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

Key scientific disciplines and main actors in research

Statement by the German Commission on Radiological Protection

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Langfristige Sicherung der Kompetenz auf dem Gebiet der Strahlenforschung und -anwendung in Deutschland – Wichtigste wissenschaftliche Disziplinen und Hauptakteure in der Forschung

Stellungnahme der Strahlenschutzkommission

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1 Introduction

Every single member of society is continuously exposed to ionising and non-ionising radiation from a great variety of sources. This is true in both occupational and private settings, and relates to visible and invisible, natural and artificially generated, “useful” and “harmful” radiation. Ever since scientists discovered the existence of ionising radiation at the end of the 19th century, its benefits and risks have been subject to research and to wide-ranging discussion in the public arena. Numerous scientific and technological advances are linked to the presence of ionising radiation or make use of radiation for a specific purpose (e.g. in medical applications, aerospace, accelerators and the dismantling of nuclear facilities). Ionising radiation plays a role in diagnostic and analytical techniques and also in procedures designed to modify or influence the properties of materials and of biological tissue, for example in cancer treatment. On the other side of the coin we are faced with the risk of radiation-induced disease, such as cancer and cardiovascular conditions. The risks and benefits of ionising radiation have also increasingly become a matter of public discourse: rapid technological progress is leading to constantly growing exposure to non-ionising radiation, for instance in connection with digital networking by means of mobile communications or wireless networks, or through the use of low-frequency electric and magnetic fields in energy supply, or the development of electromobility. Furthermore, there is increasing awareness of risks from the use of laser radiation and from exposure to natural and artificial ultraviolet (UV) light in both private and work-related contexts.

A high level of scientific expertise is needed in order to ensure the safe use of radiation in ways that are meaningful to society and to identify, communicate and mitigate the risks associated with radiation, which are often very long-term. Active interdisciplinary research is required in order to acquire, maintain and enhance such expertise, which can then be used to develop and implement useful and responsible radiation applications and scientifically sound radiation protection methods. Only then is it possible for radiation research to maximise its contribution to the common good and to the development of German research and industry. The term radiation research as used in this statement denotes research into matters relating to the presence and application of ionising and non-ionising radiation that ultimately serve the purpose of benefiting and protecting human health. This necessarily comprises both basic research and applied research.

As early as 2006 a recommendation of the German Commission on Radiological Protection (SSK) recognised the necessity to “*maintain and in the long term improve expertise in all areas of radiation research with a special emphasis on radiation protection*” in Germany, in particular in connection with cancer research. In this context the SSK focussed especially on promoting the education and training of the next generation of scientists, stating that this was possible only where excellent research and competent teaching are in place. The SSK identified three priority areas in which radiation research in Germany should be supported, and proposed research projects on topics for which the SSK found that there was an “*urgent need to maintain expertise*”. Subsequently, in 2007, the Competence Network for Radiation Research (Kompetenzverbund Strahlenforschung/KVSF) was founded on the initiative of the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The objective was to “*reinvigorate radiation research and consequently strengthen it on a sustainable basis by encouraging collaboration between universities and non-university research facilities*” (SSK 2006). At the same time, the BMBF initiated a programme setting out the framework within which national research projects have been promoted effectively and continuously to this day. By 2017 around 140 research projects had been promoted following calls for proposals by the BMBF on the topics of nuclear safety and radiation research (KVSF 2018), and more than 150 positions for PhD students and junior scientists had been established as a result. Furthermore, the first ten years of the KVSF initiative saw more than 80 graduate students achieving diplomas and bachelor's or master's degrees, with the results of their research being published in more than 150 papers in top-ranking journals (KVSF 2018). These research projects provided a lasting boost to collaboration between the research groups operating in Germany.

The nuclear accident in Fukushima rekindled public awareness of the risks associated with ionising radiation. In the wake of this accident, Germany decided to abandon nuclear energy and is currently in the process of implementing this decision. Nevertheless, it is clear that a high standard of expertise will still be needed in Germany in the long term, and particularly in respect of emergency preparedness due to the lack of an international consensus on the nuclear phase-out and the longevity of the radiation sources involved. In any case, other sources of radiation exposure of the general public (as outlined above), including the ever-increasing use of ionising radiation in medical diagnostics and its associated risks, remain unaffected by this and continue to be relevant for society. These considerations have led the SSK to note with concern that the relevance attached to radiation research within the research landscape in Germany has been steadily diminishing in recent years.

The 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). 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 preservation of expertise in radiation research in the long term."*

The following SSK statement takes stock of the current situation in radiation research, covering both basic and applied approaches to research. It should be noted, however, that in medicine, for example, there are areas of applied and basic research in which, although the objectives of radiation research are also touched upon, the personnel involved and established structures are not primarily concerned with radiation research and radiation protection but rather with other aims such as optimising treatment or mitigating side effects. For this reason these particular areas of research are not included in this survey, even though they may potentially be relevant for radiation research.

For the purposes of this survey, the aim is to identify which areas of research and which institutions currently active in the research landscape in Germany (hereafter referred to as actors) are the most important for radiation research. That said, it must be borne in mind that radiation research is a truly interdisciplinary field. Any assessment of the risks, benefits and harmful effects of ionising and non-ionising radiation and thus the justifiability of their use in the interests of individuals and of society as a whole can only be obtained through collaboration between different scientific disciplines. In order to achieve the aim of maintaining, let alone expanding expertise in radiation research in Germany, more than a few individual institutions need to be involved. In fact, this is a challenge that can only be met by coordinated cooperation between a great many institutions actively involved in the research landscape. If radiation research is to be perceived as an attractive research field when compared with other areas of research, current research topics must be addressed using state-of-the-art scientific methods (e.g. borrowing from molecular biology or harnessing the use of artificial intelligence and digitalisation). The value of research is usually measured using parameters such as the number of published papers, the publications' impact factors and the amount of funding raised from third-party donors. These parameters also have to be applied to radiation research to help guarantee high scientific standards. However, it needs to be remembered, too, that long-term institutional and financial backing of radiation research is vital if expertise in this field, which is of such importance for the common good, is to be maintained and expanded. The SSK believes that any such safeguarding of radiation research efforts in Germany is now provided to only a limited extent.

The research landscape in Germany is predominantly built on three pillars: universities and university of applied sciences (UAP), research facilities supported by institutional funding, and the Federal Government's departmental research institutions that also play a part in radiation research (Fig. 1). The scope of this statement did not allow for the inclusion of research activity in industry.

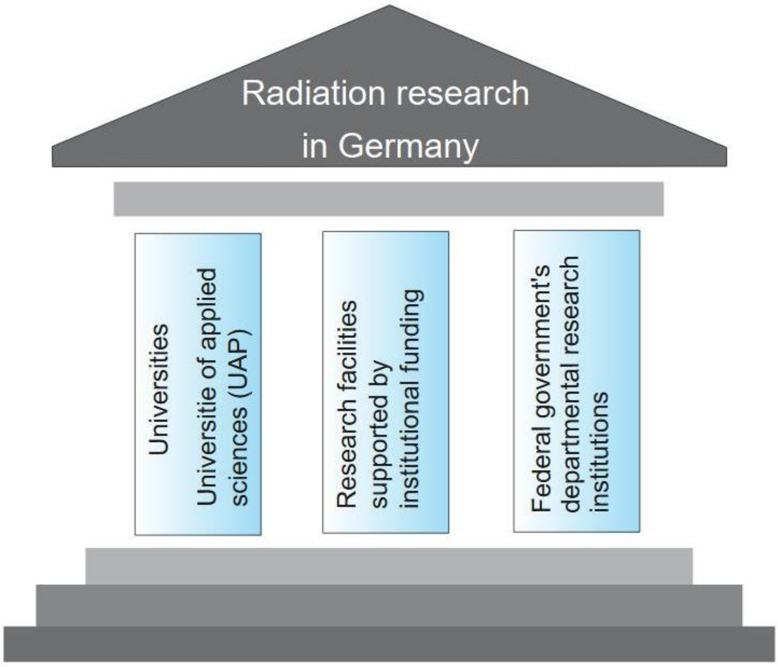

Fig. 1: The essential pillars of radiation research in Germany. As categorised by the SSK, "research facilities supported by institutional funding" include, for example, the Fraunhofer-Gesellschaft, the Helmholtz Association, the Leibniz Association and the Max Planck Society. The Federal Government's 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).

Universities and UASs, research facilities supported by institutional funding and the Federal Government's departmental research institutions were identified as key actors in basic radiation research for the purposes of this review if they had carried out or were still carrying out research projects promoted by the BMBF since the KVSF was established in 2007 and fell within the framework of the initiative to secure and develop expertise in radiation research in Germany, referred to in the following as the KVSF initiative. As at the end of 2020 there were 159 projects in total, 150 of which can be classified as research into ionising radiation and nine as research into UV radiation.

In addition, the evaluation covered the projects assigned by the BMU within the framework of the departmental research plan for radiation protection in the period between 2010 and 2020, amounting to 205 projects in total. Projects assigned under a framework agreement on cooperation in the field of nuclear safety, radiation protection, nuclear procurement and nuclear waste management between the Federal German Government, represented by the BMU, and the German Organisation for Reactor Safety (GRS) were not included in the review. Of the 205 projects from the BMU departmental research plan, 158 were classified as research into ionising radiation, five addressed UV radiation and 36 examined electromagnetic fields (EMF). A further six projects – four researching optical radiation, one ultrasound and one studying general legal matters – are disregarded in the remainder of this survey.

Departmental research is one of the topics of the radiation protection requirements analysis drawn up by a project team from the BMU, the Federal Office for Radiation Protection (BfS), the Federal Office for the Safety of Nuclear Waste Management (BASE), the BGZ (Gesellschaft für Zwischenlagerung – company for interim storage) and the BGE (Bundesgesellschaft für Endlagerung – federal company for radioactive waste disposal). The analysis is due to be published shortly. The research and development activities undertaken by the departmental research facilities provide “guidelines for policy decisions and contribute to preserving and further developing the technical infrastructure of the Federal Republic of Germany. As part of this important function, the departmental research institutions address current societal, scientific and economic issues and devise options for action to be taken in the form of government measures” (www.ressortforschung.de).

The SSK is aware that projects engaged in radiation research in a broader sense are often supported by other institutions (for example by the German Research Foundation (DFG), the European Commission, charitable foundations such as the Volkswagen Foundation or Deutsche Krebshilfe (German Cancer Aid), programmes in the German federal states, intramural programmes in research centres and Federal Government departmental research facilities, other projects supported by federal ministries etc.) or by research activities in industry. However, in light of the disparate nature of the available data, the amount of research required to take appropriate account of these projects would have been excessive. The SSK believes that the presence of such large numbers of potential funding providers indicates that radiation research in Germany could benefit from closer networking and better coordination. It cannot be ruled out that the approach chosen by the SSK has resulted in a few individual research actors in certain research areas having been overlooked. However, the SSK considers it likely that large research institutions involved in radiation research are only rarely funded solely by the above-mentioned organisations and that therefore most research institutions will be covered by the approach taken in this statement.

In the following, firstly the societal relevance of radiation research is discussed in section 2. Section 3 then identifies the scientific disciplines that, in the SSK’s view, are central to research into ionising radiation and research that makes use of ionising radiation, beginning with priority areas that international organisations consider necessary to ensure and in the long term improve protection of the population against harmful radiation effects, taking a holistic approach. To a certain degree, these scientific disciplines and areas of research also reflect the structure of the SSK, represented by its various committees: Radiation Risk (A1), Radiological Protection in Medicine (A2), Radioecology (A3), Radiation Protection Technology (A4), Emergency Management (A5) and Applied Radiation Protection and Radiological Protection in Nuclear Installations (A7). The scientific disciplines dealing with non-ionising radiation, covered by Committee A6, are described in sections 4 and 5. Protection against both types of radiation is therefore part of the SSK's remit. At an international level, on the other hand, a form of task sharing has emerged, with the International Commission on Radiological Protection (ICRP) dealing with protection against harmful health effects following exposure to ionising radiation and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) covering the area of non-ionising radiation.

The research actors identified in the survey of the institutions are each assigned to the identified priority areas for research, and the results are discussed. In light of its similarities with ionising radiation in terms of research structure and level of knowledge, as a first step section 4 looks into the topic of UV radiation separately. Section 5 then takes stock of the complex research situation in the other areas of non-ionising radiation. Finally, an evaluation of the results is presented in summary in section 6.

2 Societal relevance of radiation research

The trade-offs between the risks and benefits of ionising radiation for individuals and for society as a whole are especially apparent in medicine, for example. Thanks to the progress made in diagnostic X-ray imaging and computer tomography (CT), the role of ionising radiation in identifying, treating and curing many diseases is now taken for granted, from heart attacks to strokes and bone fractures to cancers. In the latter case, relatively high radiation doses are also a very effective means of treatment. However, there is no doubt that at the same time, in Germany, medical diagnostics is by far the biggest contributor to radiation exposure of the population from artificial sources, at a growing rate for many years now. According to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), for example, the global average effective dose increased from 0.35 mSv in 1988 to 0.62 mSv in 2008 due to diagnostic procedures in medical settings (UNSCEAR 2010). This trend has continued: according to the 2018 BMU parliamentary report, the average number of CT scans per person per year increased by just over 45% between 2007 and 2016 in Germany (BMU 2021). In 2018 the German population was exposed to an annual effective dose of ionising radiation from artificial and natural sources amounting to just under 4 mSv on average; roughly 50% of this was attributable to medical applications (BfS 2019). With regard to the collective dose, therefore, radiation protection in medicine is relevant and is subject to high standards. After years of efforts in risk communication, training and the optimisation of radiation protection technology, it is now a matter of course for particularly low-dose radiation techniques to be used routinely, such as pulsed fluoroscopy or low-dose computer tomography. Other methods employing non-ionising radiation, for example, are sought after as an alternative, and effective protection for staff is also always in place. As a consequence, despite the increasing use of advanced radiological technologies, the collective dose is being limited, and the public's confidence in the methods used is also enhanced. Moreover, new developments in this area – not least by German companies – pave the way for new products to be launched or existing products to be optimised, helping to provide the best possible health care for the population while at the same time increasing value added. Wide-ranging expertise in radiation protection is crucially important in this context.

