vital contributions to improving health care for the population, for instance in radiotherapy for the treatment of cancer or in diagnostic imaging procedures using either ionising or non-ionising radiation. Another example is the use of UVC for disinfection to deal with hospital germs or, as in the COVID-19 pandemic, viruses. Appropriately trained experts who are able to contribute expertise in radiation research and radiation protection on relevant committees are therefore also crucial in the further development of the health sector.

Another area where radiation research is essential is in the creation of strategies for protection at the workplace and in the population as a whole. In addition to occupational health and safety when dealing with ionising and non-ionising radiation, examples include protecting the public from UV exposure in the context of climate change and the development of radiological emergency preparedness and response measures, particularly in times of growing political and social uncertainty.

The opportunities described in this section can only be exploited by society if sufficient numbers of appropriately trained staff are available. In the SSK's view there is a huge need to develop curricula in education and training, for instance in medicine. Thanks to its interdisciplinary nature, radiation research can also help gain qualifications in professions beyond the world of research (e.g. at government agencies). The SSK is convinced that the labour market offers excellent opportunities for radiation researchers who have received broad, interdisciplinary training. There is also long-term demand for qualified personnel in practical radiation protection. In terms of the opportunities outlined above, therefore, there is considerable demand for training in many different areas. In light of the interdisciplinary nature of the field, there is widespread need for radiation researchers and experts in radiation protection in order to meet this demand.

3.5.5 External factors – threats

One worrying development for radiation research and radiation protection is the misjudgement of the importance of radiation research both in political circles and in society as a whole. Commonly held views are that radiation research is dominated by the "nuclear lobby" and is obsolete because of the phase-out of nuclear energy, most topics have already been researched and now only need to be put into practice, problems with radiation are under control provided the rules are followed, or radiation-induced risks such as those from UV exposure are overestimated. Views such as these culminate in a widely prevalent image of radiation research and radiation protection as an outdated, conservative and formalistic – indeed even superfluous

– field of work. Consequently, there is a potential danger that prevention and emergency preparedness and response will be neglected.

A closely related concern is a common failure to appreciate the scientific importance of radiation research. For example, its significance as fundamental research is not recognised, and people underestimate the potential that radiation research (involving both ionising and non-ionising radiation) offers in connection with topical research areas such as epigenetics, nanotechnology, systems biology and artificial intelligence. Radiation research often bears negative connotations and is seen as hampering innovation, which leads to reduced efforts being made in academic training and exacerbates the shortage of new recruits because of their limited career opportunities. This is evidenced by difficulties with the assessment of projects of a distinctly interdisciplinary nature – a typical feature of radiation research – and the closure of relevant research institutes in recent years.

Given that financial resources are limited, it goes without saying that there is intense competition with other scientific disciplines vis-à-vis many other relevant research areas of research. Radiation research is in a difficult position in this respect – especially when it is perceived as being out of fashion. There is a danger that, as is often the case in areas of knowledge whose principal theme is safety-related and precautionary considerations for humankind, cost savings and cutbacks are continued until the accumulated deficiencies become apparent from actual events and all that can then be done is limit further damage. In order to counter this trend, radiation research would need to be developed further and embedded more firmly as an integral component of all sciences.

Finally, requirements pertaining to practical radiation protection may also be perceived as impediments – another factor contributing to a negative image for radiation protection and an actual hindrance to the expansion of radiation research. Meeting such requirements is laborious and costly, so the argument goes, and they supposedly cause increasing bureaucracy and are complex and difficult to explain. In some cases, ideas for research are dropped – or taken up in other countries – because the coordinators are unwilling to grapple with the administrative rigidity of practical radiation protection in Germany.

There is no doubt that the developments outlined above are all contributory factors in the dwindling amount of funding for radiation research. Other causes include specific research funding mechanisms, which are often based on the level of funding raised from third-party donors, the number of successful patent applications or the level of impact factors assigned to scientific publications. Instead of research funding being given a strategic orientation and a sustainable foundation, it often tends to be the case that short-term or politically expedient objectives are pursued, which can lead to frequent changes of topic in the funding. At the same time, inadequate institutional funding increases dependence on external funding for radiation research (third-party funds). This underlines the importance of appropriate funding for pure basic research, on which radiation research in particular, as an interdisciplinary branch of research, is especially reliant.

3.5.6 Conclusions

The SWOT analysis of radiation research and radiation protection in Germany revealed the following strengths, weaknesses, opportunities and threats, summarised in Table 16.

Table 16: Findings of the SWOT analysis of the situation in radiation research and radiation protection in Germany.

