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"What does Germany think about radiation? Findings 2022"

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Content

1 Summary

1.1 Background

A central component of radiation protection is the education of the population about the effects and risks of radiation and about the correct protective behaviour in this respect. In order to gather information on society's handling of selected radiation topics as a basis for this educational task, the Federal Office for Radiation Protection (BfS) has for many years commissioned socio-scientific studies on the societal and individual handling of selected radiation topics as well as on risk and information perception – e.g. on the topics of mobile communication, power grid expansion, UV protection, communication of scientific uncertainties in the area of electromagnetic fields, knowledge of general practitioners regarding electromagnetic fields, reflected way of dealing with risks in radiation protection.

1.2 Objective

The objective of this research project is to detect the anchoring in society of radiation and radiation protection, the perceptions, knowledge and information needs of the population in Germany and to derive perspective recommendations for action and information. The reliability of the results on how the population deals with radiation and radiation protection is ensured by means of a method triangulation from a qualitative and a Germany-wide representative quantitative survey.

The focus is on the following questions:

- What are the views and opinions existing in Germany on the subject of radiation and radiation protection?
- What do respondents know about selected radiation protection topics?
- In which areas have the respondents already dealt with protective measures and which specific protective measures have already been taken?
- How well do citizens feel informed and protected by government radiation protection measures and what are their information needs?

The survey also intends to provide insights into the environment in which BfS operates with its scientific work as well as its information and communication measures. The results should thus provide impulses for the design of BfS's science and risk communication as well as for the elaboration of radiation protection concepts. The present study is part of a series of surveys entitled "What does Germany think about radiation?". This second survey builds on the first survey in 2019.

1.3 Study outline

The present study was conducted in two research steps: (1) a qualitative primary survey to obtain empirical findings for the development of the quantitative survey instrument and the understanding of thought patterns and logics when it comes to the perception of and dealing with radiation and (2) a population-representative survey of the German resident population aged 16 years and older on knowledge and perception of radiation in general and of specific radiation as well as risk assessment and exposure perception. The core questions of the previous survey from 2019 could thus be continued and supplemented with new aspects and questions.

1.4 Summary of the core results

People feel better informed and protected by state institutions in the area of radiation than they did in 2019. The best-known state institutions in the area of radiation protection are the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (values refer to aided awareness; 83%), the Federal Office for Radiation Protection (71%) and the International Atomic Energy Agency (68%). The qualitative interviews show that the Federal Office for Radiation Protection is a sender offering comprehensible content, to which, as a public authority and due to its name, a high level of expertise and credibility is attributed. Spontaneously, in the event of a nuclear accident, around 13% of respondents would obtain information from the Federal Office for Radiation Protection, 66% indicate the internet in general.

The qualitative results show a very heterogeneous spectrum of results when answering the question: "What does Germany think about radiation? " Knowledge, evaluations and associated emotions vary very strongly not only between respondents, but also among individuals, when it comes to comparing types of radiation. This heterogeneity can be qualitatively explained by a number of factors. These are: informedness, affectedness, risk affinity, trust in state institutions, general attitude in life, gender, geographical proximity to potential radiation sources, controllability of exposure, cost-benefit analysis, perceptibility of radiation, knowledge of protective measures as well as media presence of the respective radiation topic. The quantitative study also shows that there are different perceptions of the topic of radiation particularly depending on the level of information, gender and age. In addition, the study examined how much contact the respondents have with the type of radiation in question, to what extent one can protect oneself or to what extent the respondents feel protected from the type of radiation in question by state institutions.

From the citizens' point of view, there are types of radiation that are more familiar or present (e.g. UV radiation, radioactivity, X-ray, and mobile communication radiation, electrosmog, microwave radiation) as well as less familiar or present ones (e.g. laser radiation, infrared radiation, high-voltage power lines, "earth radiation", atmospheric radiation, satellite radiation and radon). The qualitative survey showed that citizens perceive and locate radiation in their respective contexts of life and fields of application: terms such as "optical radiation" and "ionising radiation" are unknown and do not correspond to the citizens' perception or logic of thought.

With regard to the associations in the context of radiation, radioactivity or nuclear weapons are mentioned most frequently in the quantitative study. The war in Ukraine has increased the population’s awareness of the importance of radiological emergency protection. In the event of a nuclear accident, many people would not know where to find information or what to do.

Besides radioactivity, associations in connection with mobile communication are frequent: More and more people associate mobile communication with the term "radiation". The majority of respondents assume that they have a lot of contact and that it is rather difficult to protect oneself. Nevertheless, respondents are rather less concerned about the topic of mobile communication radiation (19% Top2 box).

In addition, UV radiation / solar radiation is also very often spontaneously associated with the term "radiation". Overall, only about one third of the respondents say they are concerned about UV radiation – which could also be related to the fact that only about one third of the respondents think they have much contact. With regard to self-protection, about two thirds assume that one can protect oneself well from this type of radiation. The most common measures taken by the majority are to use sun protection cream/spray, to avoid staying in the sun for too long and to wear appropriate sunglasses. The risk posed by UV radiation as well as possible protective measures are generally known, but often the latter are not followed. Nevertheless, 75% of the respondents state that they "always" use at least one measure to protect themselves from UV radiation. In addition, the feeling of being protected by state institutions is rather high: 56% of the respondents state that they feel (very) well protected from UV radiation by state institutions, while this is

(rather) not the case for about 37%. In this context, the qualitative interviews clearly show that there are misconceptions (e.g. pre-tanned skin does not need UV protection) and that personal attitudes (e.g. tanned skin is attractive, it looks healthy) stand in the way of taking protective measures, so that there is a need for education here – although the desire for more information expressed by the respondents is low.

In addition, there are also topics in the field of radiation that the respondents are less concerned about and where they see fewer possibilities to protect themselves, namely radiation in the medical field, radiation from high-voltage power lines and radiation when flying. Interest in further information is also lowest here compared to the other types of radiation. When it comes to spontaneous associations, radiation in the medical field is mentioned rather rarely. About 70% of the respondents think that they have (rather) little contact with this type of radiation. However, radiation protection in medicine enjoys a very high level of trust: More than 80% of the respondents feel (very) well protected by state institutions – with a clear lead over all other types of radiation.

The qualitative discussion shows that the perception of the need for protection and protective measures depends on a number of factors that are assessed differently depending on the type of radiation. These factors result from the explanatory factors for risk perception and are: personal concern/experience, cost-benefit assessments, knowledge of radiation types per se, knowledge and availability of protective measures, as well as effort in feasibility and magnitude of anticipated consequences. Radiation types for which a high need for protection is perceived include radioactivity, X-ray, laser radiation and high-voltage power lines.

The fact that concern among the population is at a low level, especially with regard to X-ray and high-voltage power lines, is – as could be shown – also due to the perception of protection by state institutions.

Types of radiation for which the need for protection is perceived to be (very) low include microwave, infrared, earth, atmospheric and satellite radiation. In addition, there are types of radiation for which the perceived need for protection is polarised or varies depending on the context. These are UV radiation and radiation from mobile communication, although it can be seen that both types of radiation lead to a relatively low level of concern among the population, perhaps due to their continuous presence in everyday life.

Information behaviour with regard to radiation is mostly passive. There usually is no interest in or need for information, especially in the case of radiation types that are neither experienced as particularly risky nor as particularly relevant to one's own everyday life, or that are considered "established" types of radiation that have been known for a long time with their respective risks. Occasionally, however, the interest in information can be aroused by external stimuli, especially if a radiation topic has direct relevance for the everyday life of people or receives a lot of attention due to societal and political changes, as is the case with the Ukraine war and the possibility of a nuclear war or the attack on nuclear power plants discussed in connection with it. In this context, the general dangers associated with radioactivity and nuclear energy are increasingly perceived.

The qualitative interviews also showed that, when comparing the different types of radiation, there is a need for information above all with regard to the topic of radiation from mobile communication in general and 5G in particular, as this is where most uncertainties were found. In the population, this corresponds to around 59% who have already obtained information on the topic of radiation from mobile communication and around 13% who would like more information.

2 Research design

To answer the research questions, a two-step research design was chosen: A qualitative primary data collection is followed by a quantitative primary data collection.

2.1 Work Package 1 (WP 1): Qualitative survey

The qualitative exploration focused on the general perception of the importance of radiation, the risk perception of different types of radiation, the knowledge of protective behaviour and protective logics as well as the use of relevant information channels on the topic of radiation. A combination of group discussions and individual interviews was chosen to determine both the individual and the collective perspective in the context of radiation and radiation protection.

2.2 Work Package 2 (WP 2): Quantitative survey

The quantitative part of the study was conducted in spring 2022 (March / April 2022). The objective here was, on the one hand, to integrate the results from the qualitative study and to examine them quantitatively. On the other hand, the results were to be related to the results of the previous study that was conducted in 2019.

3 WP 1: Qualitative survey

3.1 Research design

3.1.1 Research questions for the qualitative survey in WP 1 (according to the terms of reference)

The following research questions and aspects were the focus of the qualitative survey according to the terms of reference:

- What are the knowledge and perception as well as myths and fears in the population regarding radiation in general and related to individual radiation protection topics?
- What is the meaning of the terms "risk" and "danger" in this context?
- What is the relevance of radiation protection in the context of health protection?
- What is the radiation protection behaviour or behavioural intention?
- What are the sources of information used on the topic of radiation?
- How important is the work of the BfS in the eyes of the public? How is the BfS perceived in terms of awareness, credibility and trust? What expectations are placed on the BfS?
- How much trust is there in science?

3.1.2 Method: Combination of group discussions and individual interviews

In order to understand the collective discourse relating to radiation, two group discussions, each lasting 2.5 hours, were conducted in a face-to-face setting in the studio in November 2021. Furthermore, technical terms from the context of radiation were explored in the groups.

In a second step, a total of 40 individual interviews, each lasting one hour, were conducted at four different locations in January 2022. In these face-to-face interviews, the individual perspective on radiation and radiation protection was researched and particularly individual topics such as barriers, motives, fears, individual knowledge and (mis)conceptions as well as the individual handling of risks were discussed in depth.

3.1.3 Target criteria for sampling for the qualitative survey in WP 1

The target group of the qualitative survey was compiled using a 23-question screening questionnaire. The objective of the recruitment procedure was to ensure that opinions were as heterogeneous as possible. According to grounded theory, which follows the principle of permanent comparison, heterogeneous contrast cases ("maximum contrasting") can provide a special gain in knowledge and should therefore be selected within the framework of theoretical sampling.

The following criteria were considered for sample composition:

- Gender mix: 50% men, 50% women
- Age mix: good distribution of people aged 18 – 70 years old
- Mix of household size and marital status: approx. 50% households with children < 16 years in the household
- Net household income: 50% below national average; 50% above national average
- Mix of educational background and occupational groups
    - Exclusion of 'risk experts', i.e. people who have a lot to do with risks in their professional lives (e.g. firefighters, police officers, actuaries, risk analysts).

- Exclusion of 'radiation experts', i.e. people who have to do with radiation in their professional lives (e.g. radiologists and other medical professionals specialising in radiology, dermatologists (as specialists in UV radiation), architects / civil engineers with a focus on radon remediation of buildings).

- Professional backgrounds:
  - 50% with a scientific / technical background
  - 50% without scientific / technical background
- Mix of urban & rural population
  - 50% urban population (per survey location)
  - 50% population from the surrounding area (residence in a medium-sized town, small town or village from the surrounding area of the survey locations)
- Good mix of people who live in a rented flat or house and people who live in their own flat or house
- Good mix regarding technical affinity
- Good mix regarding health awareness and awareness of health risks
- Good mix regarding trust in authorities & institutions
- Good mix regarding general life satisfaction
- People with and without a migration background
  - Definition of migration background: not born in Germany and already living in Germany for at least 5 years.

3.1.4 Sample description

The sample consisted of 16 participants divided into two focus groups of 8 people each. One focus group consisted of participants aged 18-39 years, the other group consisted of people aged 40-70 years. Another 40 people aged 18-70 were surveyed in individual interviews.

3.1.5 Survey locations and period for the qualitative survey in WP 1

The group discussions took place in Mannheim in November 2021. This was followed by 10 individual interviews each in Erfurt, Mannheim, Munich and Berlin in January 2022.

3.1.6 Research techniques for the qualitative survey in WP 1

Both the group discussions and the individual interviews began with getting to know the ways of thinking, the lifeworlds and the current basic sensitivities of the participants. This made it possible to (better) classify the knowledge gained from the discussions and interviews. The actual content-related introduction took place with an exploration of perception and knowledge related to radiation using mind maps. With the help of the mind maps, free associations in the areas of emotions, perception and semantics regarding the keyword radiation could be collected and visualised and also used as a memory aid in the further course of the survey.

This was followed by an excursus on the topic of risk. Within the framework of the excursus, the participants were asked about radiation-related risks and general life risks, which were then compared. To this end, the two comparison techniques of internal and external comparison were used. The so-called internal comparison, i.e. the comparison between risks of different types of radiation, aims at the breakdown of risks in a tighter framework. The external comparison is about the comparison of commonly perceived risks in life

and risks emanating from types of radiation, in order to be able to better contextualise the general importance of radiation risks in the everyday life of the respondents. To facilitate the comparison, all risks mentioned in the interviews were noted down on index cards, which could then be freely located by the interviewees between the two risk poles "low life risk" and "high life risk".

Furthermore, the questioning technique of laddering was used, especially in the individual interviews. This involves a graduated approach in order to identify overriding fears and anxieties from one sense level to the next sense level.

Stimulus material was only used in the group discussion in the form of terms that represent important vocabulary in BfS risk communication used as supported technical terms. The objective was to find out whether and how the following terms were understood by the interviewees: fields, exposure, contamination, radioactivity, ionising and non-ionising radiation, optical radiation, electromagnetic fields, UV radiation, waves and X-rays.

In the last part of the interviews and group discussions, which dealt with attitudes and knowledge about radiation protection measures, known prevention and protection measures in the context of the previously discussed types of radiation were first collected in an open exploration. In a second step, the individual logics as to when protective measures are actually taken and when none are taken were explored.

Following the qualitative maxim of openness, both survey forms started each thematic chapter with open exploration. After the open exploration, the contents were examined in greater depth, so that in addition to the criterion of openness, the quality criterion of depth of content was also taken into account at the same time. Initially, only the types of radiation that the respondents themselves named in the individual interviews and group discussions were explored. In this way, an individual knowledge horizon which was as uninfluenced as possible was determined. The participants were not asked about any predefined types of radiation or radiation topics. The terms that had already been mentioned – including types of radiation – were only given in the group discussions and explored with the help of the interviewer.

3.1.7 Explanations on the analysis

The method used for conducting and evaluating the interviews follows the principles of grounded theory. Against this background, there was no separation of data collection and evaluation. In the spirit of grounded theory, a continuous analysis of the data material already took place during the field phase. The continuous analysis process during data collection consisted in the writing of memos in the form of pre-structured result tables in Excel and the preparation of transcripts of the group discussions as well as their analysis even before the beginning of the individual interview field phase. A separation of data collection and analysis was also prevented at the personnel level, as the interviewers or moderators also took over the analysis.

A debriefing was scheduled at the end of the field phase in order to achieve intersubjectivity and comprehensibility through a transparent and participatory analysis discourse. The grounded theory strategy of permanent comparison and the associated search for "similar and dissimilar" was used throughout the whole analysis process.

3.2 Recommendations based on the qualitative findings

The qualitative findings suggested a more in-depth investigation of the following topics in the quantitative phase:

- General awareness of radiation types
- Reviewing the qualitatively determined factors influencing the perception of radiation

- Identification of possible causalities:
  - What is the correlation between perceived informedness and concern?
  - Reviewing the qualitatively identified factors influencing the adoption of protective measures
  - Contextualisation of radiation risks within general risk attitudes
- Information behaviour on the individual types of radiation

3.3 Results of the qualitative survey in WP 1

3.3.1 Factors influencing the perception of radiation

The results of the qualitative survey make it clear that the perception of radiation is a very heterogeneous field. The perceptions are very individual and considering the variety of types of radiation and the associated radiation topics, the assessments and the perception of risk can vary for one and the same person – depending on the type of radiation. For example, a person who has a high risk perception with regard to UV radiation and screen radiation and also takes various protective measures in this regard may turn out to be carefree when it comes to radiation in the context of mobile communication. Nevertheless, some overriding factors can be identified that influence the perception of radiation.

The following influencing factors can be identified:

- **Informedness**: A better (basic) technical understanding and a higher level of knowledge have a positive effect on the realistic risk assessment of different types of radiation.
- **Affectedness**: Personal affectedness or experienced affectedness in one's direct environment increase the involvement with regard to a radiation topic. From experiencing sunburn, to undergoing radiation therapy in the context of cancer, to drastic biographical experiences, such as childhood after the Chernobyl disaster – personal involvement shapes the perception of different types of radiation.
- **Risk affinity:** Personal perception of risk and personal willingness to take risks are character traits that also affect risk perception in the context of radiation. Individual risk affinity tends to decrease with increasing age and in certain phases of life: Older people tend to be more risk-averse than younger people, and parents tend to be more risk-averse than childless people of the same age.
- **Trust in state institutions**: The general trust placed in state institutions and public service media proves to be an important influencing factor for the perception of radiation. Thus, people who have a basic trust in the state, state institutions and public service media are significantly less concerned about possible negative effects of radiation than people who have little or no trust in state institutions.
- **General attitude in life:** The general attitude in life, i.e. whether one tends to be optimistic or pessimistic, also proves to be a relevant influencing factor for the perception of and dealing with radiation. People with an optimistic attitude also tend to be more confident in dealing with radiation. People with a pessimistic attitude, on the contrary, are more critical of radiation from the outset and often feel that their options for exerting influence are more limited.
- **Gender**: Gender was shown to be a moderately relevant influencing factor in the qualitative survey. Slight gender differences were noticeable in the area of protective behaviour: The impression was that women tend to take protective measures more consistently. In addition, women often proved to be drivers for men to take protective measures: mothers who remind their sons of protective measures and female partners who take over this function for their male partners.
- **Geographical proximity**: The proximity or distance to radiation sources (e.g. to nuclear power plants, to mobile phone masts or to radon occurrences in certain regions) has an impact on the perception and risk assessment of different radiation topics. For example, in this qualitative survey, radon was more

familiar to people interviewed in the Erfurt region, where there is a naturally elevated occurrence of radon.

- **The ability to control and influence exposure**: The conviction that one can influence one's own radiation exposure is a central factor that shapes the perception of radiation and the associated risk assessment.
- **Cost-benefit analyses**: Cost-benefit considerations play an important role in the perception of all types of radiation. This can be illustrated particularly well by the example of mobile communication: A high and, moreover, directly tangible benefit is ascribed to this technology, while the possible costs – in the form of negative effects of radiation from mobile communication – tend to be perceived as diffuse, scientifically not clearly proven and mostly not directly tangible. Similarly, costs and benefits are also weighed against each other when evaluating the other types of radiation, and the outcome of such considerations can vary greatly depending on the individual.
- **Perceptibility of radiation**: Radiation is usually invisible and not perceptible, which nevertheless has an influence on perception. Thus, only solar radiation is actually experienced as being directly noticeable – visible in the form of bright light, perceptible in the form of warmth on the skin. The other types of radiation are not directly perceptible for the majority, so, when it comes to perception, they tend to fade into the background. Only a few people in the qualitative sample reported that radiation from mobile communication has an impact of them in the form of headaches or sleeping problems.
- **Awareness and knowledge of protective measures**: The interviews and group discussions have shown that the fact of simply knowing about the existence of recognised protective measures strongly shapes the perception of a type of radiation. For example, even people who take no or few UV protective measures themselves are aware that this would actually be advisable in certain situations and they express a latent bad conscience for not taking protective measures.

  The situation is different for radiation in the context of mobile communication: The prevailing uncertainty about actual negative effects and the often lacking knowledge about protective measures often leads to the conclusion *"It won't be so bad".* The low level of concrete knowledge about recognised protective measures in the context of radiation from mobile communication leads to the fact that this radiation tends to be perceived as less dangerous than types of radiation for which clear and recognised protective measures are known. It should be noted, however, that individual respondents were also insecure precisely because, to their knowledge, no protective measures were recommended, although they had already heard about possible risks in the context of mobile communication.
- **Media presence**: Whether and to what extent radiation topics are present in the media also proves to be a factor that influences the perception of radiation. Thus, the seasonally recurring topic of UV radiation enjoys a very prominent position in the perception of the respondents, while radon, for example, is unknown to the majority. The currently intensified environmental debates around nuclear power and the Chernobyl anniversary also shape the perception of this type of radiation. Likewise, the fact that the topic of mobile communication and 5G is often taken up in social media, where it is also discussed by conspiracy theorists, among others, has an attention-grabbing influence on perception.

3.3.2 Excursus on risk: attitudes and handling

In order to gain a deeper understanding of the risk perception of radiation, it is methodologically necessary to classify this complex of topics on a higher level – personal attitudes in general and behaviour towards risks. For this reason, an excursus was made in the course of the survey on the topic of risk in general, which included the following topics: spontaneous associations with the keyword risk, a definition of the term

deductively derived from the participants' answers, personal life risks perceived by the participants, a risk self-location of the participants as well as a projective external assessment and the handling of personal life risks in general. The knowledge gained allows for a profound understanding and contextualisation of the risk perception of radiation types explored subsequently. The result of the excursus on the topic of risk shows that the concrete perception of risk depends on a variety of factors, which are explained below.

The term risk is associated with opportunities and dangers at the same time. However, depending on one's own general attitude to risk, there is often an individual emphasis on one of the two sides: Respondents who see themselves as rather willing to take risks emphasise the opportunity side of a risk. The situation is different for risk-averse participants, who associate dangers and problems more strongly with a concrete risk. Accordingly, the concrete risk perception seems to go hand in hand with the general risk attitude of the respondents.

The subjectively perceived controllability of a situation also has an influence on risk perception. One example mentioned by the participants in this context is the risk that a relative might become seriously ill or have an accident and that they would not be able to influence the situation themselves. Such a scenario evokes fear and a perceived loss of control in the respondents – especially if they have already experienced such a situation with a fatal outcome. On the contrary, confidence in one's own abilities can lead to a risk being assessed as low. For example, climbing without a rope at great heights was considered a low risk by one interviewee because the person had confidence in their own climbing abilities: *"Other people kept telling me: are you totally crazy? No, I'm not. When I do this, I am sure I can do it. I trust my hands, my feet and I know I won't fall."* At the same time, the example shows that the subjectively perceived controllability is not necessarily intersubjectively comprehensible.

Furthermore, the collected data shows that subjectively perceived concern is also a factor influencing risk perception. For example, risks such as retirement or illness are considered relatively low by some younger people, as they consider them to be in the distant future.

Another factor influencing the perception of a risk concerns the expected consequences of a risky decision. "If I give up my civil servant status, I don't know whether my new job suits me and whether I will be more satisfied with it. And a change of job is always connected with a feeling of ... You can't go back. You're closing a door." The same interviewee had a very different view of a possible loss in gambling: "I would only gamble money that I can spare. That means that the loss is limited. When I gamble, I don't assume that I will win. It would be nice, but I don't assume it."

Increased risk awareness can result from experiences that raise awareness. "You don't only get sunburn at 30 degrees and in bright sunlight. It also happens when it's 20 degrees and cloudy, and that's when you don't notice it. I experienced that myself in the Azores. It wasn't that hot there. But it's closer to the equator and the solar radiation is more intense there, even when it's cloudy. I had to use lotion every day."

Furthermore, the perception of risks can also be influenced by the social environment. For example, one interviewee reported that her parents keep warning her about radiation exposure from mobile phones: *"Parents always tell you to put your mobile phone further away, because of the mobile phone radiation and all that [laughs]."* Although the interviewee distanced herself from her parents' view, she still had residual doubts a desire for more detailed information to be able to check whether her parents are right.

In addition, existing knowledge, including possible misconstructions, as well as the lack of knowledge have an influence on whether respondents classify an issue as high-risk or low-risk. In summary, the following factors influencing risk perception could be identified: individual attitude to risk, subjectively perceived controllability, perceived concern, the scope of the anticipated consequences, experience, social environment and knowledge versus lack of knowledge.

By exploring how people deal with life risks, it is possible to derive key drivers and barriers for taking protective measures against perceived risks. For the majority of respondents, scientific evidence and well-founded expert opinions increase the willingness to take risk prevention measures. However, this requires that there is a fundamental trust in science and that the factual situation is clear and not ambivalent. The latter, in fact, has an opposite effect on some people. The orientation towards scientific expertise can also partly be interpreted as a learning effect of the population due to the Corona pandemic, since measures for overcoming the pandemic are largely based on medical expertise.

The existence of protective measures against risks is also a driver that is a basic prerequisite for taking preventive measures. There are numerous examples of reported protective measures: insurance, financial products for old-age provision, investments in education, medical screening, sport and a balanced diet to keep the body healthy, sun protection in the form of clothing and / or sunscreen or simply the light on the bicycle.

However, mental defence mechanisms act as a barrier to taking protective measures. The interviewees report that they are repressing certain risks, for example due to perceived uncontrollability, and taking refuge in positive worlds of thought, for example when picturing a positive course of a serious illness of relatives. In addition, the perception that there is no acute need for action leads to the rejection of preventive measures: "*Everything I do is unhealthy – my lifestyle, my diet. But I am fine. My values are impeccable. [...] But as long as everything is fine, I see no reason to change.*

The outcome of a cost-benefit calculation can also decrease or increase the willingness to implement protective measures. For example, an entrepreneur decided to insure his cargo based on a mathematical cost-benefit calculation: *"150€ compared to 50 000€ is 0.0 something percent. So, why save 0.0 something of the total price and take a risk? Now, if it were 20% of the main price or of the total price, I would think twice about whether I need it or not?"*

These factors identified at a general level are reflected in the following discussion on radiation.

3.3.3 Radiation: spontaneous associations and contact points

Reactions to the question of what is spontaneously associated with the term "radiation".

After initial hesitation and reflection, the term "radiation" evokes a broad spectrum of conceptual and emotional associations. Overall, associations linked with the term "radiation" are strongly determined by the respective life reality of the interviewees.