There are also a number of other applications of ionising radiation, for instance in materials testing and for sterilising items such as pharmaceuticals, medical supplies, cosmetics and foodstuffs. Other areas in which state-of-the-art expertise in radiation protection is essential, some of which at least will remain relevant for society for a long time to come, are the dismantling of nuclear facilities and the interim and final disposal of low-, intermediate- and high-level radioactive waste. Radiation research is tasked with developing the foundations for ensuring the safe use of ionising radiation in all of these applications.

The relevance of radiation research for both individuals and society as a whole is also apparent in the area of non-ionising radiation, for instance with regard to the effects of exposure to UV radiation on human health. The entire population is exposed to UV radiation from sunlight, and this form of radiation – whether from sunlight or artificially generated – is the main risk factor in developing skin cancer. In 2009 the International Agency of Cancer Research (IARC) categorised natural and artificial UV radiation as a Group 1 carcinogen ("carcinogenic to humans") (IARC 2009). The societal relevance of the effects of exposure to both natural and artificial UV radiation in Germany is put into sharp focus by the large number – around 276,000 – of newly diagnosed cases of skin cancer per year (malignant melanoma, squamous cell carcinoma and basal cell carcinoma) (Katalinic 2020) and by the fact that since 2015 squamous cell carcinoma of the skin has been an officially recognised occupational disease in outdoor workers (BK 5103[1]). Radiation research plays a major role in identifying, communicating and preventing the long-term risks of exposure to UV radiation. Ideally, this not only prevents human suffering in terms of individual lives but also reduces the socio-economic burden caused by years of life lost and by the demand on resources in the health care system.

The visible and infrared spectra lie below the UV frequency range, followed by what is traditionally referred to as the EMF spectrum, which is mainly used for radio services. Below this again is the frequency range used for electrical energy transfer, including direct current transmission (one example of its use today is "electricity highways", i.e. HVDC – high voltage direct current – transmission lines). Strictly speaking, the term "radiation" is not used any more when referring to energy transmission. Rather, as far as the protection of human health is concerned, it is necessary to distinguish between electrical and magnetic fields as two independent physical quantities.

Innovations driven by more and more new electrical engineering applications and developments often lead to people questioning whether the associated new situations of field exposure could carry new and/or additional risks for human beings. Any and every use of electrical engineering applications results in exposure to field exposures, so the level of exposure in addition to ubiquitous exposure from natural sources is therefore subject to constant change. Recent examples include the introduction of the 5G network and the expansion of power transmission lines in the course of the energy transition. The same will be true of the 6G network currently under development. These cases have triggered extensive public debate about potential new risks. Complaints are often made of a lack of research into these matters even though clear scientific strategies have led to today's high standards in protection from exposure to field exposures, which are not dependent on any specific technology. There are however clear shortcomings with regard to maintaining expertise in research, evaluation and in particular communication, i.e. ensuring an appropriate breadth of scientific activities and sufficient numbers of active participants in Germany. This is apparent simply from the fact that invitations to tender for relevant scientific research projects, for example through the BfS within the framework of BMU departmental research plans, in some cases attracted zero responses.

2.1 Contribution of radiation research to currently relevant research initiatives

In the course of the democratic process of opinion-forming, public discourse is used as the means of establishing and addressing political objectives. In order to achieve these objectives the Federal Government uses specialist and framework programmes to promote specific research and development (R&D) projects that will advance knowledge in areas of application that are important for Germany and will also act as accelerators of growth in many sectors.

1 https://www.dguv.de/bk-info/icd-10-kapitel/kapitel_12/bk5103/index.jsp

Thus, enterprises in trade and industry as well as universities, research centres and other R&D institutions are able to take part in the research funding programmes. A number of these areas of application touch on issues that by their nature are also subject matters of radiation research. Current examples of such areas include:

– the High-Tech Strategy 2025[2], with topics such as combating cancer, putting artificial intelligence into practical application and digitally networking research and healthcare – for intelligent medicine;

– the National Decade against Cancer[3], whose mission is to “work on the further strengthening and targeted promotion of cancer research in the areas of prevention, early detection, diagnosis and innovative treatments”;

– the Artificial Intelligence Strategy of the Federal Government[4], with initiatives such as promoting the usability of AI systems in the healthcare sector and AI flagship projects for the environment, climate, nature and resources[5]; and

– the Energy Transition Strategy of the Federal Government (including topics such as hydrogen, mobility and the phase-out of nuclear energy).

The SSK believes that radiation research can make a very productive contribution to these strategies and initiatives as long as expertise in radiation research and the requisite research infrastructure continue to be developed accordingly. Radiation research is an interdisciplinary research area with links to fundamental research, medicine, the environment and digitalisation, enabling it to play an important part in the pursuit of the Federal Government’s strategic objecttives. Furthermore, radiation research can serve as a model for the response to important questions for society, for instance in research into the mechanisms implicated in the development of diseases such as cancer following exposure to DNA-damaging agents and in risk assessments or the development of communication strategies. Radiation research has already made significant contributions to key findings in basic biological research in the past, for example in DNA repair and cell cycle control processes. Over time these findings have contributed to the development of therapies and pharmaceuticals.

The SSK is therefore of the opinion that it is important to integrate radiation research into national research strategies for the long term. There has been only limited success in this regard, if at all, since the responsibilities for radiation research lie with different ministries and authorities, hampering the coordinated integration of radiation research into a broader national research landscape. Given the obvious future challenges facing Germany as a hub for science and innovation, this is a clear disadvantage and will impact the competitiveness of research in Germany in various fields, such as the use of novel radiotherapy methods in medicine, new diagnostic imaging techniques, appropriate methods for dismantling nuclear facilities and disposing of radioactive waste, as well as the search for innovative solutions to protect against radiation from natural radiation sources (UV, radon). A cooperative approach to integrated radiation research is also needed in order to shape the digital transformation, which has a particular impact on data processing and measurement technology in the highly regulated field of radiation protection. In this connection there is a need to reduce bureaucracy, for example, and improve the availability of data and services. It is also worth noting the obstacles encountered by medical

2 www.hightech-strategie.de
3 https://www.dekade-gegen-krebs.de/
4 www.ki-strategie-deutschland.de
5 https://www.z-u-g.org/aufgaben/ki-leuchttuerme/

research, in particular, arising from especially strict data protection regulations that differ from one region to another.

An integrated research strategy that takes account of ionising and non-ionising radiation is also relevant when it comes to introducing new technologies (e.g. the development of ultrashort pulse lasers or laser-driven proton beam and X-ray sources, the introduction of new modalities in cancer treatment, the rollout of the 5G network and development of the 6G network etc.). In particular, greater attention should be paid to radiation research in preparatory research and technology impact assessments (for instance when measuring radiation fields or evaluating radiation risks).

2.2 Contribution of radiation research to risk communication

Specialist expertise is also vital for professional, effective and ethically sound risk communication, without which it is almost impossible to reach a consensus on the issue of ionising and non-ionising radiation. The SSK has monitored and put into context the impact that different types of risk and crisis communication have had on society during the aftermath of the accidents at the Chernobyl and Fukushima nuclear power plants for many years now, and the lessons learned from this process have been incorporated into the current German emergency response plan (SSK 2015). As in the follow-up to the nuclear accidents at Chernobyl and Fukushima, the current pandemic situation has clearly shown that risk communication in general has a key role to play in an open society, and in ideal circumstances can be the basis for society dealing appropriately and expediently with threats that it faces. Comparative analysis of everyday risks from various sources (chemicals, lifestyle choices, technological applications etc.) can serve as a link connecting various different scientific fields, since the way that people perceive risks and address them is closely coupled with public acceptance of a wide variety of behaviours and activities in private and at work. However, such risks are taken deliberately and often come with direct personal benefits, which makes it difficult to compare them to risks posed by radiation, for example from nuclear waste disposal. Close collaboration with radiation research experts, for instance in the field of technology impact assessment, thus makes sense in this regard.

However, knowledge of the latest scientific findings is not sufficient in itself for risk communication to be successful. In this context it is essential to provide information on complex interrelationships and to ensure that people appropriately process this information (e.g. by communicating the above-mentioned comparisons of life risks in non-technical language). Using traditional and modern communication channels (for example social media) can be helpful, but is no substitute for direct reciprocal communication between affected persons and scientists. This applies in particular to primary prevention measures intended to change people’s behaviour. In this case it is necessary to employ targeted communication strategies aimed at specific groups based on discourse rather than merely conveying facts. The SSK believes that it is particularly important to keep pursuing new developments in communication technology and especially in communication sciences, and to use them as early as possible to communicate radiation-induced risks but also potential benefits of using ionising and non-ionising radiation. This is especially important for radiological emergency preparedness and response.

Conversely, it makes sense to harness the lessons learned on risk communication in the area of radiation research in order to apply them to other societally relevant risk situations. This could be helpful in addressing fundamental questions about the impacts on society of introducing or developing new technologies. What factors, for example, influence the degree of acceptance of new technologies among individual members of society? How can stakeholders who expect new technologies to be either advantageous or disadvantageous be integrated into decision-making processes? What risks is society as a whole prepared to tolerate? In what circumstances is it ethically justifiable to burden individuals, groups or even future generations with additional risks without them benefiting themselves in any way?

The SSK believes that in order to be able to answer questions such as these it is necessary to engage in close dialogue with all societally relevant groups. In the SSK's opinion, radiation research could in future build bridges here, in line with its social responsibility, and intensify cooperation between the natural sciences and the humanities and social sciences in order to adopt a holistic approach.

3 Ionising radiation

International organisations agree on the fact that contributions are required from numerous different scientific disciplines in order to develop and implement useful and responsible radiation applications and scientifically sound radiation protection strategies on the basis of current findings of radiation research. These include both basic and applied scientific disciplines, covering the natural sciences, medicine, technology and the humanities.

3.1 Fields of research referenced by international groupings

The fields of research that various European and international groupings consider important for radiation research are briefly described in the following.

3.1.1 ALLIANCE

ALLIANCE (European Radioecology Alliance) is a network of 26 institutions in 13 European countries (as of 2021, the German members include the Federal Office for Radiation Protection (BfS), the Helmholtz Centre in Dresden-Rossendorf, the Thünen Institute and Leibniz University Hannover). The aim of this research community is to maintain and enhance expertise and experimental infrastructure in the field of radioecology in Europe. It addresses scientific and educational challenges that are relevant to assessing the effects of radioactive substances on humans and the environment.

The most recent position paper (June 2017) summarises short- to medium-term priorities in radioecology which ALLIANCE believes should be pursued in order to improve the scientific basis and reduce uncertainties in human and environmental risk assessments, increasing radiation protection of humans and wildlife (ALLIANCE 2017). The ALLIANCE lists four priority areas for research.

The aim of two of these priority areas is to reduce uncertainties in the assessment of radiation doses in human beings and the environment:

1. Studies into the behaviour of radionuclides in various ecosystems, taking account of physical, chemical and biological processes, and the development of validated models to describe this behaviour;
2. The development of techniques for testing such models with the aim of supporting decontamination measures in long-lasting exposure scenarios, e.g. following nuclear accidents or where radioactive substances are present in the natural environment.

The main aim of the other two priority areas is to improve the protection of plants and animals by reducing uncertainties surrounding harmful radiation-induced effects:

3. Identification of biomarkers for radiation exposure and effects in living organisms in order to be able to determine differences in radiation sensitivity between individuals

within a specific species or between individuals of different species following chronic exposure to low-dose radiation;

4. Studies aimed at understanding the interaction between different stressors and their influence on radiation-induced effects in living organisms.

3.1.2 CONCERT

CONCERT (European Joint Programme for the Integration of Radiation Protection Research; partners in Germany are the Federal Office for Radiation Protection and the Helmholtz Munich) operates as an umbrella structure under the Horizon 2020 framework programme funded by the European Commission. Based on the research agendas of the European research platforms described in this section (MELODI, EURADOS, EURAMED, ALLIANCE, NERIS), CONCERT identified the following challenges (EJP-CONCERT 2020):

1. Understanding and quantifying the health effects of radiation exposure
2. Improving dose concepts
3. Understanding radiation-related effects on plants and animals as well as on entire ecosystems
4. Optimising the use of ionising radiation in medicine
5. Improving radiation protection of workers
6. Developing an integrated approach to risk assessment following environmental exposure
7. Optimising emergency and recovery preparedness and response
8. Relevance of radiation protection in society

3.1.3 EURADOS

In 2014 EURADOS (European Radiation Dosimetry Group) published a 20-year strategic research agenda for Europe on the dosimetry of ionising radiation (Rühm et al. 2014, Rühm et al. 2016). EURADOS is a network of 79 (as of 2020) European institutions (research centres, universities, hospitals, monitoring bodies etc.) concerned with the dosimetry of ionising radiation. Its members in Germany are Berthold Industries, the Federal Office for Radiation Protection, Scienta Envinet, Helmholtz Munich, the Karlsruhe Institute of Technology, Physikalisch-Technische Bundesanstalt (German National Metrology Institute) and the Technische Universität (University of Technology) Dresden. EURADOS's mission is to coordinate and promote research and development of dosimetry across Europe and to support harmonisation of dosimetric procedures and practices.

Its research agenda, which was revised in 2020, defines five objectives ("visions") that are meant to serve as guidelines for European research in the field of dosimetry of ionising radiation:

1. Update fundamental dose concepts and quantities
2. Improve dosimetry for radiation risk estimates deduced from epidemiological cohorts
3. Develop techniques for efficient dose assessment in radiological emergencies
4. Develop integrated personalised dosimetry in medical applications
5. Improve radiation protection for workers and the public

The publication lists several research challenges and research activities (“research lines”) to address each of these visions. According to the EURADOS agenda, the prerequisites for achieving all five of these visions are Europe-wide harmonisation of dosimetry procedures, engagement in education and training and the development of numerical techniques in dosimetry (Bottollier-Depois et al. 2020, Harrison et al. 2021).