Strengths	**Weaknesses**	**Opportunities**	**Threats**
• High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively • Addressing issues of societal relevance	• Lack of visibility • Few career opportunities • Structural shortcomings (e.g. inadequate institutional funding) • Incompatibility with science management practices	• Support for social developments • Research in Germany maintaining it as a location for science • Great importance of the health sector • Great importance of protecting the public • Great need for training	• Underestimation of importance for society • Failure to appreciate scientific importance • Competition with other disciplines • Impediments due to rules on practical radiation protection • Dwindling funding

Starting out from the basis of the findings of the SWOT analysis summarised in Table 16, Table 17 shows which strengths would need to be utilised and which weaknesses changed in order to exploit the opportunities identified for radiation research and radiation protection (adaptation strategy S-O and conversion strategy W-O respectively).

Table 17: Findings of the SWOT analysis – exploitation of opportunities for radiation research and radiation protection in Germany.

Opportunities	**Usable strengths**	**Weaknesses to be changed**
Need for support for social developments	• Addressing issues of societal relevance • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Structural shortcomings (e.g. inadequate institutional funding)
Need for research in Germany as a location for science	• High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Structural shortcomings (e.g. inadequate institutional funding) • Incompatibility with science management practices • Few career opportunities
Great importance of the health sector	• High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Structural shortcomings (e.g. inadequate institutional funding)
Great importance of protecting the public	• Addressing issues of societal relevance • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Few career opportunities

Opportunities	Usable strengths	Weaknesses to be changed
Great need for training	• High degree of interdisciplinarity	• Few career opportunities and lack of training capacities

Similarly, Table 18 shows which strengths would need to be utilised and which weaknesses changed in order to reduce or avoid the threats identified for radiation research and radiation protection (neutralisation strategy S-T and avoidance strategy W-T).

Table 18: Findings of the SWOT analysis – reduction or avoidance of threats to radiation research and radiation protection in Germany.

Threats	Usable strengths	Weaknesses to be changed
Underestimation of importance for society	• Addressing issues of societal relevance	• Lack of visibility • Few career opportunities
Failure to appreciate scientific importance	• Addressing issues of societal relevance • High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Structural shortcomings (e.g. inadequate institutional funding) • Incompatibility with science management practices
Competition with other disciplines	• Addressing issues of societal relevance • High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Incompatibility with science management practices • Few career opportunities
Impediments due to rules on practical radiation protection	• Addressing issues of societal relevance	• Lack of visibility • Structural shortcomings (e.g. inadequate institutional funding)
Dwindling funding	• Addressing issues of societal relevance • High scientific quality • High degree of interdisciplinarity • Pronounced ability to work collaboratively	• Lack of visibility • Incompatibility with science management practices

The findings of the SWOT analysis summarised in Tables 16 to 18 are used as the basis for the proposed measures in Section 4 aimed at improving the situation for radiation research and radiation protection in Germany.

3.6 Summary

In the context of this recommendation the SSK has augmented and further developed the statement of 2021 (SSK 2021), for which it conducted its own analyses. This included a survey among 80 organisations that were presumed to have an interest in radiation research and radiation protection, a compilation of job offers published in 2020 and 2021 for posts requiring expertise in radiation research or radiation protection, and a sample analysis of the number of providers of and participants in radiation protection courses. In the SSK's opinion, the results achieved from these actions make it plain that there is lasting and broadly based interest in radiation research and radiation protection in Germany and a long-term need for correspondingly trained personnel. That said, the survey also demonstrates the concern expressed by most of the respondents that expertise in radiation research and radiation protection in Germany is declining. Based on these findings, the SSK subsequently conducted a SWOT analysis of the situation in radiation research and radiation protection in Germany, in which the strengths, weaknesses, opportunities and threats that the SSK considers most important became apparent. The results of the SWOT analysis together with the results of the survey, taking account of the situation in other countries, form the basis for the measures to preserve, develop and expand expertise in radiation research and radiation protection proposed in Section 4.

4 Package of measures

The SSK recommends a series of measures on the basis of the findings obtained as outlined above. The measures are described in more detail in the following sections.

4.1 Establishment of a national progress initiative on radiation research

In order to pave the way for implementation of these measures and to safeguard and strengthen radiation research on a sustainable basis, the SSK recommends launching a national progress initiative on radiation research (nationale Fortschrittsinitiative "Strahlenforschung"). The initiative should support and coordinate the funding providers in the use of all funds available for radiation research, exploiting synergies to the greatest possible extent and taking account of basic research, applied basic research and departmental research. It is vital that all funds available for radiation research in the broadest sense are used in a coordinated manner as this is the only way of dealing with major, socially relevant research topics in which radiation research and radiation protection are indispensable elements. In the SSK's view it is necessary to identify these research topics in order to be able to address institutions whose focus is not directed solely at radiation research itself but reaches beyond that. It would then also be possible to create attractive PhD and post-doctoral projects, and new career prospects would be opened up for graduates thanks to the interdisciplinary approach that is required for the proposed major research topics. In the opinion of the SSK, the progress initiative should support and coordinate the following work:

a) Identification of flagship topics

b) Networking

c) Involvement of policy at federal and state level

d) Structural development of the science and long-term maintaining of research infrastructure

e) Knowledge transfer

f) Communication

The various stakeholders who conduct or fund radiation research in Germany must be integrated into this process on a coordinated basis.

