RadoNorm
Managing risks from radon and NORM

Deliverable 6.14

Report on controversies between "radon as treatment in radon spas" and "radon as threat in health communication campaigns"

Work Package 6

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Executive summary of the RadoNorm project

EU member states, associated countries and the European Commission are implementing the European Basic Safety Standards Directive for radiation protection. The EU-funded RadoNorm project focuses on all radiation risk management cycle levels for radon exposure, as well as situations of exposure to naturally occurring radioactive materials (NORM). The project intends to reduce scientific, technical and societal concerns by introducing research and technical developments, integrating education and training (E&T) and disseminating the results of the project through targeted actions to the public, stakeholders and related institutions. RadoNorm directs research and development on all levels of the management cycle, combines biomedical and ecological research with mitigation development and social science research and brings together researchers from national radiation protection entities, universities and SMEs.

Executive Summary of the Deliverable

One of the objectives of WP6 in the RadoNorm project is to gain understanding in the controversies between “radon as treatment in radon spas” and “radon as threat in health communication campaigns”. This Deliverable provides on overview of the research conducted to explore this controversy. Results are presented on radon perceptions, enactments, and communication by radon spas and the public, aiming to understand this controversy and furthermore provide recommendations for different stakeholders on how this controversy can be handled.

A preparatory desk research identified several key issues, including a lack of academic research on radon spas from a social science perspective (Tomkiv et al., 2021, pp. 146–147; Mihók, 2021, p. 61), and challenges in primary social science research due to its inter-disciplinary nature and ethical considerations (Mihók, 2021). Moreover, we have found out variations in legal frameworks regarding radon content in spa waters in Central and Eastern European states: 1500 Bq/L in the Czech Republic (Goliáš et al., 2022, 2016), 666 Bq/L in Germany (The European Committee of the Regions, 2024), 370 Bq/L in Austria (Ritter and Gaisberger, 2020), and 74 Bq/L in Poland (Szabó, 2023). Furthermore, in the context of the non-existence of a definition of the term “spa” in social/tourism science, our research revealed significant differences in definitions of spas and non-spa facilities offering radon medical therapy (Mihók and Marčeková, 2022). Despite that some of these spa facilities might not meet the national laws to be officially considered as a radon treatment facility, we refer to these facilities as "radon spas" in this Deliverable.

Key empirical attention was directed at radon framing on the websites of radon spas. 26 radon spa facilities were identified across the European Union that advertise radon treatments on their websites, mainly in Germany and Austria. A framing analysis of these websites was then carried out, of which the results are reported in a scientific article (Geysmans et. al, 2022). While some websites acknowledged the potential risks associated with radon exposure, many downplayed or counteracted these concerns. Many websites presented radon as a natural, exclusive, and rejuvenating substance, often using visual imagery to reinforce these frames. In summary, five frames were identified, which present radon respectively as a a) source of health, b) natural gas, c) (non) risk, d) luxury and e) fountain of youth. These five partly overlapping frames are at times in clear contrast with the ways in which radon is presented in a public health context.

To further investigate the perception of radon in radon spas, 16 semi-structured interviews were conducted in spa facilities in Austria and Germany. Interviews were conducted with a) people working in or managing the spas and b) representatives of health and radiation protection authorities. Stakeholders from the first group believe in radon’s therapeutic potential and perceived radon to have healing capacities, based on anecdotal evidence and positive experiences. Some believed health benefits were scientifically proven, but disagreement existed on this point. Representatives of health authorities, radiation protection authorities and scientists are rather cautious about the healing effects

of radon but noted potential positive effects in certain situations. Most of the interview respondents that work in radon spas have little self-reported knowledge of radon. Interview results furthermore revealed that radon used in treatments is considered a controllable risk by several respondents, with measures such as medical follow-up, continuous monitoring and time limits for treatment. Paracelsus' quote that "the dose makes the poison" was referred to often in interviews with both stakeholder groups to emphasise the importance of dosage when considering radon benefits and risks. Some stakeholders from radon spas believe risk-emphasising communication about radon risks is justified. Representatives from health authorities argue that it is challenging to explain the health risks of radon spas to the broader public. In this context, some highlighted the challenges of effective risk communication due to the presence of spas, making it difficult to inform the public about health risks of indoor radon.

The survey results from the RadoNorm European Radon Behavioural Atlas (Perko et al., 2024) are used in this study to investigate the attitudes and beliefs of the population towards radon in radon spas. The harmonised questionnaire was additionally expanded in Austria, Germany and the Czech Republic to include specific questions on radon spas. The survey results show significant variation in knowledge about radon among respondents in Germany, Austria, and the Czech Republic. Particularly striking is that only slightly more than half of the people gave the correct answer that radon is linked to lung cancer. The results furthermore indicate that the majority of respondents are familiar with radon spas or caves. The highest level of familiarity was found in Austria and the lowest in Germany. The survey also revealed that a significant proportion of respondents believe in the healing power of radon. However, a large proportion of respondents disagreed with the statement that radon gas is not dangerous due to its natural origin, contradicting the general assumption of its safety. The majority did not agree with the statement about radon's effect on ageing. In all three countries, radon spas are perceived at least as a potential risk to health within the next 20 years, compared to other radiological risks. The high proportion of "don't know" answers in Germany and Austria compared to other possible risks highlights the large gaps in knowledge about radon and the uncertainty associated with possible risks.

Based on the research conducted on this topic, recommendations are formulated which emphasise the importance of recognising the existence of two radon realities, which should both be recognised and clearly communicated to the general public, especially in areas where radon spas are located.

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1. Introduction

Following the discovery of radioactivity at the turn of the 19th and 20th centuries, the scientific community became intrigued by its potential medical applications. This interest quickly led to the development of various theories about the healing properties of individual radioactive elements, including radon gas. For example, in 1906 a spa was established in Jáchymov, Czech Republic, which marketed itself with reference to the health benefits of radon (known then as 'radium emanation'). At the same time, existing spas began incorporating radon into their marketing strategies, highlighting its healing properties to bolster their reputation as therapeutic destinations. These facilities, to which we will refer in this Deliverable as 'radon spas', hence started to offer services based on the purported health benefits of radon.

In these early years, radon spas' marketing could benefit not only from the 'novelty' of ionising radiation, but also from scientific hypotheses which were formulated on the potential benefits of this radiation. The most relevant in this regard is the theory of radiation hormesis, developed in the 1920s (e.g., Calabrese & Baldwin, 2000), which suggests that low levels of radiation may have beneficial health effects. Still debated today in terms of its validity, hormesis contrasts with the linear no-threshold (LNT) model, which posits that the risk of radiation-induced cancer is directly proportional to the radioactive dose received (e.g., Wojcik & Zölzer, 2024).

It is the LNT model which contributed to the classification of radon as a Group 1 carcinogen by the WHO in 1988. Moreover, since 2009, the WHO has considered and presented radon as the second leading cause of lung cancer, after smoking (ICRP, 2014; WHO, 2009). Consequently, radon has started to be predominantly framed in terms of health risks. While our comprehensive understanding of radon thus evolved and developed gradually over time, with also increasing insight in the health risks posed by radon and its progeny, some ideas regarding its health benefits are still around today, as are the radon spas which are active in various European member states.

Considering the co-existence of public health campaigns warning about the dangers of radon and the use of radon in the context of health spas a potential controversy can exist between considering radon as a threat to health (the LNT understanding) and a potential benefit to health (the hormesis understanding). An academic article addressing the potential controversy surrounding radon medical treatment after its classification as a carcinogen was published by Zdrojewicz and Strzelczyk (2006). In line with the content of this publication, the so-called 'radon spa controversy' refers to the simultaneous framing of radon as both a therapeutic element and a health threat.

Such controversy has important implications, as it might for example implicate public confusion, complexities in the design of health communication campaigns, economic consequences for stakeholders, etcetera. As such, it is important to gain an understanding of this controversy, the stakes and stakeholders involved, and recommended ways to handle it. This study will attain to this goal, by building on social scientific concepts and methods.

More specifically, in the context of the RadoNorm project, Subtask 6.4.3 aimed at gaining a better insight in this seeming controversy, through zooming in on perceptions, framings and enactments of radon in the context of radon spas. It focused on how radon is perceived, enacted, and presented by spas and the general public, aiming to understand the best approach to handling this controversy.

Therefore, the following research questions were analysed:

- How is radon framed on the websites of the radon spas?
- How is radon in the context of radon spas perceived, enacted and presented by radon spa employees, management and radon authorities?
- How is radon in radon spas perceived by the general public?

It is a first-of-its-kind dedicated research effort to explore this topic. To be clear, this research task did not intend to study radon levels and measurements, the safety of long-term radon exposure, or the health conditions of radon spa visitors. As a social scientific study, it aims to gain insight into a yet understudied controversy, and to formulate recommendations for different stakeholders on how this controversy can be handled.

This Deliverable aims to serve as a resource for public health authorities and other stakeholders interested in this topic, offering insight into the context and current framing and enactment of radon-by-radon spas and their stakeholders. Additionally, it briefly discusses potential approaches to addressing this controversy in the context of public health communication campaigns. The practical aim of this Deliverable is hence twofold: to address an existing social sciences and humanities (SSH) research gap and to provide hands-on and empirically based guidance on how to handle the potential 'radon controversy'. Of course, given the inherent constraints of the presented research, the recommendations presented in this Deliverable should be considered as contextual and dynamic in nature, with a need to consider the specific spatial and temporal contexts in which they might be applied.

2. Background

The research on which this Deliverable is based entails – to the best of our knowledge – the first systematic SSH endeavour to address the topic of radon spas in light of a potential controversy between 'radon as threat' and 'radon as treatment'. Therefore, an extensive preparatory study, of which the results are summarised in Sections 2.2 – 2.5, was conducted to complement the review of the limited literature currently available (Section 2.1).

One of the aims of disseminating this Deliverable is to promote ethical practices in communicating about radon, considering also the 'radon spa controversy' in relevant contexts. Therefore, Section 2.2 includes a brief overview of what was considered state-of-the-art in risk communication when preparing recommendations for public health communication presented in Section 6.

2.1 Background on radon spas and healing caves: Insights from the literature

Most of the literature identified through a systematic academic literature review, using the method outlined in Section 3.1, focused primarily on medical issues or radon measurements and mapping. In terms of social scientific engagement with the topic, there is however almost no literature available. Our literature review identified only one academic author working in the field of social science and humanities addressing the topic of radon spas: Barbra Erickson, who conducted and published work on the topic at the turn of the 21st century (2004, 2007a,b,c).[1]

Using the notion of medical pluralism as a framework, Erickson (2007b) discussed the controversial nature of radon therapy and why individuals continue to seek it despite radon's classification as a carcinogen. Erickson summarised her experiences from visits to several radon medical treatment facilities. Her research included 'self-help' radon health mines in Montana (USA), where clients breathe radon-rich air, as well as radon spas in Austria, Germany and the Czech Republic. Although her paper (2007b) lacks an extensive description of the methods used, Erickson conducted interviews with clients/patients of these facilities and analysed demographic data collected from client file cards maintained by staff at a health mine in Montana.

Erickson (2007a) also published the results of a qualitative study based on loosely structured and open-ended interviews with 62 self-identified individuals with arthritis (36 women and 26 men), aged 60 to 92 years, conducted between 1997 and 2002. Generally, the participants believed that radon therapy was an acceptable treatment choice for arthritis. They perceived benefits such as more effective pain relief, avoidance of medication side effects, lower costs, and improved quality of life. The potential future risk of lung cancer from radon exposure was seen as minimal in comparison to the perceived benefits (Ibid.).

In a third article, Erickson (2007c) summarises the results of (the seemingly same) interviews with 64 clients of 'radon health mines' conducted in Montana (USA) between 1997 and 2000. The study relies heavily on unstructured or loosely structured interviews with an approximately equal number of men and women. Most interviews took place while the subjects were undergoing their self-help treatments, in most cases at the Free Enterprise Mine facility. In addition to these interviews, the research included a questionnaire distributed by the Free Enterprise Mine owner in the researcher's absence and an analysis

[1] A separate review of the studies by Erickson quoted in this section, in particular from the perspective of SSH methods applied in her research, has already been published in RadoNorm Deliverable 6.1 (Tomkiv et al., 2021, pp. 146–147).

of demographic data from client file cards maintained by the mine's staff. The self-identified health issues reported by the study participants included various types of arthritis (61%), skin conditions (4%), respiratory conditions (22%), neck and back pain (8%), and other conditions such as lupus, chronic fatigue syndrome, high blood pressure, diabetes, and thyroid conditions (5%). Participants perceived the potential future risk of lung cancer from radon exposure as minimal compared to the perceived health benefits. A specific aspect of the 'radon therapy/spa controversy' noted by the author was that "fear about [breathing] radon [rich air] and its possible health risks seemed to have little influence on the decision-making processes" (Ibid.) of the participants. This finding is particularly interesting given that 22% of the participants sought to self-treat their 'respiratory conditions' by breathing radon-rich air.

During the literature review, we identified a significant number of articles discussing the Linear No Threshold (LNT) and hormesis hypotheses, which often explicitly or implicitly reference also radon spas and/or radon medical treatments. However, due to the scope of the RadoNorm project's research on the 'radon spa controversy' – including the restriction of research methods to those used in SSH – this medical science literature is not discussed in this Deliverable.