3.1.4 EURAMED

EURAMED (European Alliance for Medical Radiation Protection Research) is the umbrella platform for five European specialist associations with an interest in the medical use of ionising radiation: EANM (European Association of Nuclear Medicine), EFOMP (European Federation of Organisations for Medical Physics), EFSR (European Federation of Radiographer Societies), ESR (European Society of Radiology) and ESTRO (European Society for Radiotherapy and Oncology). EURAMED members in Germany are the University Medical Centre Mainz and the Federal Office for Radiation Protection. The purpose of the alliance is, among other things, to coordinate European research in the field of medical radiation protection, to identify common research areas that are relevant to medical radiation protection, to improve the medical use of ionising radiation and to act as an intermediary in addressing questions and concerns of stakeholder groups.

In 2017 EURAMED, supported by all its member organisations, published a strategic research agenda (EANM et al. 2017). This highlighted the following radiation protection research areas as particularly important for effective healthcare provision:

1. Supporting medical application of ionising radiation by measuring relevant radiation fields and identifying any associated uncertainties
2. Studying radiation-induced tissue reactions, diseases (cancer and benign conditions) and long-term health effects, taking into account doses, dose rates and individual sensitivity of patients
3. Optimising radiation exposure and harmonising the procedures and practices used to measure exposure, taking into account state-of-the-art technological developments
4. Justifying the use of ionising radiation in medical practice
5. Developing the infrastructure necessary for quality assurance.

In addition, the report points out the importance of education and training of both researchers and clinical personnel.

3.1.5 EURAMET

EURAMET, the European Association of National Metrology Institutes, is the joint platform for establishing and disseminating the measurement infrastructure for units of ionising radiation (Bq, Gy and Sv) in Europe. One of its members is the Physikalisch-Technische Bundesanstalt (German National Metrology Institute), and associated members in Germany are the Federal Institute for Materials Research and Testing (BAM), the Federal Environment Agency and the Federal Office of Consumer Protection and Food Safety (BVL). EURAMET coordinates the cooperation of National Metrology Institutes (NMIs) in fields such as research in metrology, the traceability of measurements to the SI units and the international recognition of measurements on the basis of national quality assurance infrastructure[6].

6 https://www.euramet.org/

As a first step towards establishing a future European support programme for research in metrology, representatives of 45 national and international organisations from 23 countries came together in September 2020 to develop a preliminary analysis of gaps in corresponding research (EURAMET 2021). They identified deficits and saw need for increased research and development in the following areas:

1. New radiation reference fields (e.g. pulsed fields around accelerators, access to ^{137}Cs as a reference source material, realistic neutron fields, reference fields for epithermal and high-energy neutrons)
2. Managing new measurement quantities in radiation protection metrology (e.g. influencing how dosimeters are approved and calibrated)
3. Education and practical training
4. Metrology in the wake of new developments in measuring techniques (e.g. ISO 17025 accreditation – DIN EN ISO/IEC 17025:2018-03, intelligent measuring technology, approved measuring techniques for radon and thoron) and of new technological developments in general (digitalisation, higher basic technological requirements for equipment and software and new measuring techniques for use in emergency preparedness and response and in monitoring under the EURATOM Treaty (EAG 1959), for example ambient dose rate measurements using drone technology or alpha-contamination measurements using optical methods)
5. Activity standards (e.g. for new radionuclides in nuclear medicine, availability of activity standards and reference materials, mass spectrometry for alpha emitters with long half-lives in environmental samples)
6. Administrative and technological harmonisation (e.g. standardisation of limits and of areas of uncertainty, new digital data formats – Digital SI; the Digital SI system will affect every digital transfer of data measured in SI units, i.e. Bq, Gy, Sv and others).

3.1.6 ICRP

The International Commission on Radiological Protection (ICRP), which was founded in 1928, draws up recommendations for the safe use of ionising radiation without impeding useful applications. In 2017 the ICRP published a report listing ten research subjects, the study of which would, in the IRCP’s opinion, contribute to improving the system of radiological protection (ICRP 2017):

1. Effects of protracted exposures and low-dose rates
2. Mechanisms of low-dose effects and dose-response models that take account of them
3. Organ-specific, and age and sex differences in, sensitivity to cancer induction
4. The role of genetic factors in determining individual sensitivity
5. Effects other than cancer and genetic effects and their contribution to radiation detriment
6. Relating exposures, doses, and effects on population viability for non-human biota
7. Reliability of dose assessments
8. Dosimetry and protection methods in medicine
9. Ethical and social dimensions of the system of radiological protection
10. Mechanisms for interaction with stakeholders.

3.1.7 MELODI

MELODI (Multidisciplinary European Low Dose Initiative) is an association of 44 European institutions. Its members in Germany, as of 2019, are the Federal Office for Radiation Protection, Helmholtz Munich, the Karlsruhe Institute of Technology (KIT), KVSF (Network of Competence in Radiation Research) and Rostock University. MELODI is dedicated to research into biological and health effects of low-dose radiation. Since its foundation in 2010, it has published an annual research agenda detailing priority research activities that can contribute to better understanding of the effects of low-dose ionising radiation on humans. Other MELODI activities include the involvement of stakeholders in identifying areas where research is needed and exchange with international partners. The most recent update of MELODI’s research agenda dates from 2019 and describes two priority research topics and two cross-cutting topics:

Priority research topics:

1. Dose and dose-rate dependence of cancer risk
2. Dose and dose-rate dependence of risk for non-cancer diseases

Cross-cutting topics:

3. Individual variations in sensitivity to radiation
4. Effects of spatial and temporal variations in dose delivery on risk of disease

Each of these key issues is discussed from two different standpoints in the research agenda:

– Research to improve understanding of the mechanisms contributing to radiogenic diseases following low dose and dose-rate exposures
– Epidemiological research that integrates, where possible and informative, biological approaches to improve the evaluation of health risks (MELODI 2019).

3.1.8 NERIS

NERIS (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery) is a platform for dialogue and methodological development in emergency preparedness in Europe for organisations that are concerned with potential protective actions in nuclear and radiological emergencies and recovery. As of 2020 it had 67 officially registered members. In Germany, these are the Federal Office for Radiation Protection, the Karlsruhe Institute of Technology (KIT), the Radiobiology Institute of the German Federal Armed Forces, the German Organisation for Reactor Safety (GRS) and the Baden-Württemberg Ministry for the Environment, Climate Protection and the Energy Sector.

NERIS identifies research needs in the following areas (NERIS 2019):

1. Improvement of hydrological models, including urban hydrology and marine environment
2. Application of food chain models at the local level to derive sensible countermeasure strategies
3. Improvement of dose assessment models considering both environmental and personal monitoring
4. Improvement of monitoring by including monitoring by interested lay people, drones and Europe-wide harmonisation of tools and methods for dose assessments
5. Development of measuring strategies to guide practical countermeasure implementation
6. Development of recommendations for decision-makers

7. Development of strategies for lifting countermeasures
8. Improving the integration of stakeholder groups
9. Development of guidelines for emergency response following radiological accidents (e.g. evacuation, compensation etc.)
10. Development of health surveillance approaches and dose reconstruction methods, taking account of psychological and economic aspects of medical follow-up.

3.1.9 SHARE

SHARE (Social Sciences and Humanities in Ionising Radiation Research) is a European platform consisting of 30 members (25 institutions). As of October 2020 its members in Germany were the Federal Office for Radiation Protection and DIALOGIK (gemeinnützige Gesellschaft für Kommunikations- und Kooperationsforschung mbH), as well as five individuals. The aim of this association is to promote the integration of social sciences and the humanities in all aspects that concern ionising radiation (research, application and politics).

In its recently published research agenda, SHARE identified six overarching scientific subject areas (Perko et al. 2019; SHARE 2020):

1. Social, political and psychological factors influencing perceptions, expectations, behaviours and applications regarding ionising radiation
2. Holistic approaches to governance of radiation exposure situations
3. Responsible research and development in the area of ionising radiation
4. Stakeholder engagement practices in relation to applications of ionising radiation
5. Risk and health communication
6. Radiological protection culture.

3.2 Important research areas for Germany as identified by the SSK and associated future perspectives

Based on the fields of research that the international groupings listed in the previous section consider to have a key role to play in maintaining and improving protection against ionising radiation, the SSK has identified certain research areas that are important for Germany. In light of the interdisciplinary nature of radiation protection, it is self-evident that the research areas identified below are directly or indirectly relevant for all SSK committees. The listed areas correspond to the areas covered by the committees, although the order in which they are listed does not reflect their priority or significance.

3.2.1 Radiobiology

Radiobiology or radiation biology examines the mechanisms responsible for health effects from radiation exposure (e.g. cancer, cardiovascular diseases, neurological and cognitive disorders) and identifies factors that influence the probability with which they occur (e.g. genetic factors, lifestyle or medication). The findings of radiobiology thus provide a crucial basis for assessing health risks from ionising radiation and hence also for radiation medicine and all other areas concerned with radiation-induced health effects. Important questions for the future relate to differences in biological mechanisms dependent on temporal and spatial variations in exposure, interactions between radiation and other risk factors and possible interventions, systemic effects (e.g. immune system modulation), potential biomarkers for radiation effects, and the mechanisms underlying individual sensitivity to radiation. With regard to the medical response to radiation emergencies, it is extremely important to study both acute and chronic radiation damage and process the findings using innovative methods based on fundamental research.

State-of-the-art model systems (e.g. organoids, orthotopic and syngeneic mouse models), high-throughput analyses of short-term or longer-term radiation-induced changes (e.g. in the genome, epigenome, tanscriptome, proteome, secretome, metabolome) and a systems-biology based approach to evaluating and linking biological and clinical or epidemiological data promise to lead to fundamental new findings in radiobiology. In addition, radiobiology forms the basis for further developing radiotherapy techniques towards precision medicine. A thorough investigation of basic mechanisms paves the way for insights into connections, allows predictions to be made and enables swift responses to fast-changing demands on radiation protection in the future. Ultimately, radiobiology is an important link between basic and applied research.

Consequently, expertise in radiobiology will continue to be essential for future research into radiation-induced changes in biological systems in Germany. In view of recent developments that amount to a reduction in research activities in this field in Germany, and against the backdrop of an increasing focus on application-oriented research in radiotherapy, the SSK emphasises that a broad range of expertise in radiobiology can only be maintained and further expanded by continuing to conduct active basic research at a level of international excellence.

3.2.2 Radiation epidemiology

Radiation epidemiology studies directly examine the links between ionising radiation and various human diseases and enable researchers to quantify the level of risk from radiation. Radiation epidemiology is thus a key part of risk assessment. Potential connections to solid tumours and leukaemias, which may be observed at doses of around 50 to 100 mGy and above, are especially important and of particular interest to the general public. Radiation epidemiology can also deliver important insights into non-cancerous diseases and factors that influence radiation risk (age, sex, lifestyle, miscellaneous other risk factors and type of radiation etc.).

At present, the study on survivors of the atomic bombing of Hiroshima and Nagasaki still remains our most important source of knowledge of the long-term health effects of exposure to radiation. In future, however, important findings are expected from a whole series of further epidemiological studies, including in particular studies in cancer survivors who have been treated with radiotherapy and studies in children who have undergone CT examinations. The Wismut uranium miners cohort in Germany is the world's largest cohort for studies of radiation-induced lung cancer. In addition, this large cohort of occupationally exposed workers is being used to carry out numerous other radiation epidemiology investigations. Expertise in radiation epidemiology is also required when addressing issues that are currently subject to controversial debate, such as the occurrence of leukaemia in children caused by background radiation or radon. Novel approaches such as molecular epidemiological studies or the incorporation of radiobiological findings into epidemiology and identifying subgroups with specific, individually varying radiation sensitivity promise to yield new findings relevant to radiation protection.

For these reasons the SSK considers it important for epidemiological studies into radiation-induced health effects to be carried out not only at international level but also at national level in order to ensure that researchers in Germany are able to acquire and apply the necessary expertise and that radiation risk assessments are tailored to the specific situation in Germany. This is especially crucial because radiation epidemiology is the field that investigates the specific radiation-induced effects on human health that are vitally important for radiation protection (cancer, leukaemia, cardiovascular diseases etc.), and these effects cannot be identified in any other way.

3.2.3 Radiation risk assessment

In order to assess the risk of harmful radiation-induced effects on human health such as cancer and non-cancerous diseases, it is necessary to gain a full overview of cell studies, animal and human experiments and epidemiological studies. Among the general population, estimates of the risk posed by radiation vary. It is vital to determine and assess radiation-induced risks as precisely as possible in order to have a sober public debate that focusses on the advantages and disadvantages of using ionising radiation. This is particularly relevant for radiation doses below around 100 mGy with respect to cancer risk and below 500 mGy with respect to the risk of non-cancerous diseases. A comparative analysis of the effects of other carcinogenic substances (harmful chemical agents) can also be helpful in such a debate. It is to be expected that, in future, risk assessments of low-dose radiation or for particularly radiation-sensitive individuals or groups will be considerably improved by integrating radiobiology findings and epidemiological data using molecular epidemiological studies or new mechanistic models based on radiobiology findings. Expertise in risk assessment is essential in order to be able to provide satisfactory answers to the general public's legitimate questions concerning the risks and benefits of ionising radiation, and furthermore to be able to accurately identify the risks associated with the ever-expanding range of diagnostic procedures in medicine.