Due to media presence at the time of data collection, the term "radiation" was always spontaneously associated with "radioactive radiation". All respondents reported that they increasingly encountered this topic in the media recently – whether in contributions related to "35 years after Chernobyl" or in the context of current environmental discussions on nuclear power as a 'clean' form of energy. While the Chernobyl disaster still triggers feelings of horror and fear today, the discussion about nuclear power as part of the energy transition is associated with question marks and pro and con arguments. For a few respondents, Chernobyl was also an event that had a strong personal impact on their lives, as they grew up in affected regions (Ukraine, Romania, Vorderpfalz).

Many older and occasionally younger chronically ill people spontaneously thought of radiation used in medicine, such as "radiation for cancer therapy", "X-rays", "MRI and CT" and "laser radiation", because they have experienced these types of radiation themselves for diagnosis or treatment purposes or know it from their immediate environment. Younger male passionate athletes in the sample often thought of "X-rays" first in the association exercise because they had already been in contact with them (sometimes repeatedly) in the context of sports injuries. The spontaneously expressed feelings connected with these different types of

'medical' radiation were mostly feelings ranging from gratitude to fascination about the medically advanced methods of diagnosis and treatment, while at the same time respondents were aware that these types of radiation are also potentially dangerous.

The thematic fields "radiation from mobile communication" and "electrosmog" were also often spontaneously associated with the term "radiation". The spontaneous reactions in this regard were particularly often expressed at the level of opinion and emotion and ranged from concerns about the suspected but uncertain negative consequences of radiation from mobile communication and radiation from everyday technical devices (especially microwaves and monitors) to the complete dismissal of such concerns:

"I'm worried about the health of my children, because young people use their mobile phones even more frequently than we do." "You hear about mobile phones every now and then, for example how you shouldn't keep them so close to your body or on your bedside table."

Versus:

"I'm not scared at all. Some people don't even want to use a microwave because they're scared of radiation, but I think that's complete nonsense." "I think that discussions about electrosmog are quite esoteric. I don't switch off my Alexa or WiFi!"

Furthermore, the term "radiation" was often spontaneously associated with solar radiation. Solar radiation had a positive connotation, as the respondents linked it with summer, holidays, leisure time and a general feeling of well-being. This may also have been reinforced by the fact that the survey took place in winter: *"Especially now during wintertime, I am grateful for every day I can spend in the sun."* In the context of solar radiation, respondents frequently mentioned that this was "natural" radiation – meaning radiation that occurs naturally, similar to atmospheric radiation and radon. Other "natural" types of radiation were only mentioned spontaneously by few respondents. In contrast, "technical" radiation – such as radiation from mobile communication, the various types of radiation in the medical sector and radioactivity – was considered to be artificial and man-made.

Finally, the term "radiation" also triggered completely different associations: For example, some respondents thought of people's radiance, which can be good or bad: *"A person with a positive radiance has many more possibilities in life".*

Overall, it appears that in the view of many respondents there are often two sides to radiation: *"Radiation can be good or bad" "It can be beneficial, but it can also be harmful."* Only some perceived radiation as something negative and dangerous per se.

Role of radiation in one's own life and points of contact

The following quotation illustrates the view of the majority of respondents on the role radiation plays in their lives: *"Radiation is omnipresent and you are constantly in contact with it, but I don't worry about it".* This means that although radiation is perceived as omnipresent in everyday life – at least after conscious reflection – it still does not play a role, or at least not a major role, in the lives of most people (with some exceptions). Respondents reported that the omnipresent radiation in everyday life is rarely experienced consciously, simply because it is not tangible: *"You don't see or feel radiation, so you don't think about it".* Only in a few cases people reported that they consciously perceive radiation, for example when they talk on their mobile phone or using Bluetooth headphones for a longer period of time and their ear gets hot, or because they have been suffering from sleep problems since the construction of mobile phone masts near their home. However, these are exceptions.

When respondents are specifically asked about the omnipresent radiation, which the respondents rarely think about in everyday life, it is manifested in many points of contact. Radiation from mobile phones and wireless

networks is most prominent in the perception of the interviewees. Contact with this kind of radiation is permanent and is perceived as inevitable: *"Nowadays, we are reachable at all times: You always have your mobile phone with you and there are hotspots and wireless networks everywhere in public and private spaces. This type of radiation is always there." "It is impossible to imagine our everyday life without mobile phones and thus also mobile phone radiation: We use mobile phones and the various apps for everything, whether for communication, finding information, scheduling, navigation." "I live in a large apartment building and my computer displays 50 wireless networks available in my immediate surrounding."*

The radiation from various technical devices used at home and from smart home applications is perceived in a similar way, while it is also felt that this type of radiation is increasing constantly: *"We are surrounded by numerous devices at home, all of which emit radiation - monitors, microwaves, Bluetooth headphones, smartwatches, to name but a few" "More and more people are transforming their flats and houses into smart homes."*

Mobile phone masts and high-voltage power lines are mentioned as another point of contact with radiation. Mobile phone masts tend to be a more relevant contact point for urban dwellers, whereas high-voltage power lines are more likely to be perceived as a contact point by rural dwellers. In some cases, the urban dwellers interviewed expressed concern about the increase in mobile phone masts in their immediate surrounding.

Furthermore, the radioactive exposure that is still on an increased level in certain areas as a result of the Chernobyl disaster was mentioned as an unconscious but omnipresent point of contact with radiation. Some reported that they avoid mushrooms, wild berries and game meat from these areas (for example certain regions of Bavaria).

Sporadically, "earth radiation" was mentioned as an omnipresent point of contact with radiation: *"Earth radiation is always present as natural radiation".*

In addition to the permanent radiation exposure resulting from the radiation sources described above, the respondents also named points of contact with occasion-related radiation: these include, for example, extensive sunbathing during a summer holiday or medical irradiation that is carried out on a doctor's initiative as part of a diagnosis or treatment. In the case of occasion-related radiation, the radiation exposure is of limited duration and the persons are aware of it at the moment of exposure. Especially for older respondents, medical irradiation is an important point of contact with the topic of radiation, as it is for athletes. Conscious sunbathing is also still a relevant point of contact for some, although many respondents reported that they no longer consciously expose themselves to the sun as much as they used to.

It became clear that the topic of solar radiation is a particular radiation topic that differs from the others. Due to its seasonal recurrence, there are multiple points of contact on a regular and repeated basis. The topic of solar radiation and sun protection is strongly addressed by the media in summer: *"Every summer, UV radiation and the need for UV protection is a topic present in all media: you can't avoid it."* In addition, at this time of the year in Germany – or in the same way during long-distance travels in winter – the greater intensity of the solar radiation is also perceived physically. Perceptions range from a greater sense of well-being to consternation in the case of a sunburn: *"I simply feel better in summer – the sun is good for me. " "Isn't it wonderful to be tickled by the sun!" "At the latest when you get a sunburn, you will become aware of the effect of solar radiation."* This makes it clear that – unlike the other types of radiation – solar radiation can be experienced more strongly by all people, for better or for worse. At the same time, the example of solar radiation illustrates that radiation begins to play a role as soon as protective measures are considered.

Finally, a few people in the qualitative survey mentioned professional contact with radiation. They deal with specific types of radiation, such as radar waves or power lines, in their everyday work in scientific, electrotechnical or information technology fields: *"For professional reasons, I mainly deal with radiation from*

power lines, e.g. power pylons, which are being expanded due to the energy transition. " "I am in contact with the topic of radiation in my professional life, as I deal with e-mobility and the associated charging stations." The interviewees reported that they feel sufficiently informed about protective and monitoring measures in the context of occupational exposure with radiation and therefore feel well protected: *"Through my work in the aerospace sector, I deal with radar waves. I have no concerns about this because there are good protective measures and the waves are not dangerous."*

Furthermore, some respondents who do a lot of work on desktops mentioned monitor radiation as a key point of contact with radiation: *"As a legal professional, I work on the screen all day long. One of my eyes is very sensitive. I think that this is related with the work on the monitor." "Home office has increased screen time even more! That actually worries me."*

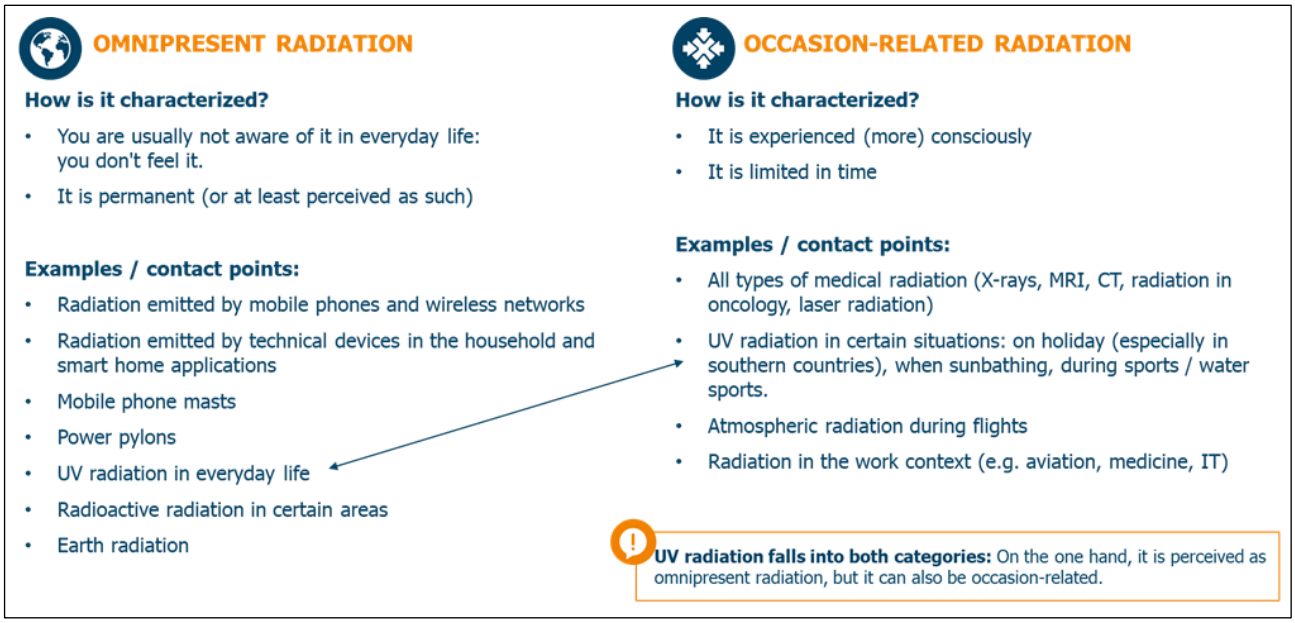

Figure 1 Distinction between omnipresent and occasion-related radiation

To what extent is "radiation" a conversation topic?

The interviews and group discussions have shown that radiation is generally not a topic of conversations with friends or family. The exception is the topic of nuclear radiation, which often comes up in conversations with friends and family in the context of the politically discussed nuclear phase-out. Parents with children going to school in particular reported that their children bring the topic home to the family from school. Otherwise, the respondents are most likely to talk about solar radiation and the need for sun protection when reminding each other about sun protection in certain situations, for example among friends, in couples or in the family. Since the need for sun protection is generally known and proven, bringing up this topic in certain situations seems to be socially acceptable. The discussion about radiation in the context of mobile communication in general and 5G in particular is different: Here, many study participants mentioned people in their environment who have a critical attitude towards "radiation from mobile communication" and "5G radiation" and talk about this to their environment. However, such attempts to talk about radiation in the context of mobile communication are often dismissed as nonsense, since the lack of clarity about possible effects and protective measures quickly makes any discussion about this appear to be speculations and fears of overly concerned people.

What role does radiation play in everyday media consumption?

The topic of radiation also plays only a limited role in media consumption. Contributions on the topic of radiation are consumed rather passively and coincidentally; the respondents usually don't actively looked for it, as the following quotes show:

"You stumble across this topic every now and then. For example, during the time of the anniversary of the Chernobyl disaster, the topic was in the media a lot and I watched a documentary about it on Netflix. "
"During summer, every women's magazine deals with the topic of UV protection."
"The energy transition is a current topic, and nuclear power is a recurring theme in this context."
"The topic of final storage of nuclear waste is in the media every now and then, that does worry me."
"Germany is planning to phase out nuclear power, but new power plants are being built in neighbouring countries. "

3.3.4 Radiation: Perception and knowledge

The qualitative survey showed that citizens perceive radiation in their respective contexts. The scientifically correct distinction e.g. between optical radiation, ionising and non-ionising radiation, etc. is largely unknown to citizens and therefore does not correspond to their perception or logic of thought. Instead, radiation is located in the respective contexts of life and fields of application. Based on the results of the interviews and group discussions, five main areas were identified to which the respondents assign the types of radiation they are familiar with:

- Radiation at home: It comes from mobile phones, wireless networks, technical household appliances and smart home applications.
- "Radiation in the medical field": It includes all radiation types in the medical sector from X-rays to MRI to CT to radiation in oncology and laser beams for medical applications.
- Radiation in the work context: These can be very different types of radiation, depending on the occupational context of the respondents (e.g. aviation, medicine, IT sector).
- "Unnatural environmental radiation": In this context, the respondents mainly perceive radiation from mobile communication and high-voltage masts. In the case of nuclear reactor accidents, such as Chernobyl or Fukushima, nuclear radiation would also fall under this category of "unnatural environmental radiation".
- "Natural environmental radiation": This includes naturally occurring types of radiation – first and foremost solar radiation, but also natural radioactivity in areas with natural uranium reserves, natural radon reserves in some regions, "earth radiation" and atmospheric radiation (during air travel).

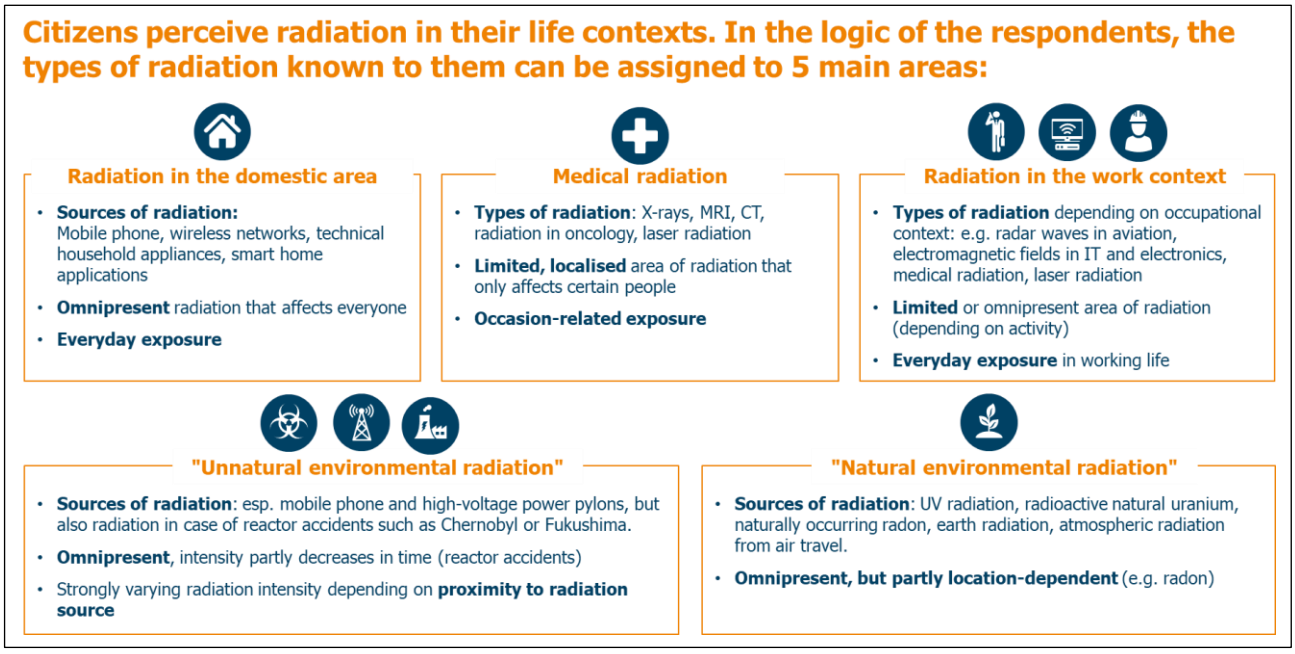

Figure 2 Perception of radiation: localisation in different life contexts

Overall, the results of the qualitative survey show that knowledge about radiation varies greatly: Respondents know more about some types of radiation, less about others, and nothing at all about some, as will be explained in more detail in the following.

3.3.4.1 Perception and knowledge of known types of radiation

The qualitative survey has shown that there are types of radiation that are known better as well as a large field of less or even completely unknown types of radiation, as the following figure illustrates:

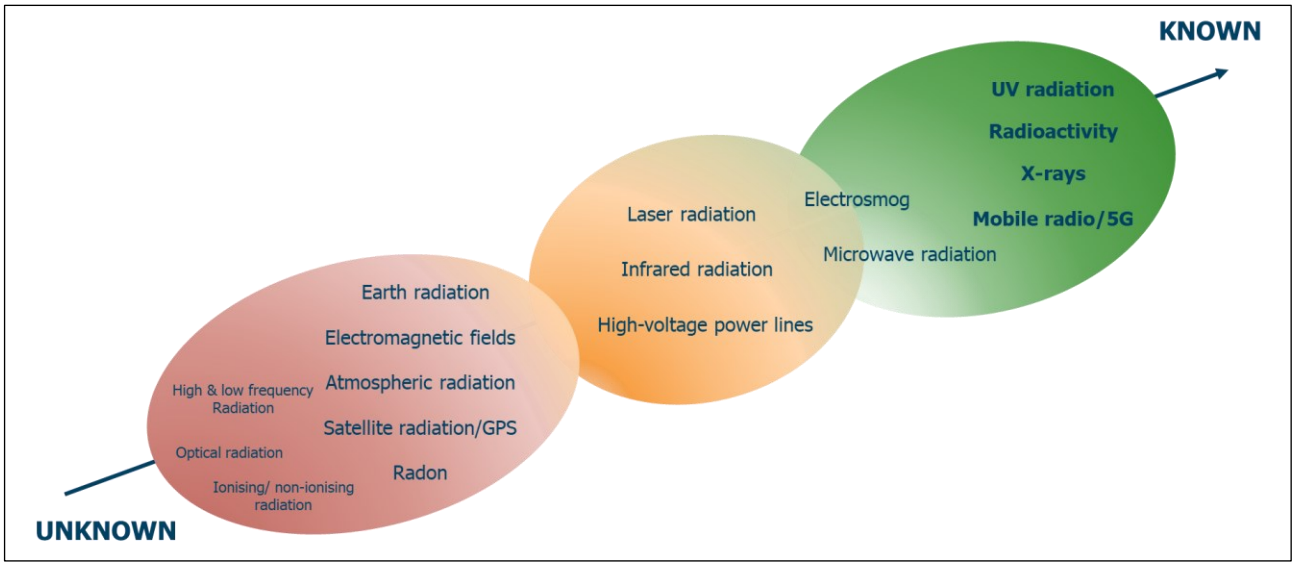

Figure 3 Awareness of different types of radiation

The following types of radiation were clearly the best known in the qualitative survey and were mentioned most frequently by the respondents without prompting: UV radiation, radioactivity, X-rays and radiation from

mobile communication. Electrosmog and microwave radiation are also known by the majority. The perception and knowledge of these types of radiation are explained below.

UV radiation

The general perception of UV radiation is rather positive: it tends to be experienced as "good" radiation because it is vital and evokes positive associations: *"It makes one think of holidays, sun, leisure time." "There is something life-giving about solar radiation." "Solar radiation simply makes you feel good." "Sun makes you healthy and attractive."* At the same time, there is a great awareness and high sensitisation to the fact that too much UV radiation can cause (severe) harm.

Compared to other types of radiation, knowledge about UV radiation is relatively extensive, also because it is fed from many sources and has been built up over a long period of time (see chapter on information). The interviewees emphasised that UV radiation is a natural and vital type of radiation that is needed for growth and life in general and specifically for vitamin D production. And the human psyche cannot do without UV radiation either. *"Humans, animals, plants - we all need this elixir of life."* The knowledge base of the interviewees also includes knowledge of the negative and proven consequences of UV radiation: It was known to all participants that (too much) UV exposure can cause skin cancer in the long term. Many – especially female – respondents also mentioned that they were aware of the medium-term acceleration of skin ageing due to UV radiation. There is also knowledge about higher UV exposures in some regions, e.g. in Australia due to the ozone hole and in southern or tropical countries. The distinction between UVA and UVB radiation was made by some respondents, but without further knowledge *"I don't remember which of the two is better or worse."* The sun, sometimes also solariums and occasionally devices for drying nail varnish were identified as sources of radiation.

Despite extensive knowledge, the group discussions and individual interviews revealed that there are also misconceptions in the context of UV radiation: The myth that pre-tanned skin does not need sun protection seems to be widespread, as is the idea that one does not need sun protection in Germany because UV radiation is not so intense in these latitudes.

Radioactivity

In the general perception, radioactivity is, on the one hand, a highly dangerous type of radiation that evokes negative associations across generations and is quickly associated with catastrophic images of reactor accidents: *"It has a pretty negative connotation." "Radioactive radiation makes you sick." "One has horrible images of Chernobyl in one's mind."* On the other hand, its advantages are also weighed rationally*: "A double-edged sword: green and emission-free energy, but extremely dangerous in case of accidents." "Very helpful in cancer therapy."*

With regard to radioactivity, the respondents have a broad general knowledge**.** All respondents were aware that humans make use of radioactivity in various areas: In energy supply, nuclear power is an economically interesting and CO_2-free form of energy, which, however, entails the problem of final storage and the risk of reactor accidents. In medicine, radiation is known as an aggressive but sometimes necessary form of therapy in oncology. Finally, the use of radioactivity in the form of plutonium in nuclear weapons is a generally known field of application. Occasionally, its use in the assassination of agents was also mentioned.

The fact that radioactivity is potentially very dangerous and can cause serious damage to humans, animals and the environment is also part of general knowledge. Burns, genetic alterations, DNA cell damage, cancer, thyroid problems, deformities, shortened of life expectancy and ultimately death are mentioned as concrete negative consequences. There is a high level of awareness that the consequences of radioactivity are both

short and long term, as evidenced by the continued high levels of exposure in areas where reactors or nuclear bombs have exploded, cited by respondents. Sporadically, the respondents mentioned that genetic alterations do not only occur in those affected, but also in future generations. Drastic historical events such as the reactor accidents in Chernobyl and Fukushima as well as the atomic bombs in Nagasaki and Hiroshima are also considered general knowledge in the context of radioactivity. Finally, in the context of radioactivity, many people know that ionising radiation can be measured with the Geiger counter. Further knowledge beyond general knowledge – such as the distinction between alpha, beta and gamma radiation – is only available in isolated cases and rather superficially: *"I know this distinction by name, but don't know any more about it."*

No noteworthy misconceptions in connection with radioactivity could be found in the qualitative survey.

X-rays

The general perception of X-rays is positive: They tend to be experiences as "good" radiation because – although dangerous and aggressive per se – they are associated with a medical purpose. X-rays also arouse a certain fascination – especially among younger men – and stand for medical-technical progress: *"It's super fascinating what you can do with X-rays.*

The knowledge of the interviewees focuses on the fields of application of X-rays and their inventor Dr. Röntgen, who is also responsible for the fact that X-radiation, is referred to as Röntgen radiation in some languages. This type of radiation is seen as an important instrument in medical diagnostics, which makes it possible to "take a look inside the body" and which is mainly used in the case of injuries (e.g. to detect bone fractures). The use of X-rays by dentists is also common and well-known. Radiation sources are medical X-ray machines, and the fact that exposure should not be too frequent was mostly known.

No noteworthy misconceptions in connection with X-rays could be identified in the qualitative survey. Only occasionally was the idea expressed that body scans at the airport work with X-rays.

Radiation from mobile communication

Radiation from mobile communication is a type of radiation that is more polarised in general perception than other types of radiation: many perceive it as highly beneficial radiation because it is associated with so many practical benefits: *"I rather see the benefits and the radiation that comes from mobile phones is harmless".* However, it is also partly perceived as "bad" and dangerous radiation that worries some people: *"Radiation from mobile communication worries me because it is increasing more and more and we don't know much about it.*

This polarising perception is certainly also related to the fact that the majority of the respondents of the qualitative sample possesses rather little factual knowledge in the context of this type of radiation. Furthermore, the respondents also address perceived scientific uncertainties with regard to radiation from mobile communication, which in their view distinguishes it from other types of radiation: *"As far as I know, there is no clear scientific knowledge about possible negative effects". "It is still a young technology in comparison and too little is known about the long-term effects."*

There was agreement among the respondents of the qualitative sample only with regard to the sources of radiation from mobile communication: mobile phones, wireless networks / internet, smart watches and other end devices as well as mobile phone masts were identified as sources. The perception that mobile phone masts emit more radiation than mobile devices was also unanimous. Beyond that, however, the perception of this type of radiation seems to be shaped less by knowledge and more by speculations and rumours – especially by assumptions about possible negative effects of radiation from mobile communication, the verification of which does not seem possible: *"This is a very diffuse topic for me, I don't know much about it."*

"From time to time, you hear about cancer caused by radiation from mobile communication." "Allegedly, when men have their mobile phones in their pants pocket, this can lead to impotence." "I once heard that the risk of breast cancer is increased when living near transmission masts." In some cases, there are "fragments" of knowledge, from which conclusions are drawn: *"It is known that mobile phones emit heat, and this might influence the brain."* Occasionally, knowledge is also derived from personal negative experience and consternation: *"My ear gets hot after long phone calls with my mobile phone and I get a headache – so there must be a negative effect of mobile phone radiation after all."*

Slightly more advanced knowledge was only shown by some respondents who, for example, knew the SAR value as an indicator and who pointed out a reduced radiation exposure from modern mobile phones: *"In the past, mobile phones emitted much more radiation than today. Radiation exposure has decreased, as has power consumption, because batteries are much better today."* Some interviewees also mentioned knowledge in the context of 5G, for example that 5G roll-out requires more transmission towers and that 5G can affect air traffic: *"It's a different micro-radiation that requires more transmission towers." "In the US, where 5G roll-out is more advanced, there seems to be an impact on air traffic."*

Respondents who live in the city occasionally shared the observation that the number of transmission masts in their neighbourhood was increasing. However, this phenomenon could not be classified and explained and was not associated with 5G by these people.