Worthwhile to note, is that our literature review yielded two lines of argument regarding the historical context and justification of radon spas. One line of argument relates to the presumption that the beneficial health effects of radon at ancient spas were likely known and utilised only indirectly, that is, without any awareness of radon and its possible health impacts. It was not until the early 20th century, possibly due to unintentional discoveries, that initial publications on radon in spa waters emerged. In this context, radon was initially presented to the public as a component of spa waters potentially contributing to the historically noted, though scientifically unexplained, therapeutic effects of bathing in these waters (Lettner et al., 2017; Becker, 2004). Another line of argument relates to the emphasis that Lettner et al. (2017) placed on stating that "the interest in radon therapy had little or no relation to the popular fashion between about 1910 and 1940, mostly in Europe, to attribute a multitude of healing powers to radium". Perhaps due to the limitations of scientific knowledge at that time, the usage of radium was potentially viewed as emblematic of modernity, with its purported health benefits being widely accepted without sufficient scientifically valid evidence.

Finally, regarding non-academic literature on radon spas, it is worth noting the self-published book by Liechti (2020), titled *Radon Spas and Health Mines: Worldwide Review of Radon Therapy*. In this non-academic book, the author presents an overview of various radon spas and related facilities around the world and delves also in topics such as the applications and potential benefits and risks of radon spas.

2.2 Legal context

As part of the preparatory activities for the RadoNorm project, attention was directed at an analysis and comparison of the regulatory frameworks governing the public health use of bathing in radon-rich water. Focus was put on six Central and Eastern European Union member states: Austria, the Czech Republic, Germany, Hungary, Poland, and Slovakia. These six countries were intentionally selected due to their shared or similar historical and cultural traditions of spa development and their current inclusion of spas in public health insurance systems.

Attention was exclusively directed at the practice of bathing in radon-rich waters, deliberately excluding other radon spa procedures, such as short-term inhalation of radon-rich air under controlled conditions or the consumption of radon-rich waters. This specific focus was chosen to ensure a more targeted and comparable analysis across the selected countries, aligning with the European conceptualisation of a spa, which traditionally emphasises balneotherapy.

The key finding was that all these six countries have legally binding regulatory frameworks allowing for-profit enterprises to administer and promote bathing in radon-rich waters as a legally recognised medical therapy.

Five of the six countries (excluding Hungary) base their frameworks on establishing minimum radon content thresholds for water to qualify for medical use:

- Czech Republic: 1500 Bq/L (Goliáš et al., 2022, 2016),
- Germany (The European Committee of the Regions, 2024),
- Austria: 370 Bq/L (Ritter and Gaisberger, 2020),
- Poland: 74 Bq/L (Szabó, 2023).

The substantial disparity in these threshold values raises questions about the scientific basis for these regulations and suggests potential influence from political negotiations.

Hungary employs a unique approach, assessing whether the medical benefits primarily derive from high radon content or other therapeutic components.

Furthermore, the federal systems in Austria and Germany add specific complexity to this topic, as spa and healthcare regulations can vary between individual states (Länder). Finally, given the nature of our engagement with this topic (desktop research), a need seems to persist for future research which would be based on primary field research to fully understand the legal and political contexts behind the disparate threshold values. This latter point was considered to be beyond the scope of our research task.

It is noteworthy that, according to Council Directive 2013/59/Euratom, employees of radon spas and healing caves in Austria, the Czech Republic, and Germany are treated as being in a planned exposure situation if radon concentrations at their working please exceed the reference level. In such cases, radiation protection authorities provide specific regulatory guidance based on workplace categories. These spa facilities are required to implement measures to reduce radon concentrations at workplace. If, despite these measures, the reference level measured at the working place in radon spa or healing cave is still exceeded, the effective dose of radon exposure for workers must be estimated. These workplaces must be registered with the authorities, and radon exposure for each worker must be regularly measured. Workers in radon spas and healing caves undergo routine monitoring to assess their exposure to radioactivity during the performance of their duties (Council Directive 2013/59/Euratom).

2.3 Ethical and scientific challenges

An earlier publication (Mihók 2021) provides an overview of desk research results concerning potential ethical and scientific challenges related to the research conducted in Subtask 6.4.3 of the RadoNorm project. For a full overview of ethical and scientific challenges, we refer to this publication, but below, a summarising overview of the main issues is presented. Specific attention is directed at the challenges faced by applied social science research on radon spas' English-language marketing activities on the internet.

The quoted article outlined four groups of challenges for the research envisioned in the RadoNorm project concerning radon spas:

- **Theoretical challenges**: Difficulties in defining and positioning radon spa treatments within broader concepts of health, medical, and wellness tourism. The interdisciplinary nature of the subject, spanning social sciences, medical sciences, and radiation protection, complicates the establishment of a clear theoretical framework.

- **Methodological and practical challenges**: Restrictions in some countries on combining social science and medical research, limiting the scope of interdisciplinary research and hindering comprehensive analysis of radon spa marketing practices.
- **Cultural and legal considerations**: The need to understand the varying legal and cultural approaches to radon medical therapy at spas across different countries.
- **Ethical considerations**: Concerns about researching potentially vulnerable spa clients seeking treatment for chronic conditions.

The quoted article also briefly discusses the notable lack of existing academic publications on radon spas from a social science perspective (dealt with in section 2.1 and Deliverable 6.1. by Tomkiv et. al. (2021)). Given this variety of potential ethical challenges characterising SSH research on radon spas, extensive attention was directed at continuous reflection and discussion regarding research ethics when conducting empirical work in subtask 6.4.3, inter alia through continuous interactions with the RadoNorm ethics committee (see also chapter 3 of this Deliverable).

2.4 Ethical risk communication

In the past, risk communication was primarily regarded as a technical endeavour aimed at educating the public about risk estimates. Over time, it evolved into a marketing strategy designed to persuade individuals to accept specific messages. Today, risk communication is viewed as a socio-centric process that emphasises public participation to bridge gaps between stakeholders and support informed decision-making (Perko, 2015). In the context of indoor radon, this approach should aim to empower individuals and communities to make decisions based on a comprehensive understanding of context related to both the cancer risks associated with radon exposure and the purported health benefits claimed by radon spas. The primary goal of risk communication about radon is, therefore, to enable informed decision-making despite the complexity of the risk, differing perceptions, and the existing controversy involving multiple perspectives.

Effective risk communication must be ethical, necessitating the consideration of values and the making of decisions in a democratic way. Ensuring diversity of views and stakeholder participation are essential to prevent the exclusion of any individuals or groups who have a stake in or make decisions regarding indoor radon, for instance whether they should test and mitigate their dwelling and/or undergo a treatment in a radon spa. The process must be legitimate, involving proper procedures for discussing the values and emotions linked to the radon risk and benefits of radon, and ethically justified, including ethical deliberation about these values and emotions. Additionally, the outcomes of communication should be thoroughly addressed, balancing the contrasting views to provide a clear and comprehensive perspective on radon risks and benefits.

Given that human behaviour is largely influenced by perception rather than facts (Renn, 2008), understanding risk perception is crucial for developing effective risk communication strategies about radon. By addressing how people perceive the risks and benefits of radon, communicators can better convey information that addresses public beliefs and concerns, and that supports informed decision-making. This approach ultimately leads to more effective and inclusive outcomes, ensuring that individuals and communities are well-informed about the true nature of radon risks and benefits in different contexts, enabling them to make sound decisions about their health and safety. The interpretation of physical threats, such as those posed by indoor radon, is not solely a subjective process undertaken by individuals; it is also heavily influenced by shared societal factors such as lifestyle, traditions, worldview, norms, values, institutions, and mass media. Consequently, addressing the controversy surrounding indoor radon in communication efforts is crucial to support informed decision-making and facilitate collective or institutional actions if needed.

In this context, it is of utmost importance to understand the interaction between psychology, sociology, anthropology, and communications theory influencing decision-making. The concept of social amplification and attenuation of risk allows to understand that within a single risk, such as the debate over indoor radon, some groups may amplify their perception of risks, while others may downplay or decrease it. The "Social Amplification of Risk Framework" (SARF) (Kasperson, 1988) aims to explain how risk communication travels from the sender through various intermediaries to the receiver, affecting the amplification or attenuation of risk perceptions. Each link in the communication chain – whether individuals, groups, or the media – acts as a filter through which information is processed and understood. In the context of radon, which is both recognised as a carcinogen and promoted in radon spas for purported health benefits, SARF is particularly relevant. The core thesis of SARF posits that risk interacts with psychological, social, and cultural factors, leading to an increase or decrease in public risk perceptions. The behaviours of individuals and groups in response to these perceptions can generate secondary social or economic impacts and can also influence the physical risk itself.

Radon risk communication should therefore elucidate how risks are either amplified, gaining significant public attention, or attenuated, receiving less attention. It should recognise radon risk as a complex phenomenon involving both biophysical attributes and social dimensions.

2.5 Distinguishing between radon spas, healing caves and non-spa facilities providing radon therapy

The research addressed in this Deliverable would benefit from a clear distinction between radon spas and non-spa facilities providing radon medical therapy. However, the initial desk research resulted in the finding that the term 'spa' was frequently used in academic literature without any definition. Furthermore, the results of this study suggest that there may be significant differences in existing definitions of this term.

The situation referred above was addressed in research conducted at Matej Bel University, with the aim to provide clarity on this matter. The results of this research activity were published as an article in the *International Journal of Spa and Wellness* by Mihók and Marčeková (2022). This article summarised the current state-of-the-art in an ongoing debate concerning a lack of consensus regarding the definition of the term 'spa' and related terms ('wellness', 'spa tourism', 'medical tourism', etc.). Research results revealed that the ambiguity related to the term ‘spa’ extends to the concept of spa tourism and its positioning within the broader framework of health tourism.

Desk research elucidated how European perspectives on spas tend to emphasise the presence of mineral or thermal waters and their therapeutic uses. The European Spa Association (ESPA) includes radon therapy among the remedies relevant to spas, listing "healing gases and mofetta" as one of the key elements. This approach aligns more closely with the traditional concept of spas as well as with the historical context of radon spas’ existence referred in Section 2.1. In contrast, the International Spa Association (ISPA) adopts a broader definition that focuses on overall well-being without necessarily requiring the presence of mineral or thermal waters. This definition could potentially encompass non-spa facilities providing radon medical therapy.

Furthermore, it was found that non-spa facilities providing radon medical therapy might be classified more correctly under the medical tourism category than under the spa tourism category. The important aspect in this regard is whether, on top of radon medical therapy, such facilities also offer other relevant spa services considered as essential by ESPA. However, under the concept adopted by ISPA, all facilities identified to offer radon medical treatments might potentially be referred to as spas, because their purpose is to support overall well-being, even though if solely by attempts to reduce for example chronical pain or chronical skin issues.

Furthermore, it is worth noting that Obodovskiy (2023) uses the term "radon hospitals" to refer, in effect, mostly to radon spas. This publication, however, also briefly explains that radon medical therapy is typically part of a spa system where various healing waters with different compositions are used.

Lastly, we have noted there may be some regional variations or exceptions with regard to the use of the term, prefix and/or suffix "Bad", respectively “bad” in the names of spa towns and/or spas in Austria and Germany.

Given all the aforementioned considerations, we have determined that, for the pragmatic purpose of enhancing readability, it is not scientifically unsound to designate all establishments who self-identified as offering radon-based medical treatments as 'radon spas'. This nomenclature is employed solely to facilitate comprehension of this report. It should be noted that our use of this term does not in any way seek to contravene extant national legislation that may differentiate between spa and non-spa facilities.

3. Methods

3.1 Academic literature search

A literature search of English language academic studies specifically dedicated to radon spas was conducted in light of the systematic review whose results were published by Tomkiv et el. (2021). This review was conducted by using the Web of Science™ and Scopus® databases and the search terms: '"radon spa" OR "radon bath" OR "radon therapy"' (Ibid., p. 146).

3.2 Framing analysis of radon spa websites

A frame analysis of radon spa websites was conducted to gain insight in the way in which these spas framed radon in their public communication. Framing in this context refers to the idea that certain aspects of a reality are selected in order to make "them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described" (Entman, 1993: 52). As such, frames are not just a mere 'representation' of reality, but actively contribute to the enactment of this reality. Moreover, this enactment of various realities is omnipresent, as communication always entails some forms of framing.

3.2.1 Identification of radon spas, healing caves and relevant non-spa facilities

The identification of radon spa websites happened through a combination of search strategies. An initial list of radon spas was obtained from the website of the European Association of Radon Spas EURADON. This list was extended using an elaborate internet search, combining a standard search engine (google.com) and the search function of a travel website (tripadvisor.com). On this travel website, reviews of facilities and activities were searched for the word "radon," which generated over 120 hits. Different partners within the RadoNorm project have also been enquired whether they had knowledge of any radon spa or a similar facility in their respective countries (Geysmans et al., 2021).

Only spas in the EU were included. Other inclusion criteria entailed that the spa needed to offer at least one service linked to radon (e.g. bathing in radon-rich waters, inhalation of radon-rich air, etc.) and that the spa had a publicly available website on which these services were presented in English and/or German.

Eventually, 26 radon spa websites were identified and selected for analysis.

3.2.2 Framing analysis

The websites referred in Section 3.2.1 were studied in two interconnected phases. In the inductive phase, a hermeneutic approach was used to identify radon frames (Schäfer and O'Neill, 2017). This was followed by a second, deductive phase, in which another set of researchers checked the found frames against an extended dataset of websites. In both phases, multiple coders were involved, in order to minimise the influence of researchers' own mental constructs on the identification of a frame (Van Gorp and Vercruysse, 2012).

In the inductive phase, 17 radon spa websites were used for the first, bottom-up identification of frames, focusing on websites which had an English version available. A double-coder strategy was used in order to minimise the arbitrariness and subjectivity often connected to inductive hermeneutic frame analysis (Matthes and Kohring, 2008; Van Gorp, 2005). Two research assistants carefully and independently read selected websites, considering both textual and visual elements. Particular attention was directed at how the websites defined or described radon and the radon-related services offered by the spa. The coders were asked to identify references to or depictions of radon, treatments, target audiences, effects (benefits or risks), and the broader facility and its surroundings. Based on the combined findings of both

coders, the principal investigators identified five frames through which radon is presented on the analysed websites.