3.2.4 Radioecology

Radioecology is the study of radionuclides in the environment and their distribution. It describes how radionuclides that are present in the environment enter plant life and animals, ultimately leading to radiation exposure of human beings. The purpose of radioecology is to gain a comprehensive understanding of the underlying processes, taking account of the chemical characteristics of the substance and any interactions with microorganisms. Studies in this field are carried out on both the macroscopic and, using advanced analytical methods, the microscopic level. In Germany, radioecology research focusses on investigating the impact of emissions from nuclear installations and disused uranium mines, for example in Saxony, on the general public's exposure to radiation, and also looks at the consequences of the accidents at the Chernobyl and Fukushima nuclear power plants. There will still be a need for radioecological research in Germany following the shutdown of the country's nuclear power plants in order to model emissions from the dismantling of the pants and provide long-term predictions of potential releases of radionuclides with long half-lives from planned repositories. Such releases may involve low-, intermediate- and high-level radioactive waste and take place over periods of up to a million years. Another area of interest, separate from the issues mentioned above, is emissions from the manufacture of radioisotopes and radioactive sources, as well as the behaviour of radionuclides with short half-lives, significant quantities of which typically enter the environment during therapeutic and diagnostic procedures (e.g. ^{99m}Tc, ^{131}I). Radioecology also investigates radiation exposure due to naturally occurring uranium and thorium and their decay products, in particular radon isotopes and their decay products. These radionuclides are responsible for most of the naturally occurring radiation exposure of the general public. Increased radiation exposure as a result of the use of technologically enhanced naturally occurring radioactive materials (technologically enhanced NORM, or TENORM) is another relevant research subject, for example the accumulation of naturally occurring radionuclides arising from the generation of energy in geothermal facilities or during fracking.

The general public also has legitimate questions regarding the consequences of the release of radioactive substances into the environment that may occur in the wake of radiological or nuclear emergencies, or with regard to the safety of intermediate or final storage of radioactive material, and researchers will need radioecological expertise to be able to provide answers in future. Increased funding for this area of research is important because, as far as the SSK is aware, there is currently only one institution in Germany that supports radioecological research, namely the Helmholtz Centre in Dresden-Rossendorf. The SSK points out that sufficient expertise in radioecology is also vital for the government and authorities to respond appropriately to radiological or nuclear emergency situations.

3.2.5 Radiation measurement technology

The term ionising radiation refers to a range of very different types of radiation. Their important characteristics are their energy levels and the spatial and temporal distribution of ionisation events in the material in question. Consequently, different types of infrastructure are required in order to test, calibrate and validate the measuring devices needed to quantify these types of radiation. The legal requirements at national level differ according to the type of radiation and are not based on the degree of risk. Alongside these, there are standards for reference fields, procedures and measuring equipment issued under the auspices of the IEC[7], ISO[8] and DIN[9], and explanatory notes within the Technical Reports Series of the IAEA[10] and recommendations from the ICRU[11] and ICRP.

The development of measurement technology is subject to a whole range of legal provisions and qualitative requirements that make it difficult for relevant suppliers to access the small German market. This brings with it the risk of modernisation being held back, which would be regrettable since new technological developments (novel detector materials, innovative dose assessment procedures, digitalisation) also open the door to new research opportunities. In many cases, measuring devices suitable for certain radiation applications have not even been developed, nor does the necessary (testing or calibration) infrastructure exist, for instance for pulsed radiation fields associated with medical accelerators or ultrashort pulse lasers in industry. To enable new technological developments in Germany to be supported, for example those that address the occurrence of fields of ionising radiation at relatively high energy levels, there is a need for a constant flow of accompanying and conclusive developments in radiation measurement technology – if possible in close cooperation with medical physics and industry. Contract award and cooperation procedures must be designed in a way that makes it attractive for actors from industry to act as research contractors and develop products that comply with national legal provisions. In recent years this has been the case ever more rarely, with the result that the process of market displacement in Germany has led to monopolisation of this sector by a small number of companies. As a consequence, it has already been impossible to continue to uphold certain legal requirements, and legal exceptions have been created, for example due to a lack of type-tested measurement technology.

As a general principle, the question of whether a limit or reference value is adhered to depends on the suitability of the particular measurement technology used. The way that the detection and decision threshold are handled, as well as the measurement uncertainty, which is often considerable in the case of radiation protection, is therefore a matter of fundamental importance: when is it certain that a limit has been adhered to?

In summary, the SSK believes that ongoing developments in radiation measurement technology – if possible through close multidisciplinary cooperation with industry – will continue to be required in future in order to prevent Germany becoming decoupled from the rapid technological progress currently being observed.

7 International Electrotechnical Commission
8 International Organization for Standardization
9 Deutsches Institut für Normung – German Institute for Standardization
10 International Atomic Energy Agency
11 International Commission on Radiation Units and Measurements

3.2.6 Dosimetry

In order to be able to quantify and communicate the risks and health effects of radiation, it is usually necessary first to calculate and measure relevant radiation doses, with a distinction being drawn between two types of dosimetry: ambient and personal. The exception is radiotherapy, where dosimeters are only used in rare cases. There are very considerable qualitative differences in the legal requirements for monitoring devices, i.e. the quality and robustness of the results depends on the type of radiation[12] rather than only on the level of exposure.

Official dosimeters for occupational radiation protection are issued by measurement bodies which then report the results to the National Dose Register. In this context, the development of smart networked monitoring devices is a technological imperative, and the transfer of certified data such as individual radiation exposures is becoming increasingly important. The digital transformation requires suitable data formats, which are being developed according to the Digital SI metadata model. The secure collection and transfer of radiation exposure data therefore needs to undergo a rethink. Relevant concepts already exist within legal metrology, but as yet, there is no provision for implementing these for radiation protection. It is to be expected that the digital transformation will also have a similar impact with regard to monitoring ambient dose rates and environmental radioactivity, which is governed by the Ordinance on the Responsibilities of Federal Authorities within the Integrated Measurement and Information System for Monitoring Environmental Radioactivity according to the Radiation Protection Act (IMIS-ZustV 2017). This transformation should be expedited so that technological preparations are in place for radiological incidents and the workload on staff in participating institutions is reduced.

The further development of dosimeters is closely linked to the field of measurement technology. In addition, radiation doses can be calculated using the Monte Carlo methods. Validated input data provides the basis for such calculations. Although the experimental determination of the data and the associated quality assurance are very time-consuming and costly, they are nevertheless indispensable.

With regard to new developments in radiotherapy, accurate determination of the applied dose is also a key factor in being able to provide personalised treatment. The same is true when it comes to ensuring that diagnostic or minimally invasive therapeutic procedures using imaging with ionising radiation are optimised for each individual patient. In these situations it is important to determine the actual organ doses received by individual patients during each procedure.

Furthermore, environmental monitoring under the EURATOM Treaty (EAG 1959) and the required Europe-wide merging of data have recently taken on added scientific importance. The use of innovative detectors can improve environmental monitoring and emergency preparedness and response by providing nuclide-specific data (with spectrometers being used as environmental dosimeters) and offer a climate monitoring interface. It can also raise the profile of radiation protection at the European level against the background of the digital transformation.

Dose determination following external or internal exposure to ionising radiation is essential in order to interpret radiobiological effects and predict potential impacts on human health and the environment. Dosimetry is also indispensable where ionising radiation is used in medical settings (both in radiological diagnostics and radiotherapy) and is key to many issues encountered

12 Photon dosimeters for radiation protection and dosimeters used for staff in X-ray departments are covered by the German measuring and verification act (MessEG) and the measuring and verification ordinance (MessEV). This does not apply to beta dosimeters, neutron dosimeters or exposimeters used to calculate radiation doses from exposure to radon.

in emergency preparedness and response. As a multidisciplinary field that covers both the development of equipment and the performance of computer-aided simulation, dosimetry is vitally important for radiation research and radiation protection. Consequently, in the SSK's opinion it is critically important to safeguard expertise in this area in the future.

3.2.7 Emergency preparedness and response

The German Federal Government and the Länder make provisions for a range of emergency scenarios involving the release of ionising radiation that may affect the entire population (such as accidents at a nuclear power plant and terrorist attacks involving the use of unsealed radioactive substances or radioactive substances in explosives). Other potential scenarios are accidents affecting comparatively small numbers of people, such as accidents when handling radioactive sources used in industry or medicine. The impacts on human health of ionising radiation have numerous special characteristics, which means that, compared to other emergencies, there are significant differences in terms of the required diagnostic measures, the clinical course and the medical procedures needed to ensure that patients receive appropriate, state-of-the art treatment. A notable and crucial aspect of being prepared for such scenarios and for the clinical symptoms involved is expertise in medical emergency response and preparedness and in the medical aspects of patient care. In addition, the response to radiological or nuclear emergency situations requires expertise in all other scientific fields mentioned in this report. Overall it is important to emphasise in this context that medical emergency response and preparedness is a specialist area in itself, which – although there are overlaps with radiation protection in medical diagnostics and therapy – may have different priorities, such as in the knowledge of radiobiology and technology that may be required. In order to enable medical staff in hospitals to treat patients with acute radiation damage, specialist knowledge and modified treatment regimes that are not standard practice in everyday hospital routine have to be in place. Acute radiation damage is a rare occurrence in Germany, which means that the appropriate knowledge and skills can only be maintained through international scientific exchange. This exchange requires the presence in Germany of partners with in-depth clinical knowledge who are actively engaged in scientific research. It is not possible for medical staff to acquire the depth of skills needed for radiation emergency preparedness during their work in specialties relevant to everyday clinical practice. Adequate numbers of qualified personnel will therefore only be available if sufficiently interested persons and appropriate capacities and strategies for education and training are in place over the long term.

There is currently very little research activity in Germany on developing the medical response to radiation emergencies in regard to clinical diagnostics, medical treatment including innovative procedures such as stem cell transplantation or model-based analysis of injuries, the development of new pharmaceuticals or appropriate healthcare research.

In one of its recommendations, the SSK recently pointed out that there are significant shortfalls in Germany with respect to healthcare in radiological and nuclear emergency scenarios and specified relevant areas in which research should be intensified (SSK 2017a). Close links between the few biological and medical research institutions engaged in relevant activities and medical staff working in clinical settings are crucially important in order to ensure a minimum level of proficiency. Investment in relevant research areas but also links to potentially needed healthcare structures are the foundation for appropriate specialist expertise.

In addition to physical dosimetry, clinical and biological dosimetry are part of emergency preparedness and response. Biological dosimetry not only covers a range of very different types of radiation exposure of humans, it is potentially also influenced by the specific reactions of each individual to such exposure. State-of-the-art analytical methods are needed to investigate such influences. Areas in which research is required include the advancement of diagnostic, biological and clinical techniques that offer sensitivity to doses well below 100 mSv as well as facilitating direct clinical management (effect prediction). New approaches to research in this field are possible using both traditional retrospective dosimetry techniques and omics-based techniques, in particular in connection with modern biostatistical methods, including artificial intelligence. In addition, it is important to revive basic research into new therapeutic concepts including the development of pharmaceuticals, as this area of research should not be left solely in the hands of institutions outside Europe.

3.2.8 Medical applications of ionising radiation

The particular role played by ionising radiation in medicine is apparent from the fact that most areas of radiation research that the SSK considers important for Germany are also relevant for medical applications (in radiology, radiotherapy and nuclear medicine). A wide range of research activities and proficiencies relating to the application and biological effects of ionising radiation has thus become established in medicine, too, alongside the optimisation of diagnostic and therapeutic procedures in purely practical terms. Radiation biology has identified mechanisms that are responsible for the effects of ionising radiation on living organisms (cells, tissues, human beings). These findings relate to a wide range of doses and different types of radiation, making them relevant for both diagnostic and therapeutic medical procedures. At the same time extensive clinical experience has been gained in therapeutic nuclear medicine and radiotherapy with respect to prophylaxis and treatment of radiation damage following exposure to high levels of radiation. It is therefore not surprising that there are numerous radiobiological research institutes in medical faculties at universities, and that these institutes have in the past published internationally competitive studies contributing to cell and tumour research, an area where there is fierce competition among researchers.

Radioecological techniques that describe the behaviour of radionuclides in closed systems can be used to study the biokinetics of radiopharmaceuticals in humans, which play an important role in diagnostic and therapeutic procedures in nuclear medicine. In addition, nuclear medicine imaging makes it possible to gain a better understanding of the biodistribution of radionuclides.

Radiation metrology and dosimetry are indispensable for ensuring that patients are protected during radiological interventions and also during radiotherapy. Furthermore, it is essential to optimise radiation doses for tumour treatment while sparing healthy tissue.

Research in the field of radiation epidemiology and radiation risk is imperative in order to be able to weigh up the harmful and beneficial effects of using ionising radiation in medical settings. There is a wealth of experience in the medical world in communicating the risks and benefits of radiation; risk communication is a matter of everyday routine as part of the mandatory informed consent conversations with patients, and requires in-depth knowledge of the effects of very low-dose and relatively high-dose radiation. This experience in combination with the “bonus” that medical professionals enjoy from their position of authority makes their expertise invaluable for communicating risks during the emergency response in the event of accidents. The knowledge and skills of experienced radiologists and medical physicists in dealing with radiation effects in practice are likewise highly relevant to emergency preparedness and response. Linking university-centred medical research with research institutes conducting basic research provides opportunities to generate knowledge that goes well beyond that acquired in clinical practice, knowledge that is useful for averting danger on a national scale after accidental exposure to radiation and for potential mass casualty incidents and terrorist threats. In this context, it is particularly important to develop innovative diagnostic and therapeutic strategies for dealing with acute and chronic radiation damage.

In medical science, radiation research is conducted in the clinical application of radiation in diagnostics and therapeutics, for example by evaluating and further developing existing methods, and in fundamental biological research. The research is usually carried out on an interdisciplinary basis in collaboration with radiobiology, medical physics, radiopharmacy, medical technology and/or image processing. In many cases it also includes cooperation with the medical technology industry, which relies on feedback from users to further develop its technological products. Although industry has technological research capacities of its own, a considerable proportion of research is conducted in non-industrial research facilities, in particular basic research and clinical evaluation. Recent developments in diagnostics, such as spectral computed tomography and novel image reconstruction techniques, which in some cases use artificial intelligence, have been preceded by many years of research at universities and at non-university institutions. This is also true of the latest developments in radiotherapy, which are primarily aimed at improving conformity so that higher doses can be delivered to the target volume while minimising the dose in normal tissue. However, these kinds of innovations, for example treatment using hybrid MRI-Linac scanners or particle therapy, pose completely new challenges in terms of immobilising patients, calculating target volumes and dosimetry. In some cases, it is also necessary to develop and explore new experimental models to enable technological or conceptual innovations to be used in clinical practice, for instance high-precision radiotherapy or particle therapy, FLASH radiotherapy or the combination of radiotherapy with systemic treatments. Apart from in medical science, the necessary expertise can be found in the areas of radiobiology, radiation physics and clinical radiobiology. As a rule, the insights gained in medical radiation research are also relevant to the knowledge base for radiation protection in areas beyond medicine. One of the key features of recent developments in the therapeutic and diagnostic application of ionising radiation is the increase in efforts to tailor radiation-based medical procedures to suit individual patients, i.e. provide personalised medicine. Radiobiology research plays just as important a role in this endeavour as artificial intelligence and technological innovations in radiotherapy and diagnostic imaging. The importance of social sciences for the categorisation of personalised approaches and the relationship with artificial intelligence should also be pointed out, especially in this context.