With regard to misconceptions in connection with radiation from mobile communication, the qualitative survey showed that the radiation exposure from mobile devices tends to be underestimated, while the radiation exposure from transmission masts tends to be overestimated. In addition, some people expressed the idea that special lamps supposedly protect them from 5G radiation and that mobile phones only emit radiation as long as they are connected to the WiFi.

Electrosmog

The perception of electrosmog is ambivalent. Some respondents assume non-existence and thus evaluate electrosmog as a misconception per se, others think that electrosmog exists. In the latter case, the general perception is negative. On the one hand, as a dysphemism, the word is negative in itself, on the other hand, electrosmog is perceived as a synonym for a conglomerate of radiation from several technical devices and is therefore clearly associated with contamination.

The knowledge of the respondents who use the term "electrosmog" colloquially is vague: There is a perception that electrosmog is unhealthy – stress, discomfort, sleeplessness and lack of concentration are mentioned as concrete negative effects. Sporadically, people have described themselves as sensitive to electrosmog: *"I am very sensitive to electrosmog and therefore switch off all devices at night."* Electronic household appliances were primarily named as sources of radiation**:** TV, radio, mobile phone, WiFi, cooker, fridge, microwave, monitors, vacuum cleaners and lawn mowers, as well as smart home applications. Power lines were rarely mentioned as a source of radiation for electrosmog.

Microwave radiation

The general perception of microwave radiation ranges from neutral to slightly negative. The majority perceive it as harmless radiation from a long-established everyday object. Only a few express slight doubts about the harmlessness: *"Microwave radiation is suspicious to me."* (More on this topic in the chapter on risk perception.) There is little concrete knowledge about this type of radiation – the respondents mainly named known rules of conduct in dealing with microwaves (see chapter on protective behaviour). There were not many misconceptions; occasionally it was mentioned that the vitamins in food are destroyed when it is

heated in the microwave, that microwave radiation causes cancer and that microwave radiation is harmful to health in general.

3.3.4.2 Perception and knowledge of less well-known types of radiation

The following types of radiation were mentioned less frequently in the qualitative survey, in some cases only sporadically, by the respondents without prompting: laser radiation, infrared radiation, high-voltage power lines, "earth radiation", atmospheric radiation, satellite radiation and radon. This indicates a lower level of awareness of these types of radiation, which are explained in the following.

Laser radiation

Laser radiation is perceived as a highly targeted instrument, which is perceived to be positive. The respondents of the qualitative survey stated that they were familiar with laser radiation from a wide variety of areas. The respondents most often seemed to know laser radiation in the medical field *"to laser things away"* as well as laser pointers in presentations. They also mentioned laser barriers (e.g. at the airport), laser communication for data exchange in research, and laser-based hair removal methods in the cosmetic field. The use of laser radiation in light laser shows, as weapons and in 3D printing was also mentioned sporadically. The sources of laser radiation are diverse: All devices that emit laser radiation are perceived as sources of radiation. Misconceptions with regard to laser radiation did not come to light in the qualitative survey.

Infrared radiation

The general perception of infrared radiation is very positive: It is experienced as "good" radiation with the ability to heal. The fields of application for infrared radiation known to the respondents were located in the areas of medicine / health and wellness. Infrared lamps for medical purposes (e.g. to relieve muscle tension) and heat radiation in the sauna were mentioned as sources of radiation. Misconceptions with regard to infrared radiation did not come to light in the qualitative survey.

High-voltage power lines

The general perception of power lines – more commonly referred to by respondents as electricity pylons or overhead power lines – is negative: *"I have a bad gut feeling near power lines".* Beyond this "bad gut feeling", the visual impairment of the landscape as well as the fear of a reduction in property values in the vicinity of high-voltage lines were also noted in isolated cases. All in all, there is a proximity to the perception of electrosmog.

"Earth radiation"

The occasionally mentioned "earth radiation" is perceived to be neutral, as it is a natural, thousands of years old type of radiation. Certain types of stones and minerals in the ground were identified as sources of radiation. The interviewees emphasised the natural occurrence of this type of radiation – depending on the type of rock, there is more or less of it in some regions in Germany. *"These minerals have been in the ground for many billions of years."*

Atmospheric radiation

Atmospheric radiation – sometimes referred to by respondents as "aircraft radiation" or "flight radiation" – tends to be perceived as negative, but not necessarily as a cause for concern, as exposure is very limited. Respondents expressed the belief that there is only an increased exposure to this type of radiation during flights. *"There is increased radiation when flying." "Pilots and flight attendants have a radiation account with a maximum value."* Misconceptions regarding atmospheric radiation did not come to light in the qualitative survey.

Satellite radiation

Satellite radiation was mentioned sporadically, and in the perception of the interviewees, the benefits associated with satellite radiation in the context of GPS positioning seemed to dominate. It was only noted that conspiracy theorists in their circle of acquaintances sometimes also refer to satellite radiation.

Radon

If known, the perception of radon is rather negative: Radon tends to be associated with exposure. The few who were aware of radon had a higher level of knowledge: They were aware of the source of radiation, the naturally occurring gas radon in the soil, as well as of the fact that its occurrence varies from region to region. *"Radon occurs naturally in certain regions of Germany, for example in Thuringia."* That radon is harmful to health in excessive doses was known to these respondents, as was the fact that protective measures can be taken (e.g. when building a house): *"Radon is deposited in houses and cellars – in affected regions, precautions can be taken with construction measures."* Misconceptions regarding radon did not come to light in the qualitative survey.

Electromagnetic fields

The term "electromagnetic fields" was generally not (correctly) mentioned by the respondents in the qualitative survey without prompting. However, the following similar terms were mentioned in very few cases: "electronic fields", "magnetic fields", "electric radiation" and "electromagnetic radiation". The term "electromagnetic fields" will be discussed in the following chapter ("Aided exploration of terminology").

3.3.4.3 Unknown types of radiation and terms

The terms "optical radiation" and "ionising and non-ionising radiation" were unknown to the respondents of the qualitative sample. The terms were known by name only very rarely, but without any further knowledge. These terms were explored in the group discussions (see following chapter). The terms "high-frequency and low-frequency radiation" were also not used by the respondents themselves. However, these terms were not explored in the group discussions.

3.3.4.4 Aided exploration of terminology

Towards the end of the group discussion, the participants were shown the following terms from the BfS risk communication in random order and their perception and level of knowledge of each was briefly explored:

- Contamination
- Waves

- Radioactivity
- Ionising and non-ionising radiation
- X-ray
- UV radiation
- Fields
- Exposure
- Electromagnetic fields
- Optical radiation

The terms "X-ray", "UV radiation" and "radioactivity" were known to all respondents and were so familiar that they were already spontaneously mentioned by the respondents in the first part of the group discussion and discussed in greater detail accordingly (see previous explanations on this).

The other terms, on the other hand, were mentioned for the first time at the end of the group discussion, when they were prompted. This can be interpreted as a sign of the lack of relevance of these terms in the everyday life of the citizens. It can be seen that some of the terms mentioned are (vaguely) understood (even if they are not actively used), while other terms cannot be interpreted and classified at all.

The term "waves" was predominantly understood as a synonym for radiation in the groups. For older respondents, it was a more neutral word than the word radiation, which tends to have negative connotations; for the younger ones, it was a much more positive word: *"Waves is a more colloquial word for rays, which is more emotionally positive than radiation because it seems more natural and less threatening, less aggressive."* Younger participants associated the word "waves" with positive, desirable, unthreatening and realistic associations, such as summer, ocean waves, flowing motion, sun and beach. Older respondents, on the contrary, rather located the term in the technical area and associated it with microwaves, radio waves, ship radio waves and different wavelengths in the medical area.

The term "fields" tended to evoke rather negative associations among respondents. The term was understood to mean a limited area where radiation occurs in high or "concentrated" intensity, for example in body scanners at the airport or when shopping in shops with electronically secured goods. The respondents also mentioned radiation from mobile communication as an example of fields and contrasted it with radiation in oncology, which is perceived as more targeted: *"With cancer radiation, the word fields doesn't fit so well because the radiation is more punctual."* In the context of the discussion on the term "fields", some participants mentioned the need to define limits in radiation-intensive fields, as the intensity is perceived as potentially threatening.

The term "contamination" clearly had a negative connotation among the respondents and was spontaneously equated with "damage". Many respondents were familiar with the term from the context of nutrition (e.g. pollution of food). In the context of radiation and in connection with the concept of fields, the following causality arises: In fields, there is a concentrated form of radiation that can exceed a limit value and thus contaminate the body and the environment, causing damage to health.

The term "exposure", on the other hand, seemed rather neutral to the respondents because they could not interpret and classify it. Only some respondents understood exposure as "being exposed to radiation".

The term "optical radiation" – also perceived rather neutrally – was not known by the majority, but was spontaneously interpreted as optically perceptible radiation and associated with various applications and types of radiation, for example laser pointers, light beams emitted by TV towers, eye lasers and laser applications for other medical and cosmetic purposes. Some people perceived optical radiation as less threatening: *"Because you can see it, it seems less threatening."*

The term "electromagnetic fields" – perceived rather neutrally due to its scientific impression – had been heard by the majority of respondents before, but the meaning was unclear. Therefore, this term triggered particularly diverse associations:

"Isn't that used in MRI? Isn't that less harmful than CT?" "I'm thinking of magnetic field therapies for back pain." "The Transrapid planned for Munich should have been a magnetic train that is super fast." "Induction cookers work with electromagnetic fields."
"Don't we have something like that around the earth?" "It reminds me of physics: magnets that attract each other." "In cosmetics, I think some devices for removing hair also work with electromagnetic fields." "Electromagnetic fields are especially strong at the poles." "Electromagnetic fields are everywhere where there are power lines."

The terms "ionising" and "non-ionising radiation" were completely unknown to the participants in the group discussions: *"I don't know anything about that." "Sounds very scientific." "Is one harmful and the other isn't?"* The participants found it difficult to classify, assess and associate these terms. After some consideration, the majority assigned the term, which sounded very scientific to them, to the field of chemistry or physics. *"Aren't ions neutral? Protons are positive. Wasn't that the case?"*

3.3.4.5 Misconceptions

In addition to the misconceptions already mentioned, the qualitative survey brought to light other misconceptions in the context of radiation. On the one hand, asbestos radiation was mentioned: *"We had asbestos ceilings in the stable and I never put my horse there, because you know: asbestos radiates".* On the other hand, some respondents from rural areas suspected that wind turbines also emitted radiation. There were isolated reports of micro-radiation in the oceans, which is mainly caused by plastic waste. In addition, radiation from greenhouses was suspected: *"Many fruits and vegetables cannot grow naturally in winter. They have to be irradiated somehow in the greenhouse and are certainly not as healthy as naturally ripened food."*

It is striking that the misconceptions described above are linked to negative (media) discourses on topics such as contamination of buildings with asbestos, wind power as an irritant in some rural regions, plastics in the world's oceans or highly modernised agriculture, which in the view of some represents an intervention in natural processes. If we also consider that the term radiation, depending on the context, can have negative connotations and sometimes even be associated with fear, the above-mentioned misconceptions can be explained. From an analytical perspective, the concept of radiation, which has negative connotations depending on the context, is mixed and linked with received negative discourses. The result is a diffuse, negative and fearful misconception in the field of radiation.

3.3.5 In depth discussion: perception of risk in the context of radiation

In the following, the risk perception when it comes to radiation is discussed in more detail based on a twofold contextualisation:

Firstly, in the sense of the external comparison method outlined above, a comparative classification of radiation risks to general life risks was made. Overall, it can be seen that the risks posed by different types of radiation are not only considered to be lower than general life risks, but also less present overall: *"There are more important things in life than dealing with the risks of radiation." "People tend to think less often about risks in the context of radiation in everyday life."*
In particular, illness, occupational risks and financial risks, as well as the Corona pandemic from the point of view of the younger people, are rated as significantly more risky. The influencing factors of concern,

knowledge, scope of the anticipated consequences, experience and the social environment are particularly effective as a basis for assessment.

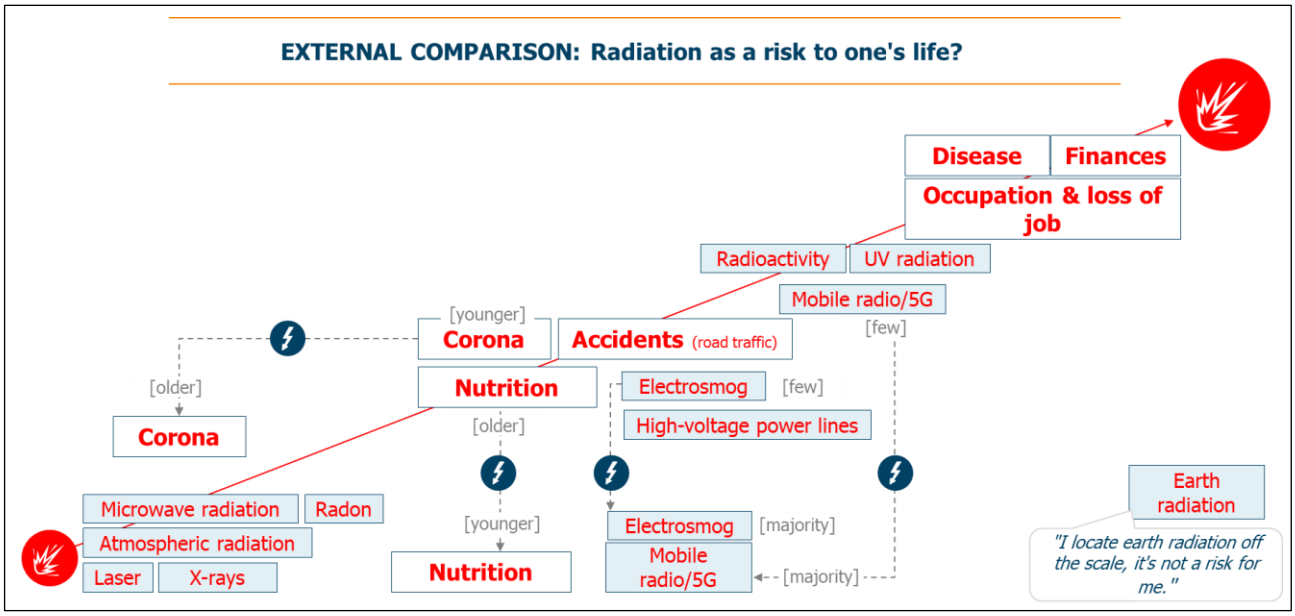

Figure 4 Radiation risks in external comparison

Secondly, in the sense of an internal comparison, the degree of concern and the degree of potential harm associated with the individual types of radiation were investigated. The qualitative exploration showed that the actual risk posed by different types of radiation differs in part from the individually perceived risks per type of radiation. For example, some types of radiation that can objectively cause great harm (such as radioactivity) are not necessarily perceived as a great risk subjectively.

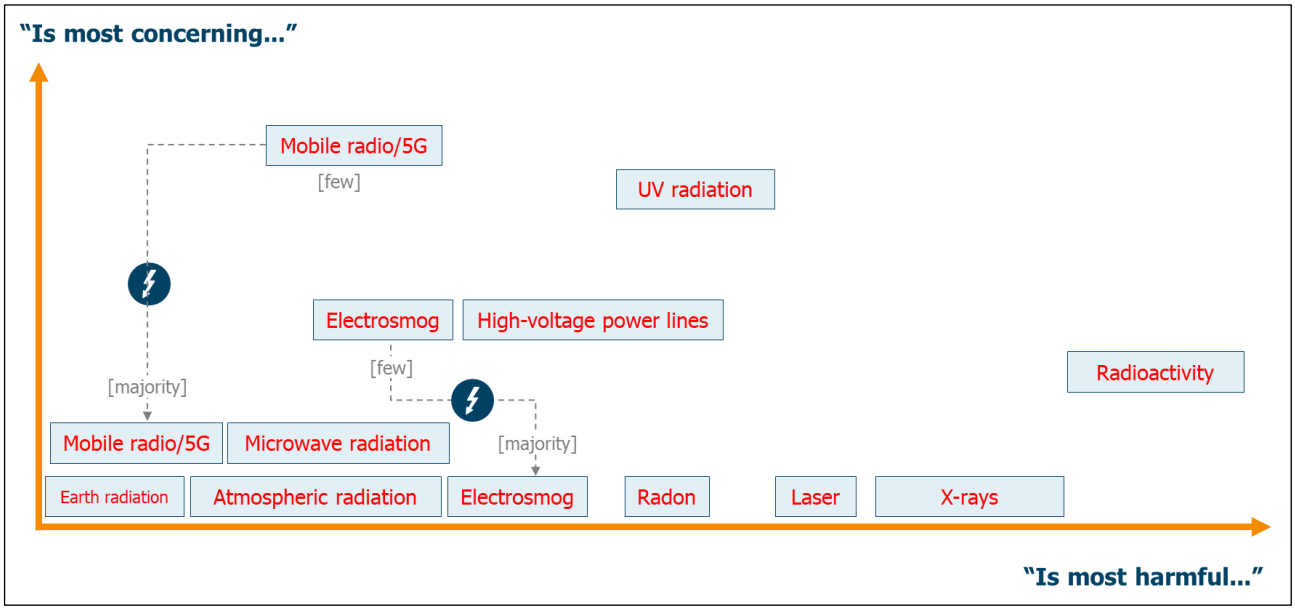

Figure 5 Radiation risks in internal comparison: level of concern and feared harm per type of radiation

UV radiation

With regard to UV radiation, the opinion of the respondents of the qualitative survey was clear: The actual risks are nowadays considered to be generally known and proven: In the long term, there is a risk of developing skin cancer; in the short term, there is a risk of sunburn and / or sunstroke. Furthermore, some respondents also emphasised the medium-term risk of accelerated skin ageing. The risk of eye damage from UV radiation was only mentioned by few. Participants emphasised that the awareness of the dangers of UV radiation had developed over time: *"In the past, people didn't know that so much and just went out in the sun."* The perception of the actual risks in the context of UV radiation is also reinforced by the perception that UV radiation exposure has increased over time, e.g. due to global warming and due to the enlarged ozone hole.

However, the extent to which these actual risks associated with UV radiation are also perceived as risks individually is less uniform. Various factors are mixed in the perception: On the one hand, the feeling of self-efficacy reduces the risk perception – after all, a variety of protective measures in the context of UV radiation are known and easy to implement. On the other hand, skin cancer as a long-term effect that only occurs much later as well as the general perception that skin cancer rates are rising are worrying – both being aspects that tend to promote risk perception. Thus, risk perception in the context of UV radiation is highly individual and differs depending on whether one is affected: People who have already experienced skin cancer (themselves or in their environment) or who often experience sunburn have a higher risk perception than people who are not affected. Similarly, middle-aged women with first signs of skin ageing are more sensitised to the risk of accelerated skin ageing due to UV radiation than unaffected persons. Finally, the individual way of dealing with long-term risks also influences risk perception in the context of UV radiation: young men, in particular, were less concerned because they rather tend to ignore possible long-term risks than women and older men.

X-rays

X-rays are perceived as a dangerous type of radiation that can cause harm. *"We know that X-rays are very aggressive."* *"That's why all the protective measures are taken."* However, it was less clear to the respondents what exactly the risk is – damage to tissues and organs as well as cancer were suspected. Nevertheless, X-ray worries the respondents little or not at all – the majority thinks that X-ray is connected with a very low radiation risk: *"X-rays don't really worry me. If X-rays are necessary, you do it and you are glad that this possibility exists."* Respondents draw a positive cost-benefit conclusion for this type of radiation, as exposure to X-rays is limited in time and associated with diagnostic benefit. The majority of the respondents think that this risk is controllable, as exposure takes place very rarely and is ordered by a doctor and carried out by medical professionals, taking precautions and protective measures into account. However, there are isolated concerns about radiation exposure from older equipment: "*I wouldn't go to any GP practice and have an X-ray with old equipment."* Some also worry about X-rays that may not be medically necessary: *"At the dental practice, you sometimes get the feeling that they are only taking an X-ray because they want to write off their equipment."* Overall, there is a presumption that exposure to X-rays has decreased over time. The participants gave two reasons for this. On the one hand, they assumed that due to technical progress, new X-ray machines emit less radiation. Secondly, some older respondents have the impression that X-rays were taken more frequently in the past: *"I remember times when childrens' feet were X-rayed in every shoe shop every time they bought shoes."*

Radioactivity

Despite the objective dangers associated with radioactivity (see chapter "Perception and knowledge"), many respondents think that radioactivity is of rather low risk to themselves. A number of factors contribute to this

perception. On the one hand, the respondents are of the opinion that they are not normally exposed to radioactivity: *"You don't normally have contact with it."* They also consider the probability of reactor accidents to be low: *"So far there have been 'only' two reactor accidents."* Trust in the state and in strict established safety measures convey a feeling of risk controllability. In addition, in the medical area, some arrive at a positive cost-benefit balance, believing that the benefits of radiation in the context of cancer therapy outweigh the potential disadvantages. Occasionally, the impression arises that there is less risk from radioactivity, since this type of radiation has been known for a long time: *"It's been around for so long that I don't really see any risks in it."*

On the contrary, a few see a certain personal risk in radioactivity. For example, the experience of Chernobyl, the geographical proximity to nuclear power plants or the risk posed to nuclear power plants by natural disasters that cannot be influenced can contribute to this. Some also took an international perspective, citing concerns about neighbouring European countries turning to nuclear power for energy and fears of nuclear war: *"I'm concerned that it's an instrument of power used as a weapon in politics.*" Subjectively, radiation exposure tends to decrease over time, according to the majority of respondents. The reason given for this is Germany's nuclear phase-out. A minority concludes, however, that radiation exposure from nuclear power tends to increase due to the fact that neighbouring countries are building new nuclear power plants.

Microwave radiation

Microwave radiation was rated as a low risk by most of the participants: This radiation does not worry most of them. One reason for this assessment is that microwave ovens are a well-established everyday item that has been ingrained in respondents' routines for years. There is also the perception that technical progress over the years has led to the devices becoming better and safer, and that testing bodies additionally guarantee the safety of microwave devices. In addition, there is the assumption that it's a myth that microwave radiation is dangerous: "*It's total nonsense that you get radiated by the microwave, but a lot of people really that."* Especially technically informed people are doing educational work in this regard: *"I'm always telling friends about it, too."* However, some respondents also have a certain perception of risk. Due to diffuse knowledge, they worry about possible harmful effects on health and count microwave ovens as a potential source of electrosmog. *"There is little you can do about electrosmog, except reducing the devices to the essentials."* Perceived radiation exposure over time tends to be seen as unchanged or reduced.

Radiation from mobile communication

The risk perception of radiation from mobile communication varies greatly from person to person. The majority sees no or only a low risk in radiation from mobile communication. They draw a positive cost-benefit balance, since for them the current benefits are opposed to the unproven disadvantages or dangers. In addition, radiation exposure is perceived as negligible, as the following quotation shows: "*A mobile phone has a transmission power of 0.5 watts, not much, you would have to be on the phone for a very long time for something in your body to heat up. Transmission masts have a higher power."* People who disagree are sometimes ridiculed: *"When an acquaintance told me that she gets headaches from mobile phone radiation, I didn't take it seriously at all."* Furthermore, a high level of trust in predefined limits and state protection as well as a certain feeling of controllability, e.g. by switching on flight mode or using a headset for phone calls, contribute to a low risk perception. In part, however, the low risk assessment also comes from long-term risks simply being ignored*: "Not knowing (of possible health consequences) is probably a blessing here."*

Few respondents have a higher risk perception and are concerned about radiation from mobile communication. Despite the undisputed benefits of mobile communication, they worry about unclear long-term consequences and show a certain basic scepticism towards new technologies in general. *"This*

technology is still so new. Some things will certainly only become clear in retrospect." They also lack confidence in governmental precautions and would like more information: *"I'm worried that people aren't being informed about this at all, while at the same time more transmission masts are being erected everywhere."* These participants have a feeling of lack of control or self-efficacy: *"Radiation from mobile communication is omnipresent. Even if I turn off my WiFi, I am still exposed to other people's radiation."* Some respondents also reported of perceived consequences of mobile phone radiation, such as sleeping problems and headaches during longer phone calls.

All respondents suspected a (strong) increase in radiation from mobile communication due to growing numbers of mobile devices, the advanced network expansion in general and the 5G network in particular (which requires more transmission towers), as well as due to the generally increased networking, for example due to public WiFis.

Electrosmog

Similar to the ambivalent general perception of electrosmog, the risk assessment also shows a split perception: The majority of the participants rate the risk of so-called electrosmog as non-existent or low, or do not even bring up the topic. Those who have heard of discussions about electrosmog and have no or a low risk perception focus on the benefits of technical devices and reject possible concerns as being unfounded: *"I find the discussions about electrosmog quite esoteric. I don't turn off my Alexa or the WiFi!"* Overall, the majority of respondents conclude that there is no such thing as electrosmog or that electrosmog is harmless because the devices that are supposed to be responsible for electrosmog are established everyday objects that are harmless to health due to technical progress and technical testing bodies.

However, some participants also have a higher risk perception. On the one hand, these respondents cite the omnipresence of radiation and the lack of possibilities for control and retreat: *"I have no influence on my neighbour's WiFi use."* On the other hand, few respondents reported that they are affected by electrosmog themselves: *"At night I hear the sockets buzzing, it seems threatening."*
The majority of respondents draw the conclusion that the perceived radiation exposure has rather increased in recent years due to the higher number of technical devices in everyday life, although some also noted that the radiation exposure of individual devices has probably decreased.