In the deductive phase, these identified frames were put to the test, by having a second set of coders check for their prevalence on an extended list of websites (N = 26), also containing webpages in German. A training was provided to the coders, to familiarise them with the five frames. Key questions were provided for each frame, facilitating the process of identification. For the framing of radon as a healing source, for example, these questions were “is there any mentioning of health benefits of radon?”, “is there any mentioning of diseases or conditions which can be treated?” “Are there any depictions of health/medical related persons, objects, or other visuals (e.g. doctor’s coats, epicurean symbols)?” This second round of analysis confirmed the five frames identified.

It should be noted that between the first, inductive phase of the analysis, and the second phase, some websites had been updated and adapted.

To ensure full anonymity, quotes from websites were presented without mentioning specific spa names, but instead letters (A – Z) were used to represent each spa in a dataset. German quotes have been translated into English (Geysmans et al., 2021).

3.3 Semi-structured interviews in Austria and Germany

In order to gain a better understanding of how different stakeholders perceive radon spas, their services, and the role of radon therein, and how they relate to the potential controversy between radon as a threat and radon as a treatment, semi-structured interviews were conducted in Germany and Austria. Two main stakeholder groups were targeted. The first group encompasses spa employees and management, the second group consists of radon authorities and scientists.

16 semi-structured interviews were conducted in total (11 interviews with respondents in Austria and 5 with respondents from Germany)[2]. 14 interviews were conducted during the summer of 2023, all in German and 2 interviews were conducted in summer 2024, in English. Interview length varied between 11 minutes and 67 minutes, with an average duration of 32 minutes.

For the first stakeholder group, 11 semi-structured interviews were conducted. Within this group, four respondents were associated with spas using 'de-radonised' thermal water, while seven were connected to facilities offering radon baths or radon tunnels. Among those linked to radon medical facilities, the respondents included a radon medical/spa facility manager, a spa manager, a spa and tourism company manager, a spa doctor, a spa nurse/therapist, a spa receptionist, as well as a frequent visitor that was also providing some voluntary work for a radon spa.

For the second stakeholder group, 5 interviews were conducted. Within this group, four respondents work in governmental organizations as radon experts (national or regional level) and one respondent works at university as a researcher.

The protocols used to guide the interviews can be found in Appendix B. Informed consent from all respondents was obtained in writing or orally (on record). Interviews were audio-recorded and fully transcribed. Interviews in German were subsequently translated in English. The data collected through these semi-structured interviews was subjected to a rigorous thematic analysis to identify key themes and patterns emerging from the respondents' responses, without any intention of pursuing a comparative analysis between the Austrian and German stakeholders. Coding was conducted with the help of NVivo software.

[2] 14 out of 16 interviews have been conducted and transcribed by job student Katrin Hirtenlehner, employed by AGES

To ensure the full anonymity of interview respondents throughout all phases of analysis and results reporting, each participant was assigned a random numerical identifier. Respondents are referred to only by these identifiers (e.g., "Respondent 1," "Respondent 2", etc.) in all documentation and findings. This approach safeguards the confidentiality of participants while allowing for clear and consistent reference to individual respondents.

3.4 Public attitudes and beliefs related to radon in spas and healing caves investigated by the RadoNorm survey

Insights in awareness and perceptions about radon spas among the German, Austrian and Czech general public were obtained through nationally representative surveys. In particular, specific questions were added in Germany, Austria and Czech Republic to the broader surveys which were conducted in the context of the RadoNorm European Radon Behavioural Atlas (Perko et al., 2024). Among others, this behavioural atlas aims to provide information on national populations' risk perceptions, confidence in authorities for risk management, radon awareness and salience, general radiation knowledge, and other related issues.

Data was collected through a Computer Assisted Web Interview (CAWI) approach, conducted over the period from May 2023 to March 2024.

In Austria, the sample consisted of 1,394 respondents, in Germany of 1,263 respondents, and in the Czech Republic of 1,029 respondents. In Austria and Germany, the participants were randomly selected from existing survey panels. In the Czech Republic, the respondents were drawn from the participants of the national radon measurement campaign. Most survey items are formulated as questions or statements, with answering categories expressed by using Likert-scales adjusted to the context of the statement or question. Agreement with a statement is typically measured on a scale ranging from "strongly disagree", to "disagree", "neither agree nor disagree", "agree", to "strongly agree". The answering category "Other" was included for all closed questions with predefined answering options to ensure completeness. The options "no answer" or "I don't know" were also available. Knowledge items were measured with "agree" and "disagree" responses.

The questionnaire also included sociodemographic characteristics such as gender, year of birth, age, education, family composition, and dwelling-related information.

The survey included an informed consent and the RadoNorm ethical committee provided ethical oversight over the study.

3.5 Research ethics

This study was overseen by the RadoNorm Ethics Committee, which also provided ethical guidance on all research protocols and dilemmas.

In addition, the publication of an open-access article by Mihók (2021), referenced in Section 2.3, introduced the intended research in Subtask 6.4.3 of the RadoNorm project, its challenges, and its ethical aspects. In addition to fostering transparency about the planned research in RadoNorm at the earliest opportunity, this publication also initiated an internal discussion on the ethical issues related to the research.

To uphold ethical standards, internal training on the ethical aspects of research was conducted during RadoNorm's 3rd Annual Meeting in September 2023 in Ustroń, Poland. This mandatory training for all RadoNorm researchers utilised the research task concerning radon spas as a primary empirical example to address the ethical challenges associated with SSH research related to radon. Specific attention was

directed at the need for strict informed consent of research participants, confidentiality in data management and reporting, and the importance of avoiding questions related to personal medical information.

4. Results

This section presents the relevant research results from RadoNorm Subtask 6.4.3. The structure follows the individual research activities. To ensure that this deliverable functions as a standalone document, Sections 4.1.1 and 4.1.2 present the full results section from the article by Geysmans et al. (2022).

4.1 Framing analysis on radon spa websites

4.1.1 Identification of radon spas and relevant facilities in the EU

Using the method outlined in Section 3.2.1, the websites of 26 different radon spas were identified within the EU to advertise services claiming health benefits from radon, in either English or German. Nine radon spas were identified in Germany, seven in Austria, two each in Bulgaria, Italy, and Poland, and one each in Croatia, the Czech Republic, Greece, Hungary, and Italy.

These 26 identified spas are referred to by letters (A – Z) when quoting text from their websites. Original texts in German are quoted in their English translations.

4.1.2 Framing analysis[3]

Using the method described in Section 3.2.2, a framing analysis of the texts on the websites of the 26 radon spas referred in the previous section identified five key frames that presented radon as:

- a source of health,
- a natural gas,
- a (non) risk,
- a luxury, and
- a fountain of youth.

These five, sometimes overlapping, frames are discussed in detail below.

4.1.2.1 Radon as a Source of Health

On all websites which were analysed, radon was framed as a source of health, meaning that it was presented as something which would alleviate or even cure several diseases and health related discomforts. By being exposed to radon, visitors could, for example, benefit from its “effective pain relief and anti-inflammation” (Spa B) or its claimed positive influence on “disorders of the locomotor system and asthma” (Spa L), to name only a few of the medicinal powers attributed to radon by the analysed websites. This frame is supported by various visuals, depicting what seem to be medical settings, in which spa visitors are consulting or being treated by people wearing doctors’ coats or nurses’ uniforms.

To legitimise the idea of radon as a source of health, this frame builds on two strategies. First, it connects radon’s claimed health benefits to science. Here, legitimacy is drawn from references to scientific proof provided by experiments, double blind studies, or significant numbers of scientific publications. Visitors to the website of radon spa Y can, for example, learn how “various studies indicate a pain-relieving and anti-inflammatory effect of radon,” and spa A states how through “precisely controlled double-blind studies, in which neither the patients nor the examining doctors knew which patient received radon and

[3] This text has previously been published in Geysmans et al. (2022)

which did not, its therapeutic effectiveness was substantiated." These framing devices emphasise empiricism and rationality, and as such help communicate the notion of radon as a legitimate medicine. These calls to empiricism and scientific rationality are in many ways similar to the historical ways in which modern medicine gained legitimacy (Weatherall, 1996). A second strategy for legitimising radon as a healing source, is through emphasising the long periods of time over which radon has been attributed with/used because of its healing powers. By illustrating how radon "has been valued as a remedy for over a century" (Spa X) and how "local miners knew this in 1900, when they healed their wounds by immersing them in this "magical water" (Spa R), legitimation is sought in historical narrative and tradition.

4.1.2.2 Radon as a Natural Gas

A second frame, found on 25 out of 26 websites, presents radon as a natural gas, by highlighting its natural origins and characteristics. Visually, this frame is supported by pictures of wide landscapes, mountains and rocks, caves and mines, lakes, springs or rivers. Radon is often described as a natural remedy or a treasure of nature, and emphasis is put on its presence in "natural springs" (e.g., Spa K) or in "air and earth" (Spa Y). Its origins are described as laying in "the entrails of the earth" (Spa M), or – more elaborately – as the consequence of "a series of successful geological processes over a considerable period of several million years" (Spa E).

4.1.2.3 Radon as a (Non) Risk

A third frame relates radon to the presence and/or absence of risk. On 16 out of 26 websites, radon and/or radon therapies are framed as risky or containing a certain need for precaution. The website of Spa C, for example, reads how "radioactive radiation in high doses can cause cancer or harm unborn babies in the womb, and also Spa W mentions "the fact that high doses pose an undisputed risk of lung cancer." However, references to (lung) cancer are rather rare (only being mentioned on three websites), and most websites frame risk in much more implicit terms. In these more implicit framings, the risk of radon is brought forward by mentioning that therapies can only be taken after a doctor's visit, or by excluding certain groups (e.g. pregnant women) from radon therapy. Why this doctor's visit is necessary or why these groups cannot be exposed to radon is not explained. As such, what the risk exactly entails remains unclear. Visually, the framing of radon as a risk is not supported (except on one website which warns pregnant women that they cannot take radon therapy).

Moreover, on 9 out of 16 websites which frame radon as risky, a counter-frame is also presented which minimises the risk or reassures the reader that there is no need to worry. In addition, two websites provide only such reassurance, without a reference to potential risk as such. In some cases, such reassurance is provided through reference to a form of external control or oversight. Spa B, for example, states that it "has all the necessary radiation protection permits" and Spa M highlights how "as part of the regular measurement of air by [the national nuclear regulatory authority] it was found that [...] one person could pass more than 800 baths per year to reach the maximum limit of inhaled radon in these areas." In other cases, the reader more explicitly has to trust on the claims and expertise of the spa and its staff. Statements like "radon treatment has no side effects", "the best cure taken in excess is harmful and dangerous poison applied in minimum amounts becomes the cure" (Spa L) or "radon therapy [...] is naturally gentle and without known side effects" (Spa U) are telling in this sense.

4.1.2.4 Radon as a Luxury

A fourth frame presents radon as a luxury and was encountered on 21 out of 26 websites. The framing devices coded under this frame refer to radon as an exclusive substance, with unique and desirable characteristics or a rare prevalence. As such, being able to be exposed to and benefit from radon is a luxury and visiting a radon spa makes this splendour accessible and affordable. Radon provides a sort of unique selling proposition to the radon spa: on the analysed websites, links are regularly drawn between the spa, its location and its access to/use of radon in order to highlight its uniqueness and desirability, thus setting it apart from potential competitors. The exclusive character of radon is

emphasised by quotes such as “the rare noble gas radon is one of the most effective remedies in spa science” (Spa C), “the ionisation, the mineral salt content, and the special gases and metals also make the water so distinct” (Spa P) or “the unique combination of the precious and rare noble gas radon and the cold chamber, as a non-drug form of pain therapy, are proving to be our recipe for success” (Spa F).

Furthermore, radon is often referred to as a natural noble gas on the analysed websites. Obviously, the “noble” in this context can be interpreted as referring to is classification as a chemical element. Radon is one of seven noble gases listed in the periodic table, which all share similar properties, e.g., a very low chemical reactivity. The sheer multitude of references to the “noble” gas is, however, striking. This multiple mentioning of “noble” hints at another meaning of the word: something which is “grand,” “majestic” or of high quality, hence implicitly strengthening the framing of radon as a luxury.

Finally, a visit to the radon spa is also presented by some analysed websites as an indulgence because of the relaxing, luxurious and comfortable atmosphere offered. Spa H, for example, seduces customers with the catchword “let us pamper you” and Spa L quite lyrically targets potential customers by stating that “in a specific atmosphere of a picturesque gallery, lying comfortably, being protected against excessive chill and listening to relaxing music you have an opportunity to breathe in cold and humid air.” In these instances, an implicit link is made between radon and the treat of visiting a lush spa, thus also reinforcing the framing of radon as a unique luxury, an exclusivity. This frame is further supported by numerous visuals of inviting spa environments with marble interiors, tempting pools and happy people indulging in different spa treatments.

4.1.2.5 Radon as a Fountain of Youth

Finally, on half of the websites, radon is framed as a fountain of youth. This fifth frame on first sight is closely related to the first frame in which radon is presented as a healing source. Indeed, here as well reference is made to the beneficial powers of radon, but this time emphasis is not so much on healing, but rather – arguably taking this a step further – on rejuvenation. Radon makes you young (again), it revitalises your body and provides strength. Websites talk about “regaining vitality” (Spa D), the “radon fountain of youth” (Spa F), a “rejuvenating effect” (Spa I), or how “radon accelerates the renewal processes in tissues” (Spa K).