A strategy of this nature, aimed at securing radiation research for the long term, requires the provision of significant and sustainable financial resources that must be on a larger scale than the funds that have been made available for radiation research to date in the departmental research budgets (BMUV) and applied basic research budgets (BMBF).

4.2 Identification of flagship topics

Strengthening radiation research for the long term is not a realistic prospect without attractive scientific visions (that are also up-to-date and societally relevant) and the research activities required to realise these visions. In this respect, in the SSK's view, the actors engaged in radiation research in the past have not been active enough. These visions and the associated flagship topics must be developed and organised by the progress initiative along the lines of a think tank. They should encompass a wide range of areas in order to address all organisations actively involved in radiation research in the broadest sense, and in that way promote interdisciplinary and transdisciplinary cooperation. The size of such flagship topics means that they would be beyond the scope of purely national implementation and would initiate international cooperation projects with scientists in other countries where work may be carried out on similar projects. In addition, it would be attractive for junior scientists if working on flagship projects were to offer them plentiful opportunities to get themselves published in high-ranking scientific journals. For such visions to become reality it will be necessary to institute a research programme that utilises the strengths of radiation research in Germany as a whole but at the same time enables its weaknesses to be minimised. Existing competence networks or similar advisory bodies could contribute their expertise relating to current developments and needs in radiation research. In particular, their members have direct experience of which research topics excite and inspire young people so that they can be attracted to engage in radiation research.

One example of an overarching flagship topic could be developed if radiation were to be viewed as part of the exposome, the totality of non-genetic, endogenous and exogenous environmental influences to which a person is exposed. One possible vision would then be to obtain a comprehensive understanding of these influences on the effects of ionising radiation and on human health and thus make a significant contribution to preventive health care. In order to achieve this understanding, one possible flagship topic would be a study of the interaction between ionising radiation, non-ionising radiation and other environmental factors and stressors. Little is known to date of such cocktail effects or combined effects, despite their considerable relevance for the future, for instance for personalised medicine.

Another vision could be that radiation research and radiation protection would be seen as societal tasks that contribute towards achievement of the United Nations Sustainable Development Goals (SDGs) (UN 2015), thereby supporting the sustainable development of our planet. In order to realise this vision, as part of an overarching flagship topic it would be possible to identify and promote projects that explicitly address one or more the 17 SDGs. A variety of possibilities would open up for radiation research and radiation protection here, such as supporting the achievement of SDG 3, Good Health and Well-being, SDG 14, Life on Land, or SDG 15, Life below Water.

The SSK is aware that other visions of this type can be developed and appropriate flagship topics identified accordingly. Whatever the case, working on flagship topics such as these would mean conducting research for a period of many years and call for the use of the very latest technological methods.

In addition, the SSK sees potential for such topics to be linked to a wide range of Federal German Government initiatives, such as the National AI Strategy[8], the expansion of the 5G network and development of the 6G network, the National Decade against Cancer[9], the High-

8 https://www.ki-strategie-deutschland.de
9 https://www.dekade-gegen-krebs.de/

Tech Strategy 2025[10], the Federal German Government's energy transition strategy[11] (covering issues such as hydrogen, mobility and ending the use of nuclear energy for commercial electricity generation), the German Strategy for Strengthening Resilience to Disasters[12] and the Future Research and Innovation Strategy[13]. The recently announced Gigabit Strategy[14] should also be mentioned in this context.

In this, radiation research would be able to make full use of the strengths identified in the SWOT analysis (scientific quality, interdisciplinarity, ability to work collaboratively, addressing issues of societal relevance). Some of the identified weaknesses would be rectified (lack of visibility, few career opportunities, incompatibility with science management practices). Others, such as structural shortcomings, could be reduced, provided appropriate financial backing is ensured. At the same time the identified opportunities could be exploited and the identified need served (support for social developments, research in Germany as a location for science, importance of the health sector, protection of the public, training) and most of the identified threats could be reduced or minimised (failure to appreciate societal and scientific importance, competition with other disciplines, dwindling funding) (see Table 16).

Apart from the national level, the European level is also key to the future of radiation research. This is why it is also necessary to boost the role of radiation protection at EU level and to work towards an expansion of research funding via the relevant networks and official bodies.

Similarly, an organised, forward-looking analysis (horizon scanning) should be conducted in order to ensure that the future need for radiation research can be linked to technological developments in good time.

4.3 Networking

In the interest of improving networking and strengthening the competitiveness of radiation research vis-à-vis other branches of research, the progress initiative should exert influence on current science management structures wherever the latter place radiation research at a systematic disadvantage, for example in the assessment of research results on the basis of impact factors. Networking with other areas of research beyond the world of radiation research and radiation protection should be intensified in order to exploit some of the identified strengths of radiation research (interdisciplinarity and ability to work collaboratively) and to enable the topics and expertise available within radiation research to be utilised in other societally relevant research fields. Along with this, methodologies and expertise in metrology, epidemiology or radioecological modelling, for example, can be incorporated into health-related research activities or support the development of emergency preparedness and response. Networking would be of mutual benefit to all involved, as radiation research enriches other disciplines and at the same time can work in collaboration with them to harness their full potential for important research topics of the future (see Section 4.1.1). A radiation research progress initiative could systematically determine needs, create overviews and establish networks between specific actors.