High-voltage power lines

High-voltage power lines are only perceived as a higher risk by the respondents if they are in the immediate vicinity. For many, an uneasy feeling arises in such a case: "*I don't walk under electricity pylons."* Others do not want to live near high-voltage power lines. The risk perception arises in some cases due to safety concerns when it comes to the stability of high-voltage lines, possible (long-term) health consequences and a rapidly advancing expansion. The perceived expansion is also the reason why there was talk of increased exposure to high-voltage power lines over time.

Laser radiation

Despite the objective risk of accidents and injuries, laser radiation is perceived as less of a danger by the respondents. In particular, the use of lasers at work is considered to be less dangerous, since there are usually strong control and protection possibilities: *"We always wear glasses at work to protect our eyes from lasers."* In addition, the fact that the interviewees are not exposed to laser radiation regularly or even permanently contributes to the fact that its risk is hardly classified as a danger.

Perception of risk with other types of radiation

Infrared is a type of radiation that is not perceived as dangerous. On the contrary, infrared in certain quantities is attributed a positive, healing effect by the respondents. "Earth radiation" is also not perceived as a risk: *"I don't even have to include that in the risk scale, because it doesn't pose a risk to me."* Perceived radiation exposure over time is considered to be constant: *"It has always been there, hasn't changed."* The respondents don't perceive atmospheric radiation as a risk to themselves because exposure during air travel rarely occurs. However, against the background of the increase in air travel, the subjectively perceived radiation exposure has grown over time.

The largely unknown radon tended to be classified as a lower risk by those who had heard of radon, as they did not think they were affected by radon: In their opinion, radon only occurs locally in a very limited way and is only a risk in basement flats. *"More in the lower area. We live in an area where it is not so extreme that it would be a concern. That's why I'm less affected by it."* In addition, the exact radon contamination is easy to measure and it is possible to take protective measures, e.g. by insulating houses.

3.3.6 Protective measures in the context of radiation: attitudes, logics and knowledge

The extent to which a need for protection is perceived depends on a number of factors that are assessed differently depending on the type of radiation. These factors, which are derived from the explanatory factors for risk perception, are: personal concern/experience, cost-benefit considerations, knowledge of radiation types per se, knowledge and availability of protective measures, as well as effort in feasibility and scope of the anticipated consequences. The qualitative survey revealed large differences in some cases, which is why the attitudes to the topic of protection are explained for each type of radiation separately.

The following rough classification can be made in advance: Types of radiation for which the need for protection is perceived to be high include radioactivity, X-rays, laser radiation and high-voltage power lines. In contrast, types of radiation for which the need for protection is perceived to be (very) low include microwave, infrared, earth, atmospheric and satellite radiation. In addition, there are types of radiation for which the perceived need for protection is polarised or varies depending on the context. These are UV radiation and radiation from mobile communication.

Radiation types with a high perceived need for protection

In the context of radioactivity, the need for protection is perceived to be very high. The risks and potential harm of radioactivity are undisputed and very high, so that any contact with this type of radiation must be avoided at all costs. Many protective measures are known in this context: They primarily concern protective measures that are not taken individually but at the state level, such as the strict security standards for nuclear power plants as well as political diplomacy to prevent (nuclear) wars. In this context, the respondents expressed high confidence that protective and control measures are consistently implemented in German nuclear power plants. Protective measures that can be taken at the individual level include refraining from consuming food from contaminated regions and participating in anti-nuclear demonstrations – both measures taken by few people in the qualitative sample. However, there is a great lack of clarity regarding the safe final storage of nuclear waste. Protective measures are not known in this respect, which leads to the concern of many *"This is an issue that urgently needs to be solved."* Finally, it was also expressed in isolated cases that some things defy all protective measures: *"You cannot protect yourself 100% against natural disasters (e.g. earthquakes, tsunamis)."*

In the context of X-rays, the need for protection is also perceived as very high. The risks and potential harm of this type of radiation are considered to be proven and all respondents named the same set of protective

measures that are considered common knowledge: reduction of exposure to a minimum, and in case of exposure: exclusion of an existing pregnancy, wearing of lead vests and local limitation of radiation. These protective measures are automatically taken by the medical staff. Additional, individual protective measures are only taken by a few. For example, interviewees occasionally reported that they had refused x-rays suggested by a doctor in order to avoid exposure: *"I then also sometimes told the doctor that I did not consent to the x-ray."* Deliberate choice of doctor's office was also mentioned occasionally:
"I only have X-rays taken in radiology specialist practices or in hospitals – the equipment there is more modern and has less radiation."

In the case of laser radiation, there is also a clear need for protection. The focus of the respondents was primarily on eye protection. The following known protective measures were named: Do not direct the laser beam into the eyes, do not look directly into the laser beam, wear protective goggles when coming into contact with laser radiation in an occupational context. All protective measures were perceived by the respondents as intuitive and easy to implement.

In the context of high-voltage power lines, the need for protection is perceived to be rather high, but the possibilities for protection are perceived to be limited: "*You need the electricity."* Only the reduction of exposure is seen as a protection option: Keeping distance with the logic 'the more distance, the less exposure' as well as keeping the duration of exposure low: *"You should not stay directly under an electricity pylon for a long time."* In isolated cases, respondents mentioned that they watched out for high-voltage power lines when building a house: *"I wouldn't build my house under one of those things."*

Radiation types with mixed perceived need for protection

With UV radiation, the need for protection is perceived differently. It depends on various factors. A high need for protection is felt especially in the case of deliberate exposure (e.g. sunbathing in the garden, at the lake, in the open-air swimming pool, at the beach). In this case, the assumption of prolonged exposure reinforces the need for protection. A high need for protection is also seen during certain times of the year (spring and summer) and during holiday trips to southern and tropical countries because the UV radiation is perceived as more intense and thus more harmful. In some cases, the need for protection is also considered to be particularly high for outdoor sports*: "Sweating makes you burn more easily"* and on the water or during water sports: *"Water reflects the radiation."* The need for protection against UV radiation is perceived as low in the case of unconscious exposure, during everyday activities (shopping, city strolls) and in autumn and winter.

Various protective measures are known to protect the skin from UV radiation. They range from reducing exposure – some of the female interviewees knew the skin type-specific values for the self-protection time of the skin – to regular application of sunscreen with a high sun protection factor and avoiding the midday sun, to wearing light-coloured, long-sleeved clothing and a hat. To protect the eyes from UV radiation, wearing sunglasses and avoiding looking directly into the sun were mentioned sporadically.

The qualitative survey showed that the majority of the respondents take protective measures in the context of UV radiation, but to varying degrees and with varying consequences. The following logics could be identified: First, the factor of being affected leads to protective measures being taken: People having experienced skin cancer (themselves or in their environment) take protective measures more consistently than people without this reference or previous experience. The same applies to people frequently experiencing sunburn. Apart from the factor of being affected, individual cost-benefit analyses can lead to taking or not taking protective measures. For example, before taking sun protection measures, people evaluate how great the risk of sunburn might be: *"My friend has a white skin, she uses sunscreen all the time, but I don't because I rarely get sunburned and putting sunscreen on is annoying for me."* Similarly, the long-term risk of skin cancer is weighed: *"I spent so much time in the sun as a kid and teenager, I've gotten enough sun already and I pay more attention now."* Middle-aged women in particular also include the risk of

premature skin ageing into their cost-benefit considerations when thinking about taking sun protection measures. Finally, the correct assessment of a situation also leads to protective measures being taken. Some respondents reported misjudgements that led to not taking protective measures, e.g. in spring when the strength of the radiation was underestimated *"I thought the sun wasn't that strong yet"* or in situations where the duration of exposure was misjudged in advance: *"I don't put sunscreen on my daughter for a short visit to the playground. This is of course stupid when the visit turns out to be longer. "*

In the context of radiation from mobile communication, the perceived need for protection is polarising. The majority of respondents in the qualitative sample felt a rather low need for protection in this context. This is especially the case for people who associate a high benefit with mobile communication and who also have a high basic trust in governmental protective measures (e.g. in the form of fixed limits). Some respondents, however, also expressed a latently perceived need for protection: This applies to people who have an "uneasy gut feeling" about radiation related to mobile communication but suppress their concerns – not least because of the unclear facts and the high benefits they associate with mobile communication. Few expressed a clear need for protection from mobile communication radiation: This is the case for people who feel affected and people who have a strong focus on possible long-term consequences.

Concrete protective measures are known to a limited extent in the context of radiation from mobile communication. The following protective measures were mentioned in some cases: putting the mobile phone on flight mode at night, not taking the mobile phone into the bedroom, using the mobile phone less often to make phone calls, using a headset or loudspeaker for phone calls, not keeping the mobile phone close to the body (especially not in the breast pocket and men not in their trousers) and keeping a distance to mobile phone masts. Overall, the interviews and group discussions gave the impression that there is significant lack of knowledge about existing protection options and that not everyone is aware of simple measures such as going to flight mode. In addition, there is another important aspect: In the context of radiation from mobile communication, the perception seems to be widespread that it isn't possible at all to protect oneself: *"How am I supposed to protect myself against omnipresent radiation from mobile communication?" "There are mobile phone masts everywhere in the city – you can't avoid them."*

Thus, protective measures in the context of radiation from mobile communication are only consistently taken by a few. The following logics could be identified: Protective measures are taken by people who are personally affected *"I feel I sleep better when the mobile phone is not in the bedroom"* as well as by people who generally have a high health awareness and pronounced prevention behaviour. Furthermore, protective measures are partly also taken by other persons if the effort and the sacrifice are not too high: *"I already turn off the WiFi at night, so I don't need it and it's done quickly."* Against the background of uncertainty as to what harm radiation from mobile communication actually does, the factor of low effort plays a role that should not be underestimated. On the other hand, the following factors lead to the fact that protective measures are not taken: convenience, the feeling of not being able or not wanting to do without the mobile phone, and lack of knowledge of protection options (e.g. flight mode): "*I also use my mobile phone as an alarm clock, so it has to remain switched on at night.*" A decisive barrier when it comes to taking protective measures is simply the lack of perceived need for protection or the suppression of possible negative effects: *"Everyone has a mobile phone and uses it all the time, so it can't be harmful."* Finally, the lack of clarity about the actual radiation exposure in connection with mobile communication is also a factor that promotes the omission of protective measures. For example, it was unclear to the respondents how radiation from mobile communication can be measured at all, which makes it even less 'tangible' than other types of radiation for which measurement possibilities are more familiar (e.g. Geiger counters for ionising radiation).

In connection with radon, a certain need for protection is felt by those who knew radon. However, this need for protection is only seen in areas with high radon occurrence. The first measure known was the measurability of radon in houses and the fact that measures can be taken to insulate houses if necessary. In this case, a main barrier for not taking protective measures is the lack of knowledge about this type of radiation.

"I did not know about radon at all before. In the run-up to this study, I heard about it for the first time. I found it a bit alarming. I have since done some research and my apartment building is so new that it is well insulated, but my office is in an older building – I would like my employer to take a measurement. It seems easy and straightforward to do that."

Radiation types with a rather low perceived need for protection

The need for protection from microwave radiation is perceived as rather low, limited to the moments when the appliance is in use. The respondents named a generally known set of protective measures when the microwave is running: do not look into it, do not stand directly in front of it and cover the food. Few also mentioned the possibility of leaving the room and additionally closing the kitchen door. Uncertainty was noted by a few who expressed questions about the correct safety distance: "*I don't know how close you're allowed to get."* These protective measures are taken intuitively by the majority, as they are easy to implement, do not require any additional effort and are already internalised as measures: *"You just don't look directly into it." A* few people also mentioned that they had decided against a microwave– after a cost-benefit analysis: *"This radiation can easily be avoided by not using a microwave." "My wife and I prefer to cook fresh meals anyway and we have the time."*

For infrared radiation, limiting exposure is perceived as the only necessary protective measure.

In the case of "earth radiation", no need for protection is seen, since this type of radiation is not perceived as a risk. Protective measures are therefore not known.

In the context of atmospheric radiation, a need for protection is only perceived for flight personnel, as they experience increased exposure that may be of concern. For people who fly less frequently, however, no need for protection is perceived. The only possibility to protect oneself that is perceived is avoidance of exposure: *"If you want to fly, you can't avoid radiation – so you can only avoid flying or minimise it."* For flight personnel, some respondents mentioned so-called radiation accounts, in which maximum limits are set and thus exposure is controlled. For the normal population, infrequent exposure is already protection enough, and only a few respondents mentioned cost-benefit considerations in this context: *"Every now and then, you want to take a long-distance trip, and then you accept the radiation."*

3.3.7 Information behaviour in the context of radiation

In the qualitative survey it became clear that the information behaviour regarding radiation is mostly passive. Radiation topic that is not so present that the respondents feel the need to constantly gather information on it. As a rule, there is no interest in or need for information, especially about types of radiation that are neither particularly risky nor particularly relevant to one's everyday life. Occasionally, however, interest in information can be aroused by external stimuli – namely when a radiation topic has direct relevance for the everyday life of the persons. The following qualitative findings emerge for the most frequently discussed types of radiation:

The greatest need for information exists probably with regard to radiation from mobile communication in general and 5G in particular. The unclear facts repeatedly mentioned by all respondents in this context lead to great uncertainty among some participants with regard to a possible risk potential. They would therefore like to have a clear statement on the extent to which radiation from mobile communication is harmless to health or exactly what dangers are associated with it. The high need for information of some respondents can be explained on the one hand by the high everyday relevance: "*The mobile phone is always present."* On the other hand, the desire for information can be explained by the fact that 5G is a new technology and therefore possible negative long-term consequences cannot be conclusively clarified at the present time – at least from

the point of view of some respondents. In addition, some participants reported that 5G involves "more intensive" – in the sense of more dangerous –radiation than previous standards. Irrespective of the participants' desire for more information, it is also objectively necessary to provide clarification in order to counteract the spread of rumours and to gain sovereignty of interpretation in the discourse. Many participants currently mostly gather information on radiation from mobile communication in everyday conversations, e.g. with colleagues, friends and acquaintances, or from news broadcasts. An active search for information on the topic of radiation from mobile communication is rather rare, although some have taken the introduction of the new mobile phone standard 5G as an opportunity to get informed.

When it comes to UV radiation, the information behaviour is mostly passive. Occasionally, the respondents actively deal with the topic due to impulses such as themselves or a family member being affected by skin cancer. The high level of awareness regarding UV radiation was often built up continuously over time through educational campaigns by official bodies, doctors or dermatologists and mainstream media or through conversations with the family and peer groups. Typically, sensitisation to the topic of UV radiation takes place in the context of socialisation: *"Parents always tell you to put on sunscreen. [...] After having heard about this from everyone, you are confident that it must be true."* Overall, the participants hardly have an acute need for information in the context of UV radiation. In view of existing misconceptions, however, there is an objective need for education in order to correct ideas such as the belief that pre-tanned skin does not need sun protection or that sun protection is not necessary in Germany because UV radiation is not so intense at our latitudes. However, the difficulty of an educational campaign lies in raising further awareness on a topic on which the majority already feels well informed.

Many of the respondents had encountered the topic of radioactivity in one form or another in their (daily) media consumption in the past: *"The anniversary of Chernobyl was an occasion. I watched a series. The series was called "Chernobyl". It was a small TV series with 3 or 4 episodes. Afterwards, you inevitably do some research. What can cause this radiation? Is it really true how it is portrayed? Is it enough to keep your distance?"* As in this example, passive consumption can also trigger an active search for information, but this was reported less frequently than passive information intake. The participants had hardly any further need for information on the topic of radioactivity – except for the unresolved question of the final storage of nuclear waste. The low need for information can also be explained by the fact that the health risks posed by radioactivity are known and undisputed.

With regard to X-rays, the information behaviour is very passive. Most of the interviewees are informed by doctors in advance of medical examinations, and there is no further involvement with the topic because most of them have no further need for information.

Role of the Federal Office for Radiation Protection

Looking at the reported information behaviour of the respondents, it becomes clear that the Federal Office for Radiation Protection currently plays a very subordinate role as a source of information. In this context, it should also be mentioned that those who visited the BfS website to look for information were positive about the information offered. The main reason for the low status of the BfS as an information platform lies in the fact that the population is largely unfamiliar with the BfS: very few had heard of the BfS before taking part in the study. Despite the relative unfamiliarity, the population has a basic trust in the BfS: A clear majority of respondents associate the name Federal Office for Radiation Protection with attributes such as objectivity, scientific character, impartiality and an educational mandate with regard to radiation protection risks. Consequently, when being prompted, the interviewees generally perveive the BfS as a trustworthy and relevant source in the context of radiation protection.

3.3.8 Notes on communication in the context of radiation and radiation protection

How can citizens be reached?

As the information behaviour of the respondents is usually passive, information on the topic of radiation should be placed in such a way that citizens come across it by chance in their everyday media consumption or in their everyday lives. Based on the results of the qualitative survey, a broad mix of offline and online communication channels is recommended, as the media usage of the respondents varies. The following information sources are relevant based on the media usage of the respondents: YouTube, Instagram, TikTok, Facebook, public television channels, news programmes on radio and television, popular information formats such as Galileo, Stern TV or talk shows, daily newspapers, general internet searches, Wikipedia, flyers at public authorities and offices, advertising posters at highly frequented locations as well as streaming services such as Netflix and Amazon Prime.

The sources of information mentioned can be roughly classified according to the age of the respondents. For example, information channels such as YouTube, Instagram, TikTok and streaming services are of particular interest to respondents aged 18-35, with TikTok appealing specifically to the youngest respondents who have just reached the age of majority. Facebook as an information platform is most popular with respondents aged 45-55. Traditional media such as television and print media are particularly relevant for the over 50s.

What should be communicated in terms of content?

If respondents have a need for information, it generally concerns the question of the extent to which a type of radiation poses a concrete danger in their everyday lives. Or formulated differently: The respondents are concerned with the personal relevance of a type of radiation for their lives. The content of the communication should also be geared to this in order to establish connectivity with the citizens. In addition to informing people about the potential danger of a type of radiation in everyday life, it also makes sense to communicate preventive measures in the case of a factual danger, in order not only to raise awareness but also to empower people. Background information on a type of radiation that goes beyond hazard potential and protective measures, such as the exact mode of action or the origin of a type of radiation, is rather secondary for the majority of respondents. Nevertheless, a small group wanted this kind of information. In order to meet the different information needs of citizens for one source of information, a multi-level information offer may be appropriate. Such an offer could look as follows: On the first level, information is provided on the hazard potential of a type of radiation and – if required according to the current state of science – on possible protective measures. Via a hyperlink, background information on the type of radiation and, if applicable, scientific studies can be viewed at a further level.

How should communication take place?

Across all age groups and educational levels, the need for easily understandable, and scientifically sound communication was expressed. The terms "transparent" and "honest" communication by a "neutral" sender who acts independently of business and politics were mentioned very often in this context. Honest communication also includes the occasionally desired open communication in case of lack of knowledge regarding the hazard potential of types of radiation. *"They should honestly say if they do not (yet) know something exactly."* The majority wanted a clear position on whether a type of radiation is dangerous or harmless. This wish becomes understandable when one considers that ambiguous assessments of the potential danger present individuals with a problem of action: What does this information mean for me? Should I take protective measures or not? If so, which ones? However, the scientific state of research is partly characterised by uncertainties and competing opinions and thus does not always allow for an unambiguous position on the hazard potential, as the majority would like – which in turn poses a problem for radiation

protection communication. One way of at least partially solving both the communication problem and the problem of action for citizens is not to take a clear position with regard to the hazard potential, but to make at least a recommendation of possible protective measures with reference to the current state of science.

4 WP 2: Quantitative survey

4.1 Research design

4.1.1 Research questions for the quantitative survey in WP 2 (according to the terms of reference)

The survey "What does Germany think about radiation?" is planned as a recurring survey in order to determine changes in attitudes and the development of knowledge levels as well as the need for information. Against this background, about half of the questionnaire includes questions whose results are updated over time.
The following research questions and aspects were the focus of the quantitative survey 2022 according to the terms of reference:

- Knowledge and perception, myths and fears in the population with regard to radiation in general and related to individual radiation protection topics
- Relevance of the topic of radiation protection in the context of health protection, radiation protection behaviour and behavioural intention
- Change in awareness, attitude, behaviour over time
- Importance of the work of the BfS in the eyes of the public: awareness, credibility, trust, expectations of the BfS, expectations when it comes to (the comprehensibility of) information materials or measures.

The following radiation topics are the subject of the recurring surveys:

- Radioactivity in the environment: radon, building materials, cosmic radiation;
- Optical radiation: UV radiation, application of optical radiation in wellness and medicine;
- Awareness of ionising radiation;
- Radiological emergencies, radiological emergency protection.

Further, questions on improving communication, on the mindset (life satisfaction, social network), on respondents' view of Germany in the event of a nuclear accident as well as on contact points in the context of information search have been surveyed as new thematic focal points. In order to investigate the influence of everyday exposure to different types of radiation in connection with concerns and protective measures, the perceived intensity was determined. On the basis of the results, the aim is to derive indications for target-group and topic-specific communication and to gain insights into where radiation protection measures should be improved.

4.1.2 Method: telephone survey (CATI) representative of the population

In order to survey a cross-section representative of the German-speaking resident population aged 16 and older, telephone interviews were conducted on the basis of a dual frame sample (combined landline and mobile phone sample). An overview of the study design is described below.

Table 1 Study overview quantitative survey

Elements quantitative survey	Key data
Survey method	CATI survey (Computer Aided Telephone Interviews)
Survey period	Pretest 30 telephone interviews in the period 24.03.2022-28.03.2022 Main survey 2000 telephone interviews in the period 06.04.2022-05.05.2022
Number of interviews	n=2000 persons aged 16 and older
Average interview length	27 minutes
Population	German-speaking resident population aged 16 and older
Selection frame	ADM Dual Frame Mastersample
Fieldwork	Implementation: GIM DiCom
Data preparation	Final plausibility check, representativeness check, weighting
Evaluation	Tabulation, descriptive and statistical analyses

4.1.3 Dual-frame sampling

As a member of the telephone sampling working group of the ADM (Arbeitskreis Deutscher Markt- und Sozialforschungsinstitute e.V.), GIM uses the ADM sampling system for telephone surveys to conduct population-representative studies. The sampling frame is based on the number ranges provided for use by the Federal Network Agency on an annual basis. In principle, these number ranges include all telephone numbers that can be used in the Federal Republic of Germany – including mobile phone numbers. Since the proportion of households that do not have their telephone number published is steadily increasing, the ADM telephone sample includes both registered numbers and numbers generated according to the Gabler-Häder method. For differentiations in sampling, the resident population or private households were subdivided according to the following criteria (regional classification) and integrated in the GIM Sample Management System (SMS): federal states, administrative districts, independent cities, counties, municipalities (with 2000 and more inhabitants), total of municipalities up to 1999 inhabitants per county, differentiated according to BIK municipality size classes.

Since the proportion of people who can only be reached via mobile phone ("Mobile Onlys") or primarily use it ("Mostly Mobile") is continuously increasing, a representative sample can no longer be achieved today on the basis of a landline sample alone. The combination of the sample selection frames contributes decisively to the proportional representation of the population. In order to take into account the increase in mobile phone use, a dual-frame distribution of 60 / 40 (landline / mobile) was taken into account for the study.

In the dual-frame design, the different selection methods of the target person in the household must be taken into account: While in the fixed-network sample a target person in the household is selected by the last-birthday method, in the mobile phone sample the person who answers the call on the mobile phone is considered the target person. In order to compensate for inequalities in selection chances and design-related skewness, the data were subjected to a weighting in which both subsamples were included in a design and a structural weighting. As reference data, the weighting was based on the distribution of the current microcensus. The following variables were included in the weighting for the German-speaking resident population aged 16 and older: age, gender, West Germany, East Germany, education, household size, political location size, federal state.

4.1.4 Fieldwork

The interviews were conducted by GIM's wholly owned subsidiary, GIM DiCom in Wiesbaden. The following quality standards were used:

- Computer-assisted telephone interviews with automated sample management system (SMS)
- Intelligent control concept for the distribution of calls and processing of the contact scheme per telephone number over different times of day and days of the week for the best possible utilisation of the sample
- Use of permanently employed, experienced, native-speaking interviewers. Continuous support by permanently present supervisors
- Project-specific training.

4.1.5 Survey instrument

In accordance with the terms of reference, the main questions from 2019 were continued in the questionnaire on the one hand and new questions on the above-mentioned topics were included on the other hand. The new contents were derived from the results of the qualitative survey and mainly concerned questions on general attitudes in life, exposure perception in everyday life with regard to different types of radiation, as well as questions on informedness and self-efficacy. Further questions were developed on the basis of the current requirements of the BfS. Among other things, they concerned the view of protective measures and contact points for obtaining information in Germany in the event of a nuclear accident.

The survey instrument consisted of the following thematic blocks:

- First contact with the household or the target person
- Target selection based on the last-birthday method
- Interest in topics related to health and consumer protection
- Informedness about technology
- Willingness to take risks
- Life satisfaction
- Social network measurement
- Association with radiation
- Awareness of state institutions
- Sense of information and protection
- Knowledge on the subject of radiation and sources of radiation

- Health risks of modern societies including radiation
- Exposure in everyday life in relation to different types of radiation
- Perception of protection, self-efficacy and need for information regarding different types of radiation
- Measures for one's own protection against types of radiation as well as concrete precautions against UV radiation
- Nuclear accident: assumptions and first points of contact for information
- Health awareness and informed choice
- Concrete sense of protection and potential for improvement in communication on the subject of protective measures / precautions
- Radiation sources in the living environment
- Dealing with radiation
- Socio-demographics and place of residence

4.1.6 Note on the presentation of results

This final report presents the results of the year 2022. With the aim of highlighting the development of the level of knowledge, attitudes and protective measures with regard to the topic of radiation in general as well as individual types of radiation, the results of the previous waves are also presented where the same questions were available in previous waves. The report shows weighted results. If the sum of the values shown in the graphs differs from 100%, this is explained by the categories "Don't know" or "No answer", which sometimes are not shown separately.