In spite of recent developments in dose reduction, radiation used for diagnostic purposes in medical settings constitutes a significant, and still rising, proportion of the mean radiation exposure of the general population. Everyday time and cost pressures in hospitals make it unrealistic to expect doctors to critically evaluate requested procedures involving ionising radiation and substitute them with other suitable procedures that do not require ionising radiation, even though the doctors may have the expert knowledge to do so. The situation is much the same in the outpatient sector. Consequently, it is crucial that the person who requests the medical procedure in the first place has some knowledge of radiation protection. A good understanding of the risks of ionising radiation and of the strengths and weaknesses of alternative imaging techniques such as ultrasound or MRI must therefore already be acquired at university level. This was pointed out by the SSK as long ago as 2003 (SSK 2003). The national competency-based catalogue of learning objectives (Nationaler Kompetenzbasierter Lernzielkatalog, NKLM 2015) lists radiation protection knowledge merely as one of the learning objectives.

In summary, the SSK believes that further development of appropriate applications of ionising radiation for diagnostic and therapeutic procedures is a key element in the provision of medical services for the general population. The inevitable conclusion drawn from all of the above is that the various research areas that contribute to this process must therefore continue to be supported in future.

3.3 Relevant research facilities in Germany

3.3.1 Approach

Facilities that are actively conducting basic and applied radiation research in Germany were identified using the following information:

a) A list of research facilities that, from 2008 onwards, have received and/or are still receiving funds within the framework of the KVSF initiative via the BMBF calls for proposals on nuclear safety and radiation research (basic research)[13]

b) A list of contractors and researchers that made successful bids in response to invitations to tender within the framework of the BMU departmental radiation research plan between 2010 and 2020.

A comparative evaluation of this information was carried out with the aim of identifying the actors conducting research into ionising radiation in Germany, taking particular account of the research areas listed in section 3.2, which the SSL identified as being important for Germany. To this end, 150 research projects on ionising radiation that were funded by the BMBF within the framework of the KVSF initiative were evaluated. It was not possible, however, to take account of the funding volume received by individual projects or the number of scientists involved in each project. The evaluation also included 158 projects addressing the area of ionising radiation that were and/or are still funded by the BMU under the departmental research plan for radiation protection between 2010 and 2020. Support projects were not taken into account, with the focus being placed on application-oriented research projects instead.

At this point it should be noted that it was not possible to include the successful procurement of funding from international third-party donors (e.g. through participation in EU projects) in the evaluation. However, the SSK assumes that internationally successful German institutions also were and/or are still active on a national level, too, so most of them will already be included in the lists of institutions receiving funding from the BMBF under the KVSF initiative or from the BMU under the departmental research plan. That said, the SSK is aware that there are also research facilities in Germany that are less dependent on procuring funding from third-party donors, thanks to their healthy financial situation. One example of such a facility is the Institute of Radiobiology of the German Armed Forces.

3.3.2 Identification of current research actors

a) Research projects funded by the BMBF within the framework of the KVSF-initiative

The list available to the SSK comprised 150 research projects that received funding within the framework of the KVSF initiative according to the BMBF calls for proposals on safety and disposal research from 2008 (BMBF 2008) and 2011 (BMBF 2011) and on nuclear safety and radiation research from 2019 (BMBF 2019) (as of the end of 2020). Of these, about 40 institutions were able to obtain at least one of the funded research projects.

Roughly half of these projects were carried out at eight institutions (Helmholtz Munich, Department of Radiation Sciences; Technical University of Darmstadt, Department of Biology; University Medical Center Hamburg-Eppendorf, Radiobiology Laboratory; GSI Helmholtzzentrum für Schwerionenforschung, Department of Biophysics; Essen University Hospital, Institute of Medical Radiation Biology; Dresden University of Technology, departments of medicine, mathematics and natural sciences; University Medical Centre Mainz, Institute for Medical Biostatics, Epidemiology and Informatics; LMU University Hospital

13 www.gsi.de/work/forschung/biophysik/kvsf/verbundprojekte

Munich, Radiotherapy Centre). About one third of the projects were carried out at just four institutions (Helmholtz Munich, Department of Radiation Sciences; Technical University of Darmstadt, Department of Biology; University Medical Center Hamburg-Eppendorf, Radiobiology Laboratory; GSI Helmholtzzentrum für Schwerionenforschung, Department of Biophysics).

The fact that half of the BMBF-funded projects evaluated here have been or are being carried out by only eight institutions means that the other half of the projects have been or are being carried out by a large number of other research facilities.

b) Research projects funded by the BMU within the framework of departmental research

Between 2010 and 2020, a total of 158 research projects on ionising radiation were funded by the BMU within the framework of departmental research in the area of applied radiation research (not including support projects and projects awarded without a tendering process). It is notable that the participating institutions include a significant number of private-sector consultancy firms. Eleven institutions received four or more funding awards (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH – German Organisation for Reactor Safety; Helmholtz Munich, Department of Radiation Sciences; Brenk Systemplanung GmbH; TÜV Nord AG and TÜV Süd AG; German Institute for Standardization (DIN); Leibniz Institute for Prevention Research and Epidemiology – BIPS GmbH, Städtisches Klinikum Braunschweig GmbH; University Hospital Düsseldorf; Risk Dialogue Foundation; University Medical Centre at the Johannes Gutenberg University Mainz; University of Münster). Around half of these projects were carried out by eleven institutions, and about a third by only six institutions. One special case among these is GRS, as it is a not-for-profit organisation providing technological and scientific research and expert services and is part-owned (46%) by the Federal Republic of Germany. GRS provides consultancy services to the BMU on nuclear safety and radiation protection, with a certain proportion of BMU research funding earmarked for this purpose. Other aspects of the cooperation between the BMU and GRS are governed by the framework agreement of 10 August 2017.

3.3.3 Key actors in the identified research areas

The categorisations set out below should be seen as being only an approximate breakdown because – as already mentioned – it is often difficult to allocate a project to a specific research area due to the interdisciplinary nature of radiation research. For example, dose determination within medical cohorts was allocated to the category of dosimetry and not medicine, although a project in this field is obviously linked to medicine. Similarly, it was often not clear whether a project should be placed in the category of radiation risk or rather that of radiation epidemiology. Furthermore, in certain research areas there are a few other research actors that have not been or are not being funded within the framework of the departmental research plan or the KVSF initiative but by other programmes (e.g. institutions conducting radiation research in a broader sense in the area of radioecology that have been or are being funded by the BMWi in connection with research into the final storage of nuclear waste).

a) Research projects funded by the BMBF within the framework of the KVSF initiative

A more detailed evaluation of the list of 150 projects that have been or are being funded by the BMBF within the framework of the KVSF initiative for research in the area of ionising radiation also enabled to identify the institutions that had been awarded projects in the research areas which the SSK considers important (section 3.2). However, in many cases it proved to be difficult to allocate a project to a single research area because of overlaps in subject matter due to the interdisciplinary nature of radiation research. The evaluation nevertheless provides a rough overview of which actors, and how many, have been or are still working in the identified areas. In order to narrow down which actors are most relevant within a specific research area, it was examined which institutions had carried out the largest number of projects in each area.

– Approximately 60% of the projects involved radiobiological research. Radiobiology was therefore the area by far the most likely to receive funding. That said, it should be emphasised that radiobiology is the field in which the basic research is conducted for many subareas that investigate the effects of radiation exposure on human health. A total number of 28 institutions were involved in the projects, but slightly more than half of them were carried out by only five institutions (Technical University of Darmstadt, University of Hamburg-Eppendorf, GSI Helmholtzzentrum für Schwerionenforschung, Helmholtz Munich, University Hospital Essen). In two of the latter five institutions, facilities conducting research in the area of radiobiology have recently been closed down (Institute of Radiation Biology, Helmholtz Munich; Institute of Medical Radiation Biology, University Hospital Essen).
– Radioecology was the research subject of 15% of the projects that received funding, roughly half of which were carried out at four facilities (Karlsruhe Institute of Technology, Helmholtz Munich, University of Jena, Leibniz University Hannover). Helmholtz Munich has since suspended research into radioecology, and the Karlsruhe Institute of Technology is cutting back on work relating to this area in the broadest sense, with future developments as yet unclear.
– Only a few projects (1%) could be allocated to the category of radiation metrology and dosimetry. These were carried out by the Dresden University of Technology and the University of Oldenburg. It is important to bear in mind, however, that metrology and dosimetry play an important part in many of the other research areas identified in this section and therefore also feed into the corresponding research.
– Projects on radiation epidemiology accounted for approximately 10% of the projects that received funding, mostly carried out at two institutions (University of Mainz and Leibniz Institute for Prevention Research and Epidemiology Bremen - BIPS). Radiation epidemiology no longer has its own professorship in Mainz any more, as a result of which it is less visible and less integrated into the institution.
– Not a single project was found that was dedicated explicitly to the category of radiation risk. However, some projects in the radiation epidemiology and radiobiology categories included a number of ancillary projects that addressed the subject of radiation risk. As far as the SSK is aware, research into radiation risk is currently conducted at only a few locations in Germany, one of them being Helmholtz Munich, albeit now to only a limited extent following cutbacks.
– The category of emergency response and preparedness accounted for 3% of the projects, carried out by five institutions (Helmholtz Centre in Dresden-Rossendorf, Dresden University of Technology, University of Hannover, VKTA – Radiation Protection, Analytics & Disposal Rossendorf and Karlsruhe Institute of Technology).
– About 11% of the projects received funding for research into medical applications, conducted by eleven institutions, with half of the projects carried out by three of them (Heidelberg University, Helmholtz Munich, Technical University of Munich).
– There were no projects on risk communication.

Apart from the institutions mentioned above, the SSK is aware of other institutions that contribute to research in the identified areas and are at risk of cutbacks or closure.

b) Research projects funded by the BMU within the framework of departmental research

The research projects funded by the BMU within the framework of departmental research (not including the support projects previously mentioned and projects awarded without a tendering process) can roughly be allocated to the following areas:

- Radiobiology – 11% of the projects (a third of which were carried out by the University of Göttingen, Helmholtz Munich and University Hospital Düsseldorf);
- Radioecology – 13% of the projects, with a third of them carried out by Brenk Systemplanung GmbH and two by the German Organisation for Reactor Safety (GRS);
- Radiation metrology and dosimetry – 28 % of the projects (four projects carried out by the German Organisation for Reactor Safety (GRS) and two each by IAF Radioökologie GmbH, the Federal Institute for Materials Research and Testing and the Städtisches Klinikum Braunschweig GmbH;
- Radiation epidemiology – 12% of the projects, carried out by eight different institutions;
- Radiation risk – 4% of the projects, of which three were carried out by Helmholtz Munich;
- Emergency response and preparedness – 11% of the projects, of which four were carried out by the German Organisation for Reactor Safety (GRS);
- Risk communication – 8% of the projects, of which three were carried out by the Risk Dialogue Foundation;
- Radiation applications in medical settings – no projects; however, several projects on radiation protection in medical settings were allocated to other research areas;
- Other – 14% of the projects, of which almost a third were carried out by the German Institute for Standardization (DIN) and 10% each by VDE (Association for Electrical, Electronic & Information Technologies), Dr Joachim Kemski Sachverständigenbüro, Städtisches Klinikum Braunschweig and the German Technical Inspection Associations TÜV Nord AG and TÜV Süd AG.

3.4 Discussion

3.4.1 The research areas identified by the SSK

In the opinion of the SSK the research areas listed in section 3.2 are, as already described above, critically important for radiation research in Germany. This section examines to what extent these areas received or were still receiving funding within the framework of the KVSF Initiative between 2007 and 2021 or within the framework of the departmental research plan between 2010 and 2021.

The evaluation of the funded research projects revealed that in some cases different and frequently complementary priority areas were defined when funding support was provided by the BMBF (KVSF initiative) and the BMU (departmental research plan) within the research areas considered important by the SSK. The BMBF programme, for example, often supported basic research relating to radiobiology (61% of the projects), followed by projects in radioecology (15%), medical applications of radiation (11%) and radiation epidemiology (9%), whereas other projects received little or no funding, namely emergency response and preparedness (3%), radiation metrology and dosimetry (1%), radiation risk (0%) and risk communication (0%).

The situation with regard to projects funded by the BMU (departmental research plan) was different inasmuch as the research areas that rarely received funding from the BMBF (KVSF initiative) were supported much more frequently, namely radiation metrology and dosimetry (28%), emergency response and preparedness (11%), risk communication (8%) and radiation risk (4%). In contrast, radiobiology projects, which made up by far the largest share in the case of the BMBF (KVSF initiative), accounted for a significantly smaller proportion (11%).

These differences in research funding may be due to the different overall goals of the research programmes supported by the BMBF and the BMU (BMBF research: more oriented towards basic research and aimed at educating and training the next generation of scientists; BMU research: more application-oriented and aimed at bridging the gap between science, politics and society by providing advice for political decision-makers (www.ressortforschung.de)). However, these differences also show that the two funding programmes complement each other at least in part, and make important contributions to providing extensive support for radiation research.

3.4.2 The research actors identified by the SSK

This section examines which actors have worked on or are currently working on the largest number of projects in the identified research areas and can therefore be considered to be main actors in the respective areas.