10 https://www.hightech-strategie.de

11 http://swww.bundesregierung.de/breg-de/themen/energiewende/energiewende-im-ueberblick-229564

12 https://www.bbk.bund.de/DE/Themen/Nationale-Kontaktstelle-Sendai-Rahmenwerk/Resilienzstrategie/resilienz-strategie_node.html

13 https://www.bmbf.de/bmbf/en/research/future-research-and-innovation-strategy/future-research-and-innovation-strategy.html

14 https://bmdv.bund.de/SharedDocs/DE/Anlage/K/gigabitstrategie.pdf?__blob=publicationFile

4.4 Involvement of policy at federal and state level

The key task of the national progress initiative in relation to politics and science would be to convey a realistic picture of the importance of radiation research to political decision-makers in Germany and to scientific organisations both in Germany and abroad. The aim is to work toward maintaining and improving the conditions under which radiation research is supported on a sustainable basis so that this continues over the long term in accordance with the importance of this field of research. One way of achieving this could be to elucidate the role of radiation research in strategies such as the BMBF's Future Research and Innovation Strategy[15]. This would also have to involve better coordination of federal and state (Länder) policy on university-level research.

In this connection the SSK recommends, for example, that under the progress initiative the governments of the federal states should be encouraged to strengthen the first pillar in the German research landscape shown in Figure 1 (universities and other higher education institutions) in the interest of radiation research and to find ways of counteracting further cuts to relevant professorships and to support the preservation of existing professorships and the creation of new ones.

At the same time, at federal level the SSK recommends supporting the second pillar in the German research landscape shown in Figure 1 (research facilities supported by institutional funding, such as the Helmholtz Association with its national research centres) in addressing also the major and urgent multidisciplinary issues facing science, society and the economy that radiation research deals with. In light of the interdisciplinary nature of radiation research, university institutions are not able to take on this work alone. It is important to see the provision of infrastructure for radiation research as a sovereign function contributing to a service of general interest and embed this on a cross-state basis. This means setting up and maintaining institutes at research centres for which the Federal Government is responsible but also providing modern apparatus and instrumentation.

If the aim is to identify need for research and develop long-term, international research agendas, it is essential that relevant actors participate in radiation research, and likewise in socially important developments in Germany, the development of national research strategies, the drafting of research roadmaps and not least in quality assurance with regard to the appointments made to expert advisory bodies and the work they carry out. Networks must be established between actors in a targeted, specific manner so that needs, services offered etc. are pooled and made transparent, and in order to harness synergies (cf. Section 4.1.3).

4.5 Structural development of the science and long-term maintaining of research infrastructure

One of the findings of the SWOT analysis conducted by the SSK was the existence of structural shortcomings in radiation research. For example, the institutional support setup is too weak and there are insufficient research activities in certain subjects, for instance in radioecology and radiation epidemiology, relevant training courses and prospects for young scientists who are interested in radiation research. Furthermore, in order for forward-looking, up-to-date research to take place it is essential that the relevant infrastructure is in place, for example the operation of state-of-the-art irradiation and exposure facilities as a permanently available scientific service. This is true of both ionising radiation and non-ionising radiation. The know-how

[15] https://www.bmbf.de/bmbf/en/research/future-research-and-innovation-strategy/future-research-and-innovation-strategy.html

needed for setting up exposure facilities within research projects is often built from scratch with much effort and expense, and is lost again once the projects are completed. Over the past two decades the SSK has noticed this in research in the non-ionising sector in particular, and in studies on the biological effects of UV radiation or studies relating to mobile communications frequencies or exposure to magnetic fields in the context of the energy transition. This approach is seen as being extremely inefficient. It would make sense to create a common infrastructure for radiation research covering the fields of ionising radiation and UV radiation.

Consequently, it is urgently necessary to work towards coordinating the research policy of the Federal Government and the federal states in order to enhance the attractiveness of radiation research at universities and other higher education institutions, national research centres and departmental research institutions (see Section 4.4). This can be achieved by establishing and providing appropriate funding for coordinated, separate "radiation-research-driven basic research" in the fields of ionising and non-ionising radiation with the involvement of all stakeholders (federal and state ministries, project executing agencies, professional associations, representatives of research institutions). In particular this should also include flagship projects (see Section 4.2) and interdisciplinary training courses. Close consultation and coordination between the participating actors is vital. Thanks to their experience in teaching, members of competence networks such as the KVSF (Network of Competence in Radiation Research) or KVKT (Alliance for Competence in Nuclear Technology) can also identify research topics that can generate enthusiasm among the next generation of scientists.