Visually, this frame is supported by numerous pictures of young people taking baths and other radon therapies” (Ibid.). This use of young people in visual materials is particularly noteworthy because we can assume that these are not the prime clientele of the spas. In a study on visitors of a radon health mine in Montana (United States), Erickson (2007c) noted how 84% of the more than 800 visitors she analysed were aged 60 years or older.

4.2 Semi-structured interviews in Austria and Germany

This section provides a structured overview of the outcomes from the semi-structured interviews discussed in Section 3.3.

Research findings are organised as follows:

- Results of stakeholder group 1 (section 4.2.1)
  - Perceptions of radon spas
  - Awareness about radon
  - Perceptions of radon, including its health benefits and risks
  - Perceptions of the “radon spa controversy”
- Results of stakeholder group 2 (section 4.2.2)
  - Perceptions of radon spas
  - Perceptions of radon, including its health benefits and radon as manageable risk

- Perceptions of the “radon spa controversy”

To illustrate the breadth and diversity of respondents' perceptions and opinions, verbatim quotes are also included, for example to exemplify key themes that resulted from the thematic analysis. As noted, to ensure the full anonymity of interview respondents, they are referred to only by numeric identifiers (e.g., "Respondent 1," "Respondent 2," etc.).

4.2.1 Results related to stakeholder group 1 (workers)

4.2.1.1 Perceptions of radon spas

For those working in a spa with de-radonised water, the main perception of their specific spa is that it is a place of leisure, closely tied to the history and locality of the community (many local people learned to swim there, for example). Visitors are thought to come there to relax, enjoy their time, and potentially do some sports/get fit. The healing potential of the (de-radonised) thermal water is mentioned by some, but is more perceived as a ‘side-effect’, rather than really being at the core of the spa.

“*Of course, the health aspect has always run parallel with this for us, because the thermal water - without radon, we'll talk about that later anyway - the thermal water has a healing effect also for leisure guests, and that's the case with us too, it has always been advertised and communicated. Because with us you can actually combine both things very well: leisure fun and also the health aspect*” (Respondent 1).

This is different for those working in spas with radon baths and/or radon tunnels. In these facilities, the emphasis is put first and foremost on the health aspect. In those cases, respondents refer to the facilities much more in terms of treatments and medical therapies, rather than wellness or leisure (only in some cases, the word ‘spa’ is used). This link to medical treatments is also emphasised by pointing out e.g. connections to insurance companies who refund visits to the facility or referring to the referral and follow-up of visitors by medical personnel.

“*A classic hotel business and also a state-certified pool operation. Mainly for private treatments, but also with direct billing with an Austrian health insurance fund and two German health insurance funds*” (Respondent 3).

Interestingly, visitors are in some instances not just referred to as ‘clients’ but also as ‘patients’.

“*Our health resort is a centre for the musculoskeletal system. So, we don't have rehabilitation status, but rather we are a so-called health resort. This means that we have patients here who are taking a treatment from the* [name insurance company], *from the* [name insurance company*], or the new treatment from the* [name insurance company]” (Respondent 7).

In some cases, it is recognised that the treatments offered are comfortable, or that a pleasant, leisure-like atmosphere is created, to make the visit to the spa enjoyable.

“*And there are very nice people there who welcome the patients when they register. Everything is going smoothly. New loungers have been purchased over the years and are very comfortable. With a thick cushion so that you can lie there for a good hour - the treatment always lasts an hour - especially if you have a back problem. And you also have the option of borrowing books there. So, it's really, I'll say... you can lie down on the loungers in comfortable street clothes*” (Respondent 10).

According to some, this nice and comfortable atmosphere also sets a particular spa in a more advantageous position in comparison to other treatment facilities.

“*And we're pretty much at the top in [name country] because our facility is a bit smaller. We have around 150 spa guests and around 100 private guests. If a facility is a little smaller, it's a little more family-like. You are perceived as a human being, and with us people always have the feeling that everyone has time. Here I can talk, here I can say whatever I want. That's exactly what people often miss*” (Respondent

5).

However, the nice and comfortable atmosphere is an add-on. The core of the identity of the radon spa facility according to our respondents are the treatments and health services offered in the facility. Or as one of the respondents put it: "*you have the feeling that it's wellness - but it's not, it's a medical treatment*" (Respondent 9).

In terms of treatments, a distinction can be made between radon-related services offered at the spas, and non-radon related services. In terms of non-radon related services, there is a wide variety of services offered in some spas, ranging from whirlpools in de-radonised water, to massages, physiotherapy or electrotherapy. Some of the spas offering radon treatments also provide such non-radon related services, but in other instances, radon-related treatments are the only service offered.

Radon-related treatments come in two main ways: in the form of radon baths and in the form of radon inhalation spaces/tunnels. In the former case, people sit in water, which is stated to be rich in radon, while in the latter case, they are exposed to radon through the air in an enclosed space (in the cases we encountered: tunnels in a mountain, used in previous times as mining sites). Spas offering radon baths in some cases also offered different sorts of baths, e.g. 'vapour baths' or 'hydroxeurs', 'bubbling' baths or 'quiet' baths. Interestingly, there were some differing views expressed by respondents in terms of how respondents exposed themselves to radon. While some respondents emphasised that such exposure would happen through inhalation and through the skin (by sitting in radon rich water), others claimed that such absorption through the skin was not possible, and only happened through inhalation.

"*It is also a fact that, on the one hand, the radon is absorbed through the skin when I sit in the water. And the second route of absorption into the body is through the respiratory tract. This means that if it bubbles out a bit, it also enters the body via the respiratory tract. And then there is the discussion: What is better? The quiet radon bath or the air pearl bath? The theory behind the air bubble bath is that the slight bubbling of the water changes the skin's resistance, so that the skin absorbs the radon better*" (Respondent 7).

"*And yes, there are radon baths too, and they definitely work. But it is a misconception that the water has any healing properties. The water has an additional pleasant, relaxing effect* […] *the effect of radon baths in terms of radon content is solely that radon gas is released from the water when you splash around and is inhaled. And that is the radon effect*" (Respondent 9).

4.2.1.2 Radon awareness

All respondents in category 1 were aware about radon, which is of course not surprising given the selection of respondents based on their association with radon spas. What was however noteworthy, was that on numerous occasions, respondents in one way or another made statements in which they referred to their self-perceived limited knowledge on the subject. Often, this was done in a context of stating that they were not a chemist, a physicist, a medical professional or any other 'expert', but had knowledge to an extent that fitted their experience and/or professional activities.

"*I'm not a doctor, I'm a lawyer; But all I understood about it: There are all sorts of scientific side effects with T M S, Alpha, Beta, Hema, and what not, I don't know everything. I understand far too little about it that I would like to give a lecture on it*" (Respondent 9).

"*[Interviewer]: Do you know anything about radon? [Respondent]: Yes and no. So, radon… we, we live with it, we grow up with it. We know that radon is in our environment*" (Respondent 6).

When then probing on what they knew about radon, mostly recurring in respondents' descriptions of radon was that it is a radioactive gas. Also references to radon being odourless and colourless were mentioned by various respondents, as well as it being a natural gas and a noble gas. Some respondents provide some more detailed descriptions, mentioning for example how radon is an alpha emitter, that it

is a decay product of radium and uranium, or that it has a very short half-life. Remarkably, in one instance, radon was also referred to as a 'valuable' gas ("*there is this valuable radon gas in this healing tunnel*" – Respondent 8). Also, several respondents explicitly connected radon to the specific locality in which the radon spa they are connected to is situated, hence implicitly making reference to radon prone areas. Finally, in some descriptions of radon, the factual correctness of what respondents said could sometimes be disputed. One respondent for example seemed to make a distinction between 'natural radon' and 'chemically produced radon' ("*And it cannot be compared with chemically produced radon. That's something different, right? So, there is also this nuclear, I would say, chemical history that is used to make weapons of war. But of course, that has nothing to do with it*" – Respondent 8), while another referred to the presence of radon in X-rays ("*And we also know about X-rays, which also contains radon*" – Respondent 2).

4.2.1.3 Perceptions of radon's health benefits and risks

This section provides an overview of respondents' perceptions regarding both the health benefits and risks associated with radon.

Perceptions of radon's health benefits

In terms of how respondents perceived radon, a very dominant view was that radon has – at least in some circumstances – clear healing capacities. A wide range of respondents emphasised how radon can be used for treating certain medical conditions, with chronic pain and (related) inflammations as main conditions mentioned. In some cases, also other conditions, complaints or symptoms were mentioned, ranging from menstrual problems to skincare and nasal polyps.

"*Radon is used for the entire joint support system, really for people who are looking for help. Radon is really a cure for... anti-inflammatory, pain relieving too*" (Respondent 5).

Respondents also attributed more general or abstract characteristics to radon and its healing powers, emphasising how radon "*stimulates the body's own cell metabolism* […] *it renews cells*" (Respondent 3) and "*regenerates*" (Respondent 5).

As a treatment for chronic pains, several respondents highlight how radon exposure can have sustainable positive health effects, but also mention that the timeframes in which these health effects start and how long they last vary from one individual to another. Despite these differences, several respondents perceive a high 'success rate' of people who are positively affected by radon treatments, with numbers of 80% or even 90% of those exposed also experiencing health benefits.

"*Some remain pain-free for two years, others only for six months, but the success rate is almost 90% - so we are at almost 10% where the therapy does not respond*" (Respondent 3).

Interestingly, while such high success rates and positive experiences are mentioned in several interviews, contradictory views seem to exist on the 'scientific' basis of these successes. Almost all respondents explicitly highlight how they have experienced positive health effects of radon, either witnessing these effects among people visiting the radon spa, or even having personally been exposed to radon in the spa.

"*For example, we got three ladies out of wheelchairs with multiple sclerosis. We have regular guests who arrived for the first time with two crutches; Now they go up the mountain and back again. There are people who had special cutlery for their osteoarthritis so that they could eat at all; now they can play the piano again*" (Respondent 3).

"*We do surveys and have done so extensively for several years. And if you want to carry out scientific evaluations, we can also make the questionnaires available, as there are now hundreds of them. And the result is that up to 80% of people say: 'Yes, it helped me. I am completely free of my pain; I'm*

essentially rid of them; or I have to take significantly less painkillers; or no painkillers at all" (Respondent 9).

"*I have to notice for myself when I put my hands in radon water... first of all, I also have a bit of osteoarthritis... so that's also my predisposition. I think it might help me. Exactly… it's good for the skin. And how should I put it... afterwards, I often have the feeling, exactly... like my fingernails often grow faster*" (Respondent 5).

In some cases, such positive experiences are not only connected to what respondents have witnessed or experienced first-hand but are also backed up by historic claims and arguments.

"*It was actually discovered here through mining, through tunnels. In the mining industry, it was the miners who were suddenly healthy again, even though the working world hadn't been so fun before. But then they... various complaints were then alleviated*" (Respondent 1).

"*They did experiments there and discovered that there was a healing effect that was inexplicable at the time. So that people who worked there didn't have certain pain symptoms that others should have had*" (Respondent 9).

And finally, there are those accounts in which perceived health benefits of radon exposure are explicitly linked to scientific studies. In several instances, claims have been brought forward that the positive health effects of radon exposure have been scientifically studied and demonstrated.

"*And we also did this study, we also took part in [name local place]. This was a large study done by [name of study initiator]. From 2009 to 2011 it was, I think. And that's what it was all about. We recruited around 50 or 60 patients from our company, so to speak, and that was also about the question. It was a double-blind study where we looked: Did the patient really experience a lasting reduction in pain in the radon water, or similarly when he was in a normal bath? And it was also found that the patients actually had demonstrably less pain for nine months and also needed fewer painkillers*" (Respondent 7).

"*But it is a good alternative. It is precisely from various studies over the last few decades that it helps for so many people and gives freedom from pain and provides pain relief*" (Respondent 10).

Others, however, disputed the idea that scientific proof currently exists, by stating that no large-scale scientific studies have been conducted on the potential positive health effects of radon exposure.

"*And of course, we have the problem that we cannot prove the benefit in an evidence, i.e. in a randomized double-blind study, according to the current standards of proof of effectiveness. Yes. It's basically a question of faith*" (Respondent 11).

"*There is in fact no truly scientific study to date. There is also a very simple reason: Because none of the others - neither us nor the other radon operators - can afford to spend one or two million euros on a study. That would mean double blind study; scientifically supported for over three years*" (Respondent 9).

Perceptions of radon's health risks

The potential health risks of radon were also discussed in all interviews, but respondents' views on these risks did sometimes differ quite strongly. First, various respondents seemed to be rather sceptical to the risks of radon, and considered this risk not very significant, especially not in the context of radon spas and treatments.

"*Well, I just make sense of it that for me it simply has a positive aspect, and I actually completely suppress the negative. Because, as I said, it can't be that harmful if we actually use it for health*" (Respondent 6).

"*But you can just see the importance of this pain-relieving and anti-inflammatory effect, which is above and beyond what could possibly happen. But where there is no proof either. The only thing that has*

been proven is that it could be that the radon can also accelerate lung cancer somewhere" (Respondent 3).

Other respondents indicated more explicitly that the risks of radon exist, also in the context of radon spas, and that these risks should not be trivialised, and require good risk management. In those instances, respondents highlighted that radon could have negative effects on health.

"*If you use radon for a long time or in high doses... or even worse, if you combine them, long and high doses, it is fatal*" (Respondent 9).

"[Some patients] *also underestimate radon, this therapy*. Interviewer: *To what extent is it underestimated?* Respondent: *Insofar as it's all about radiation*" (Respondent 8).