4.2 General attitudes in life

Against the background of the task to derive indications for target group and topic-specific communication and to gain insights into where communication on radiation protection measures should be improved, also with a view to the different needs of the addressees, basic characteristics of attitude were surveyed that allow a more differentiated description of individual groups than would be possible with a purely socio-demographic view.

In the following, the attitude questions and the distribution of the different basic attitudes in the population are described. In the further course of the report, these are examined in terms of their explanatory power and their influence on attitudes and fears with regard to different types of radiation, but also with regard to other health risks of modern societies. Likewise, the possibility of a connection to the perception of one's own informedness, the trust in governmental protective measures as well as the attitude towards preventive measures will be analysed.

Overall, more than three quarters of the population are interested in the topics of consumer protection and health in 2022 (25% very interested / 53% somewhat interested). Compared to 2019, the overall interest is thus at a comparable level (80% in 2019). However, the proportions for "very interested" have shifted from 35% to 25% and for "somewhat interested" from 45% to 53%. It can be assumed that the social crises between the survey waves (COVID-19 pandemic and the war in Ukraine) had an influence on the assessment of the relevance of the topics.

The socio-demographic differentiation shows that, as in 2019, interest increases with age, and women (83%) express interest more frequently than men (72%). A higher level of life satisfaction also seems to go hand in hand with a more pronounced interest in these topics. Thus, at 78%, more than three-quarters of

respondents who feel a high to medium life satisfaction say they are interested in the topics of consumer protection and health – among people who are rather dissatisfied with their lives, the proportion is significantly lower at 67%.

Technology is playing a more and more important role in all areas of life and has led to a further increase in the level of digitalisation during the Corona pandemic[1]. According to a recent study by the Fraunhofer Institute, the German digitalisation index has reached 70.2 points in 2021, which is higher than in 2019 (68.3 points). A comparable increase has also been determined in other studies (including the D21-DIGITAL-INDEX 2021 / 2022). What does this mean for the topic of radiation? First of all, it can be noted that the self-assessment of the informedness about "technical things" is at the same level as in 2019, at 51% (Top2 box). As expected, with 64%, the proportion among men continues to be at a significantly higher level (compared to 38% for women Top2 box), as well as among young adults aged 16-29 (40-64 years around 48% | 65 years and older around 46%). An increasing proportion of people interested in technology can also be seen among people who deal a lot with the topic of radiation (2019: 74% | 2022: 79%), even if the overall proportion of those who have already dealt (a lot / somewhat) with the topic of radiation is slightly declining (2019: 47% | 2022: 42%). So, the increasing digitalisation has apparently not led to a more intensive engagement with the topic of radiation.

The assessment of risks and the way they are dealt with is shaped by the personal willingness to take risks. When asked about their willingness to take risks in everyday life, in 2022, around 34% said that they were (rather) willing to take risks (Top3 box, 7pt. scale), compared to 39% in 2019. Whether this indicates a trend towards decreasing willingness to take risks can only be assessed on the basis of further measurements. Socio-demographically, it can be seen that men (41% Top3 box) and young adults aged 16-29 (43% Top3 box) are significantly more willing to take risks than women (27% Top3 box) and older people (30-64 years around 30% Top3 box). Likewise, the proportion of respondents who are (rather) willing to take risks is significantly higher among those who feel very well informed about technical things (around 50% Top3 box) and among people with high life satisfaction (37% Top3 box) than in the respective comparison groups.

Overall, 52% of respondents say that they are (very) satisfied with their lives (Top2 box, 7pt. scale), and even 76% (Top3 box) are very satisfied to rather satisfied. Women (80% Top3 box) and young adults aged 16-29 (82% Top3 box) are more satisfied than men and older people. The proportion of satisfied people also increases with the level of formal education (primary school / lower secondary school 74%; Abitur 84%).

[1] German Digitalisation Index 2021; 31.05.2022.

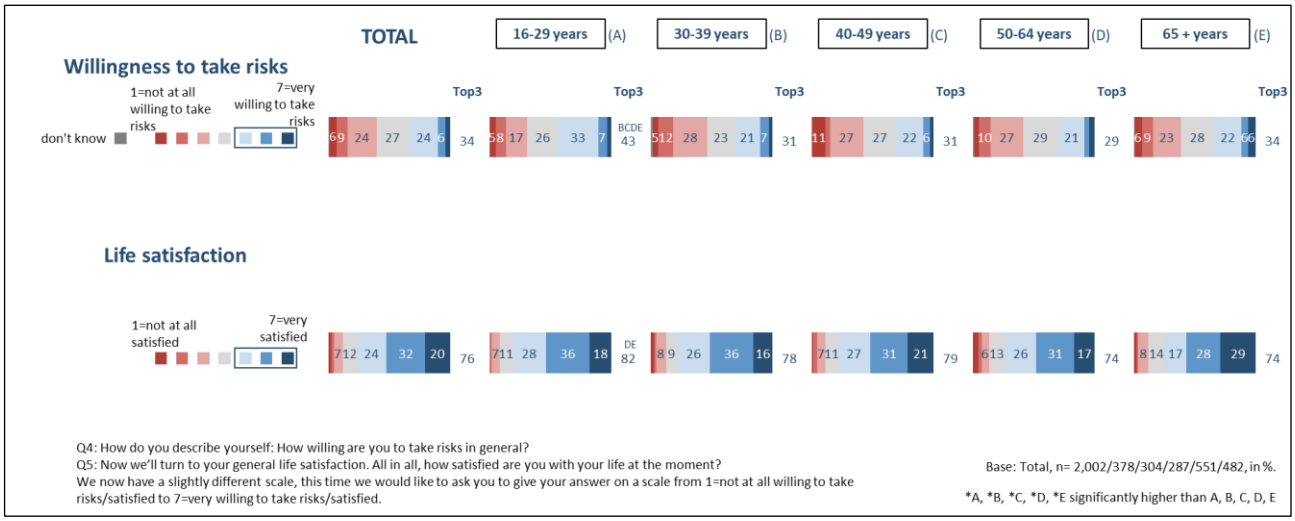

Figure 6 Willingness to take risks & life satisfaction by age

Interpersonal trust is also a general attitude in life that helps to compensate for uncertainties in situations that are perceived as new or complex. Various studies have shown that trust is associated with higher life satisfaction and an optimistic attitude in life, increases with the level of education and declines with increasing age.[2]

Interpersonal trust was determined in the current study using the Interpersonal Trust Short Scale (Kurzskala Interpersonales Vertrauen, KUSIV3). The findings described are also largely reflected in the present study. On average, important topics were discussed with 5.5 people in the last 6 months. People with low life satisfaction name an average of 3.7 people, respondents with high life satisfaction name 5.8 people. People with a formally low level of education name an average of 4.5 people and respondents with a high level of education name 6.2 people. It can also be seen that people who have dealt a lot with the topic of radiation talk to a larger circle of confidants than people who have never dealt with the topic (7.1 people compared to 3.9 people). This is also the case for people who feel very well informed about technical matters (7.3 persons compared to 4.3 persons for people who are "hardly informed") as well as people who are very interested in the topics of consumer protection and health (5.7 persons) compared to those who are (rather) not (4.5 persons) and among people who feel (very) well informed (6.0 vs. 5.2) and/or protected (5.7 vs. 4.8) by state institutions of radiation protection. The circle in which important topics are discussed is thus significantly larger among persons who have already dealt with radiation or who feel well protected and informed.

In the course of the report, the influence of life attitudes on the areas of informedness, concern and prevention in connection with different types of radiation will be discussed in more detail, and the confidence in the protection provided by measures of public institutions will be considered.

[2] Constanze Beierlein, Christoph J. Kemper, Anastassiya Kovaleva & Beatrice Rammstedt: Kurzskala zur Messung des zwischenmenschlichen Vertrauens. Die Kurzskala Interpersonales Vertrauen (KUSIV3); 31.05.2022.

4.3 Radiation: perception, knowledge and level of information

4.3.1 Associations with radiation

When spontaneously asked about associations with radiation, most people mention terms related to radioactivity / nuclear radiation / nuclear threat or nuclear weapons (52% of respondents, net count). An increase can be observed here compared to 2019 (33%). Socio-demographic differentiation shows that this field of association is currently mentioned more often by men than by women (59% of men | 45% of women) and also by people with formally higher level of education (Abitur 62% |Total 52%). Overall, the topic is spontaneously present to more than half of the 16-64 year-olds in 2022. A closer look shows that older persons aged 65 and over mainly think of atomic radiation (20% | 12% of persons aged 16-29), while younger persons aged 16-29 more often associate it with nuclear (power) plants (23.1% | 12.3% of persons aged 65 and over) and radioactivity / radioactive radiation / nuclear radiation (22% | 10% of persons aged 65 and over). The latter applies significantly more often to men (20%) than to women (10%). Nuclear accidents such as the ones in Fukushima and Chernobyl are cited by just under 7% in 2022, compared to 4% in 2019. Overall, all aspects that are spontaneously mentioned in relation to radioactivity are mentioned more frequently by people with a more pronounced interest in technology. An examination of the age groups shows that, with a good 8%, nuclear accidents are more familiar to the youngest (16-29 years) and oldest group of people (65 years and older) than to the other age groups. While older people remember Chernobyl (1986) as a drastic event, the current social discussion of the topics of environmental protection, sustainability and climate change can contribute to the presence of the topic for younger people. In the qualitative interviews, the current discussion about nuclear power as a "clean form of energy" and the reports on "35 years after Chernobyl" were referred to with regard to the presence of the topic of radioactivity as well as the topic of nuclear accidents. Another relevant aspect at the time of the quantitative interviews is the topic of nuclear threat due to the Ukraine conflict, which is reflected in around 7% of the mentions (nuclear threat, nuclear weapons, Putin, Ukraine conflict). In 2019, "nuclear bombs / war" were mentioned by only 1% of respondents.

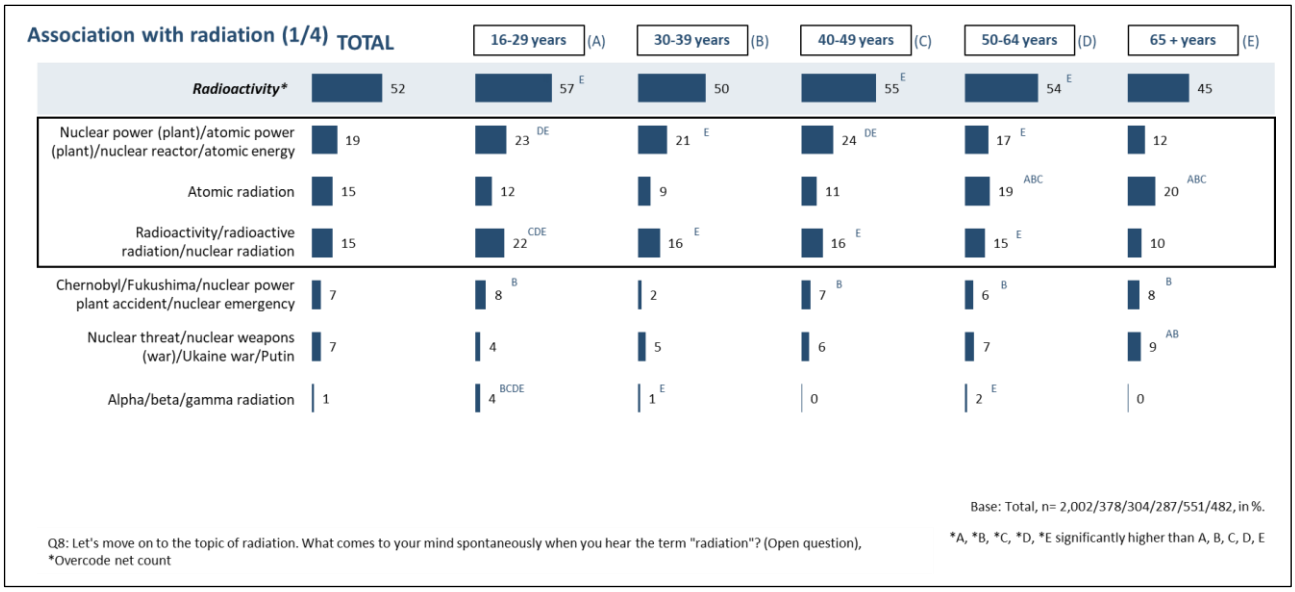

Figure 7 Associations with the topic of radiation: radioactivity

The topics "mobile communication" (33%, net count) and "sun / light" (32%, net count) are also very frequently associated with radiation. Radiation from smartphones / mobile phones / cell phones is more present among people up to 49 years of age than among older people – for example, this sub-category is mentioned by 33% of the youngest group aged 16-29 years, while only 16% mention it in the 65+ age group.

The topic including all individual aspects is also more present among women (38%) than among men (28%). Compared to 2019, there has been a significant increase in the number of mentions of the topic area: While in 2019, only 23% spontaneously named aspects related to "mobile communication", it's 33% of respondents in 2022. Mobile networks (4G / 5G) as an aspect of the net group "mobile communication" are mentioned by just under 8% in 2022. The proportion rises with increasing interest in technology, and so, mobile networks are spontaneously mentioned by around 12% of people who consider themselves to be well informed in the technical field. Radio masts are only spontaneously associated with radiation by around 4%, the proportion increasing with age (16-29 years 1% and 50+ years around 6%).

In an age comparison, the sun / solar radiation is mentioned most frequently by younger people (16-29 years) with 39% (people aged 65 and over: 27%). As expected, the share among people who are interested in health topics is also higher (35%) than among those who are (rather) not interested (27%). Based on the qualitative interviews, it can be assumed for the frequent mention in the youngest age group, that the concerns of parents and the introduction of prevention measures in the everyday life of families (sunscreen with a high protection factor, avoiding the sun around noon, etc.) have contributed to the presence of the topic.

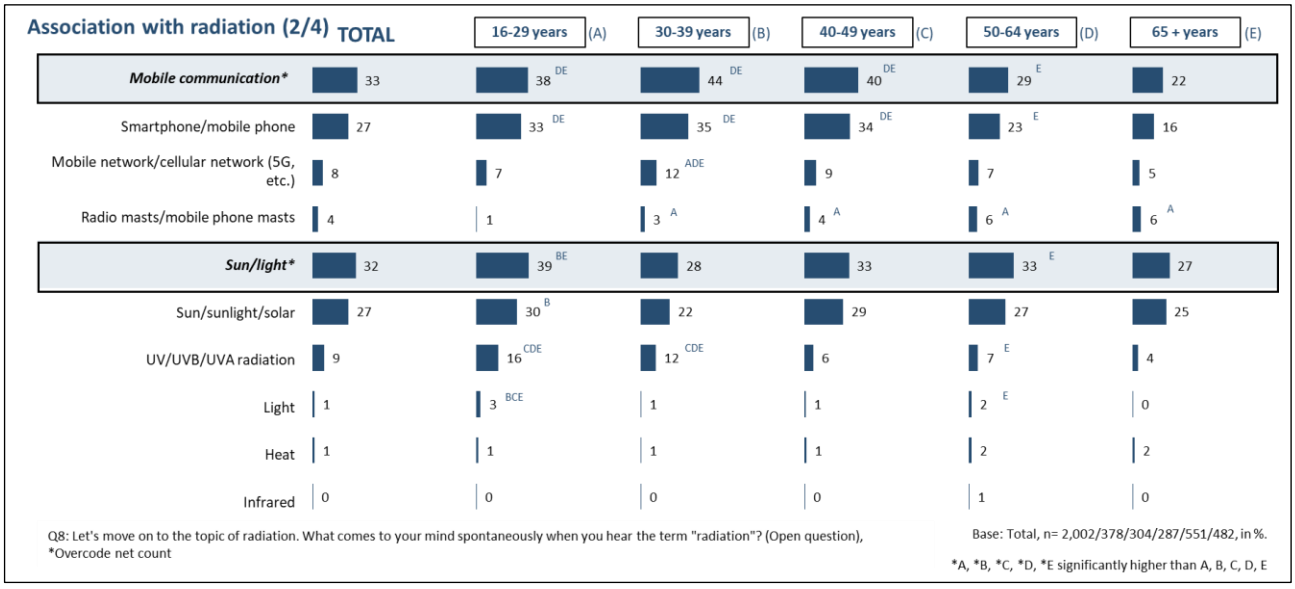

Figure 8 Associations with the topic of radiation: mobile communication & sun

In the ranking of the most frequently mentioned aspects, radiation in the medical area comes in fourth place with around 26% (net count); in 2019, this topic area was spontaneously mentioned by 15%. With 21%, X-ray radiation is named most often in this topic area and is mentioned significantly more often by people aged 50 and over than by younger people (aged 50 and over: 23% | 16-49: 18%). Radiation therapy / cancer treatment is mentioned by a total of 6%, with women (around 7%) mentioning it more often than men (5%).

Electrical radiation from appliances / WiFi comes to the mind of 21% of respondents when they hear the topic of radiation (net count). Overall, large electrical appliances such as TVs and PCs are the most frequently mentioned sources of radiation (11%), followed by microwave radiation (6%). Electrosmog and WiFi / internet are mentioned by 4% and 3% of respondents in 2019 and 2022.

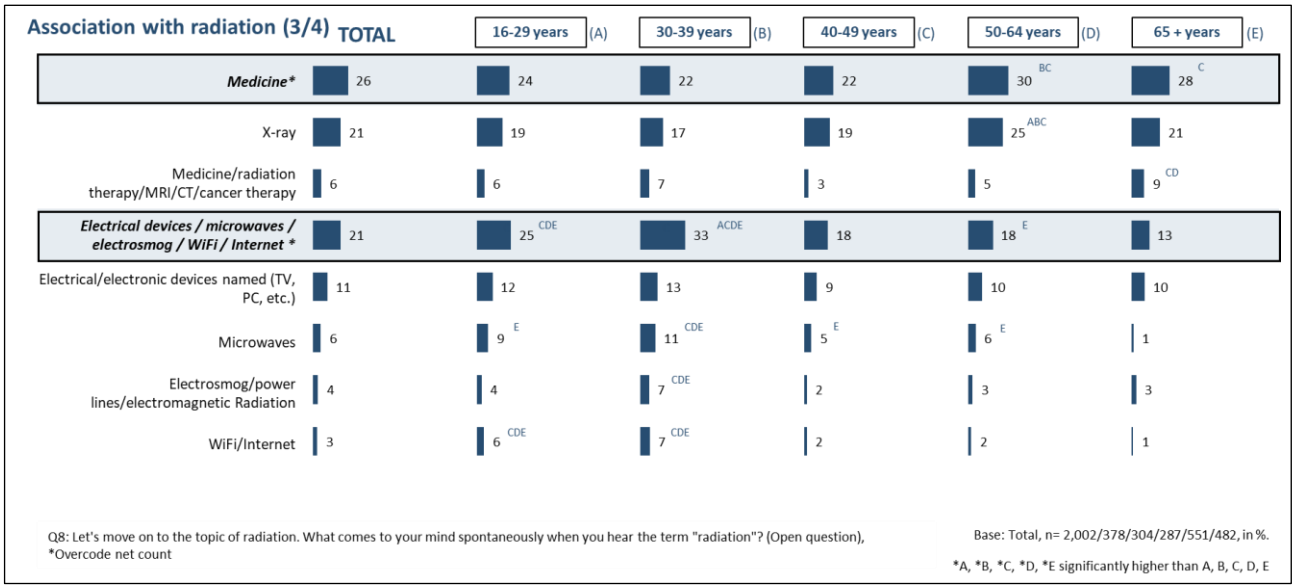

Figure 9 Associations with the topic of radiation: medicine, WiFi / electrical radiation

Around 11% of respondents spontaneously think of concerns about radiation in particular in 2022, compared to 7% in 2019 (negative feeling / unease / dangerous to health / dangerous). Natural radiation such as "environmental radiation", "cosmic radiation" or "high altitude radiation" is named by around 7% of respondents in 2022, in 2019 this proportion was significantly higher (around 15%).

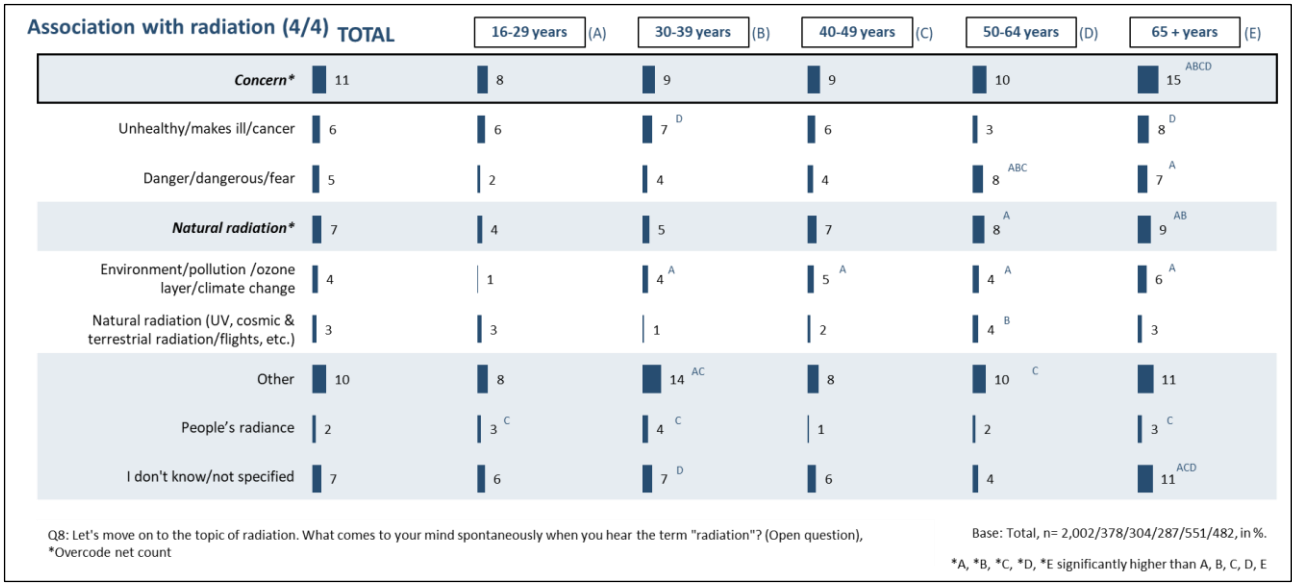

Figure 10 Associations with the topic of radiation: concern, natural radiation

Overall, the wave comparison clearly shows that there has been a shift in the spontaneous association with radiation aspects. The clearest increase is recorded for the topic area "radioactivity / nuclear power / nuclear radiation / nuclear weapons", which is certainly to be seen against the background of the current conflicts. This is followed by the topics "mobile communication" and "radiation in the medical area", which show clear increases. The increased presence of the topic of mobile communication is to be seen in the context of the broad debate on the expansion of digitalisation and 5G– which is also suggested by the qualitative interviews. In addition, the mentions also show the logic of the people, which is strongly based on their living environment and names types of radiation the way they are discussed in their environment. More scientific terms such as alpha, beta or gamma radiation hardly occur (1%), high-frequency or low-frequency radiation is

not used as a term at all. This aspect seems to be relevant especially for communication in order to reach people with the topic of radiation.

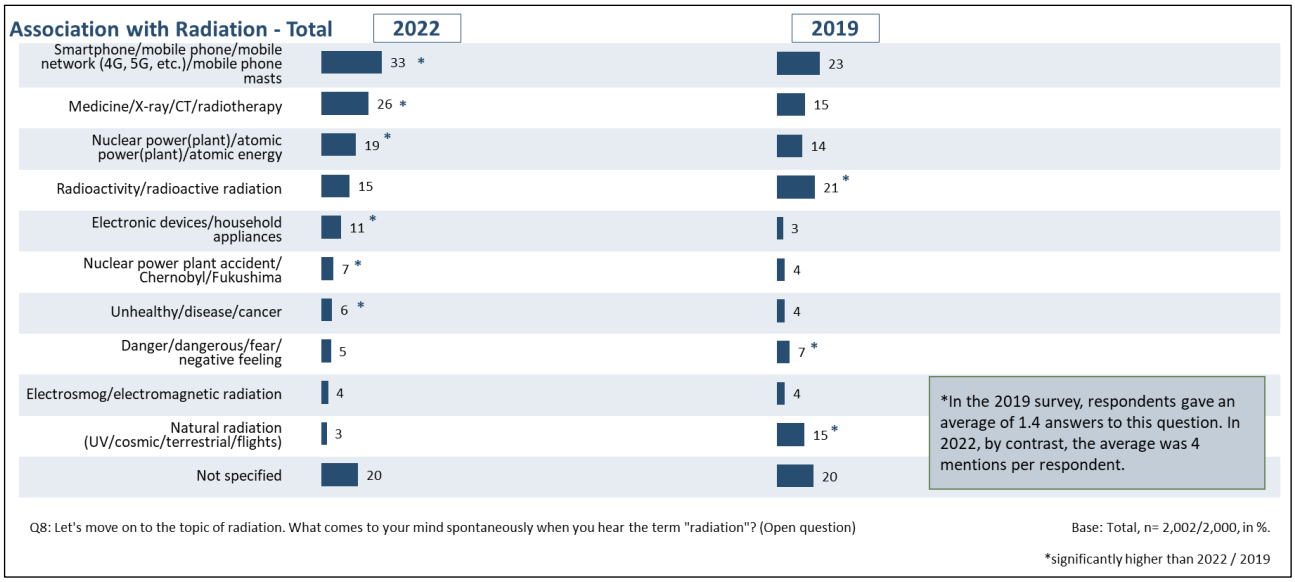

Figure 11 Associations with radiation: wave comparison

4.3.2 State institutions: awareness, sense of information and protection

After prompting the respective names, the majority of respondents are familiar with government institutions in the field of radiation protection. 83% of the respondents know the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, 71% know the Federal Office for Radiation Protection and 68% know the International Atomic Energy Agency. The Commission on Radiological Protection (47%) is significantly less well-known. The awareness of all institutions increases with age. Younger people are more likely to have visited the website of the institutions in question than older people: for example, around 4% of 16-29 year-olds and 5% of 30-39 year-olds have already visited the website of the Federal Office for Radiation Protection – compared to only 1% in the group of people aged 65 and over.