The advantage of this type of approach is that it enables effective recruitment of new talent while also increasing the attractiveness of radiation research by opening up future career prospects with opportunities for further advancement for young researchers.

4.6 Knowledge transfer

A great majority of participants in the SSK survey proposed measures that should lead to improvements in knowledge (in the broadest sense) of radiation, radiation research and radiation protection. The target groups identified for these measures were school pupils, students, doctoral candidates and junior scientists. The importance of continuing professional development and training was also emphasised, however (Section 3.2.4). This was confirmed by an SSK evaluation of existing provision of such services (Section 3.4). Examples of suitable instruments that were mentioned include the recognition of relevant courses, the creation of appropriate graduate schools and university professorships or the establishment of dual training systems. The identified target groups differ in multiple respects (e.g. age, prior knowledge, media use, interests), which means that knowledge transfer geared to suit each target group is required (teaching formats and teaching content), and particular attention should be paid to the interdisciplinary nature of radiation research. In the SSK's view, the proposed progress initiative should target support at making use of existing options and developing new courses where options are lacking. It also appears to make sense to include relevant courses in other European countries.

4.7 Communication

The progress initiative should also help to communicate the importance of radiation research to society on a target-group basis, and likewise illustrate the strengths of radiation research in Germany. This would counteract the lack of visibility from which radiation research suffers – one of the key weaknesses identified in the SWOT analysis.

In this context it is essential to stress the contribution made by radiation research (including both ionising and non-ionising radiation) to issues of the future, such as health protection, quality of life and services of general interest, for instance in order to reduce mortality from cancer by taking appropriate protective measures and issuing relevant recommendations to the public. In addition, providing expert and comprehensible information about radiation research can help to reduce concerns about the use of ionising radiation and radioactivity, but also non-ionising radiation. One example of this is the use of advanced mobile phone networks. If the population is better informed and has greater knowledge, this could facilitate the nationwide expansion of the latest mobile phone networks, which in turn would contribute to services of general interest. This would create redundancy in communication, for example in emergency situations, thereby contributing to the resilience of society – an issue that was addressed in September 2022 at the BfS radiation protection forum 2022, “Resilience in a multi-crisis”[16]. The importance of risk and crisis communication should also be emphasised in this connection. As well as the vital contribution made by radiation research in the health sector, a realistic description of radiation risks in comparison with other risks is also important.

The quality and breadth of radiation research, its interdisciplinarity, its relevance for other areas of research and the resultant opportunities for joint research must be explained much more powerfully than before both to the public and within the political sphere in order to draw attention more effectively to the strengths of radiation research in respect of current Federal German Government research initiatives. It must become clear that radiation research is able to provide active scientific backup and support for socially relevant developments. It is not enough, either, to pass on the information in the same way as before via the traditional channels (printed media such as newspapers and journals, press releases, websites etc.). Modern communication tools have considerable impact and can play a significant part in intensifying communication.

4.8 Summary

The SSK proposes launching a national progress initiative on radiation research in order to coordinate the measures listed above.

Within the framework of the progress initiative, overarching scientific and social visions should be used as a basis for identifying flagship topics, which then, when addressed, will make a significant contribution to the preservation and expansion of expertise in radiation research and radiation protection in Germany. Radiation protection is by its very nature interdisciplinary – hence why it is so important that radiation research be networked with other branches of research. Germany’s federal structure makes it essential for there to be close collaboration at federal and state level in order to coordinate and implement the necessary research programmes and integrate national research centres and universities, and to ensure the systematic future development and long-term maintaining of the requisite research infrastructure. The dissemination of knowledge on radiation and radiation protection is a vital part of this and must extend to the widest possible range of target groups, from school pupils to the working population. The contribution that radiation research makes to the future issues affecting Germany must be explained to policy-makers and the public in an impactful and comprehensible manner in order to make it clear – more effectively than has been the case to date – that radiation research can provide active scientific backing and support for socially relevant developments.

5 Summary of recommendations

The German Federal Ministry for the Environment issued an advisory mandate on 11 November 2020 asking the SSK to review and if necessary revise its 2006 recommendation

[16] https://www.bfs.de/SharedDocs/Pressemitteilungen/BfS/DE/2022/015.html

on ensuring the long-term preservation of expertise in the area of radiation research in Germany (SSK 2006). In a subsequent statement (SSK 2021) the SSK identified the most important scientific disciplines and actors in radiation research, which was the first step in executing the advisory mandate. Building on that foundation, as a second step, in this recommendation the SSK proposes a package of measures to support research relating to ionising and non-ionising radiation in Germany and to safeguard expertise in radiation protection for the long term. This is meant to ensure that in future Germany will continue to be in a position to participate in the further development of international radiation protection while also presenting the case for the country's interests.