What seems to be key, and connects the above seemingly differing standpoints on radon, is that radon is considered to be a controllable risk in the context of radon spas. It is all about controlling the exposure, and hence making sure that clients receive the 'right' dose. Control over the radon risk is exerted in various ways, with many respondents pointing to continuous radon measurements in the spa facilities and a strict timing of how long and how often clients can be exposed to radon in the spa.

"*And if we care for outpatients with radon, serial application like this makes sense for six to nine baths, a maximum of twelve, so to speak, in a continuum of several weeks. And then you take another nine-month break because there is a certain amount of radioactive radiation. It is minimal*" (Respondent 7).

"*There is also a measuring station there so that the radon level is not too high*" (Respondent 5).

Furthermore, a range of restrictions regarding who could enter the radon treatments were regularly mentioned. Particular attention was directed at making sure that recent cancer patients were not exposing themselves to a radon treatment, or that pregnant women and children did not enter the treatment facilities.

"*Medical supervision ensures that we do not admit people with counter-symptoms to the therapy and only admit those where there is an indication*" (Respondent 11).

In terms of exerting these controls, strong reference was made to doctors and medical professionals as key gatekeepers. It was repeatedly stated that doctors need to prescribe the radon treatments, that medical personnel follow-up with the patients during the treatment, and that these medical professionals also made sure that the restrictions mentioned above were adhered to. Moreover, it can be remarked that by putting a strong emphasis on the presence of and control exerted by medical professionals in and around the spa, the spas themselves also gain a certain legitimacy.

"*Before a patient even goes into the radon bath, he goes to the doctor. This means that the spa doctor looks at him and his blood pressure is measured. There is also a limit where you say: Okay, beyond this point it no longer makes sense. 160:90 is the limit at which one says: From then on it is better not to take a radon bath anymore, because the radon tends to increase blood pressure and carbon dioxide baths tend to lower blood pressure*" (Respondent 7).

"*Of course, it is strictly monitored there. Health monitored. Every guest, or in this case even more patients, is monitored by a doctor. This is prescribed by a doctor so that no one gets too much of the radon. Only in the form where it is naturally beneficial for health*" (Respondent 1).

As stated, these controls are focused on limiting the dose to which clients of the spas expose themselves, and making sure that exposure is only offered to the 'right' clients (those with specific diseases or complaints and without contra-indications). This latter aspect in the accounts of some respondents also referred to clients with the 'right mindset', meaning that they also needed to believe in the therapy and not be afraid of it.

"*If anyone is so afraid or has even the slightest concern about this radon radiation, then they won't get a radon bath. Because then the treatment makes no sense if he thinks about it all the time: "Is it perhaps negative for me? Could that trigger something in me?"*" (Respondent 7).

"*If someone has really serious concerns or fears, then I would advise against a treatment. Because overall, a successful treatment also lies in the fact that you have a fundamentally positive attitude in your head. And otherwise it makes no sense*" (Respondent 3).

In this context, it is worth noting that various respondents indicated that they regularly did get questions from clients regarding the presence of radon in the spa facilities, the ways in which the radon therapy works and what effects it might have. Interestingly, one respondent, who in another part of the interview referred to people needing to have the right mindset, also made a reference to a need to sometimes 'persuade' (in German: 'Überzeugungsarbeit zu leisten') visitors to a certain extent, in order to let them overcome their concerns or fears.

"*This is associated with radon pollution in houses and so on. And of course, some guests or patients are unsure whether it can be good for them when they hear other things. And doing so much persuasion is the big challenge. I'll do that to some extent*" (Respondent 3).

Zooming in on exposing clients to controlled doses of radon, brings us to a key aspect of how our respondents differentiate radon exposure at the radon spa from exposure in other contexts. Recurring statements were made on how the healing potential of radon is all about attributing the 'right dose'. In most cases, this 'right dose' was not very much specified, but in other cases, specifications were quite detailed, by making statements about maximum (and minimum!) doses for attaining the healing effects of radon.

"*You need a certain minimum dose for therapeutic effectiveness. If you stay below this minimum dose, you will have a radiation effect, but no measurable improvement in your health. And that is the case if you stay below 30,000 Becquerels. Conversely, if the radiation dose is too high, it is of course also undesirable. And the upper limit is 100,000 Becquerels*" (Respondent 9).

By referring to a 'right dose' of radon, respondents extend the issue of radon risk to a broader discussion on what makes something a risk, and how risks and benefits can be assessed. Interestingly, various respondents made the similar statement that in their view it is all about "the dose making the poison" (a statement which is attributed to the medieval Swiss physician Paracelsus, as recognised by some respondents). The notion of 'the dose making the poison' is then used by respondents to argue that in essence anything might have negative effects if used in excessive amounts.

"*But if you look closely, it's not a really deep question, because it actually applies to all forms of application, so if you think about... Yes, you can even do gymnastics in such a way that you get to a critical point...*" (Respondent 11).

"*That's the case with every medicine, it depends on the dose. No matter what you do*" (Respondent 1).

In these conceptions, radon is considered as a medicine similar to other medicines, and hence essentially good, if not used in excessive amounts. Moreover, it might actually replace the excessive use of other medicines, and hence their potential negative side-effects.

"*So that's basically the reason why the tunnel is visited; because the patients have this experience that it helps and that they are also very interested in, for example, not having to constantly use medication for pain therapy, which in many cases also brings with it the risk of side effects such as internal bleeding and the like*" (Respondent 11).

In this sense, using radon treatments in a radon spa can be considered as a cost-benefit assessment, which in view of various respondents tends to favour the use of radon treatments over the use of 'traditional' medicines for at least some medical conditions.

"So again: I don't want to trivialize this, but as a patient you have to weigh it up and say: Do I take painkillers for 30 years, where I'm sure to get some side effects, or do I go to the tunnels once a year. And it cannot be ruled out that there are side effects, but between us; Are they really that great in relation to pain relief, with everything else you experience" (Respondent 9).

Respondents invigorate arguments on the limited health risks of radon if used in 'the right dose' by drawing on comparisons with other potential exposure contexts, thus emphasising the limited negative effects radon has in light of its potential health benefits.

"*I understood it this way: If you go on holiday in the high mountains for three weeks, for example, the radiation that your body absorbs is the same as if you did four weeks of radon therapy. Or the frequent flyers, for example, would be exposed to the same - or even more - radiation than the concentrated radiation dose if the therapy was carried out for four weeks*" (Respondent 10).

Interestingly, such comparisons can also be understood as a rather implicit recognition of a certain risk related to radon. While 'the dose making the poison' can be understood as a reference to the idea that 'in the right amount' radon offers health benefits rather than risks, comparisons to other exposure contexts rather seem to start from a recognition that there is a risk, but this is no greater (or smaller) than some other exposure contexts. Such slightly different – and largely implicit – argumentations in their basis can be brought down to ongoing discussions on the existence of a linear no-threshold model in radiation protection. One respondent – a medical professional working in a radon spa – explicitly refers to these discussions, seemingly distancing themselves from the linear no-threshold model:

"*Every medication I take has the potential to have side effects and I have to accept that if I want to have an effect. And that's exactly how it is with this radon therapy. And in this minimal dose, as I said - there is this theory anyway where they say: only from a certain threshold dose. The so-called hormesis theory: Potential side effects are only present above a certain threshold dose. Of course, there is also the other view that there is no threshold dose, but rather this linear dose-response relationship, that is: As soon as a little bit of radon is there, it can potentially do something. But as I said: the dose makes the poison. For us, that's a maximum of nine baths in a three-week treatment*" (Respondent 7).

4.2.1.4 Perceptions of radon spa controversy

In order to delve deeper into the position of the respondents regarding a potential discrepancy between putting an emphasis on the health benefits versus putting emphasis on the health risks, respondents were asked about their opinions regarding public communication (e.g. from health authorities) on radon risks.

In two cases, respondents indicated to actually not be familiar with such messages. For one of these respondents, this information seemed moreover to provide potential confusion or uncertainty regarding how to handle such radon risk communication, as it seemed to contrast with their views on radon as beneficial to health:

"*This is difficult now, because I've never really dealt with it before. I've never read anything or anything like that. Well, if I'm being honest now. Because then I would have to weigh it up for myself personally, because I also find it exciting to see the negative aspects being reported, I have to say. But we actually see these positive experiences up close*" (Respondent 4).

The other respondents did seem to be familiar with public health messages on the risks of radon but positioned themselves quite differently with respect to such messages. Some respondents considered these messages emphasising radon risk justified, correct and/or necessary.

"*If it comes from the authorities, then I see that as correct. Then I think that's right and important, because of course the authorities have to provide detailed information about such things*" (Respondent 8).

"*This is the state's duty to provide information*" (Respondent 11).

Some of these respondents added that although risk-emphasising communication might be justified, it does not mean that radon might not be of benefit (at least to some), and also in this context referred to the adage 'the dose makes the poison'. In this sense, a balanced communication should be aimed for according to some of these respondents, which also leaves room for potential health benefits.

"*Well, let me put it this way: that the risks are pointed out and that the radiation protection authority certainly pays close attention to them - perhaps sometimes a little, let me say, too strict... or how should I put it […] That's exactly what I think you should offer. Both point out the risk so that afterwards you can't say: 'Yes, no one said that,' no. But you should also point out the positive effects*" (Respondent 10).

"*It is justified to look at it critically. It's always like, 'The dose makes the poison'. Paracelsus already said that back then, and of course it also applies here in a very special way*" (Respondent 7).

One respondent indicated to be aware of the existence of public health campaigns focusing on radon risk but did not connect it to the locality of the radon spa. Finally, some respondents took a rather sceptical position towards communication and information campaigns pointing out the health risks of radon. The most outspoken quote in this regard comes from a respondent who states:

"*You shouldn't take everything you hear everywhere so seriously, because then you won't be able to do anything anymore. And it's not for nothing that hundreds and thousands of spa guests who want to get well come to the [name local area]; Because of our thermal water, because of healing tunnels, because of natural occurrences… so it can't be that bad*" (Respondent 6).

Interestingly, the images of radon posing a health risk – irrespective of who communicates them – are perceived by multiple stakeholders as a main challenge when operating a radon spa. The perceived fear that people might have of radon – due to its connection to radiation risks – is repeatedly brought up as posing a threshold for potential clients to come visit the radon spa (cfr. also the reference to 'persuasion' above).

"The biggest challenge is of course... how should I put it... this noble gas naturally has such a negative connotation for many people. This is associated with radon pollution in houses and so on" (Respondent 3).

4.2.2 Results related to stakeholder group 2 (radon authorities and scientists)

4.2.2.1 Perceptions of radon spas

All the respondents in group 2 (radon authorities and scientists) we talked with were familiar with radon spas. While mostly referred to in a medical context (e.g. *"I would describe it roughly as: A medical use of radon, especially in high concentrations, but with a specific purpose"* (respondent 12)), one respondent also considered an important leisure aspect to radon spas, arguing how *"people go [to that region] for skiing during the day and go to this spa in the evening and then go home"* (respondent 16).

In terms of their personal position towards radon spas, some respondents showed a disliking towards the spas, while others were more in favour of their existence.

"So, I would very much like people to continue to exercise a certain degree of caution. I'm not a fan of it, I admit it openly. I'm not a fan of it because often a very excessive, exclusively positive... a positive image is sold that doesn't really fit in with the scientific image that I represent" (Respondent 14).

"If there is now a radon bath in [name country] or something like that, I see it as positive" (Respondent 13).

In terms of their professional roles and positions vis-à-vis the radon spas, various respondents indicated not to have a professional responsibility or connection to the radon spas, while for others, these spas were connected to their jobs primarily as places in which workers and employees need to be protected from excessive radiation. In this regard, different respondents indicated that radiation protection for workers in radon spas proved to be a particular attention point.

"Well, the employees need to be protected. The staff just has to be trained. They have to know how to behave correctly so that they get as little radon as possible, because they have it every day. This cure, so to speak [laughs]. So, employee protection has to be right for the staff" (Respondent 13).

"What is of course more difficult when using radon as a medication than elsewhere is the issue of employee protection. So, medications that people usually take in tablet form or otherwise, it is automatically ensured that the doctor who administers it to the person does not get any of it themselves. This doesn't work quite as well with radon. That's why we also have a number of 'radon protection at work' rules, including for radon sanatoriums and the like" (respondent 12).

In one case, a respondent indicated that this remained actually an open issue, in which discussions between radon spas and (national) radon authorities are still ongoing on how to deal with the (economic) reality of providing thermal water to radon spas and the need to protect those providing this water from receiving excessive radiation doses.

4.2.2.2 Radon perceptions

This section provides an overview of respondents' perceptions regarding both the risks associated with radon and its health benefits.

Radon as a (manageable) risk

For experts working for authorities or at universities, it is clear that radon poses risks for your health. An important part of their job is directed at protecting people from these risks, by limiting exposure to radon at their homes or workplaces or understanding how such protection can ultimately be improved. As a prime health risk, respondents refer to the risk of developing lung cancer, which they do not consider as an acute risk, but rather something which might develop over time as a consequence of radon exposure.

"*It's about making it clear to people who have no idea and who don't voluntarily work with radioactive materials: Guys, this is radiation protection and that would be so that you don't have lung cancer in 20 years*" (Respondent 12).

"*You don't want them in the respiratory tract, especially in the lungs, because they are very strong, high-energy particles, alpha particles, which then lead to a risk of bronchial cancer. Since bronchial carcinoma is a very unpleasant disease – especially when it comes to different histological types – then I would say that is of course a major driving force why people are concerned with radon. It's a definite carcinogen*" (Respondent 14).