As expected, the (aided) awareness of all institutions grows with the increase of dealing with the topic of radiation. 92% of the persons who have dealt with the topic a lot know the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and 90% know the Federal Office for Radiation Protection. Among those who have not yet dealt with the topic, 64% and 54% know the two institutions at least by name. Likewise, the level of awareness is significantly higher among persons with a greater interest in technology and / or in the topics of health and consumer protection. This also refers to knowledge of the institutions' responsibilities, especially among those who are "very interested / very informed". In addition, 10% of respondents who are "very well-informed about technology" have already visited the website of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (total average: 6%) and 6% the website of the BfS (total average: 3%).

It is interesting that, compared to the national average, the awareness of the institutions is not higher for people who live within 20 kilometres of a nuclear power plant or have a high-voltage power pylon within one kilometre of their home. This is somewhat different for people who live in a radon precautionary area, where 97% know the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, 56% also know its responsibilities. And there is another difference with regard to the Federal Office for Radiation Protection. Although the Federal Office for Radiation Protection is not better known

among persons living in an area with increased radon exposure compared to the national average, the detailed knowledge of 26% stating "I also know the responsibilities" is significantly higher (total average: 14%).

Overall, awareness of the individual state institutions has remained stable over time, but respondents are more and more frequently dealing with the responsibilities of the institutions. For example, 14% are now familiar with the responsibilities of the BfS (2019: 12%), 23% with those of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2019: 17%), 7% with those of the German Commission on Radiological Protection (2019: 6%) and 16% with those of the International Atomic Energy Agency (IAEA) (2019: 14%).

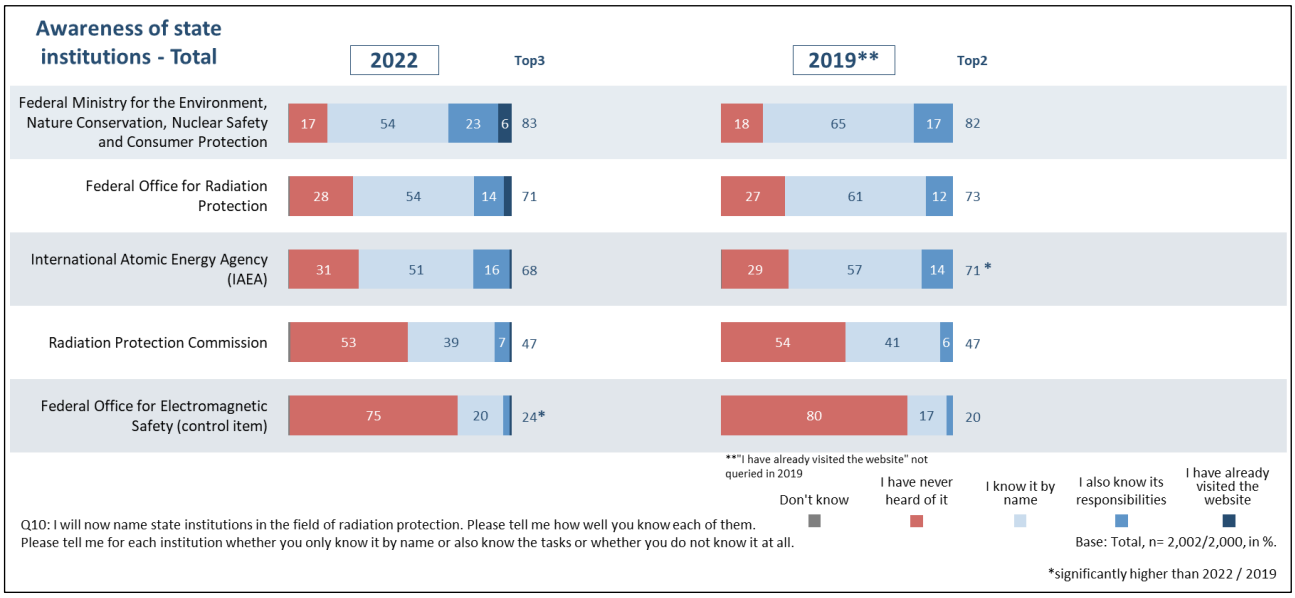

Figure 12 Awareness of state institutions: wave comparison

What about the respondents' feeling of being informed and protected? Overall, 31% of respondents feel "well" or "very well" informed by state institutions of radiation protection in 2022, i.e. around 7 percentage points more than in 2019 (23% Top2 box, 4pt. scale). The feeling of being "well" or "very well" informed by state institutions of radiation protection increases slightly with age (total 31% | persons aged 65 and over 38%). Similarly, men feel (rather) well informed compared women (Top2 box 34% | 27%). The proportion of persons who feel "poorly" or "very poorly" informed is 64% overall; for persons living in a radon precautionary area, with 81%, the share is high.

The personal feeling of protection has also increased overall compared to 2019: Whereas 38% of respondents stated then that they felt "well" or "very well" protected by the state institutions of radiation protection, the value in 2022 is 51% (4pt. scale). The survey reveals that young people up to 29 years of age in particular have a higher level of trust in the institutions and feel well protected (Top2 box 65% among up to 29 year-olds | 50% total), just as for men, the value is higher than for women (Top2 box 55% | 46%).

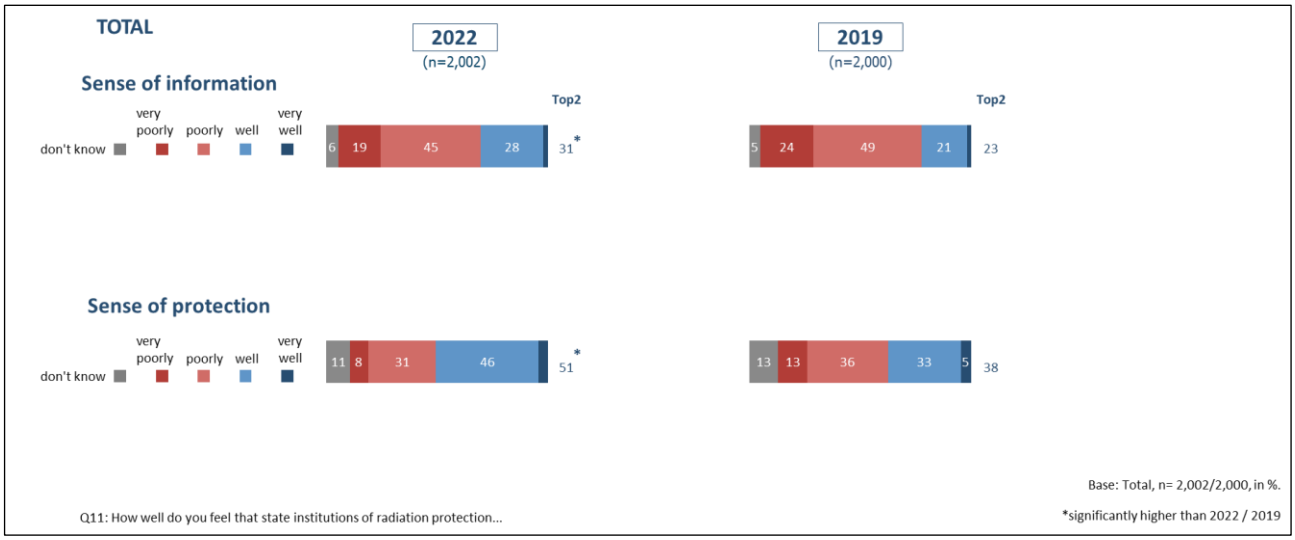

Figure 13 Sense of information and protection by state institutions: wave comparison

In addition to socio-demographic variables, factors such as life satisfaction, willingness to take risks or the feeling of being well informed about technical matters also have an influence on the perception of the sense of protection and of being informed by state institutions. For example, 64% (Top2 box) of those who state that they would (rather) be willing to take risks feel (very) well protected, which is significantly higher than the average (51% Top2 box). And, with 37%, they are also more likely to feel (very) well informed (average: 31% Top2 box). Compared to people who are rather dissatisfied with their lives, those who are satisfied are significantly more likely to feel (very) well informed (35% Top2 box | 21% among the dissatisfied) and (very) well protected (55% Top2 box | 42% among the dissatisfied). The approval ratings of people who feel (very) well informed about technical matters are also comparable.

It is interesting – also with a view to future communication on the topic of radiation – that the perception of being protected by state institutions is at a significantly higher level than the perception of being informed. This shows a "leap of faith", as it was also explicitly formulated regarding the Federal Office for Radiation Protection during the qualitative interviews. It stands for objectivity, scientificity, impartiality and has a mandate to protect and educate with regard to radiation protection risks, causing a subjective sense of protection.

4.3.3 Nuclear accident: attitudes and contact points

The majority of respondents are not very worried about a nuclear accident (over 50% of respondents, Low2 box, 5pt. scale). Younger people in particular are relatively carefree. Among people aged 50 and over, however, the concern about a nuclear accident increases significantly. Women tend to be somewhat more worried about a nuclear accident than men.

In addition, it can be seen that the less pronounced the interest in health and consumer protection issues, the higher the proportion of people who are not concerned (65% Low2 box among people who are (rather) not interested in consumer protection / health issues | 38% among people who are very interested in consumer protection / health issues). The assumption that geographical proximity to a potential hazard also increases the proportion of concerned persons is supported when considering the persons living in the vicinity (20km) of a nuclear power plant. In this case, the proportion of concerned people is significantly higher, at 36% (Top2 box), compared to 27% for people who do not have a nuclear power plant near them.

Opinions are divided on the question of whether Germany is well prepared for a nuclear accident: 26% (rather) agree, 35% (rather) disagree and 35% are indifferent. Men are more likely to think that Germany would be well prepared for such an incident compared to women (31% | 20%). This is also the opinion of 33% of those who live near (20km) a nuclear power plant (compared to 25% who do not have a nuclear power plant near them) and citizens who feel (very) well informed (29% | 24%) and/or protected (31% | 18%) by state institutions of radiation protection.

More than half of the respondents would not know what to do in the event of a nuclear accident (57% Low2 box, 5pt. scale). A total of 21% of respondents said they would know (Top2 box, 5pt. scale), for men this figure is as high as 26% (compared to 16% for women). 38% of people who consider themselves to be very well informed about technical matters even state this, as do 31% of those who consider themselves to be willing to take risks (compared with 16% of those who are (rather) not willing to take risks). If a nuclear power plant is located in the vicinity of the home, the proportion of those who know what to do rises to 32%; if the person lives in a radon precautionary area, it is 42%. The proportion of those who know what to do in an emergency is also higher among people who feel (very) well informed (29% | 18%) and/or protected (25% | 19%) by state institutions of radiation protection.

The personal feeling of information and protection is also related to the extent to which one trusts that the state will immediately implement all important protective and information measures in the event of a nuclear accident. A total of 46% of respondents agreed with this statement (Top2 box, 5pt. scale). Middle-aged people (40-49 year-olds) are the most critical and only 34% agree with this statement. More than half of younger people, on the other hand, trust the functioning of state protection measures (16-29 years: 54% | 30-39 years: 51%). This also applies to people who are more willing to take risks (Top2 box 54%) as well as to people who feel (very) well informed overall (Top2 box 54%) and / or protected (Top2 box 57%), as well as to respondents with high life satisfaction (Top2 box 51%). People living near a nuclear power plant are also more likely to trust the implementation of government measures (53%).

The risk assessment of the consequences of a nuclear accident is also made clear by the assessment of the following statement: "I consider the consumption of food (e.g. fruit, vegetables, fish) from regions where there has been a nuclear accident to be very dangerous". 86% of respondents agree with this statement overall (Top2 box) and 71% give the highest approval rating, the proportion even rises to 81% among respondents aged 40-64 (Top box).

In summary, it can be said that there is some uncertainty about whether Germany would be well prepared in the event of a nuclear accident. 35% place themselves in the middle of the scale, thus signalling undecidedness, another 35% (rather) do not believe this. The fact that 57% would not know what to do in the event of an emergency and another 25% place themselves in the middle of the scale, i.e. have a rather vague idea of what they could do, can also give cause for reflection. Then again, almost half of the respondents trust the state measures, a “leap of faith” that should be strengthened further with targeted communication.

In this context, a look at the typical contact points is also important in terms of communication placement. When asked who or what would be the first point of contact in the event of a nuclear accident when seeking information on protective measures / radiation exposure / recommended behaviour, etc., most respondents mention the internet (66%), followed by television (20%) and radio (18%). 13% would call the municipality / local authority / a state authority, 8% would visit their websites. 13% would contact the Federal Office for Radiation Protection. When it comes to contact points, there are age-specific characteristics. For example, significantly more older persons aged 65 and over would seek information via television (26%), radio (24%) or the fire brigade (6%), and more than 80% of persons aged 49 and under in particular would seek information primarily on the internet (compared to 32% of older persons aged 65 and over). A total of 12% of respondents would seek information from friends / family / colleagues – especially young people up to 29 years (18%). Other contact points mentioned were the fire brigade (3%), the consumer advice centre / consumer

protection (1%) or daily and weekly newspapers (7%). In addition to the internet (68%), persons who have already dealt a lot with the topic of radiation would more often turn to the radio (26% | 10%) and television (26% | 13%) for information than persons who have not yet dealt with the topic. Around 25% of those involved and 21% of those well informed would contact the Federal Office for Radiation Protection. Those involved would call the municipality more often than those less involved (16%), and 15% would visit its website. 5% of those who had not yet dealt with the topic of radiation so far would call the fire brigade.

In addition to the internet, the classic information media, but also locally based institutions such as the municipality and the fire brigade appear to be suitable and trustworthy contact points for the consumer, which can be used as multipliers of information. A diversified communication in terms of communication channels seems promising and rounds off the recommendation of the qualitative study.

What is striking is the relatively high proportion of people (10%) who do not know whom they would contact.

4.3.4 Sources & types of radiation

In order to investigate the question of what the level of knowledge is with regard to different types of radiation, it was first asked (with prompting) which sources or objects emit radiation. Radiation that most respondents recognise as such are smartphones / mobile phones (89%), the sun (85%) and WiFi devices (80%). Wireless phones and (high voltage) power lines as sources of radiation are recognised by 77% and 73% of respondents respectively. Air travel and ground / underground are less frequently mentioned as sources of radiation (57% each). Railway and tram lines are classified as sources of radiation by 40% of the respondents. Significantly fewer people think that building materials or electric razors emit radiation (33% and 30% respectively), and 13% of respondents consider tap water to be a source of radiation.

Overall, it can be seen that people aged 65 and over are less likely than younger people to be aware of the radiation emitted by the most frequently mentioned sources of radiation (smartphone / mobile phone, sun, WiFi devices, wireless phones). In contrast, the youngest people (16-29 years) tend to be least aware of the fact that (high-voltage) power lines emit radiation (16-29 year-olds 57% | Total: 73%).

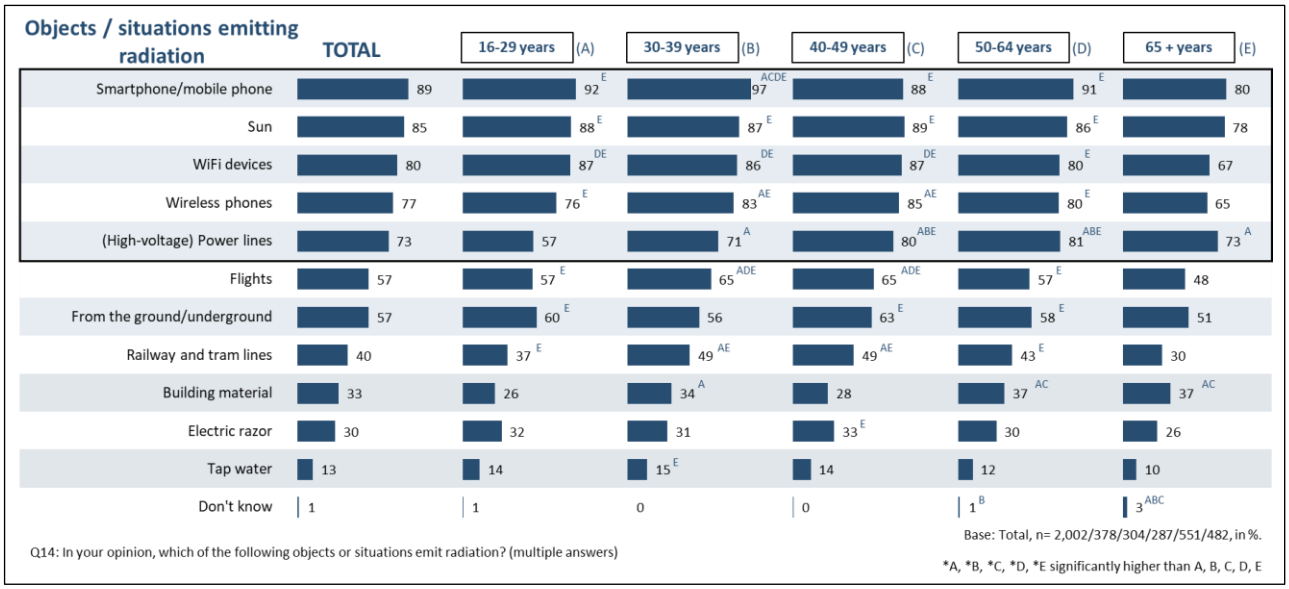

Figure 14 Sources of radiation: age split

As expected, respondents who have previously dealt "a lot" or "somewhat" with the topic of radiation recognize more sources of radiation among the objects or situations shown than people who have previously dealt less with the topic. Likewise, people who feel affected by radiation in their living environment (living within a radius of 20 kilometres from a nuclear power plant, near a high-voltage power line, in a radon precautionary area) are in most cases significantly more likely to attribute radiation to the objects mentioned than people from other residential areas do.

Compared to the study from 2019, the individual sources / objects are positioned equally in terms of the order of frequency in which radiation is attributed to them. However, the frequency level was mostly higher in 2019. More people were aware of the fact that radiation emanates from smartphones / mobile phones or the sun in 2019 than in 2022 (smartphone / mobile phone 2022: 89% | 2019: 95%; sun 2022: 85% | 2019: 95%).

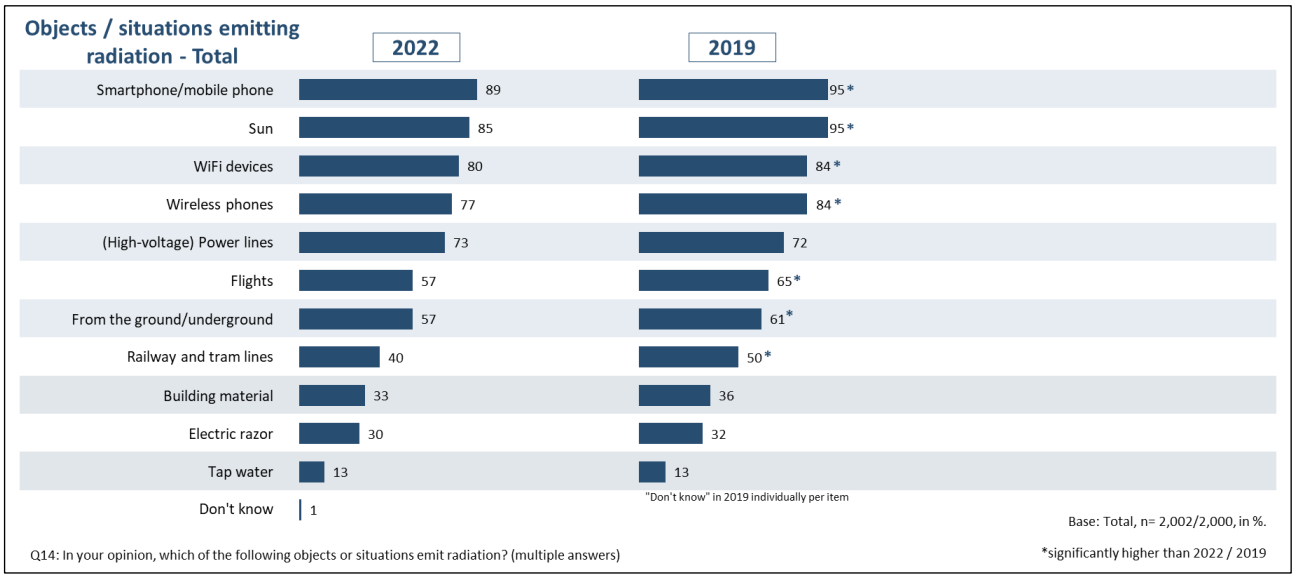

Figure 15 Sources of radiation: wave comparison

When asked specifically about the radiation types high-frequency radiation, low-frequency radiation, optical radiation, ionising radiation and "earth radiation", more than half of the respondents said indicate that they know the respective type of radiation "well" or at least "by name". Persons with a formally low level of education are less likely to know the different types of radiation than persons with a higher level of education. As expected, the awareness of the types of radiation increases with the degree of involvement with the topic and is highest among persons who have dealt a lot with the topic of radiation. The same applies to the increase in knowledge about technical topics; the awareness of the types of radiation also rises with increasing knowledge of technology. And this is also the case for people who feel well informed. People who are very interested in health topics or consumer protection are also significantly more often aware of high-frequency radiation (77% | 65% among "uninterested" respondents), optical radiation (57% | 47% among "uninterested" respondents) and "earth radiation" (81% | 63% among "uninterested" respondents). Compared to 2019, the awareness of the individual types of radiation is almost exactly at the same level.

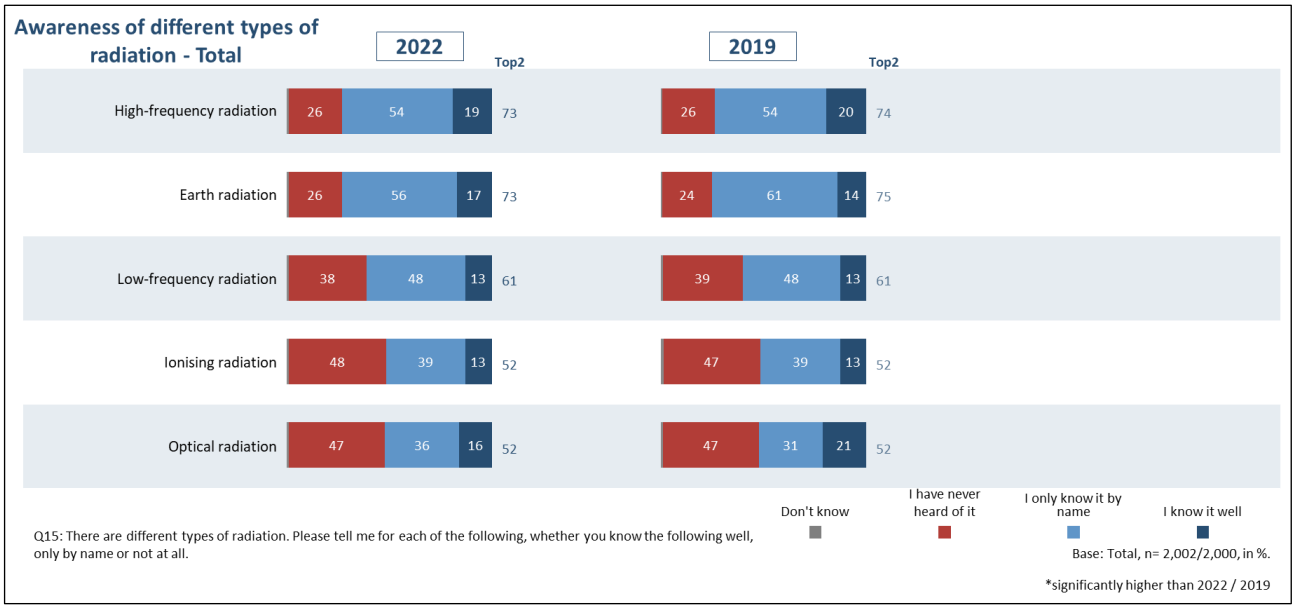

Figure 16 Awareness of different types of radiation: wave comparison

The ranking of awareness of types of radiation is led by high-frequency radiation – 73% say that they know this type of radiation "well" (19%) or "by name" (54%). There are no significant differences between the age groups, but there are differences in gender: men more often say that they know high-frequency radiation than women (76% | 70%). In addition, people who live near a high-voltage power line know high-frequency radiation "well" significantly more often than people who do not live near a high-voltage power line (25% | 18%).

Of the 73% who are aware of high-frequency radiation overall, 77% can also name specific examples. The most frequently mentioned examples are radio waves / 5G / satellites / radar (24% of mentions), followed by domestic devices – household (15% of mentions). Radiation in the medical field (13%), cell phone / telephone / mobile phone (10%), domestic devices – entertainment (10%), high-voltage power lines (10%), WiFi / router / Bluetooth (9%), radioactivity (9%) or natural radiation (9%) are named less frequently. Examples that are mentioned rather rarely are electricity / power lines, electrical appliances, transformer buildings, MRI, ultrasound.

"Earth radiation" is also very frequently known: 73% of the respondents state that they know this type of radiation "well" (17%) or "by name" (56%). People over 40 years of age know this type of radiation more often than younger people, and women more often than men. Of the 73% who know this type of radiation, only 63% can name specific examples. The examples named most frequently are radiation from the ground / soil (22%), radon / ore / granite (17%), radioactivity / radioactive elements (15%), the earth's magnetic field (11%), geothermal heat / core of the earth / volcanoes (10%). Examples that were mentioned less frequently include water veins (8%), natural radiation (7%), rock fractures / faults (7%), electromagnetic fields (3%), radiesthesia (1%).

Low-frequency radiation is known by 61% of the respondents ("well" 13% / "by name" 48%), the proportion of those who know it being higher among men than among women (67% | 55%). Three quarters of those who know it can also name concrete examples of low-frequency radiation. The top mentions include domestic devices – entertainment (26%), radio waves / 5G / satellites / radar (16%), electricity / power lines (12%), cell phone / telephone / mobile phone (10%). Less frequent mentions include thermal radiation / infrared / light (8%), domestic devices – household (8%), electrosmog (7%), infrasound / sonar / sound (6%), WiFi / router / Bluetooth (5%), high-voltage power lines (4%), electrical / technical devices (3%), natural radiation (3%), radiation in the medical field (2%), radioactivity (1%), transformer buildings (1%).