In response to the advisory mandate, the SSK first analysed the viewpoints of other institutions in Germany and abroad (see Section 0). The analysis found general agreement that there is a need for long-term, sustainable efforts to promote research into the health effects of radiation. The interdisciplinary nature of radiation research was repeatedly highlighted, with disciplines oriented towards both basic and applied research contributing to it. This is the only way that useful and responsible radiation applications and scientifically sound radiation protection strategies can be developed and implemented on the basis of current findings of radiation research.

The SSK then conducted its own analyses to complement its statement of 2021 (SSK 2021) and take it to the next stage.

The SSK asked 80 organisations in Germany about the key messages of its statement published in 2021 (SSK 2021) and about possible measures that would help to safeguard expertise but also to develop and expand it (see Section 3.2). The research areas that had been identified as important for radiation research in SSK 2021 were largely confirmed by the participants in the online survey, with the addition of two other fields: risk communication and radiochemistry. The overwhelming majority of participants saw deficiencies in expertise in the identified research areas to a greater or lesser degree.

Like the SSK, the participants were of the opinion that a broad spectrum of fundamental research, applied research and technological development in Germany can or could benefit from expertise in radiation research. Conversely, the current technological developments listed by the participants as being important or potentially important for radiation research and radiological protection should be exploited in order to enable radiation research and radiological protection to continue to meet the demands made of a modern scientific discipline into the future. The scientific, technical, organisational, economic and other measures proposed by the participants were analysed by the SSK and were incorporated into the measures proposed by the SSK in this recommendation.

An analysis conducted by SSK of job advertisements relating to radiation research and radiation protection published in 2020 and 2021 revealed that there was annual demand for several hundred skilled personnel with expertise in radiation research or radiation protection in Germany in those two years. In all likelihood this demand will persist over the coming years, especially as the baby-boom generation reaches pension age (see Section 3.3).

Furthermore, evaluation of the information on professional education and training in radiation protection that was available to the SSK confirmed that there was a relatively stable number of providers of relevant radiation protection courses in Germany over the last ten years. There was also a rising trend over the last ten years in the numbers of participants in events at 14 training centres, which were investigated by way of example. In the SSK's view, this suggests that ionising radiation continues to be used on a large scale in everyday professional life even after the decision to phase out the use of nuclear energy. A loss of expertise in radiation research and radiation protection would therefore be disadvantageous for Germany as a location for science and technology.

All three analyses make it plain that there is lasting and broadly based interest in radiation research and radiation protection in Germany and a long-term need for correspondingly trained personnel. The survey demonstrates the concern expressed by most of the respondents that expertise in radiation research and radiation protection in Germany is declining.

Based on these findings, the SSK conducted a SWOT analysis of the situation in radiation research and radiation protection in Germany, in which the strengths, weaknesses, opportunities and threats that the SSK considers most important became apparent. The results of the SWOT analysis together with the results of the survey, taking account of the international situation, form the basis for the proposed measures to preserve, develop and expand expertise in radiation research and radiation protection in Germany (see Section 3.5).

To sum up, the SSK concludes that a broad spectrum of basic research, applied research and technology development in Germany has benefited from expertise in radiation research in the past and will also benefit in future if relevant measures are put in place (see Section 3.2.3, responses to question 5). This is true irrespective of the phase-out of electricity generation from nuclear power plants that has now been completed in Germany, which does not diminish the importance of radiation research for services of general interest for the public in any way. We encounter radiation – both ionising and non-ionising – in a huge variety of circumstances in our everyday lives. Appropriate protection is required in all such cases. In order to strengthen the position of Germany as a location for research and technology, the SSK therefore proposes the following measures:

- Establishment of a national radiation research progress initiative

  The SSK proposes launching a national progress initiative on radiation research that supports and coordinates the following measures, thereby securing and strengthening radiation research on a sustainable basis. In particular, the various stakeholders who conduct and fund radiation research in Germany must be integrated into this process in a coordinated manner.

- Identification of flagship topics

  Within the framework of the progress initiative, overarching social visions should be used as a basis for identifying scientific flagship topics, which then, when addressed, will contribute to the preservation and expansion of expertise in radiation research and radiation protection in Germany. The scope of these flagship topics would also reach out to institutions whose focus is not directed solely at radiation research itself. It would be possible to create attractive PhD and post-doctoral projects, and new career prospects would be opened up for graduates thanks to the interdisciplinary approach that is required for the proposed flagship topics.

- Networking

  Since radiation protection is by its very nature interdisciplinary, it is important to pay attention to networking between radiation research and other branches of research.

- Involvement of policy at federal and state level

  In light of Germany's federal structure, the aim should be to achieve close collaboration at federal and state level in order to coordinate and implement the necessary research programmes. In particular, this should ensure close coordination between national research centres, universities and departmental research institutions.

- Structural development of the science and long-term maintaining of research infrastructure

  The purpose of structural development is to boost institutional support for radiation research, intensify research efforts in relevant subjects and create suitable courses and attractive prospects for young scientists who are interested in radiation research. Relevant infrastructure should be maintained or created in order to enable forward-looking, up-to-date research to take place.