In one of the interviews, the respondent also explicitly connects radon exposure to the broader context of indoor air pollution, emphasising hence a more holistic approach to radon risk and its management. Related to this management, respondents consider radon risk controllable, which is not surprising, given their professional activities are directly or indirectly aimed at managing radon risks. But they also recognise how in reality, radon risk management is often a challenging task, not in the least due to the unwillingness of stakeholders to take action on the topic.

"I think when lots of people are aware of this, this radiation topic, and start renovating, there will be followers, but as long as there is not 10% or not 20% of the people talking about 'I renovated my home and it has improved', it will be hard to discuss as I can't see [radon], I can't smell it, I can't feel it" (Respondent 16).

"Sometimes people are angry, they don't want to do it. They just want to push the problem away. Um,… I don't know the term in English um it's a psychological term, that you just ignore problems, if you know problems" (Respondent 15).

Part of the job of some of the respondents hence consists of convincing stakeholders that they need to take action. For several respondents, risk communication is a key part of their responsibilities, and something which they consider should be prioritised in attempts to improve radon management in society.

"Professional risk communication is really needed. It is important that you react quickly and that politicians also make this possible. And the last thing I keep seeing is that raising awareness is still... So, there is still room for improvement. That's clear to me" (Respondent 14).

This communication can present radon risks in several ways. For some of our respondents, risk communication should directly point out the detrimental consequences of not taking action on radon. As one respondent puts it:

"You always have to take a lot of effort to go step for step. And I always tell them you are responsible here for 80 persons a year who could get cancer from radon. It's your responsibility and it's my responsibility and I do everything that I can do, that people don't get cancer" (Respondent 15).

Other respondents point out it might not always be a good idea to focus too much on detrimental effects of radon in risk communication, as such messages might scare or confuse members of the public.

"So, we try to just stay at the very general level. On describing it's a gas and it's there and it's in the stone and it will be there, anyway, if as long as you live there, but it's not like starting with you will die if you don't …. Or you might get cancer if you don't do anything with your house" (Respondent 16).

"People cannot distinguish between high and low doses. Yes… there is this reference value; 300 Becquerels per cubic. And I've had cases where a person... yes, got really nervous because it was 350 for a short time. And one who couldn't explain: This is the average. And that is very difficult now. I also see videos about radon on TV stations and on the Internet, and the radioactivity symbol always appears very prominently. […] *And that is then immediately linked to Chernobyl"* (Respondent 13).

Particularly relevant, is that some of the respondents highlight how in their communication with the general public on radon and its risks, a complicating factor is offered by some people's perception about radon as something which is good for their health.

"What we otherwise always have, especially in radiation protection, is the communication problem: always the good and the bad radiation. Of course, we have that with radon in particular, where people are tempted to say: 'Yes, but that's medical radiation, that's the good radon and when you're at home, then it's the bad radon'" (Respondent 12).

The issue of 'bad' and 'good' radon this last quote refers to, is a direct hint at the existence of another set of radon perceptions, in which radon does not feature as (only) a risk to health, but also a potential benefit for health. Interestingly, some of the respondents emphasised that such perceptions were not only something they were facing among the broader public, but also reflected to some extents their own perceptions of radon. This is further described below.

Radon as beneficial to health

When it comes to radon's potential positive effects on health, some of the respondents showed some hesitancy. In one instance, a respondent indicates to be aware of such claims, and to have met people who are convinced of its positive health effects, but that he himself "*wouldn't say that [positive health effects] are because of radon, or only of radon*" (Respondent 16). Instead, this respondent believes that the way in which radon treatments work, - where people travel to specific sites, are taking a bit of holiday, eating healthier during their stay etc. - offers a range of factors, which if all added up could indeed have

positive health effects for some. While not considering radon as a placebo either, this respondent believes that a range of factors, with radon as a potential added factor, could be of benefit to people. Another respondent showed similar hesitancy, avoiding any clear statements in which positive health effects are attributed to radon.

"If there is, as far as I'm aware - I've learned a bit about it - but in principle, if there is any benefit at all, it's for very, very chronic inflammatory diseases with high levels of pain" (Respondent 14).

Others, by emphasising that they are no doctors, and hence not qualified to make any kind of claims on positive health effects, leave some room for interpretation. When talking about radon's potential health benefits, one respondent for example states how he "*think*[s] *it's possible. I'm not a doctor, so it could be inaccurate*" (Respondent 12).

Similarly, another respondent indicates:

"There are studies around now. But I'm not a medical doctor. I can… I'm not an epidemiologist and I only know that there are studies around that seem really [to confirm].. to fix this knowledge that it really helps so um I can't. I can't really prove. I'm a geologist" (Respondent 15).

Both of the above respondents however also clearly demonstrate a personal conviction that radon might at least in some cases and instances have positive health effects.

"*The only diagnoses I really know, because I have a personal acquaintance, is Bechterew's disease, where the spine ossifies[…]. And especially with something like this, there are a lot of reports that after such a radon treatment – I know that in particular at [name local radon spa] – that the number of painkillers can be reduced over weeks to months and the quality of life increases*" (Respondent 12).

"In the beginning I was very sceptical when I learned about it, I myself was very sceptical, but then I really met people who. Who went to these baths and they said. Oh, you can't imagine how much it helps me my bones didn't hurt me for over a year now. And if I have to take other treatment, it may be worse" (Respondent 15).

"Although [radon] causes damage as an alpha emitter, it obviously also has healing effects for many. And you can at least alleviate certain illnesses through radon baths or in the radon healing tunnel. Promote pain relief. Yes" (Respondent 13).

The authorities we interviewed hence to various extents perceive radon as having some potential health benefits, although disagreement seems to exist on the extent to which these benefits can be attributed (only) to radon, and the conditions under which such benefits manifest themselves. Also, the existence of scientific proof of radon's positive health effects was disputed among the various respondents. As illustrated in an above quote, one respondent stated that "*there are studies around that seem really [to confirm].. to fix this knowledge that it really helps"* (Respondent 15). Others were more hesitant, referring to indications of proof of radon's health benefits for very specific and serious conditions. In various interviews, respondents expressed uncertainty, emphasising how scientifically, it is not clear whether/how radon can positively affect peoples' health.

"We don't yet know exactly how it works scientifically" (Respondent 13).

"We know that those radon spas can have a positive effect. But we actually don't know why, or we don't know how" (Respondent 16).

Interestingly, and largely in line with findings from interviews with respondents from group 1 (radon spa management and employees), those respondents who indicate that positive health effects could in some cases be attributed to radon emphasised the importance of dosage. While extended exposure to radon (e.g. due to elevated radon levels at home or the workplace) was considered to be detrimental to human health, a short (and controlled) exposure could according to some respondents alleviate symptoms of specific diseases or medical conditions.

"The difference is simple: the patient receives a high dose – a high intensity of radon – in a short period of time. But the dose is actually not that big if you do, let's say, three weeks of treatment, while someone who has slightly elevated radon levels at work or in my living room, who basically spends their entire life in it" (Respondent 13).

Also, here – as in interviews with respondents from group 1 –, a spontaneous reference was made to Paracelsus, and this attributed statement that 'the dose makes the poison'.

"It really helps people, and there are a lot of studies around and so it's like Paracelsus already said it depends on the dose if a thing is a poison or a cure. And he said that in the fifteenth or sixteenth century, I don't know [laughs]. But I think it's easy to understand because whatever cure, medicament you have, you wouldn't take it if not for your disease" (Respondent 15).

"I would compare it to a laxative: If I have a problem, I take a laxative. It works once and it works, and I don't take a mini tablet of laxative every day just because I'm funny" (Respondent 13).

Following this logic of 'the dose making the poison', various respondents argued that ultimately the exposure to radon for potential positive health effects was a trade-off between benefits and risks. In some cases, the negative effects of taking large amounts of medicines such as heavy painkillers were considered to be equally or more negative than the effects of radon exposure. Or, in a slightly different argumentation, the potential benefits of radon were considered to be of a more acute nature in some cases than the potential negative effects of radon on the longer term. This latter point was particularly brought forward in the case of older people who might suffer from chronic pain conditions, and for whom the risk of developing cancer over a period of various years was considered less relevant.

"The thing is, if you constantly give painkillers, it's not a walk in the park for the body. In fact, every medication intake is a form of toxic effect on the body, although we usually think of poison as the unwanted thing. But even where we want to achieve an effect, the body is still busy with degradation and side effects and so on. So even if I continually give painkillers to a person who is in severe pain, it's not as if it has a completely ineffective effect on the body, apart from relieving the pain. And if I therefore – to put it very bluntly – protect the liver and accept a higher risk of lung cancer, then that is a trade-off that is fundamentally okay" (Respondent 12).

"This is mostly for people over 60. And, I mean these days also younger people have… many younger people have rheumatic problems, but I wouldn't recommend it easily for somebody to go to get information about that. If somebody is in the 20s or 30s, um I just wouldn't say anything about it [laughs]. But when people are over 60, you know about the um that that everything goes slower in the body. These cells divide slower and everything, so the danger to get cancer is much lower than in younger years" (Respondent 15).

4.2.2.3 Perceptions of radon spa controversy

Various respondents emphasised that radon spas proved for them a challenging topic due to the complexities these spas add to radon communication. In several interviews, respondents indicated that the existence of radon spas made it challenging to explain to the broader public that radon offers a health risk in your home or workplace.

"Why is radon bad when there are actually radon treatment centres where it is good? So, to work out this difference" (Respondent 13).

"Separate things so that things don't get mixed up and everyone says: 'My God, great, that's just plain anyway; I have some cool gas with me [laughs]. This is used in various health resorts, so thank God I have it at home with me.' That of course that's not true and that it's complete nonsense. But it's not easy when it comes to communication because there is ultimately a radon industry" (Respondent 14).

This challenge was attributed to the perception that radon spas tend to emphasise health benefits, hence creating an idea among people that radon is good for them, something they can enjoy.

"When you start with medical applications, not just wanting to treat people, but generally making money, when it goes in the direction of marketing and cure and joy and vacation and so on, then it becomes with communication increasingly critical. Especially in public perception" (respondent 12).

One respondent indicated that they considered this aspect as a main challenge in their communication with the general public, as some people – especially those living in areas with radon spas – seemed to know about radon first and foremost through the context of radon spas and hence its claimed benefits for health. This respondent shared experiences during the interview of being faced with reluctance or hesitancy among certain population groups, which he attributed to their familiarity with radon in the context of positive health messages.

"Actually, when we call, and we say we will be here for this day and we can offer you to be there and for instance […] people say: 'go home. We don't need you here. We have enough problems with our own. Don't come with radon. We are not interested'. That's something we discover" (Respondent 16).

For various respondents, this challenge meant a need existed for radon communication to be more aware of the potential existence of other radon realities. As one respondent put it, in reference to previous radon communication she remembered from a former job:

"It's like a good radon and bad radon. Yeah, and um and it was the same information I just told you. It's a question of dose, there are some experiences that it helps, and that you need a doctor's indication" (Respondent 15).

This statement refers to a need of recognising two radon contexts or realities, with an emphasis on the medical context of (and control over) the 'good' radon which people might associate with radon spas. This respondent continued by highlighting a need for understandable but objective information, provided by experts, in order to better handle the seemingly conflicting messages about radon risks and radon benefits.

"Maybe the information about it should be more should be better published in a better understanding way, but not by governments, but by medical organizations, or also by government, we can take it over but, but it should come from the people who did the research work." (Respondent 15).

4.3 Public attitudes and beliefs related to radon in spas investigated by the RadoNorm survey[4]

In this section, results are presented from surveys conducted in Austria, Germany and Czech Republic, in light of the RadoNorm European Radon Behavioural Atlas (cfr. section 3.4).

4.3.1 Public awareness of radon spas or caves

Respondents in Austria, the Czech Republic, and Germany were asked about their awareness of radon spas or caves. Overall, these are relatively well-known in these countries, with 67% of respondents indicating they either know of or have heard about radon spas or caves. Awareness is highest in Austria, where 58% of respondents are familiar with radon spas or caves, and an additional 26% have at least heard of them. In contrast, awareness is lowest in Germany, where approximately half of the respondents indicated some level of familiarity with radon spas or caves. To conclude, the majority of

[4] The figures provided in this chapter have been created by job student Alenka Žumer, subcontracted by SCK CEN

respondents in Austria, the Czech Republic, and Germany are aware of radon spas or caves, with the highest level of familiarity in Austria and the lowest in Germany.