A joint evaluation of all research projects showed that just over a third of the 150 projects funded by the BMBF within the framework of the KVSF initiative were carried out by just five institutions (Helmholtz Munich, Department of Radiation Sciences; Technical University of Darmstadt, Department of Biology; University Medical Center Hamburg-Eppendorf, Radiobiology Laboratory; GSI Helmholtzzentrum für Schwerionenforschung, Department of Biophysics; Institute of Medical Radiation Biology and Institute of Cell Biology, Essen University Hospital). In line with their specialist orientation, the Technical University Darmstadt, the University Medical Center Hamburg-Eppendorf, the above-mentioned institutes at Essen University Hospital and the GSI Helmholtzzentrum für Schwerionenforschung mainly conduct basic research, covering the biology- and physics-related aspects of radiation research. The GSI Helmholtzzentrum für Schwerionenforschung focuses particularly on further developing and finding new applications for particle therapy, while also addressing issues surrounding radiation protection in space, biological effects of radon and dosimetry. Helmholtz Munich was engaged in the largest number of research areas that were classed as important in section 3.2.

Similarly, just under 30% of the projects funded by the BMU within the framework of departmental research were carried out at just four institutions (German Organisation for Reactor Safety (GRS); Helmholtz Munich; Brenk Systemplanung GmbH; TÜV Nord AG and TÜV Süd AG). Helmholtz Munich was the only institution among these four, which also carried out projects that received research funding within the framework of the KVSF initiative.

Radiation risks are studied and assessed in cooperation with international partners (international research consortia and bodies such as the ICRP and UNSCEAR). German participation in these debates is only possible if relevant expertise is available in the field of the quantification of radiation-induced risks. The evaluation of existing data (see above) showed that only very few teams in Germany are actively involved in research into radiation risks. Expertise in this area in Germany is under threat of disappearing altogether. An analysis of research projects in the field of radiation epidemiology yielded a similar result. Hardly any research groups in Germany are working in this area any more either, and the SSK believes that the critical mass needed is no longer present.

Research groups investigating radioecological issues are few and far between in Germany. GRS and engineering consultancies (foremost Brenk Systemplanung GmbH) mainly conduct research into applied science, whereas basic research is carried out by only a few groups at Helmholtz centres or at universities. Because radioecological research is subject to or under threat of cutbacks at present, particularly within the Helmholtz community (Helmholtz Munich, Karlsruhe Institute of Technology, Forschungszentrum Jülich), the SSK believes there is a risk that in the foreseeable future Germany will no longer have sufficient expertise in the area of radioecology, which would be urgently required in the event of a radiological or nuclear emergency.

In this context it is worth recalling that the SSK already drew attention to the loss of expertise for dealing with a potential radiological or nuclear emergency not very long ago. In particular, the SSK appealed for adequate medical capacities to be put in place, listed relevant research areas (SSK 2017a) and also made recommendations regarding the necessary education and training for personnel involved in providing medical support in emergency situations (SSK 2017b). In the opinion of the SSK, these recommendations remain valid. By way of example, it is worth pointing out that Helmholtz Munich, which for decades played a major role as a training centre for radiological emergency preparedness and response, now no longer does so, and has not been replaced.

Metrology and dosimetry research is, as described above, of vital importance for radiation research as a whole. The SSK has recently observed that the number of research actors working in Germany in this area has fallen significantly, in particular at some research centres within the Helmholtz community (Helmholtz Munich, Karlsruhe Institute of Technology).

Finally, it should be emphasised that around half of the 235 projects funded by the BMBF and the BMU and evaluated in this statement were or are being carried out by just 15 institutions, whereas almost 100 different institutions worked or are currently working on the other 50% of the projects. The research landscape in the field of ionising radiation in Germany has thus been characterised by a few major institutions focussing on radiation research with a large number of other institutions providing supplementary expertise. In the SSK’s view this makes sense because – as already repeatedly emphasised – to be able to address relevant issues, radiation research requires a markedly interdisciplinary approach, which a small number of individual institutions on their own are not able to deliver. This complementary division of labour proved successful in the past, and in the SSK’s opinion contributed to the excellent international reputation of German radiation research. This is reflected by the fact that German scientists hold or have held leading positions in many international organisations that play a major role in radiation research and radiation protection (e.g. chair of EURADOS, EURAMED, EURAMET, ICRU, IRPA and UNSCEAR, member of ICRP Main Commission, chair of ICRP Committee 1 and Committee 2).

The Institute of Medical Radiation Biology at Essen University, which made significant, internationally acclaimed contributions to radiation biology in the past, has recently been closed. Universities are sometimes forced to respond quickly to changes in the science landscape, adapt their research priorities and may even have to close deserving facilities and institutions. However, it is concerning that not one university appears to have a clear strategy for ensuring that expertise in radiation research is preserved at the necessary academic level.

Lastly, it should be pointed out that, in the past, Helmholtz Munich particularly reflected the interdisciplinary nature of radiation research in that it conducted research into almost all of the areas listed as being important in section 3.2 (radiobiology, radiation risk, medical applications, dosimetry, metrology, radioecology, emergency response) and received funding from both the BMBF within the framework of the KVSF initiative and from the BMU within the framework of departmental research. The SSK notes that Helmholtz Munich significantly reduced its activities in the field of radiation research not long ago (the Department of Medical Radiation Physics and Diagnostics and the Institute for Radiation Protection were dissolved and the

Institute of Radiation Biology was shut down). Similar changes occurred in the field of radiation protection (the evaluation office was sold and radiation protection training courses were stopped). As a result, in future Helmholtz Munich will no longer fulfil its role as one of the most important representatives of radiation research in Germany.

4 Non-ionising radiation – ultraviolet radiation

UV radiation (UVC, UVB and UVA) damages the human genome in many ways. The photophysical effects that are the underlying cause of this have been extensively studied. The damage includes UV-specific mutations that are found in a high proportion of skin tumours. The mechanism behind the carcinogenic effect of UV radiation has thus been scientifically proven, as is the case for ionising radiation. In this section, therefore, UV radiation is described separately from the traditional range of electromagnetic fields and optical radiation.

Exposure to UV radiation from the sun affects the entire population. Additional exposure due to sunbed use and the use of UV in medicine for therapeutic purposes must also be taken into account. The general public can take their own precautions against exposure to UV radiation from natural sources, based on behavioural changes, but these must be supported by situational prevention measures. These create conditions that enable UV radiation protection to be implemented at the level of the individual within the general population by changing the circumstances. Since 2019, occupational health regulations for outdoor workers include a requirement for employers provide certain types of preventive care under certain conditions (Sections 4 (Mandatory health care) and 5 (Optional health care) of the German Ordinance on Occupational Health Care (ArbMedVV) 2008).

4.1 Fields of research referenced by international organisations

Numerous international organisations are involved in developing recommendations for the protection of the population against UV radiation. The International Commission on Non-Ionising Radiation (ICNIRP), the WHO UV programme INTERSUN and the European Society of Skin Cancer Prevention (EUROSKIN) are just a few examples that can be mentioned here.

An ICNIRP guideline from 2004 (ICNIRP 2004) and a statement from 2010 (ICNIRP 2010) proposed a limit for occupational UV exposure to the eyes and skin of $E_{max} = 30\ J\ m^{-2}$ (biologically effective UV radiation). Compliance with this limit is very difficult under actual work conditions over an eight-hour day, and the limit does not include UV exposure during leisure time. Under the latest work plan (2020 to 2024)[14] a task force has been formed that addresses long-term effects of chronic UV exposure and is tasked with revising the current UV guidelines.

The goals set out by the WHO's INTERSUN programme[15] are as follows:

- To provide information, practical advice and sound scientific predictions on the health impact and environmental effects of UV exposure.
- To encourage countries to take action to reduce UV-induced health risks.
- To provide guidance to national authorities and other agencies about effective sun awareness programmes.

14 https://www.icnirp.org/en/activities/work-plan/index.html, last visited on 4 June 2021
15 https://www.who.int/uv/intersunprogramme/en/, last visited on 4 June 2021

The European Society of Skin Cancer Prevention was founded in Germany in 1999 with the aim of developing recommendations on the pillars of skin cancer prevention through international consensus:

– Basic research into the effects of UV radiation
– Epidemiology
– Primary prevention
– Secondary prevention

The 8th International EUROSKIN Conference in 2016, for example, issued a recommendation on the further development of biomarkers for UV-related skin cancers based on fundamental research[16].

The conference discussed risk communication, an area that is important for primary prevention, with EUROSKIN recommending that evaluation of prevention schemes should always be included in the design of any intervention project. The conference also recommended to “strengthen research which evaluates the actual need for information in the public, the kind of information which is considered useful by the public and the willingness in the public to accept more information.”

In this context, an updated version of the S3 guideline “Prevention of skin cancer” was publicshed in Germany at the beginning of 2021 (AWMF 2021). This document describes the currently available international scientific and medical data relating to skin cancer, taking this as a basis for addressing issues surrounding primary prevention, climate change and UV radiation, occupational skin cancer, secondary prevention and health economic evaluation.

4.2 Important research areas for Germany as identified by the SSK

The examples outlined above demonstrate that the focus of research is on UV protection in the private sphere and in occupational settings. In addition, however, it is important not to disregard the use of UV radiation as a treatment in medical settings and its use in the development of new technologies (e.g. water and air disinfection). The preservation of expertise in the field of UV radiation research is fundamental to the ability to develop recommendations on UV protection. To this end, the SSK has identified the following research areas in which it sees a need for action in Germany.

4.2.1 Radiobiology

In terms of expected new findings, radiobiological research on UV radiation is in principle just as important as radiobiology relating to ionising radiation as described in section 3.2.1. However, in the context of UV radiation, research focuses on different health effects, namely skin cancer (malignant melanoma, squamous cell carcinoma and basal cell carcinoma), damage to the eyes and UV-induced immunosuppression. With regard to skin cancer, several acquired and genetic risk factors have been identified that contribute significantly to an increased risk in connection with UV radiation. The molecular mechanisms underlying this connection still need to be further elucidated, however. A potential route to achieving this is to study the response of epidermal and dermal stem cells and their microenvironment to exposure to UV radiation, taking into account patterns of exposure and the effects of exposure to a single type of radiation compared to exposure to a combination of UV and/or infrared radiation and/or visible light. In

16 https://www.euroskin.eu/en/activities/EUROSKIN-Conferences/2016/recommendations.php, last visited on 4 June 2021

future the identification of biomarkers will become increasingly important as a means of determining an individual person’s risk of contracting skin cancer.

Fundamental new findings can be expected – as in the case of ionising radiation – from research using the latest model systems (e.g. organoids, orthotopic and syngeneic mouse models) and high-throughput analyses of short-term or longer-term radiation-induced changes, for example in the genome, epigenome, transcriptome, proteome and metabolome, and from a systems-biology based approach to evaluating and linking biological and clinical or epidemiological data. Examining blood samples for the presence of biomarkers, i.e. performing liquid biopsies, should also be mentioned in this context. As a general rule, research into the radiobiological effects of exposure to UV radiation overlaps to a large extent with that into the effects of ionising radiation, and joint discussion of these effects will contribute to further gains in knowledge. Ultimately, radiobiology is an important link between basic and applied research.

4.2.2 Radiation epidemiology

Epidemiological studies are an important instrument for investigating the link between UV exposure and skin cancer and other UV-related endpoints (e.g. cataracts). Molecular-biological research identified underlying mechanisms, while epidemiological data showed that the risk of developing different types of skin cancer is associated with different exposure patterns and can also help to identify risk groups. Integrating molecular-biological findings and biomarkers into epidemiological data, an approach also known as molecular epidemiology, will become more and more important for radiation protection. Furthermore, there are epidemiological studies that link the incidence of skin cancer to specific levels of UV radiation measured at different latitudes, for example. The problem these studies face is that individual UV exposure depends not only on ambient UV radiation levels, for which more or less high-resolution data is available from UV monitoring networks or measurements taken by satellites, but also very much on the behaviour of individuals (leisure time, work, holidays etc.). Data from personal dosimeters makes it possible to take this factor into account and to model individual UV exposure within specific population groups. Consequently, it is important in future on the one hand to continue collecting data on ambient UV levels with as much detail as possible (impacts of geographical latitude, altitude above sea level, cloud cover, air pollution, sunlight reflecting from the environment) and on the other hand to press ahead with the use of personal dosimeters to measure UV exposure. The GENESIS project by DGUV (see below) collects data from personal dosimeters of outdoor workers; taken together with measurements of ambient UV levels, this enables UV exposure to be modelled for various situations. It may then even be possible to draw conclusions as to a dose-effect relationship with respect to skin cancer incidence in occupational settings.

4.2.3 Radiation risk assessment

As yet there is no robust data on the relationship between skin cancer incidence and the relevant UV radiation levels and concomitant dose or exposure measurements of natural or in some cases artificial UV light. Such data would enable reproducible dose-response relationships for skin cancer to be determined. In contrast to ionising radiation, there are also no risk coefficients derived from available data on doses and incidences which would allow estimates to be made of the frequency of skin cancer cases in connection with specific levels of UV exposure.

The lack of a scientifically proven dose-response relationship poses a major challenge for UV radiation protection, especially against the background of the demographic changes in Germany combined with the fact that many types of skin cancer (basal cell carcinoma and squamous cell carcinoma) are cancers of old age. Another confounding factor is potential behavioural changes among the population in the wake of climate change. For these reasons there is expected to be a dramatic increase in the incidence of skin cancers as the proportion of elderly people in the population continues to rise. It is therefore essential to collect new data and/or create new models which enable scientists to predict and determine dose-response relationships with regard to the incidence of skin cancers.