- Knowledge transfer

  Since knowledge of radiation, radiation research and radiation protection should be disseminated to the widest possible range of target groups, in the SSK's view, from school pupils and students to the working population, appropriate activities should be offered via a central facility, with the addition of services that are currently lacking, which should also include relevant events and activities in neighbouring countries.

- Communication

  Greater efforts should be made to emphasise the contribution made by radiation research to future-oriented issues that are important for Germany in order to draw attention to the fact that radiation research can drive socially relevant developments in conjunction with other disciplines.

A programme of this type, aimed at securing radiation research for the long term, requires the provision of significant and sustainable financial resources that must be on a larger scale than the funds that have been made available for radiation research to date in the departmental research budgets (BMUV) and applied basic research budgets (BMBF).

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Annex

Questionnaire on the preservation of expertise

German Commission on Radiological Protection
- Chair -

German Commission on Radiological Protection

- Chair -

Prof. Dr. Werner Rühm

c/o Scientific Secretariat at the Federal Office for Radiation Protection (BfS)
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4 March 2022

Dear Sir or Madam,

I am writing to you as Chair of the German Commission on Radiological Protection (SSK) to ask if you can help us. The SSK would like to evaluate the situation surrounding radiation research and radiation protection in Germany with regard to ionising and non-ionising radiation so that we can submit suggestions to political decision-makers for improvements as and where they may be needed.

In an advisory mandate issued in 2020, the German Federal Ministry for the Environment asked the SSK to answer the question "who in Germany will be capable in future of undertaking basic research in radiation protection and what measures can be taken to promote radiation research." The aim was to assemble a package of measures "the implementation of which will support research in the field of ionising and non-ionising radiation in Germany and ensure the preservation of expertise in the long term."

The background to the advisory mandate was the impression that support for radiation research in Germany had been decreasing in recent years and consequently the preservation of expertise in radiation research and radiation protection could be under threat. The SSK considers any such trend to be critical, because radiation research makes or has the potential to make significant contributions to many areas that are relevant for society.

As a first step, therefore, the SSK identified the areas of research that it considered to be the most important for radiation research in Germany and the institutions actively involved in the German research landscape (SSK Statement of 9 June 2021).

At the next stage the SSK would like to formulate recommendations on what measures can be taken to enable research in the field of ionising and non-ionising radiation in Germany to be supported and expertise in radiation protection to be secured for the long term. For these reasons I would be very interested to find out from you whether you see a need for expertise in these areas, and if so, where.

I would therefore be very grateful to you if you could let us have your responses by 25 March 2022, via the following link: https://survey.lamapoll.de/Kompetenzerhalt/

Yours sincerely,

W. Rühm

Chair of the German Commission on Radiological Protection (SSK)

List of addressees

Professional societies and associations	
Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V. (AWMF) (Association of the Scientific Medical Societies in Germany)	office@awmf.org
Deutsche Gesellschaft für Epidemiologie (DGEpi) (German Society for Epidemiology)	geschaeftsstelle@dgepi.de
Deutscher Verein des Gas- und Wasserfaches (DVGW) (German Technical and Scientific Association for Gas and Water Industry)	info@dvgw.de
Bundesverband der Energie- und Wasserwirtschaft (BDEW) (Federal Association of the Energy and Gas Industries)	info@bdew.de
Gesellschaft Deutscher Chemiker (GDCh) (German Chemical Society)	gdch@gdch.de
Medizinischer Fakultätentag (MFT) (German Association of Medical Faculties)	berlin@mft-online.de
Verband der Universitätsklinika Deutschlands (VUD) (Association of University Hospitals in Germany)	info@uniklinika.de
Deutsche Gesellschaft für muskuloskelettale Radiologie (DGMSR) (German Society for Musculoskeletal Radiology)	info@dgmsr.de
Deutsche Gesellschaft für Radioonkologie (DEGRO) (German Society of Radiation Oncology)	office@degro.org
Deutsche Gesellschaft für medizinische Physik (DGMP) (German Society for Medical Physics)	office@dgmp.de
Deutsche Röntgengesellschaft (DRG) (German Radiological Society)	office@drg.de
Deutsche Gesellschaft für Nuklearmedizin (DGN) (German Society of Nuclear Medicine)	office@nuklearmedizin.de
Deutsch-Schweizerischer Fachverband für Strahlenschutz (FS) (German-Swiss Association for Radiation Protection)	FS-sek@fs-ev.org
Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP) (German Society for Non-Destructive Testing)	mail@dgzfp.de
Deutsche Physikalische Gesellschaft (DPG) (German Physical Society)	dpg@dpg-physik.de
Deutsche Krebsgesellschaft (DKG) (German Cancer Society)	service@krebsgesellschaft.de
Deutsche Gesellschaft für Biologische Strahlenforschung e.V. (DeGBS) (German Society for Biological Radiation Research)	verena.jendrossek@uni-due.de
Deutsche Gesellschaft für DNA-Reparaturforschung (DGDR) (German Society for Research on DNA Repair)	caroline.kisker@virchow.uni-wuerzburg.de
Verband Deutscher Ingenieure (VDI) (Association of German Engineers)	vdi@vdi.de