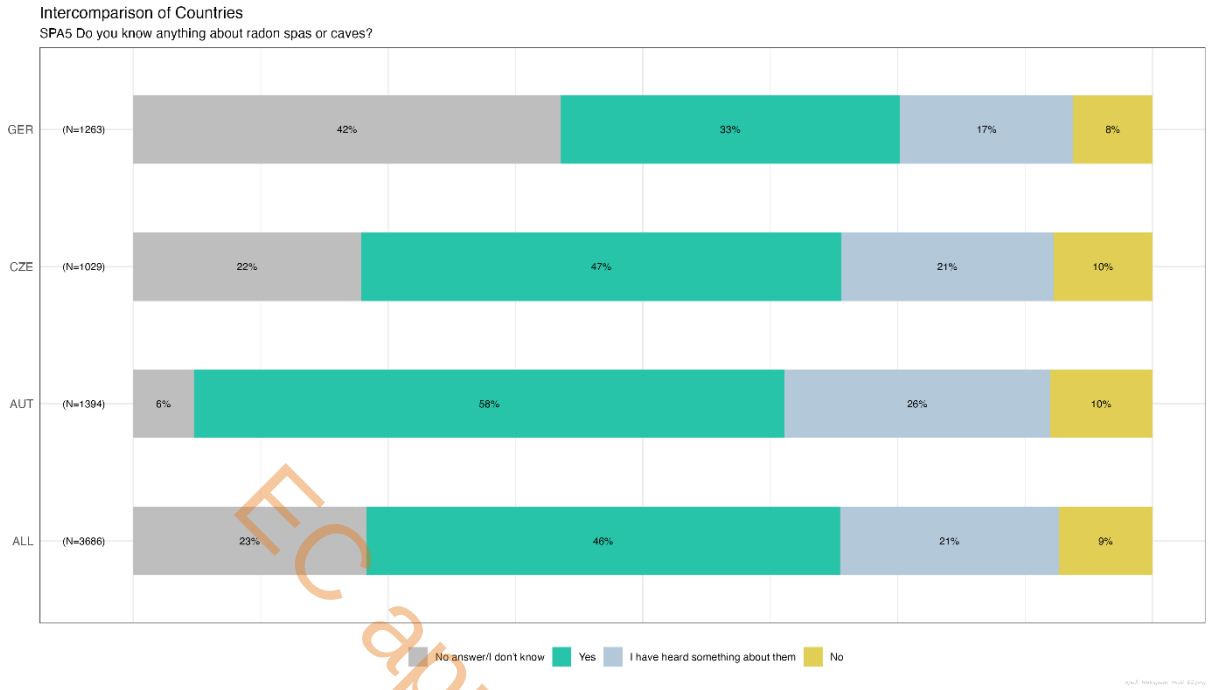

Figure 1: Awareness of radon spas or caves in Austria, Czech Republic and Germany

Additionally, we asked respondents to briefly describe what they have heard about radon spas. Below, we present the findings categorised into different frames, as identified by Geysmans et al. (2022). These statements illustrate how radon is perceived across various discourses, including its health benefits, natural origins, potential risks, association with luxury, and its historical reputation as a rejuvenating therapy. The content analysis of the open-ended question confirms that, in all three countries, these five frames are present among respondents. Below are some examples of how individuals in Austria, the Czech Republic, and Germany express their views on radon spas.

1. Radon as a Source of Health

- *"Used for various diseases."*
- *"Healing effects, especially for chronic diseases."*
- *"Alleviates pain, especially for rheumatism."*
- *"Therapeutic application of radon in health spas and treatment tunnels."*
- *"Positive effects on health, especially for lung and joint problems."*
- *"Scientifically disputed, but allegedly healthy."*

2. **Radon as a Natural Gas**

- *"Natural release of radon from the ground."*
- *"Radon as a component of thermal water."*

3. Radon as a (Non) Risk

- *"Scientific uncertainty about its effects."*
- *"Controlled radiation exposure in the treatment tunnel."*

- *"Safety concerns, especially for cancer patients."*
- *"Controversial scientific opinions."*

4. **Radon as a Luxury**

- *"Gastein is often mentioned as a place for treatment tunnels."*
- *"Bad Gastein as a specific place for radon applications."*

5. Radon as a Fountain of Youth

- *"Strengthening of the immune system."*
- *"Traditional applications since antiquity."*

4.3.2 Risk perception of radon spas or healing caves

Risk perception refers to how individuals assess the likelihood and potential consequences of negative events. It is a subjective judgment that often determines which hazards concern people and how they choose to manage them. People's perceptions of risk are shaped by personal experiences, beliefs, values, and external influences.

This study explores the risk perception of radon spas and caves across three countries. To provide context, the risks associated with radon spas and caves are examined alongside various types of hazards, both radiological and non-radiological. Including multiple risks in the study allows for a more comprehensive understanding of risk perception. Focusing on a single risk in isolation may give the impression that its perceived danger is high. However, comparing it with other risks may reveal that some are viewed as even more significant. By considering a range of risks, the study can offer insights into how individuals prioritise and manage different hazards in their daily lives.

Respondents' personal risk perceptions were measured using the following question: "How do you perceive the potential risk to your health within the next 20 years from each of the following sources?". Responses were recorded using a 6-point Likert scale, with options ranging from (1) "no risk at all" to (6) "very high risk."

Out of the representative population for gender, age, region and education, respondents being aware of radon spas or radon caves were asked to evaluate the risk of radon spas and caves, as well as 9 other risk areas: 1) environmental pollution, 2) climate crisis, 3) radioactive waste, 4) indoor air pollution due to radon, 5) accidents at nuclear installations, 6) natural radiation (from soil or space), 7) the use of ionising radiation for medical purposes, 8) using recycled building materials with low levels of radioactivity, and 9) the presence of naturally occurring radioactive gas radon indoors.

To examine the impact of different formulations, or "framing," on radon risk perception, as observed in Perko & Hevey (2024), two distinct statements were used: "indoor air pollution due to radon" and "the presence of naturally radioactive gas radon indoors." Respondents were split into two groups, with one group given the "indoor air pollution" statement and the other the "naturally radioactive gas" statement.

The figure below presents the perception of radon spas and other investigated risks in Germany.

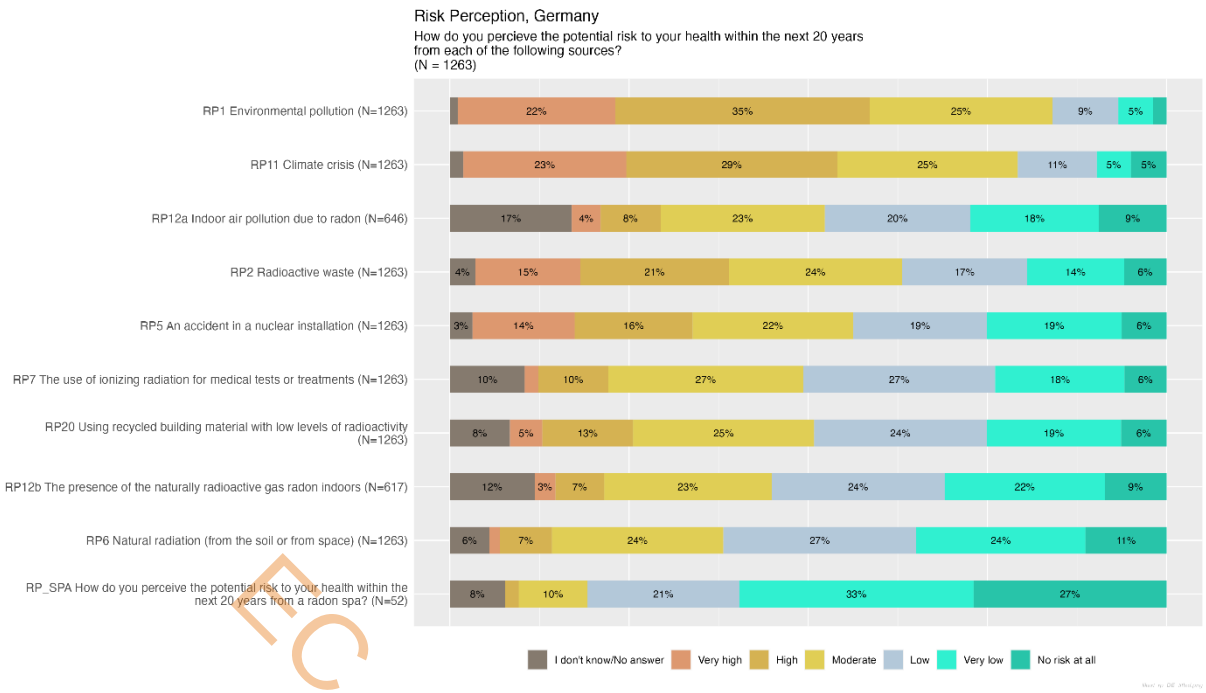

Figure 2: Perception of risks from radon spas and other (radiological) risks in Germany

The figure below presents mean and standard deviations for perception of radon spas and other investigated risks in Germany.

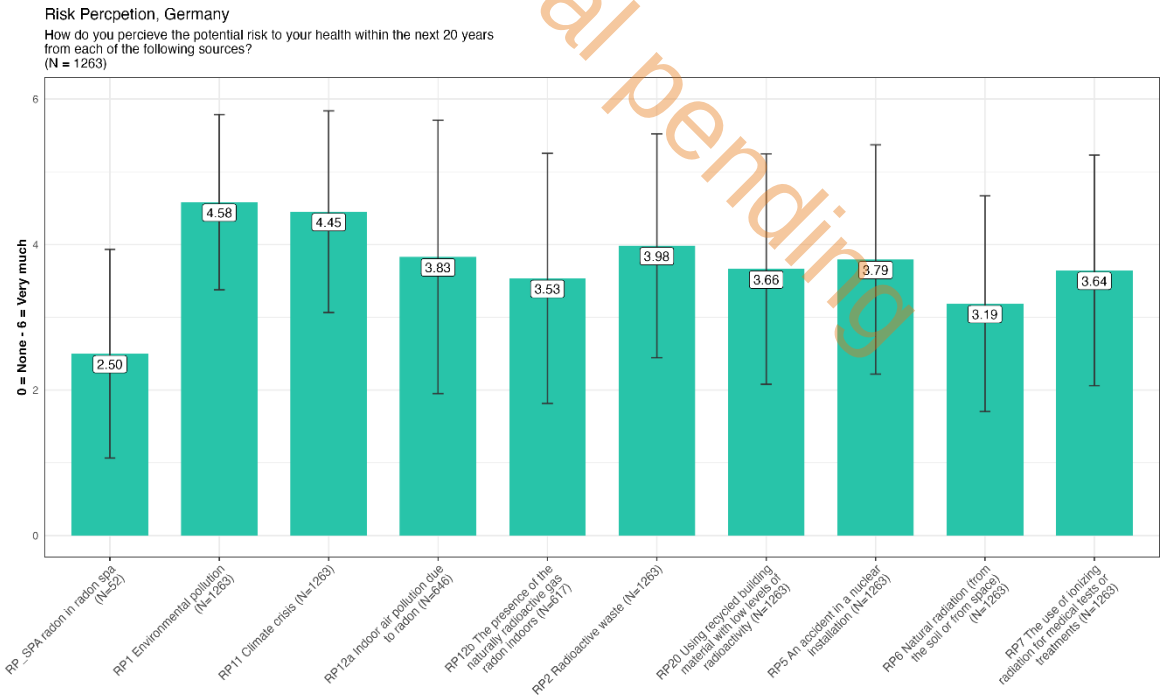

Figure 3: Means and standard deviations for perception of risks from radon spas and other (radiological) risks in Germany (1=no risk at all, 6= very high risk)

The figure below presents the perception of radon spas and other investigated risks in Austria.

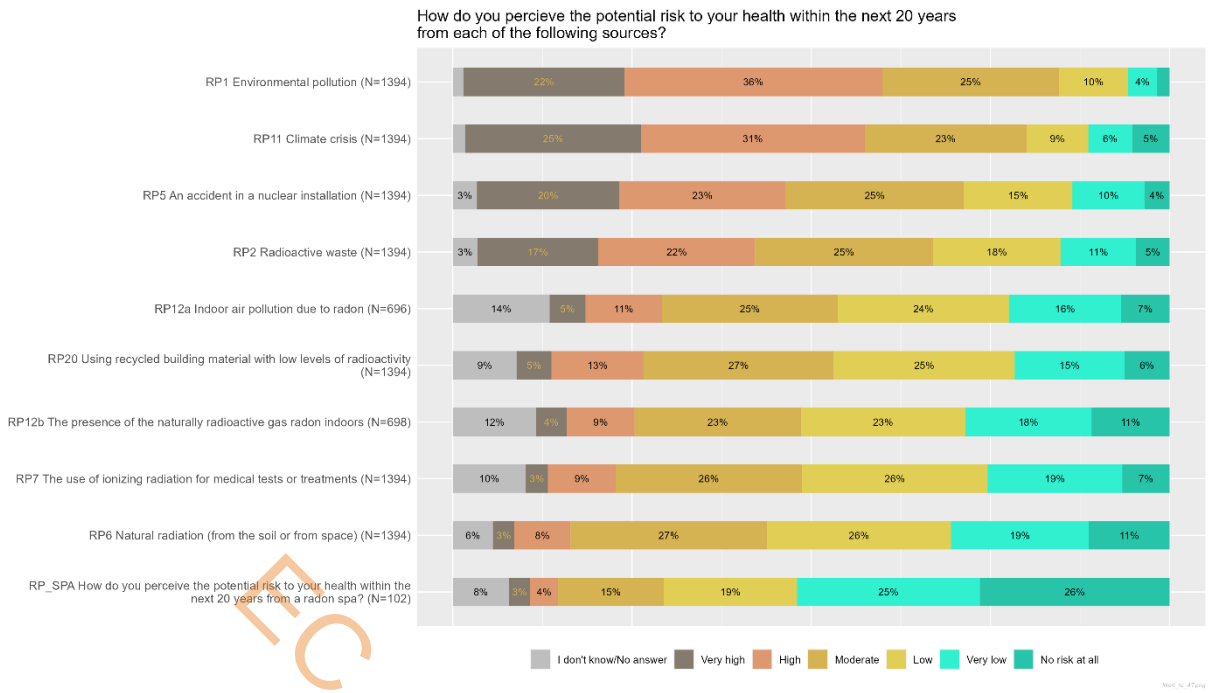

Figure 4: Perception of risks from radon spas and other (radiological) risks in Austria

The figure below presents mean and standard deviations for perception of radon spas and other investigated risks in Austria.