Ionising radiation and optical radiation are known "well" (13%) or "by name" (39%) by 52% of the respondents. Men are slightly more likely to know about ionising radiation than women, and people younger than 65 are slightly more likely to know about it than people over 65. Of those who know about ionising radiation, 72% can also name specific examples. Examples mentioned most frequently are radioactive radiation (32%), radiation in the medical area (21%), natural radiation (18%). Electricity (8%), electrical household appliances (6%), medical applications (MRI) (3%), water / water treatment (2%), batteries (1%) are mentioned less frequently. Of those who know about optical radiation, 84% can name specific examples: light / light bulb / LED / neon tube etc. are mentioned most frequently (45%), followed by UV radiation / sun / lightning (42%). Examples named less frequently include lasers (14%), screens (7%), infrared / red light (6%) and X-rays (2%).

If one compares the aided awareness of the above types of radiation and the examples mentioned with the associations with radiation that were formulated spontaneously, it becomes clear that the various types of radiation – high-frequency, low-frequency, optical, ionising radiation – are not mentioned in this form. The associated terms clearly rather originate from the life worlds of the interviewees (sun, UV in the beginning of summer, mobile communication, smartphones, high-voltage power pylons) and also reflect parts of current reporting (nuclear threat, nuclear power, etc.). This analysis is supported by the qualitative survey, which showed that citizens themselves do not think in these rather scientific terms and would not search for them if they needed information. With regard to communication on the topic of radiation, a language and a classification of the types of radiation that is oriented towards the areas of life of the citizens is therefore better suited to support the findability of information and its comprehensibility.

4.3.5 Knowledge questions

In order to further determine the actual knowledge regarding a possible damaging effect of radiation, some statements on the topic of radiation were read out to the respondents, for each of which they were asked to indicate whether the statement was correct or incorrect. More than half of the respondents were able to correctly classify the statement on the topic of radiation from mobile communication and genetic heritage ("The radiation of a mobile phone can damage genetic heritage." [incorrect]) and the statement on X-rays ("X-rays always damages the body." [correct]). Knowledge about the topic of radiation from mobile communication has improved slightly compared to 2019, while knowledge about the damaging effect of X-rays has deteriorated. The statement on the exposure by radiation from mobile communication ("Which radiation from mobile communication exposure is higher for the average user: radiation from mobile phone masts, radiation from one's own mobile phone / smartphone or both equally?") was answered correctly by 57% of respondents ("radiation from one's own mobile phone / smartphone"). In a time-series comparison, the values are stable.

The majority of respondents (89%) knew that radioactive substances also occur in nature. The statement on the harmfulness of natural radiation was also correctly classified by the majority of respondents ("Natural radiation is never harmful." [incorrect: 77%]). In both cases, knowledge is at the same level as in 2019.

Laser pointers are known to 91% of respondents, with the lowest proportion in the 65+ age group (81%). The fact that lasers can cause damage to the eyes if you look directly into the light beam is known to the vast majority of those who know laser pointers (92%).

Overall, with regard to knowledge of a harmful effect, a correlation can be established between education, involvement (as the degree of dealing with the topic of radiation), the perceived informedness about the topic of radiation as well as the self-assessed technical expertise and the proportion of correctly answered questions and thus the level of knowledge for most of the types of radiation surveyed. The higher the level of formal education, involvement, information and technical expertise, the greater the proportion of correct

answers and, vice versa, the greater the risk of misconceptions. An exception is the question "X-rays always damage the body" [correct]. Overall, just under 40% of respondents assume that this statement is incorrect. The proportion is higher among people who claim to be very technically informed (44% | 35% hardly / not at all informed), who feel (very) well protected (43% | 38% (very) poorly protected) and people who have already dealt a lot with the topic of radiation (42% | 34% never dealt with it). In this context, the qualitative results have shown that X-ray is perceived as very aggressive and dangerous on the one hand, but on the other hand, the protective measures taken (e.g. appropriate lead vests / X-ray aprons during treatment) minimise the actual perceived risk posed by X-ray. In addition, there is the positive cost-benefit ratio attributed to X-rays, since a targeted dose of radiation used in medical diagnostics helps to maintain health.

The respondents were asked to rate the following types of radiation in order to find out, which radiation source causes the highest average radiation exposure in their opinion: medical examinations, natural radioactivity in food, radon in houses, nuclear power plants. With 35% and 34% respectively, nuclear power plants and medical examinations are most frequently cited as the greatest sources of radiation exposure. Significantly fewer people consider natural radioactivity in food (14%) or radon in houses (13%) to be the radiation source that causes the greatest average radiation exposure for a person in Germany.

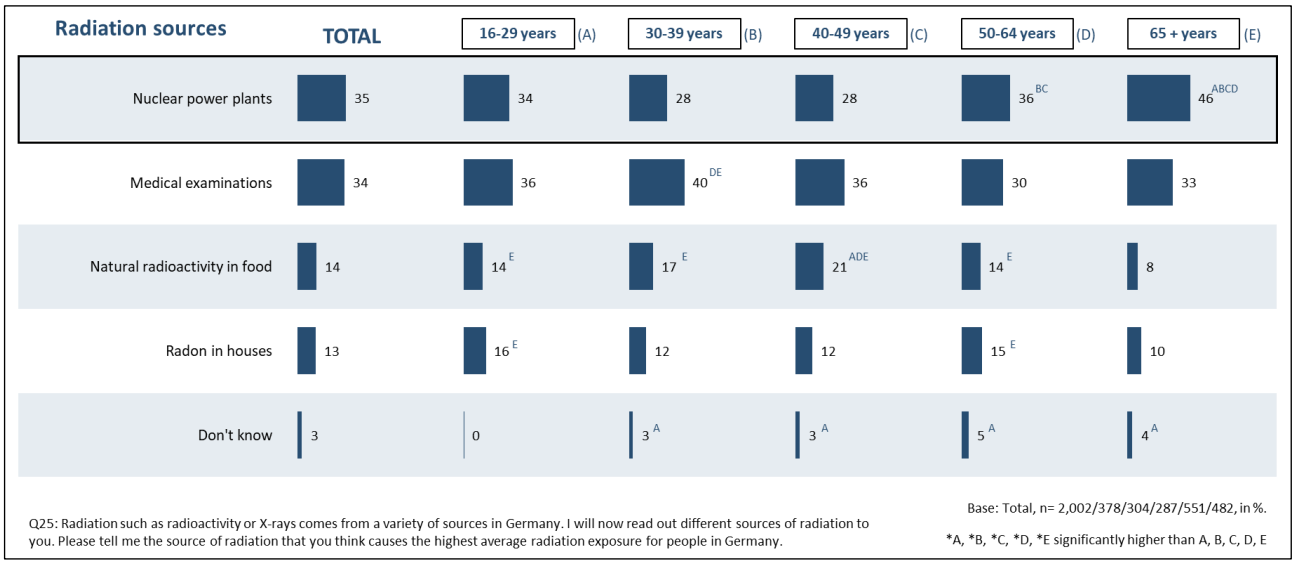

Figure 17 Radiation source causing the highest average radiation exposure according to respondents

4.4 Perception of risk, concern and self-efficacy in the context of radiation

4.4.1 Modern health concerns

Which are the topics that the population is in general most worried about in the context of radiation and health? These topics were measured on a 5pt. scale (1= "does not worry me at all" to 5= "worries me a lot"). By far the most worrying topic was radioactive contamination from nuclear power plants after an accident / disaster (78% top2 box, concern). Other issues that cause great concern are multi-resistant bacteria in hospitals (62%), nanoparticles and plastics in food (56%) and pesticides in food (54%). The population is much less concerned about genetically modified food (46%), air pollution from car traffic (44%), UV radiation from sunlight (32%) or radioactive contamination from nuclear power plants in standard operation (27%). Likewise, fewer people are concerned about radiation from mobile phone masts (23%), radiation from mobile phones / smartphones / tablets (19%), radiation from high-voltage power lines (18%), effects of vaccinations (18%), X-

ray radiation at the doctor's or dentist's office (18%), natural radiation from radon (14%), radiation during flights (13%), radiation emitted by a (standard) microwave oven (12%).

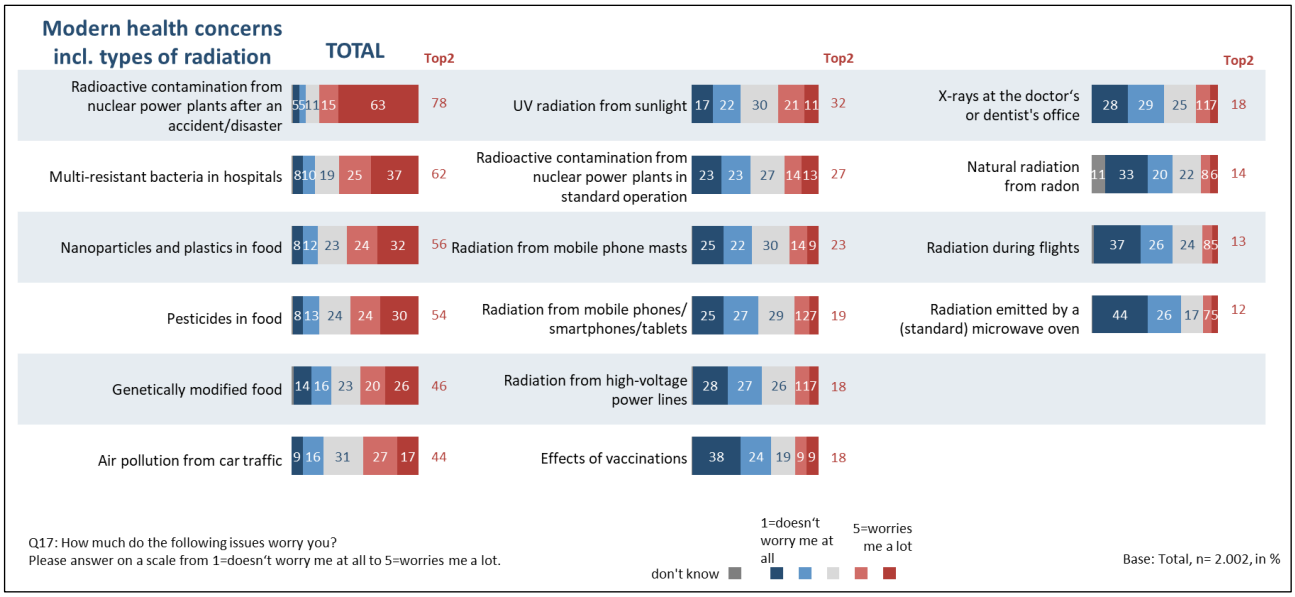

Figure 18 Modern health concerns including types of radiation

Women are more worried than men about all aspects. In addition, the level of concern tends to increase with age for most issues. In general, the youngest age group (16-29 years) is significantly less worried about all the issues mentioned compared to the oldest age group (65 years and older).

Furthermore, a correlation between the degree of involvement in the topic of radiation and the intensity of the concern can also be identified – the greater the involvement with the topic of radiation has already been, the lower the respondents' concern that about the various types of radiation queried. For example, around 67% (Low2 box) of respondents who have dealt with the topic of radiation a lot do not worry about X-rays at the doctor's office, but only 49% of the "uninformed (who have never dealt with it)". This is similar for radiation emitted by a (standard) microwave. Around 77% (Low2 box) of the first group are unconcerned, but only 61% (Low2 box) of the second group. Analogously, people who feel well protected by state institutions of radiation protection or who claim to have a high level of technical expertise are significantly less concerned. For example, around 59% (Low2 box) of those who feel well protected are unconcerned about radiation emanating from high-voltage power lines (48% Low2 box of those who feel (very) poorly protected), 52% (Low2 box) of this group are also not concerned about radiation from mobile phone masts (41% Low2 box of those who feel (very) poorly protected) and 57% (Low2 box) are not concerned about mobile phone radiation (45% Low2 box of those who feel (very) poorly protected). On the other hand, people who are very interested in the topics of health and consumer protection are clearly more concerned about all the topics queried. These people are particularly concerned about radioactive contamination from nuclear power plants after an accident / disaster (84% Top2 box), multi-resistant bacteria in hospitals (73% Top2 box), nanoparticles and plastics in food (68% Top2 box), pesticides in food (67% Top2 box) and genetically modified food (62% Top2 box).

People who are dissatisfied with their lives are also significantly more concerned about most of the areas surveyed than people who are satisfied.

Looking at the results of the 2019 survey, it can be seen that in terms of their relation to each other, the topics were ranked comparably in the 2019 survey. However, the values cannot be directly compared with each other, as they were measured on a 4pt. scale in 2019. In addition, the item "radioactive contamination by nuclear power plants after an accident / disaster" was not queried in 2019 and was probably mixed with

the answers on the topic of "radioactive contamination by nuclear power plants in standard operation", which had a significantly higher relevance in 2019 than in the current study.

4.4.2 Radiation contact points & protection options

In order to be able to look more deeply into the connection between exposure, self-efficacy in the sense of the possibility of protection and concern with regard to different types of radiation, the respondents were asked to indicate for different types of radiation how much contact they have with the type of radiation in question, and to what extent they feel that they can protect themselves from it. The question was asked on a 5pt. scale (1 = "no contact" to 5 = "much contact", respectively 1 = "I cannot protect myself at all" to 5 = "I can protect myself very well"). As expected, respondents have the most contact with radiation from mobile phones / smartphones / tablets (62% Top2 box), followed at a considerable distance by UV radiation from prolonged exposure to the sun (31%) and radiation from mobile phone masts (20%). While only 29% (Top2 box) feel that they can protect themselves well from radiation from mobile phones / smartphones / tablets, most people have the impression that they can protect themselves well from UV radiation by staying in the sun for a long time (67% Top2 box). In the case of radiation from mobile phone masts, 20% (Top2 box) think that they can protect themselves well.

The majority of respondents have relatively little contact with X-rays at the doctor's/dentist's office: Only 15% say they have a lot of contact (Top2 box); however, only 30% think that they can protect themselves well (Top2 box).

The majority also has little contact with radiation from high-voltage power lines (74%), radiation from nuclear power plants (90%) and radiation during flights (87%) (Low2 boxes respectively – for comparison, the Top2 boxes are 20% for high-voltage power lines and 5% each for nuclear power plants and flights). In each case, half of the respondents or more also state that they cannot protect themselves well either.

Figure 19 Intensity of contact with different types of radiation

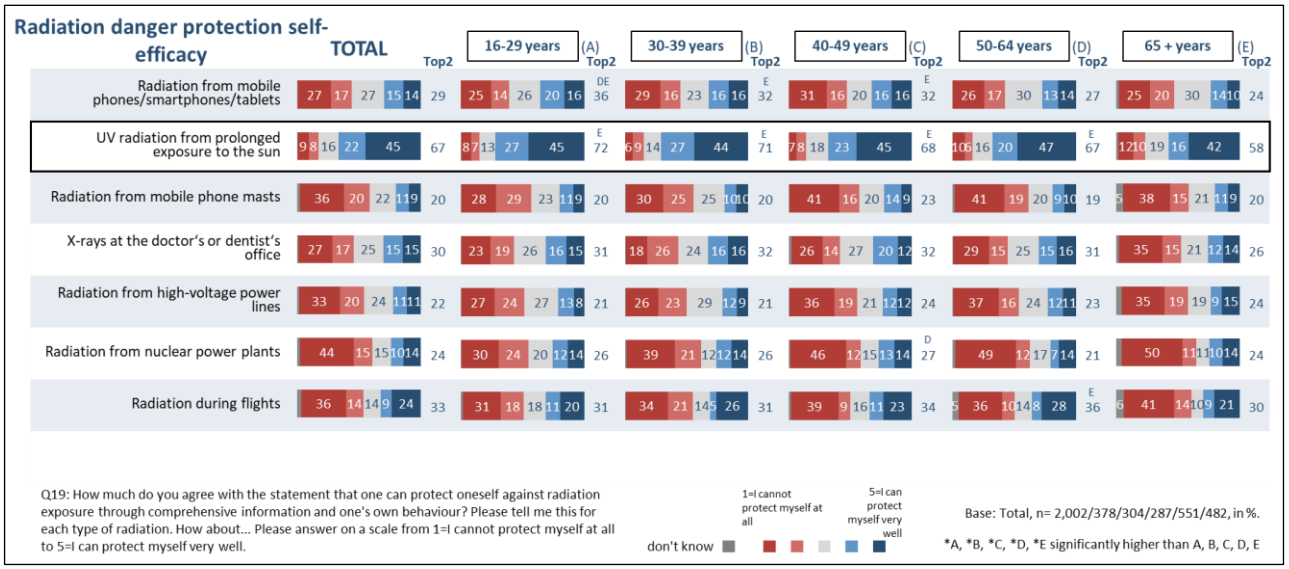

Figure 20 Extent to which one can protect oneself from different types of radiation

As already shown elsewhere, the involvement with regard to the topic of radiation and the feeling of being (very) well informed by state institutions of radiation protection also has an influence on the perception of one's own protection possibilities. It is higher-rated for almost all types of radiation (exception: radiation from mobile phone masts is at an average level) than is the case for people with lower involvement.

In the qualitative interviews, a correlation was reported between the intensity of exposure and the degree of concern that the interviewees had about the harmful effects of radiation on health. In the representative survey, this correlation was found for all types of radiation. 31% of the persons who had a lot of contact (Top2 box) with radiation from mobile phone masts said they were worried about radiation from mobile phone masts (Top2 box). For people who had little contact (Low2 box), the share is 19% (Top2 box). The ratio is similar for high-voltage power lines: 32% of those who say they have a lot of contact with this type of radiation worry a lot, compared to only 15% of those who say they have little contact. For X-rays, the ratio is 34% to 13%, for UV radiation 39% to 27%, for mobile phones 22% to 12% and for flights 20% to 12%.

For some types of radiation, it is also evident that people assuming that they can protect themselves against harmful effects are more often less concerned. For example, 53% of people who say that they can protect themselves (very) well against radiation from mobile phone masts are unconcerned (Low2 box of concern), compared to 67% for X-rays.

4.5 Desired information, health awareness and protective measures in the context of radiation

4.5.1 Desired information

In order to align communication with the information desired by citizens, it was first of all of interest to find out which topics the respondents had already been informed about and on which topics they would like to receive further information. In the qualitative interviews, the question about information needs showed that the focus was on information about radiation from mobile communication. The representative survey was able to identify further details and to provide a broader data basis. The main radiation topics on which respondents have already obtained information are UV radiation during longer stays in the sun (78%), X-rays at the doctor's office (62%) and radiation from mobile devices such as mobile phones, smartphones and tablets (59%). Subordinate topics are radiation from nuclear power plants (48%), radiation from mobile phone masts (36%), radiation from high-voltage power lines (28%) and radiation during flights (25%). Contrary to the

frequency of information behaviour, the areas of radiation from mobile phone masts (16%) and radiation from high-voltage power lines (16%) are the most frequently named answers to the question in which of the named topic areas the citizens would like to have more information. There are gender-specific differences in the desire for more information with regard to the examples of mobile phone masts and high-voltage power lines: Women want more information significantly more often than men. Men, on the other hand, are more likely than women to be already informed about radiation coming from mobile phone masts and high-voltage power lines. Further differences in information behaviour and the desire for additional information can be found between the different age groups: 16-29 year olds have already been looking for information about the topics of radiation in mobile devices and radiation from nuclear power plants more often than 50-64 year olds. Young people see a high additional need for information in the area of radiation from high-voltage power lines and thus stand out significantly from the rest of the citizens. In order to classify the results, it is also necessary to take into account the proportion of people who neither are informed nor would like to be informed. The need for information regarding flights is the least pronounced. 62% of the respondents have not yet dealt with this issue and do not see any need for further information, followed by information on radiation from high-voltage power lines (56%) and radiation from mobile phone masts (48%).

If we take a look at the age groups again comparing all types of radiation, respondents up to 39 years of age generally show significantly more interest in further information on all topics, with the exception of UV radiation. For this topic, the qualitative interviews show that many participants had the impression that they were sufficiently informed. On the other hand, there are misconceptions such as the belief that pre-tanned skin does not need sun protection or that sun protection is not necessary in Germany because UV radiation is not that intense here. This suggests that education is still necessary.

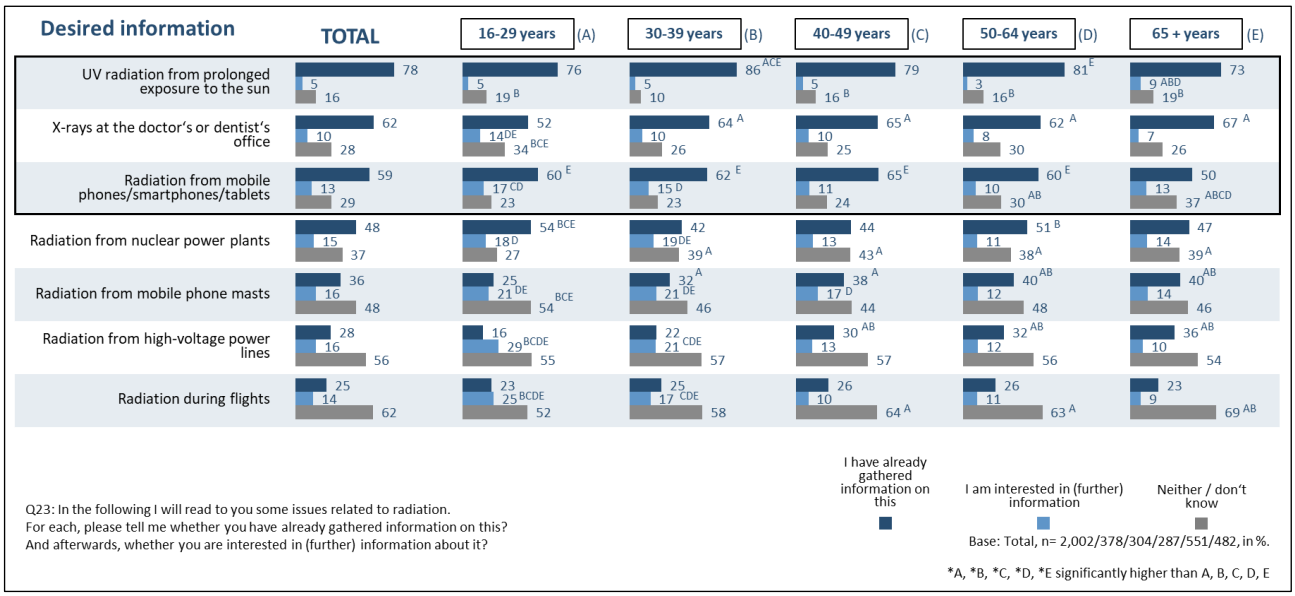

Figure 21 Information behaviour in relation to types of radiation

4.5.2 Measures for own protection for types of radiation

Overall, very few citizens take protective measures with regard to radiation – apart from solar radiation and when it comes to flying – for all other types of radiation, it is consistently less than 8% of respondents per type of radiation. Only in the case of flying slightly more people (11%) state that they take protective measures, mostly consisting of flying less or not flying at all.

In the case of UV radiation, protective measures mentioned mostly include applying sunscreen (77% "sometimes" / "always") or avoiding prolonged exposure to the sun (76%). Wearing appropriate sunglasses

(68%) or long clothes (46%) are other measures taken to protect oneself against UV radiation. The majority "never" keep themselves informed about the daily UV index (64%). Overall, women implement protective measures in the context of UV radiation more frequently than men. Likewise, the frequency of implementing sun protection measures increases with age. In the wave comparison, there has been no change in terms of the frequency with which protective measures are taken in relation to each other.

In the wave comparison, changes are particularly noticeable with regard to the topic of radiation from mobile phone masts: In 2019, 53% of respondents stated that they lived as far away as possible from a mobile phone mast or even had moved for this reason. In 2022, this is the case for only 36% of respondents. Generally keeping a distance from mobile phone masts has dropped from 27% in 2019 to 22% in 2022. The tendency to protest against radiation from mobile communication has also declined (2022 0% | 2019 12%). In contrast, not using a mobile phone or using it less frequently as a self-protection measure has increased significantly (2022 19% | 2019 7%). Shielding oneself from radiation from mobile communication, e.g. with the help of different foils or special curtains, is a measure that is taken comparatively rarely (2022 9% | 2019 6%).

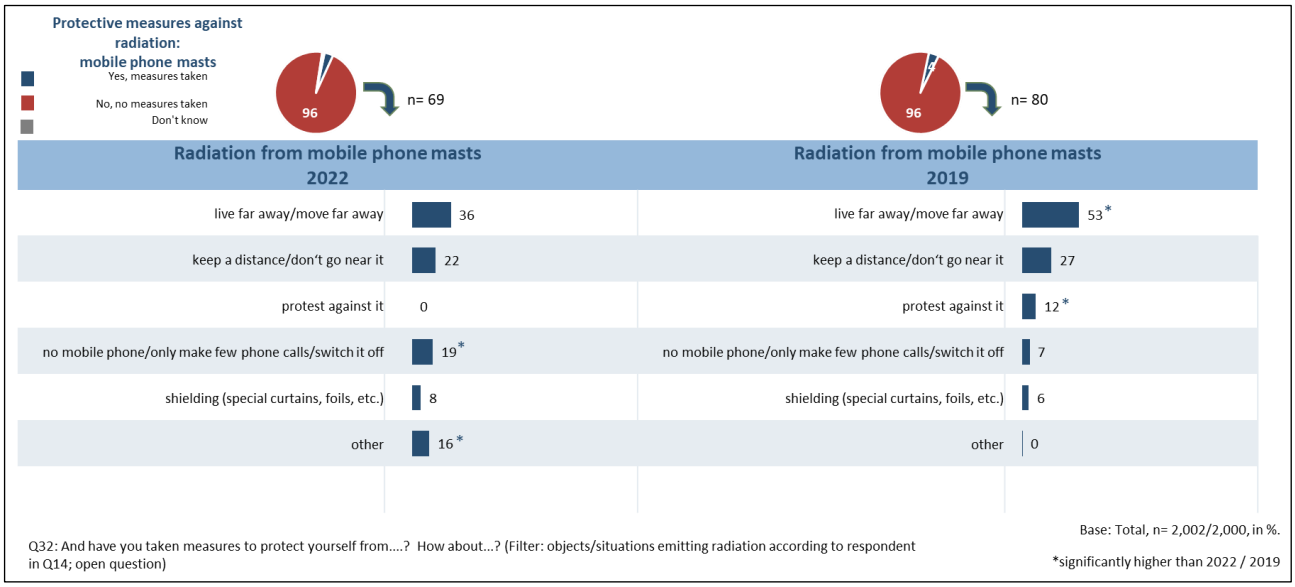

Figure 22 Protective measures against radiation: mobile phone masts

The protective measures against radiation from high-voltage power lines are largely stable in the wave comparison. Keeping a distance from high-voltage power lines or not going near them if possible as the most important protective measure increased slightly again in the 2022 survey (2022 57% | 2019 52%). People also prefer to live as far away from high-voltage power lines as possible (44% in both years), while other measures are hardly ever taken.