4.2.4 Use of UV radiation in medicine for therapeutic purposes

UV radiation is used for various purposes, including the treatment of chronic inflammatory skin disorders such as psoriasis and neurodermatitis. These treatments involve either phototherapy on its own using UVB (broadband ultraviolet B or 311 nm) and UVA or UVA + psoralen (PUVA), also known as photochemotherapy. In these cases physicians weigh up a potentially increased risk of skin cancer against therapeutic benefits. In particular psoriasis patients undergoing PUVA treatment have a slightly increased risk of developing skin cancer, as shown in scientific studies. After successful treatment, patients with chronic skin disorders are typically symptom-free for a time before they suffer another acute attack, sometimes only a few months later. Such patients therefore undergo repeatedly individual courses of treatment during their lives, which in some cases significantly increases their cumulative lifetime dose. Looking forward, it would make sense to record and document the UV doses received by each individual patient in order to obtain a reliable set of data on the level of UV radiation exposure from UV treatment. At present, UV treatment is regulated only by development stage 1 guidelines, namely the S1-Guidelines on UV phototherapy and photochemotherapy[17].

4.2.5 Radiation metrology and dosimetry – photobiological evaluation

In the interest of scientific research and in connection with the raising of awareness of the risks of UV radiation among the general public, it is essential to gather reliable data on natural (but also artificial) UV radiation exposure and make this data available. Data relating to UV radiation levels on the earth’s surface is recorded using space-based satellite monitoring and also fixed-position broadband radiometers or spectroradiometers on the ground (e.g. the BfS UV measuring network). It is important to determine the relative biological effectiveness of the UV radiation spectrum in question, which varies widely as a function of wavelength. In the case of measurements from spectroradiometers, this is achieved with the help of a mathematical convolution using the relevant spectral weighting function, while for broadband spectrometers, UV sensors matched to a corresponding weighting function are used. The erythema dose rate is frequently stated to illustrate the biological effectiveness of UV radiation, and is used to calculate the UV index, for example, which is a measure of the maximum erythema dose level on any given day. The UV index is often used by the media as part of the daily weather forecast and is a key instrument in primary prevention of skin cancer. Although it is already possible to calculate the biological effectiveness of different UV spectra using various weighting functions, research in this area should be further accelerated in order to, for example, identify the weighting functions that are most relevant to the development of skin cancers and other biological endpoints (e.g. UV-induced immunosuppression). One question that is still largely not understood is whether the same UV wavelengths responsible for the development of melanomas are also responsible for squamous cell and basal cell carcinomas.

Since UV exposure of an individual is always partly dependent on behaviour, the use of personal dosimeters is a key aspect in the development of models that help to quantify UV exposure of specific population groups. In addition, innovations such as diode array dosimeters

17 https://www.awmf.org/uploads/tx_szleitlinien/013-029l_S1_UV-Phototherapie__Photochemotherapie_2015-08-abgelaufen.pdf, last visited on 4 June 2021

use both spectral and time-resolved measurements for personal dosimetry. Such developments should continue to be pursued.

4.3 Relevant research facilities in Germany

4.3.1 Approach

In order to identify facilities and institutions actively involved in research in the area of UV radiation in Germany, the same approach was taken as that used to identify those actively engaged in basic and applied research in the area of ionising radiation (see section 3.3). As before, the authors analysed the list of research facilities that, from 2008 onwards, have received and/or are still receiving funds within the framework of the KVSF initiative via the BMBF calls for proposals on nuclear safety and radiation research (basic research)[18]. Projects that received funding from the BMU within the framework of the departmental research plan between 2010 and 2020 were also evaluated. Support projects were not taken into account, with the focus being placed on application-oriented research projects instead. The total funding received by individual projects and the number of scientists involved in each project were not taken into account.

4.3.2 Key research facilities in the identified research areas

a) Research projects funded by the BMBF within the framework of the KVSF initiative

The list available to the SSK comprised nine projects on UV radiation research that received funding within the framework of the KVSF initiative following the BMBF calls for proposals on nuclear safety and radiation research from 2008, 2011 and 2019 (as of end of 2020).

These nine projects were carried out by five different institutions. The Leibniz Research Institute for Environmental Medicine (IUF) at the Heinrich Heine University in Düsseldorf and the Elbe Kliniken Stade-Buxtehude carried out six of the projects.

All nine projects investigated issues relating to radiobiology in UV research, whereas none of the other research areas classed as important in section 4.2 was addressed by the evaluated projects.

b) Research projects funded by the BMU within the framework of departmental research

During the period covered by the report (2010 to 2020), five projects on UV radiation received funding: one investigated mechanisms of action (Dresden University of Technology), three looked at risk communication with respect to UV radiation (infas Institute for Applied Social Science, IFT-Nord Institute for Therapy and Health Research, ConPolicy GmbH) and one examined UV exposure (Leibniz University Hannover).

4.4 Discussion

4.4.1 The research areas identified by the SSK

In the opinion of the SSK, the research areas identified in Section 4.2 are critically important for research in the area of UV radiation in Germany. This section examines to what extent these areas received or were still receiving funding within the framework of the KVSF Initiative between 2007 and 2021 or within the framework of the departmental research plan between 2010 and 2021. It should be pointed out that Deutsche Krebshilfe (German Cancer Aid) also

18 www.gsi.de/work/forschung/biophysik/kvsf/verbundprojekte

provides funding for UV-related projects, in particular addressing intervention measures directed at skin cancer prevention. These projects were not included in this evaluation, however.

Exposure to UV radiation from sunlight affects the entire population. Additional exposure due to sunbed use and the use of UV in medicine for therapeutic purposes must also be taken into account. Knowledge of the underlying physics (UV dosimetry, absorption spectra etc.) and of photobiological effects (specific spectra that damage DNA, immunosuppression, vitamin D production etc.) and their long-term consequences (skin cancer, damage to the eyes etc.) is essential in order to properly assess the effects of UV radiation.

Basic research in radiobiology is a fundamental prerequisite for maintaining expertise in radiation protection. All nine of the BMBF-funded projects were engaged in radiobiological research. It was only within the framework of departmental research that three projects on risk communication were funded, while one other addressed UV exposure models, so can be categorised as belonging to radiation epidemiology in the broadest sense. The other research areas identified as important (radiation risk assessment, UV therapy and UV metrology) did not receive any funding during the period under review. Nevertheless, all research areas listed in section 4.2 are important elements of a comprehensive approach to radiation protection and are closely interconnected. This is particularly true of protection against UV radiation from the sun and UV exposure in tanning studios. Findings from radiobiological research, together with radioepidemiological data that is collected and evaluated (using personal dosimetry and data from UV measuring networks), enable a risk assessment to be carried out that then provides the foundation for official recommendations for the general public on how to deal with UV radiation. Another important step is ensuring that UV-related risks are appropriately communicated, along with the recommendations deriving from those risks.

Physicians have to weigh up the risks and benefits of UV treatment, but to be able to do so, they need a good understanding of the risks associated with the therapeutic use of UV radiation. In addition, it is necessary to document the UV radiation levels to which patients are exposed during UV treatment.

The SSK believes that basic research in UV radiobiology must be further expanded and it should be embedded within radiobiological institutions and in education at university level. In order to establish a comprehensive UV radiation protection strategy, it is also necessary to support the other identified research areas (radiation epidemiology, radiation risk assessment and UV metrology). This is the only way of ensuring that expertise in UV radiation protection is maintained and can be incorporated into education and training and into the work of advisory bodies.

4.4.2 The research actors identified by the SSK

This section examines which actors have worked on or are currently working on the largest number of projects in the identified research areas and can therefore be considered to be main actors in the respective areas.

Currently only three out of the five research facilities funded by the BMBF are engaged in active research: the Leibniz Research Institute for Environmental Medicine (IUF) at the Heinrich Heine University in Düsseldorf, the Laboratory for Molecular Cell Biology at the Elbe Kliniken Stade-Buxtehude and the Cell Biology and Epigenetics Group, Department of Biology at the Technical University of Darmstadt. These institutions carry out projects in collaboration with each other, which enables their various areas of expertise to be put to best use. Against the backdrop of the societal relevance of exposure to UV radiation and the associated need for expertise within national and international advisory bodies (such as the SSK, ICNIRP, WHO and EUROSKIN) but also with regard to the preservation and further development of the identified research areas, the fact that only three institutions are actively engaged in research and education must be seen as a matter of concern.

5 Non-ionising radiation – other electromagnetic fields with frequencies below the UV spectrum (review)

Following on from UV radiation, addressed in Section 4 above, Section 5 looks at electromagnetic radiation at lower frequencies. During the process of identifying a potential and/or actual loss of expertise in non-ionising radiation, it is necessary to distinguish between UV radiation, visible optical radiation including the infrared range, and electromagnetic fields (EMF) with frequencies in the range between 0 GHz and 300 GHz. There are no specific learning formats for these three ranges, nor even specific in-depth courses within related university degree programmes, apart from those in the field of ophthalmology in medicine.

The breadth of knowledge needed to gain the relevant expertise across these ranges is drawn from multiple disciplines, from life sciences such as biology, epidemiology and medicine to natural sciences such as physics and optics, and extending to electrical engineering. German universities do not currently offer any combined interdisciplinary courses covering these types of radiation yet (in contrast to the medical physics course in the field of radiation protection for ionising radiation). The expertise required in practice, in particular that needed to monitor and comply with exposure limits and radiation protection regulations, is almost always the result of individuals' professional experience and specialisation (training on the job). The same has been and continues to be true of research (and consequently also of teaching, see below), so much so that as far as general expertise in non-ionising radiation in Germany is concerned the status quo is highly diverse, and the loss of expertise can only be pointed out in terms of certain examples.

There is an established approach to protection against optical radiation and EMF based on a robust concept and corresponding limit values, which takes account of the sources of exposure currently in use in practical applications and research laboratories. The limits are based on the mechanisms of action, which are very well understood. All the experimental knowledge and the empirical findings relating to the observed biological effects are also consistent with these mechanisms. From time to time scientific studies are published suggesting that physiological and/or biochemical effects occur at exposure levels below the prescribed limits, but to date it has not been possible to reproduce and verify any of their findings. Consequently, research is sometimes guided by epidemiological data that is subject to controversial debate. Particular examples include the weak correlation between childhood leukaemia and exposure to low-frequency magnetic fields, and between frequent use of mobile phones and the development of gliomas. In spite of extensive research, using both in vivo and in vitro techniques, scientists have been unable to reproduce these correlations. There is also no accepted theoretical model that would explain such effects. This, ultimately, is the underlying cause of the heterogeneity of the work in these fields, not only in Germany but also throughout the international research landscape. As yet, no clearly defined working hypotheses have emerged regarding potential biological and health effects at frequencies below the established limits. Research groups therefore frequently look for an EMF-induced biological effect as a "byproduct" in their biological experiments, which were specifically designed to investigate other endpoints.

As already mentioned in Section 2, there are clear shortcomings in Germany with regard to maintaining the appropriate expertise in evaluation and especially communication. This is apparent simply from the fact that invitations to tender for relevant scientific research projects, for example through the BfS within the framework of BMU departmental research plans, in some cases attracted zero responses. Similarly, the number of experts who are able to present sound, easily understood scientific viewpoints in public debates is very limited. This creates additional problems when it comes to communicating with the general public.

5.1 Identification of important research areas

ICNIRP, an organisation specialising in non-ionising radiation protection, assesses the potential risks of EMF within the frequency range up to 300 GHz. These assessments are more or less uniform around the world and are repeatedly updated, for example in numerous national and international reviews and statements (e.g. WHO and ICNIRP)[19]. At present, these reveal just a few unanswered scientific questions, such as the biological effects of high-field applications using pulses of extremely short duration. In contrast to research on ionising radiation, research on non-ionising (not including UV) radiation should therefore now focus on identifying specific areas that may contribute to improving understanding of the effects of EMF on human health, especially given the fact that the current research agenda published by the WHO is already more than ten years old (WHO 2010).

In 2018, the WHO launched an international survey with the aim of identifying potential impacts of EMF on human health, which included participants being asked to prioritise these impacts. In 2019, as a second step following on from this survey, the WHO published a call for expressions of interest in producing reviews addressing the following topics: a) cancer (human observational studies), b) cancer (animal studies), c) adverse reproductive outcomes (human observational studies), d) adverse reproductive outcomes (animal and in vitro studies), e) cognitive impairment (human observational studies), f) cognitive impairment (human experimental studies), g) symptoms (human observational studies), h) symptoms (human experimental studies), i) effect of exposure to radio frequency (RF) on biomarkers of oxidative stress, and j) effect of exposure to heat from any source on pain, burns, cataract and heat-related illnesses. The intention is to use these reviews to update the international research agenda. Taking the updated agenda as a basis, it will then be possible to determine the relevant research areas that are most important for Germany.

On the other hand, it can justifiably be argued that the ever increasing and in many cases deliberate application of electromagnetic fields makes it necessary to research and/or rule out potential and so far unknown biological and health effects that occur after exposure to EMF below established limits even if such effects are minute. In addition, it would be desirable to improve the quantitative determination and hence the understanding of established mechanisms of action, for instance with regard to the effects of minor thermal influences, in particular over long periods of exposure. As a general principle, the SSK therefore considers the following research areas to be important: possible molecular mechanisms underlying the effects of exposure to electromagnetic fields, epidemiology and risk communication.

Other areas of scientific interest in the optical range are physiological effects dependent on the spectral distribution of modern light sources (blue light effect of LEDs, circadian rhythm) and more detailed identification of potential harmful effects of laser pointers in particular (flash blindness).

The above-mentioned research areas are also listed in the current ICNIRP work plan for the period 2020 to 2024[20].

Furthermore, ongoing technological advances in possible sources of exposure will make it necessary to build scientific expertise in non-linear interactions as a result of exposure to very

19 Listed under https://www.ices-emfsafety.org/expert-reviews/
20 www.icnirp.org/en/activities/work-plan/index.html

high-strength electromagnetic fields with extremely short pulsed activity. This applies both to direct non-linear interactions in biological tissue and to so-called parasitic effects, which can be indirectly harmful to human health. Relevant sources in this connection include ultrashort pulse lasers within the optical spectrum used for laser beam machining. Due to the power density of this beam, a plasma is formed locally on the material surface which, among other effects, produces parasitic X-rays, making it necessary to put protective measures in place for operating personnel. Whether such pulse power densities will be technically feasible at lower frequencies (< 300 GHz) in future is an unanswered question, but fundamental knowledge in this field is an essential part of responsible radiation protection and must be developed accordingly.