Industry associations	
Zentralverband Elektrotechnik- und Elektronikindustrie (ZVEI) (German Electro and Digital Industry Association)	zvei@zvei.org
Verband Deutscher Maschinen- und Anlagenbau (VDMA) (German Industry Federation for Machinery and Equipment Manufacturing)	serviceteam@vdma.org
Deutscher Industrieverband für Optik, Photonik, Analysen- und Medizintechnik (SPECTARIS) (German Industry Association for Optics, Photonics, Analytical and Medical Technologies)	info@spectaris.de
Bundesverband Medizintechnologie (BVMed) (German Medical Technology Association)	info@bvmed.de
Bundesverband der Arzneimittel-Hersteller (BAH) (German Medicines Manufacturers' Association)	bah@bah-bonn.de
Hauptverband der Deutschen Bauindustrie (HDB) (Federation of German Construction Industry)	info@bauindustrie.de
Bundesverband Baustoffe – Steine und Erden (BBS) (German Building Materials Association)	info@bvbaustoffe.de
Verband der chemischen Industrie (VCI) (German Chemical Industry Association)	vci@vci.de
Bundesverband der deutschen Recycling-Baustoffe (BRB) (German Recycled Building Materials Association)	info@recyclingbaustoffe.de
Research institutions	
Karlsruher Institut für Technologie (KIT) (Karlsruhe Institute of Technology)	info@kit.edu
GSI Helmholtzzentrum für Schwerionenforschung (GSI Helmholtz Centre for Heavy Ion Research)	info@gsi.de
Deutsches Krebsforschungszentrum (DKFZ) (German Cancer Research Centre)	kontakt@dkfz.de
Forschungszentrum Jülich (FZJ) (Research Centre Jülich)	info@fz-juelich.de
Deutsche Zentrum für Luft- und Raumfahrt e.V. (DLR) (German Aerospace Center)	contact-dlr@dlr.de
Helmholtzzentrum Dresden-Rossendorf (HZDR) (Helmholtz Centre in Dresden-Rossendorf)	kontakt@hzdr.de
Deutsches Elektronen-Synchrotron (DESY) Deutsches Elektronen-Synchrotron (DESY) – A Research Center of the Helmholtz Association)	desyinfo@desy.de
Max-Planck-Institut für Plasmaphysik (IPP) (Max Planck Institute for Plasma Physics)	info@ipp.mpg.de

Questionnaire on the preservation of expertise

1. Modern radiation protection (ionising and non-ionising radiation) should be based on the best currently available scientific knowledge. Which of the following areas of radiation research does your organisation consider to be important for Germany?

   ☐ Radiobiology

   ☐ Radiation epidemiology

   ☐ Radiation risk assessment

   ☐ Radioecology

   ☐ Radiation metrology

   ☐ Dosimetry

   ☐ Radiation physics

   ☐ Practical radiation protection

   ☐ Emergency preparedness and response

   ☐ Medical radiation applications

   ☐ Other ________________________________

   Additional remarks ____________________________

2. Is expertise in radiological protection and/or radiation research in Germany in danger of being lost? If so, in which areas (these may also be outside your own specialist area) and what are the possible reasons for this?

3. In which of the areas listed under point 1 is it necessary to build additional expertise in order to further improve radiation research and radiological protection in Germany?

4. Are there other areas of research that could be developed through the use of radiation or radiation research?

5. What new technological developments could benefit from expertise in radiation research or radiological protection?

6. What new technological developments could be of benefit to radiation research or radiological protection?

7. What measures to improve radiation research and/or radiological protection would you propose and what specific benefits do you hope will be obtained from them?

   ☐ Scientific measures (e.g. studies of certain mechanisms of action)

   ☐ Technical measures (e.g. developments of certain instruments)?

   ☐ Organisational measures (e.g. to improve training)?

   ☐ Economic measures (e.g. structural support)

   ☐ Other measures

8. Has your organisation already taken steps of its own to maintain or improve expertise in radiation research or radiological protection?

9. What type of organisation are you answering on behalf of?

   ☐ Professional society or association

   ☐ Industry association

   ☐ Research institution, university or other higher education institution

   ☐ Agency or departmental research institution

   ☐ Expert commission

   ☐ Employer’s liability insurance association

   ☐ Organisation or office providing expert services

   ☐ Commercial enterprise

   ☐ Other

10. What field do you/does your organisation work in?

    ☐ Radiobiology

    ☐ Radiation epidemiology

    ☐ Radiation risk assessment

    ☐ Radioecology

    ☐ Medical radiation applications

    ☐ Radiation metrology

    ☐ Dosimetry

    ☐ Radiation physics

    ☐ Practical radiation protection

    ☐ Emergency preparedness and response

    ☐ Other