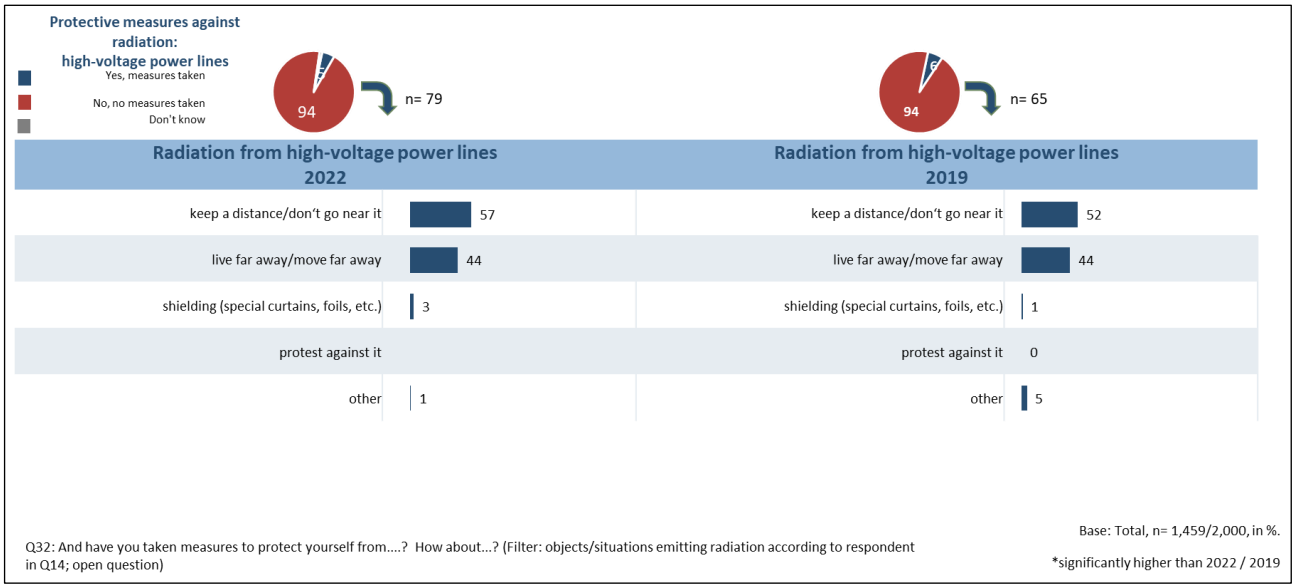

Figure 23 Protective measures against radiation: high-voltage power lines

The most common measure to protect oneself from radiation during flights is not to fly or to fly less. This has decreased by 3% compared to 2019 (2022 37% | 2019 40%). However, it is important to bear in mind in this context that the global COVID-19 pandemic lies between the two survey dates, which is likely to have had an influence on the results due to the various restrictions also in terms of travel options.

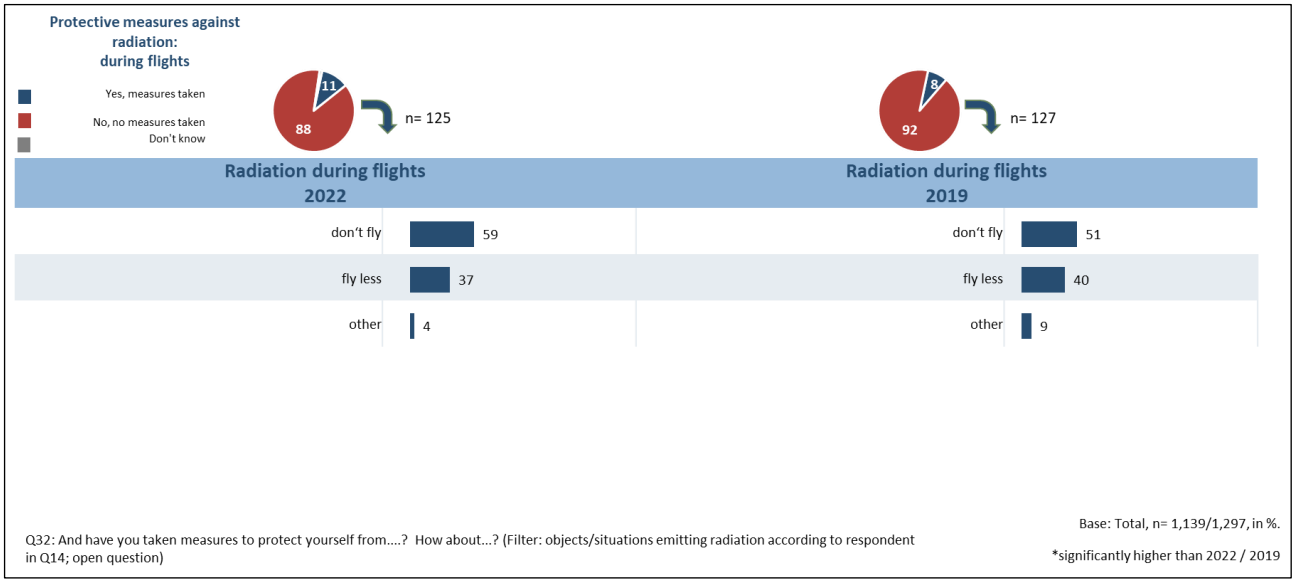

Figure 24 Protective measures against radiation: flights

Protective measures with regard to radon are very varied: The measure taken most frequently is regularly opening the windows (2022 29% | 2019 35%), followed by taking measurements (2022 26% | 2019 14%). Living in a region with low radon levels was mentioned slightly more often in the current survey (2022 17% | 2019 5%). 13% of the citizens who take protective measures against radon in 2019 and 14% in 2022 mentioned taking construction measures against radon. Other protective measures are of rather minor importance. When comparing the two survey waves, it must be taken into account that comparatively few people have taken measures for their own protection with regard to radon (2022: 7% of those who state that radon emits radiation | 2019 3%) and thus the range of variation of the results is correspondingly high.

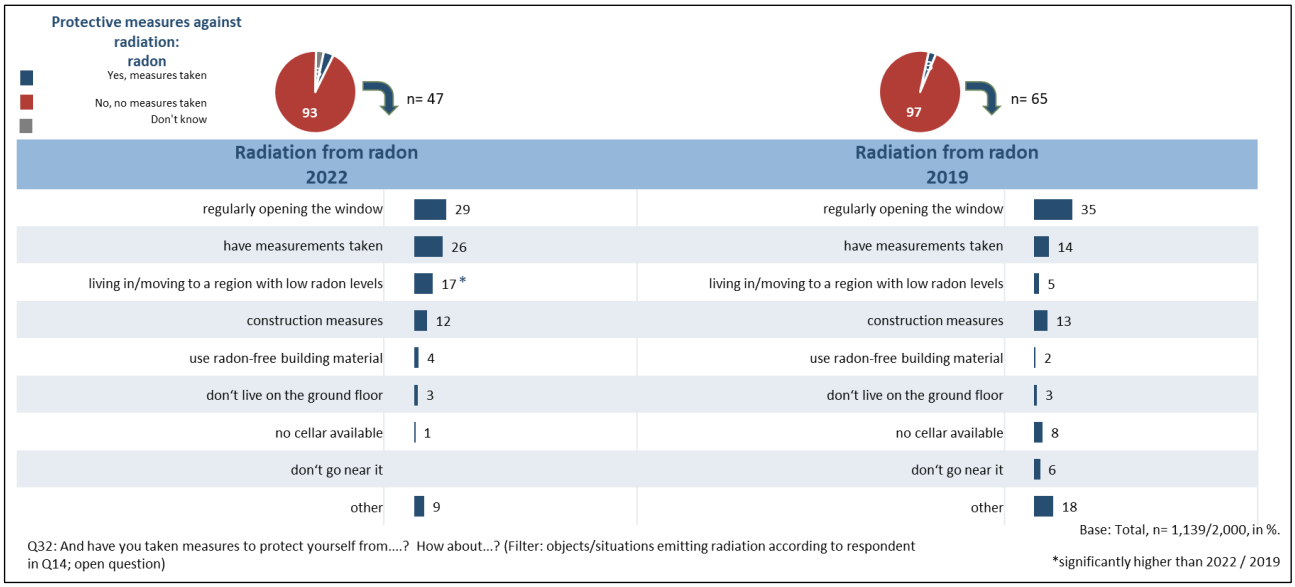

Figure 25 Protective measures against radiation: radon

In order to obtain a more differentiated picture of the information desired by citizens, on which they ultimately also base their precautionary measures, the respondents were asked to say how well they feel protected by state institutions regarding different types of radiation. People feel most protected when it comes to medical applications (e.g. X-ray, CT) (Top2 box 82%). This is followed at a distance by UV radiation (54% Top2 box) and radiation from high-voltage power pylons (52% Top2 box) as well as radiation from mobile phone masts (48% Top2 box). 41% (Top2 box) feel protected from radon – however, with 23%, the share of "I don't know" is high, as could be expected considering to the comparatively great lack of knowledge about radon. Overall, it can be seen that younger people aged 16-39 feel better protected against all types of radiation than older people, except for UV radiation, where especially 16-29 year-olds feel (very) well protected (65%), and for medical applications, where the feeling of protection is very high for all age groups (over 80% Top2 box).

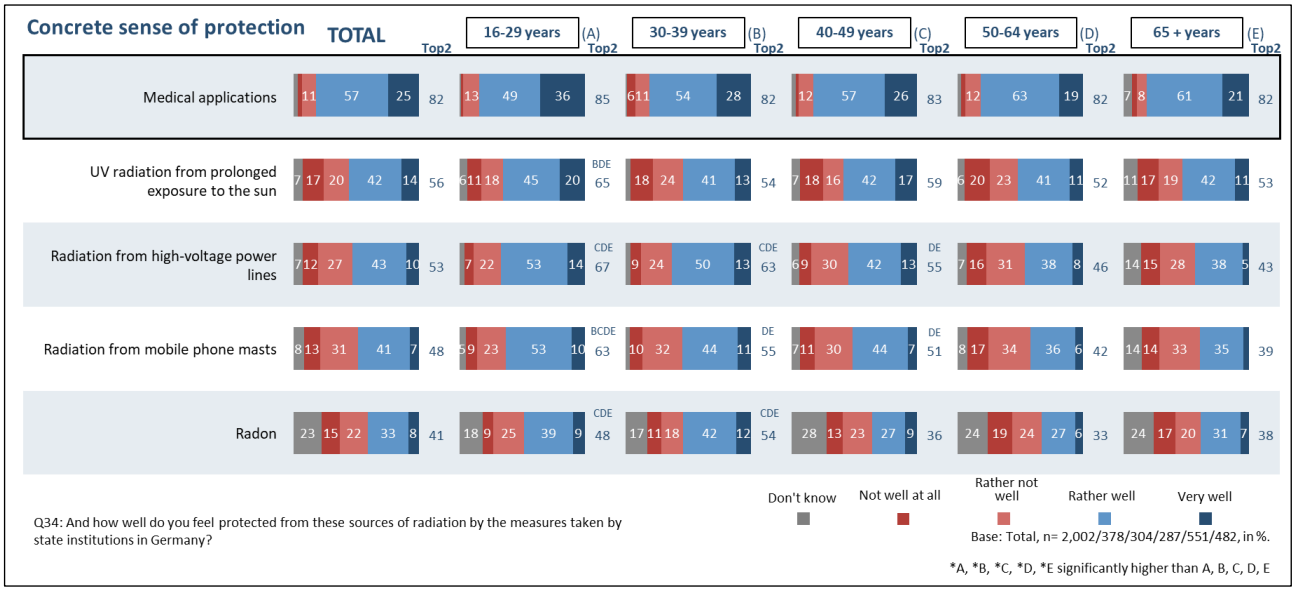

Figure 26 Extent to which people feel protected from different types of radiation by state institutions

Respondents who feel rather not or not at all protected by the measures taken by state institutions with regard to individual radiation sources were then asked to indicate what state institutions could improve so

that they would feel better protected. In the first place, regardless of the source of radiation, citizens would like more information and more education about radiation and its risks.

In the case of radon, this improvement measure for more information and education is mentioned almost exclusively (87%). Only few respondents (9%) would like to see more measurements or better radiation shielding. Some respondents mention state requirements for building houses (2%) as a measure for improvement or would like to see financial support for measurements and renovations (1%).

Citizens would also like more education and information to improve their sense of protection against radiation from mobile phone masts (61%). In particular, people who have only dealt a little with the topic of radiation would like more information on this topic (64%). The second most important point (18%) is the desire for more research that would make it possible to find alternatives reducing radiation exposure. 12% of dissatisfied respondents who have suggestions for improvement say that mobile phone masts should not be placed in residential areas. 9% say that fewer masts should be erected in general, or that existing masts should be removed. 6% of those who have suggestions for improvement would want warning signs or maps with the locations.

When it comes to protection against radiation in medical applications, more information / advice on the risks is named as the main suggestion for improvement in order to increase the personal sense of protection by state institutions (60%). Avoiding unnecessary X-rays (19%), improving or modernising existing technology (13%) and better protective measures such as better protective clothing (10%) are further suggestions for improvement.

In addition to education and information (57%), suggestions for improving the feeling of protection against radiation from high-voltage power lines include better shielding or burying transmission lines underground (28%), as well as keeping a distance to residential areas (13%). It is striking that the younger the respondents are, the more pronounced the desire for more information and education on risks (16-29 years: 74%|30-39 years: 73% | 40-49 years 64% | 50 years and older: 44%).

With 47%, the subjective need for information is lowest for the topic of sun protection. 20% indicate that the state is less frequently asked for information when it comes to solar radiation, but that this is rather everyone's own responsibility. Environmental protection and the protection of the ozone layer are other aspects mentioned. Installing more objects that provide shade, such as parasols, is also mentioned. However, at this point we would like to refer to the findings of the qualitative survey: Even if the participants do not feel a need for information in the context of UV radiation, objectively speaking there is a certain need for education in order to correct widespread misconceptions. In the individual interviews as well as in the group discussions, misconceptions, such as the belief that pre-tanned skin does not need sun protection or that sun protection is not necessary in Germany because UV radiation is not that intense here, were brought to light. A challenge for communication is to raise further awareness on a topic on which the majority already feels well informed.

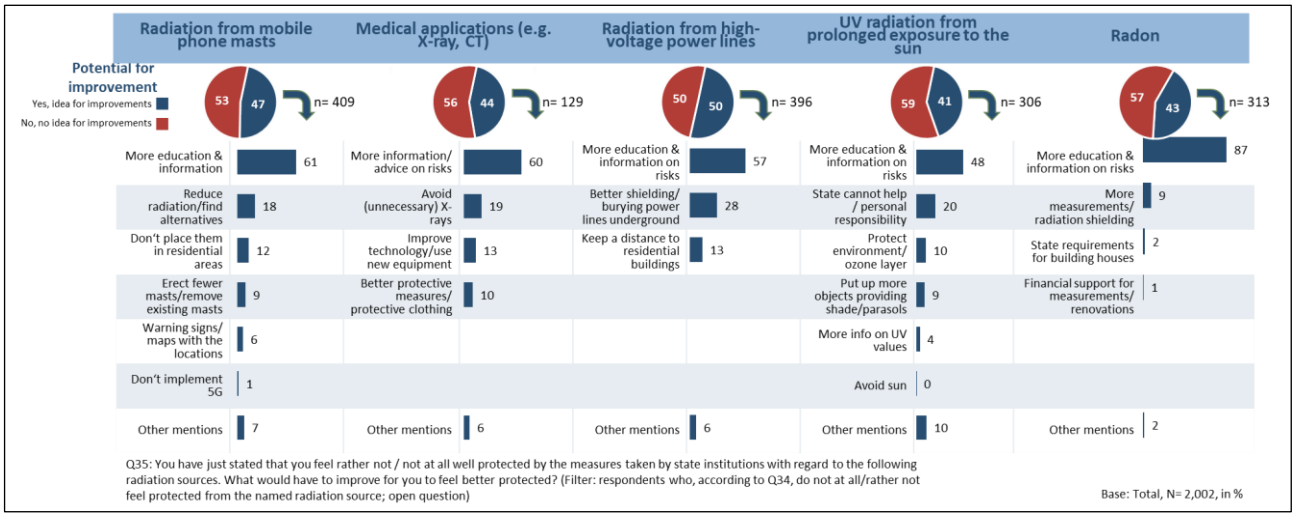

Figure 27 Suggestions for improvement to feel better protected by state institutions

In the context of the sense of protection and the need for information, the decision can also be examined to what extent people have medical examinations in which they are exposed to radiation carried out or postpone them, for example, as part of a weighing process. For a good 62% (Top2 box) of the respondents, the doctor's advice is decisive for the performance of further corresponding examinations. For persons who feel well protected and/or informed by state institutions with regard to the topic of radiation, as well as with an increasing degree of dealing with the topic of radiation, the proportion of respondents who decide in favour of the doctor's advice increases. On the other hand, about 66% (Top2 box) of the respondents reserve the right to make a final decision for or against an examination in which they are exposed to radiation on the basis of personal consideration. With 72% (Top2 box), women in particular agree with the statement "I decide for myself whether to have an examination in which I am exposed to radiation, such as X-rays" significantly more often than men (59% Top2 box).

In summary, it can be stated that respondents who feel well-protected from various types of radiation by state institutions less often feel the need for their own measures to protect themselves. The prerequisite for being able to take measures for one's own protection is the knowledge about and availability of protective measures (see e.g. radon). The main measures for one's own protection consist in avoiding or at least reducing exposure (e.g. flying, radiation in the medical area, reduced use of mobile phones) as well as in increasing the distance to radiation sources (still applies especially to high-voltage power pylons, but has lost relevance for mobile phone masts). With regard to the need for protection, radioactivity, X-rays, laser treatments and high-voltage power pylons were identified in the qualitative interviews as types of radiation with a high need for protection. When it comes to UV radiation and radiation from mobile communication, there is only medium need for protection. The broader data base of the representative survey makes it clear that the topic of radioactivity is very present, whereas concerns regarding X-rays (17% Top2 box), high-voltage masts (18% Top2 box) and radiation from mobile communication (19% Top2 box) are at a comparably low level. It is higher for UV radiation (32% Top2 box). The perceived protection by measures of government information is around 50% or more for all mentioned types of radiation (excluding nuclear power), and even 82% (Top2 box) for X-rays. The fact that the need for additional information is rather low (mobile phone masts 16%, high-voltage power pylons 16%, X-rays 10%, UV radiation 5%) also shows that, due to the firm anchoring of the radiation sources in the living environment, many citizens do not perceive the questions about health risks in connection with the types of radiation in everyday life as so prominent. This poses an additional challenge for the preparation of communication materials, as they will have to generate attention in this topic area.

4.6 Conclusion and derivations for communication

4.6.1 What do citizens think about radiation?

The extent to which citizens feel informed and protected by state institutions on the subject of radiation was a central component of the survey. Overall, there was a slight improvement in the feeling of being informed compared to 2019: In 2022, 31% of respondents feel "well" or "very well" informed by state institutions of radiation protection, compared to only 23% (Top2 box, 4pt. scale) in 2019. The feeling of being "well" or "very well" informed by state institutions of radiation protection increases slightly with age, and men also feel (rather) well informed more frequently than women. The personal feeling of protection has also increased compared to 2019 (2019: 38% of respondents who feel "well" or "very well" protected | 2022 51%; 4pt. scale). Younger people up to 29 years of age are more likely to feel well protected than older people, and men are more likely than women.

The best-known government institutions in the field of radiation protection (prompted) are the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (83%), the Federal Office for Radiation Protection (71%) and the International Atomic Energy Agency (68%).

What do citizens think of first when they hear the word radiation? The topics that are currently most present are radioactivity / nuclear radiation / nuclear threat or nuclear weapons, followed by radiation in connection with mobile communication. In addition, the topic of UV radiation / solar radiation also plays a central role in the perception of citizens. Radiation in the field of medicine, radiation from WiFi / electrical devices as well as natural radiation are also an issue, but clearly less important. Spontaneously, about 10% of the citizens simply express concern or fear when the term radiation is mentioned.

All in all, the extent to which one is concerned about the type of radiation, the extent of contact with it and the extent to which one has the possibility to protect oneself from it depends very much on the type of radiation.

The majority of respondents say they have a lot of contact with radiation from mobile phones (62% Top2 box) – while only just under 30% think that they can protect themselves well here. Overall, however, the topic of radiation from mobile communication is of less concern – respondents can’t imagine their everyday life without mobile phones anymore. In the case of mobile phone masts, significantly fewer respondents said they had a lot of contact with the radiation in question (20%). However, the majority (56%) think that it is not possible to protect oneself well (at all) from radiation from mobile phone masts. About the same number of respondents feel (very) well protected (48%) or (rather) not well protected (44%) from radiation from mobile phone masts by state institutions. 13% would like more information on the topic of mobile communication, 16% on the topic of mobile phone masts.

In the case of UV radiation, the assessment of contact intensity and possibilities to protect oneself is different from that of mobile communication / mobile phone masts: Only about one third of the respondents are concerned about UV radiation. This could be related to the fact that only about one third of the respondents state that they have a lot of contact with it, while about two thirds think that they can also protect themselves well from this type of radiation. The most common measures taken by the majority are to use sunscreen, to avoid staying in the sun for long periods of time and to wear appropriate sunglasses. UV radiation is also the type of radiation on which respondents have most frequently already obtained information and feel well informed, as only 5% of respondents express interest in further information. By comparison, for the other types of radiation, 10% or more of respondents expressed interest in further information. The majority also feel (very) well protected from UV radiation by state institutions (56% of respondents), while around 37% say that this is (rather) not the case.

Topics where there is less concern and where fewer possibilities are seen to protect oneself are, on the one hand, radiation in the medical area, radiation from high-voltage power lines and radiation during flights. At the same time, this is also where there is the least interest in information.

Radiation in the medical area seems to be a rather distant topic for the majority of respondents. Almost 70% of the respondents think that they have (rather) little contact with it. However, around 44% also think that one cannot protect oneself well (at all). 10% of the respondents would like to have more information. The vast majority (82%) also feel (very) well protected by state institutions here – with a clear lead over all other types of radiation.

Similarly low is the extent to which one has contact with radiation from high-voltage power lines (10% (rather) much contact). However, the majority think that one cannot protect oneself well (at all) from this type of radiation. Overall, the majority also feel well protected from this type of radiation by state institutions (53%). 16% of the respondents would like to have more information.

When it comes to radiation during flights, only 5% of respondents think they have (rather) much contact. However, 50% say that one could not protect oneself well (at all) from this type of radiation. In general, the need for information is also low in this area.

When it comes to radiation, the issue of radioactivity concerns citizens the most. In this context, respondents were also asked to assess the role of state institutions in the event of a nuclear accident. The majority of respondents are less concerned about a nuclear accident (over 50% of respondents, Low2 box, 5pt. scale). Younger respondents are relatively unconcerned, while older respondents aged 50 and over are significantly more concerned. Women also tend to be more concerned than men. Overall, it can be stated that there is a certain insecurity about whether Germany would be well prepared in the event of a nuclear accident. 35% select the middle of the scale, 35% (rather) do not think so. More than half of the respondents would not know what to do in case of an emergency, another 25% place themselves in the middle of the scale. However, almost half of the respondents trust the government measures, a leap of faith that should be further expanded with targeted communication.

In the event of a nuclear accident, typical contact points for information on topics such as protective measures / radiation exposure / recommended behaviour, etc. would be the classic information media in addition to the Internet, but also, to a far lesser extent, locally based institutions such as the municipality and the fire brigade. About 13% of the respondents would contact the Federal Office for Radiation Protection. Overall, however, a relatively large number of citizens would not know whom to contact (20%).

4.6.2 Derivations for communication

The topics on which many citizens have already obtained information and would also partly like more information are UV radiation, X-rays at the doctor's/dentist's office, radiation from mobile phones, tablets, etc. In contrast, the need for information on the topics of high-voltage power lines, mobile phone masts and flying is generally lower. People who do not feel well protected by state institutions often indicated better / more information or education as suggestions for improvement. Thus, it would be recommended to offer a broad range of information on all types of radiation. It would be advisable to focus communication on the topics of UV radiation, X-rays at the doctor's/dentist's office and radiation from mobile phones, tablets, etc. However, educational measures on topics that are less frequently associated with radiation, such as natural radiation / radon, are also important, considering that awareness of a topic may first have to be created for requests for information to be formulated / information and education to be mentioned as suggestions for improvement if one does not feel well protected.

Radioactivity is a topic of great concern to respondents overall and is often associated with radiation. Information materials, especially on the subject of nuclear accidents, are important. In particular, information should be provided on where to turn in the event of an accident. It should also be communicated which measures are already being taken by the state in this context to increase the personal feeling of protection.

5 List of figures