5.2 Research facilities in Germany

5.2.1 Approach

In order to identify facilities and institutions actively involved in fundamental EMF research in Germany, the same approach was taken as that used to identify those engaged in basic research in ionising radiation and UV radiation. As before, the authors analysed the list of research facilities that, from 2008 onwards, have received and/or are receiving funds within the framework of the KVSF initiative via the BMBF calls for proposals on nuclear safety and radiation research (basic research)[21], as well as projects that have received funds from the BMU within the framework of the departmental radiation research plan 2010 to 2020. As already explained in Section 4, in the field of non-ionising radiation funding from the KVSF initiative was used solely for projects on UV radiation.

The following is therefore an analysis of the research projects and programmes advertised by the BMU via the BfS since 2010. Other projects in the same research areas but funded by other sources were implemented only sporadically and appear rather unsystematically or on a case-by-case basis. This includes, for example, projects funded by employer’s liability insurance associations, accident insurance companies or similar institutions with the aim of monitoring compliance with the established limits in specific occupational exposure scenarios or examining the safety of medical implants currently in use that may expose the human body to radiation. Other projects include some funded by the DFG (German Research Foundation) with the aim of meeting the demand for basic research into the development of suitable simulation techniques, and BMBF-funded projects investigating technologies that may minimise exposure to high-frequency EMFs (miniwatt technology).

5.2.2 Research facilities receiving funds from the BMU within the framework of departmental research planning

Among the 206 projects listed for the period from 2010 to 2020, 158 came into the category of ionising radiation (see section 3.3), six investigated UV radiation (see section 4.3) and 36 were concerned with EMF. In addition, four projects on optical radiation were funded, one project on ultrasound and one project dealing with general legal matters. These last six projects are not considered further in the remainder of the text.

Of the 36 projects, 42% were in the field of radiobiology or mechanisms of action (four by the Fraunhofer-Gesellschaft, four by Charité – Universitätsmedizin Berlin and three by Jacobs University Bremen GmbH (now Constructor University)), 28% involved research on exposure to radiation (two conducted by RWTH Aachen University and two by IMST GmbH) and 25%

21 www.gsi.de/work/forschung/biophysik/kvsf/verbundprojekte

in the field of communication. One project addressed epidemiological issues (University Medical Centre at the Johannes Gutenberg University Mainz), and one project investigated another topic.

5.3 Discussion

With regard to the overall view of EMF research expertise in Germany over the past two decades it must be stated that no research institution has established itself as being primarily engaged in the area of EMF radiation protection over the long term. The EMF-Portal at RWTH Aachen is the only one to be continuously supported by in-house and third-party funding; it assembles a highly comprehensive collection of the scientific literature on EMF and presents it in the form of a structured, knowledge-based database.

In 2020 the BfS founded the Competence Centre for Electromagnetic Fields (KEMF) in Cottbus. The centre is currently in the setup phase. Its remit covers EMF research and evaluation from the perspective of radiation protection, as well as communication and information on this topic.

However, there are currently no institutions or working groups focussing specifically on EMF research as part of their actual scientific research activities.

A small number of university institutes and non-university research facilities have had a temporary (typically five to ten years) partial focus on such research, depending on the funding available at the time; apart from the German Mobile Telecommunication Research Programme (DMF), there are also smaller-scale programmes run by some federal states, for instance North-Rhine-Westphalia. This has led to cyclical highs and lows in relevant expertise during these periods. Specific examples worthy of mention are the construction of exposure laboratories at the University of Wuppertal and at IMST GmbH in Kamp-Lintfort, and exposure studies on animals (mice, rats etc.) in the low-frequency and radio-frequency range at ITEM in Hanover and at the Jacobs University in Bremen.

With regard to the preservation of expertise, criticism of this situation is warranted inasmuch as it requires much effort and years of experience to establish exposure laboratories for the purpose of experimental biological research on potential mechanisms of action and to set up the associated state-of-the-art temperature monitoring that is required, in particular for exposures in the RF range, and a very careful approach has to be adopted for such experiments, with repeated checks (reproducibility!). In this instance the limitations of the normal tendering procedure (e.g. within the framework of departmental research planning) and the practice of financing research mainly through third-parties become apparent, because the groups interested in becoming involved almost never have the necessary experience or infrastructure. Another reason for these difficulties is the fact that the biological research described in section 5.1 and section 5.2 (departmental research plans) covers a large variety of heterogeneous topics. Dedicated groups of specialised researchers are already working on almost all of these topics, but most of them have never conducted experiments involving exposure to EMF.

The SSK believes that, as a prerequisite for maintaining expertise and the ability to research and/or analyse new hypotheses regarding the biological mechanisms underlying the effects of EMF exposure within a reasonable timeframe, it is important to ensure that the technical and scientific expertise needed to conduct EMF exposure experiments and develop EMF measuring techniques is maintained over the long term.

Against this background it is necessary to ask how young people’s interest in these tasks can be kindled when they come to choose their careers. The SSK has found that advanced courses (master degree courses) in subjects relating to radiation research do not include lectures covering basic knowledge of complementary scientific areas at least as an elective option. In practice this means that biology or medicine students, for instance, are not offered basic lectures on electromagnetic fields including optical and UV radiation and their uses, addressing topics such as the nature of electromagnetic fields, the significance of frequency and quantum energy and the interactions between non-ionising radiation and biological tissue etc. Conversely, university courses in physics/optics and electrical engineering do not include lectures on physiology or biological macromolecules (and how the latter respond to the effects of external fields). Moreover, teaching students communication skills, not least in these scientific areas, is important in sociopolitical terms, as demonstrated by the ongoing public debate on EMF safety. Academically trained individuals, especially, should be able to participate competently in sociopolitical discourse on the opportunities and the supposed or real risks arising from the introduction of new technologies. At present, this is rarely the case.

6 Summary and evaluation

As part of an advisory mandate, the BMU asked the SSK to identify the scientific research areas and research actors that are most important for ensuring that expertise in radiation research in Germany is maintained. In this context, the term radiation research embraces all areas of basic and applied research that ultimately contribute to beneficial outcomes for and the protection of human beings, their environment and their health.

The background to this is that support for radiation research (not least in financial terms) in Germany has been decreasing in recent years for various reasons, which has in turn jeopardised the preservation of expertise in radiation research. The SSK views this situation as critical, because radiation research makes or has the potential to make significant contributions to many areas that are relevant for society. This includes many of the initiatives launched by the Federal Government with the aim of strengthening German research (e.g. the National Decade against Cancer), for example, and many scientific disciplines that benefit from contributions made by radiation research (e.g. biology, materials sciences and technology development).

In order to identify the most important research areas and research actors, a list was available of research projects that have received and/or are still receiving funding since the start of the KVSF initiative in 2007 within the framework of Federal Government support programmes (as of end of 2020) along with a list of projects that have received and/or are currently receiving funding from the BMU within the framework of the 2010 to 2020 departmental research plan on radiation protection.

It was not possible to take account of information on other research institutions that may have funded projects on radiation research. Nevertheless, the SSK believes that the evaluation of the roughly 370 research projects on ionising radiation and non-ionising radiation (including UV and EMF) that have received funding from the BMBF and the BMU allowed to provide a general overview of the institutions actively engaged in radiation research in Germany. Departmental research within the Federal Government is examined separately in a BMU requirements analysis.

The SSK makes the following points concerning the research areas that are important for radiation research in Germany and the research institutions actively engaged in radiation research in Germany:

1) Exposure to ionising and non-ionising radiation and the associated potential effects on human health have an impact society as a whole. Conducting research into radiation and research making use of radiation calls for interdisciplinary scientific approaches.

Equally, other scientific disciplines benefit from methods used in radiation research and from the results it yields. The SSK is of the opinion that this mutual interaction has a positive impact on the development of German research.

2) In the past, radiation research ranked very highly in Germany, founded on a long tradition, and German radiation researchers still enjoy an excellent reputation at international level. The SSK considers it important to maintain this position and to further consolidate it in order to strengthen Germany's role in research.

3) After analysing current international developments in the field of ionising radiation, the SSK considers the following 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. The evaluation of research projects funded by the BMBF within the framework of the KVSF initiative and by the BMU within the framework of the departmental research plan showed that around half of the research projects on ionising radiation were carried out by only 15 research institutions, some of which are now no longer actively engaged in radiation research or to only a limited extent (e.g. the Institute for Radiation Biology and Institute for Radiation Protection, Helmholtz Munich; Institute of Medical Radiation Biology at Essen University). The future direction and current status of radiation research at some other institutions is unclear. Similar trends can be observed in departmental research facilities, too, with one example being the closure of the department for radiation effects at the PTB. Alongside the activities of those 15 institutions, a large number of other institutions carry out the remainder of the research projects. The SSK stresses that a minimum number of institutions is needed in order to cover the breadth of scientific topics that are relevant for radiation research. The same is also true of non-ionising radiation.

4) The SSK likewise considers contributions made by universities and universities of applied scineces to radiation research in Germany to be important. Universities are sometimes forced to respond quickly to changes in the science landscape, adapt their research priorities and may even have to close deserving facilities and institutions. However, it is concerning that not one university appears to have a clear strategy for ensuring that expertise in radiation research is preserved at the necessary academic level. The SSK is looking for clear signals from universities that radiation research will be granted the academic attention that is needed to conduct research at a high level, a status that it deserves in light of its importance to society.

5) The SSK singles out the Helmholtz community with its national research centres as being predestined to operate as a main actor in radiation research, since it is particularly dedicated to answering questions that relate to society as a whole. The SSK notes that radiation research has become a less important part of programme-oriented research within the Helmholtz community.

6) While efforts need to be made to maintain existing expertise in some of the identified areas in Germany, there are several other areas of research in ionising radiation where the SSK has found signs of worrying shortfalls, in particular basic radiobiological research, radiation epidemiology, radiation risk assessment, radioecoloy, radiation metrology and dosimetry.

7) Given the relevance of radiation exposure and the effects of radiation for society as a whole, the SSK believes that a holistic approach, i.e. collaboration with the humanities

and social sciences, is becoming ever more important. Several areas of radiation research need input from the humanities and social sciences alongside the scientific viewpoint. This integral approach is already well established in medical practice and research, for example in the application of medical ethics in assessments, but requires further reinforcement with regard to individualised medicine and the use of artificial intelligence, in particular. Collaboration with communication sciences is essential for emergency response and preparedness, and also in connection with radon precautions. Initial steps towards interdisciplinary and recently transdisciplinary research are being taken in nuclear waste disposal research. The SSK considers it important to broaden such collaboration on radiation research in future.

8) Just over half of the radiobiology projects involved in UV radiation research and funded by the BMBF within the framework of the KVSF initiative were carried out by five institutions, one of which no longer exists, and another of which has now reduced its activities in this field. The departmental research plan mainly provided funds for projects on communication, which were carried out by various institutions.

9) Given that exposure to UV radiation is a highly relevant issue for the general public, the SSK is concerned that only three institutions are actively engaged in radiobiological research involving UV radiation since it will be impossible to meet the demand for expertise in the long term if this situation persists. 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.

10) In order to maintain the level of competence and the ability to research and/or analyse new hypotheses regarding the biological mechanisms underlying the effects of EMF exposure within a reasonable timeframe, it is essential that the technical and scientific expertise needed to conduct EMF exposure experiments and EMF metrology research remains available in the long term.

11) Another precondition for maintaining expertise is preservation and expansion of the infrastructure for ionising and non-ionising radiation research (e.g. EMF exposure facilities with state-of-the-art temperature monitoring, or ion accelerators that are not linked to routine patient care and generate the broadest possible range of types of radiation and also allow for variations of exposure patterns over time including ultra-high dose rates and pulsed radiation). The SSK believes that in order to facilitate work on fundamental issues in radiation research, it is imperative to engage in sustainable planning that is geared toward both preserving proven research infrastructure facilities and further developing state-of-the-art forms of infrastructure.

12) The analysis conducted for this statement showed that the funding of research projects through the KVSF initiative (BMBF) is key to ensuring the long-term preservation of expertise in radiation research in Germany, complemented by funding of departmental research from the BMU. Over the past 15 years, this combined structure has been very successful in terms of networking, maintaining expertise and supporting young researchers and has therefore, in the opinion of the SSK, proved its worth.

13) In addition, the SSK considers collaboration between all actors such as university and non-university research institutes and departmental research facilities to be crucial.

14) The SSK recommends that radiation research should be integrated on a sustainable basis into national research strategies such as the High-Tech Strategy 2025, the National

Decade against Cancer, the National AI Strategy and the Federal Government's energy transition strategy.

The Federal Government has launched numerous initiatives aimed at bolstering and advancing the position of German research. All initiatives involving the development and use of new technologies always require systematic accompanying research such as preparatory research, technology impact assessment and implementation support. The SSK believes that the integration, preservation and expansion of existing radiation research activities is essential in all instances where ionising and/or non-ionising radiation are involved.

In the opinion of the SSK, it is therefore important as a general principle 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, in order to raise awareness of radiation research and increase its competitiveness vis-à-vis other research disciplines.

The SSK is convinced that German research will stand to benefit substantially if scientific expertise in the areas identified in this statement as being important for radiation research is restored, maintained and strengthened. Only then will it be possible for Germany's interests in the field of radiation protection to continue to be put forward in international debate in future.

Lastly, it must be emphasised that ionising and non-ionising radiation from natural and artificial sources have become an integral part of everyday life to such an extent that it is impossible to avoid exposure. These sources include radon, a radioactive noble gas naturally present in the environment, cosmic rays, modern medical techniques used in diagnostic and therapeutic procedures, solar UV radiation, and electromagnetic fields created in the expansion of the 5G network and the subsequent 6G network and the development of electromobility. 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.

Following on from this statement and in line with the BMU advisory mandate, the SSK will draw up recommendations on what measures can be taken to promote radiation research in order to ensure that research in the field of ionising and non-ionising radiation is supported in Germany and corresponding expertise can be secured for the long term.

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