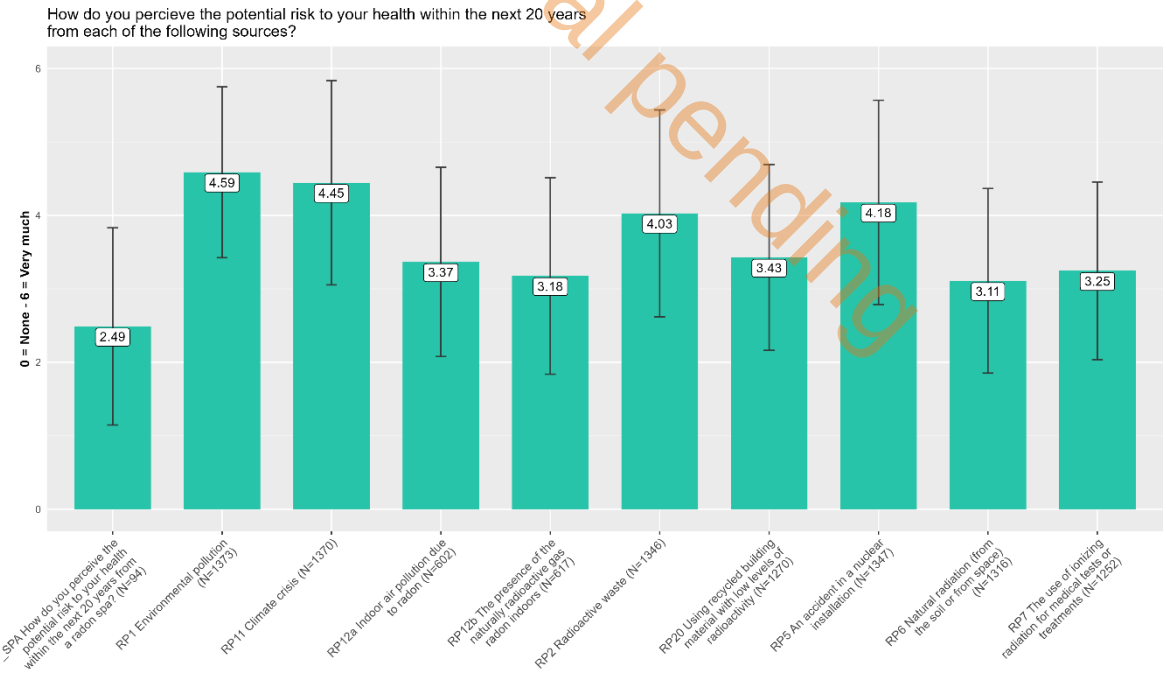

Figure 5: Means and standard deviations for perception of risks from radon spas and other (radiological) risks in Austria (1=no risk at all, 6= very high risk)

According to the results, people in both Austria and Germany perceive radon spas as a relatively low-risk activity (average scores of 2.50 in Austria and 2.49 in Germany, on a scale where a higher number indicates a higher perceived risk). This suggests that people in these countries believe radon therapy, despite its association with radiation, is relatively safe or at least not very dangerous. The use of ionising radiation in medical procedures (such as X-rays, CT scans, or radiation therapy) is seen as moderately risky. People in Austria gave this an average score of 3.25, while in Germany the average score was slightly higher at 3.64. Although people recognise the potential dangers associated with medical radiation, the perception is less extreme than with radioactive waste. In contrast, the public perceives radioactive waste as a much more serious risk. In Austria, the perceived risk is significantly higher (mean score of 4.30), and it's also high in Germany (mean score of 3.98). This reflects widespread concern about the dangers posed by the radioactive waste.

In the Czech Republic, most respondents were not able to answer the question on risk perception of radon spas or caves, as they either did not know what radon was or were not familiar with radon spas. Only 27 out of 1,029 respondents were able to provide a response to this question, and among them, 8 selected 'I don't know'.

In addition to the questions above, we found that some respondents in all three countries, when asked to briefly describe what they knew about radon (open-ended responses), associated radon with positive effects.

Health impact:

"Therapeutic treatments"

Medical applications:

"Application in therapeutic mines"

"Healing for certain diseases"

"Medical treatments"

4.3.3 Public beliefs regarding radon's healing properties

Respondents were asked to indicate their level of agreement with the statement, "Radon has healing powers. According to the figure below, 45% of respondents did not answer, either because they were unfamiliar with radon or unsure of its potential effects. Among those who did respond, 18% in Germany, 23% in Czechia, and 27% in Austria agreed or strongly agreed that radon has healing properties. On the other hand, 19% of respondents in Germany, 25% in Czechia, and 18% in Austria disagreed or strongly disagreed with this statement. To conclude, among those familiar with radon, a greater number believe in its healing properties than those who do not.

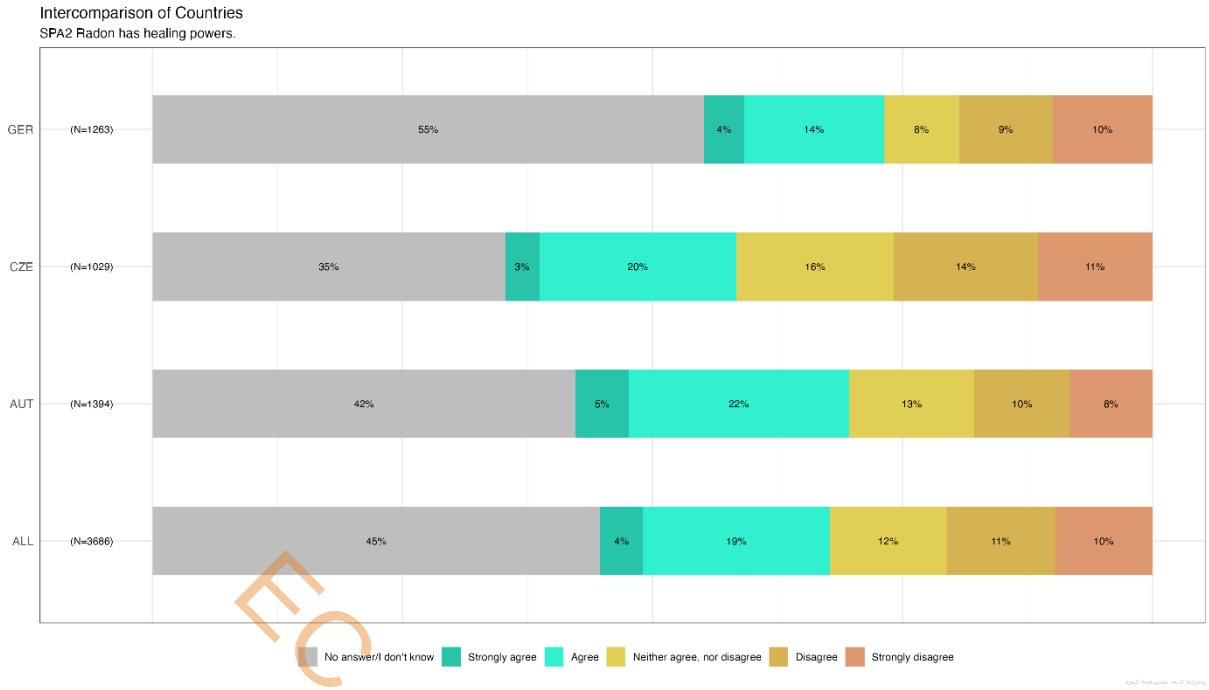

Figure 6: Public beliefs regarding radon's healing properties

4.3.4 Public perceptions of radon's therapeutic effects

Respondents were asked to indicate their level of agreement with the statement, "Radon, when taken in specific doses, relieves symptoms of certain diseases," reflecting a perspective on radon's potential health benefits. This question aims to understand whether people perceive radon as having positive health effects, particularly in therapeutic settings like radon spas. In our study, 30% of respondents agreed or strongly agreed with this statement, while only 10% disagreed or strongly disagreed. Notably, half of the respondents were unable to express a clear opinion, either because they were unfamiliar with radon or selected the "I don't know" option.

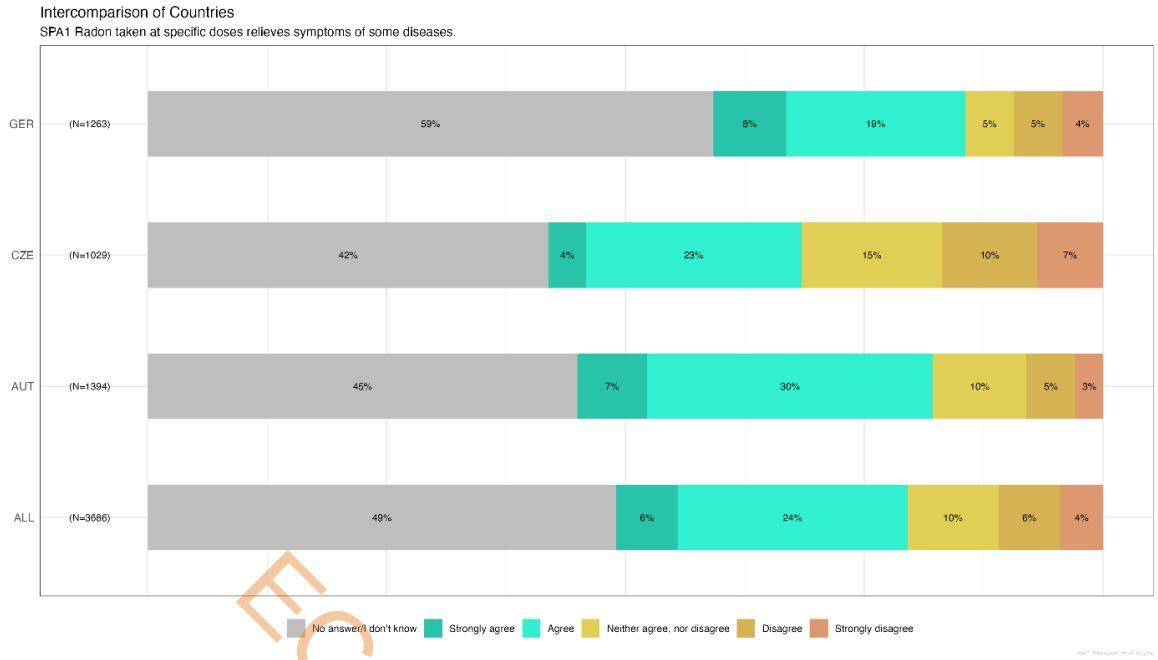

Figure 7: Public beliefs regarding radon's therapeutic properties

4.3.5 Public perception of radon gas as (un)safe although it's natural origin

Respondents were asked to express their level of agreement with the statement, "Due to its natural origin, radon gas is not dangerous," as often described in spa tourism (Geysmans et al., 2022). The figure below shows that a significant portion of respondents either lacked awareness of radon or were unable to form an opinion on this statement. For example, in Germany, 51% of respondents did not answer or choose "don't know" answer, while Czech respondents had the least difficulty, with 26% unable to respond. Among those familiar with radon, the majority strongly disagreed or disagreed with the statement, with only up to 6% believing that radon is not dangerous due to its natural origin.

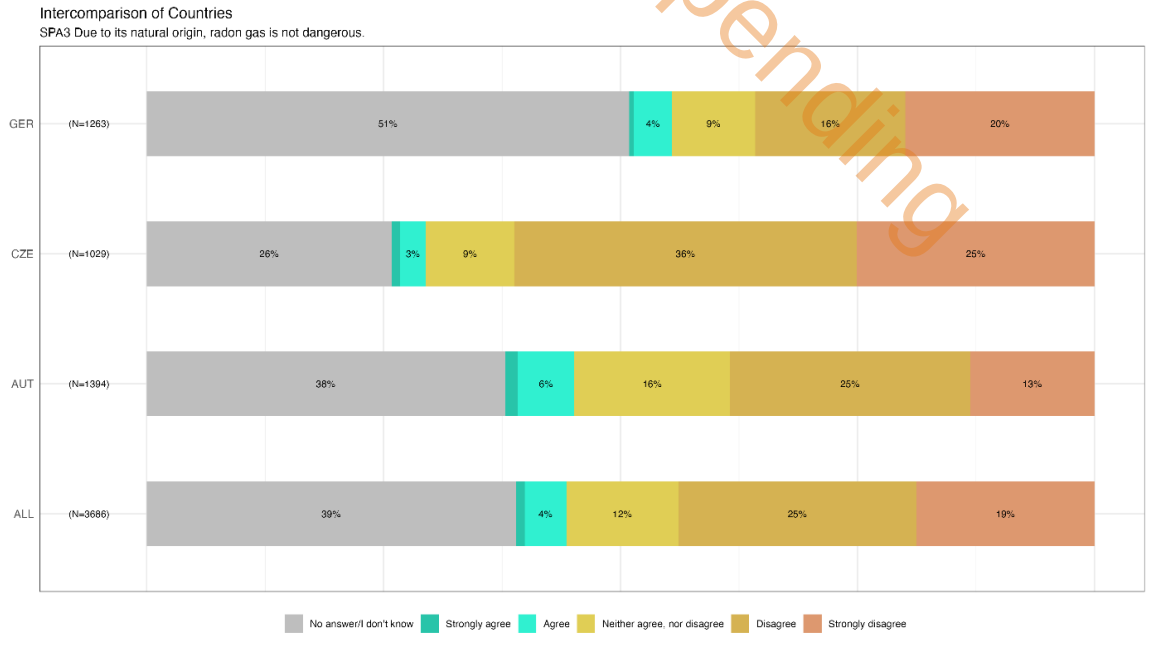

Figure 8: Public perception of radon gas as unsafe although it's natural origin

4.3.6 Public perceptions of radon's effect on aging

Next, respondents were asked to indicate their level of agreement with the statement, "Radon slows down the aging process," reflecting another framing found in the Geysmans et al. (2022) study. In this case, 54% of respondents either did not answer or were unsure how to respond. Among those who did, 34% primarily disagreed with the statement. However, in each country, a small percentage of respondents believed in the positive effects of radon on aging.

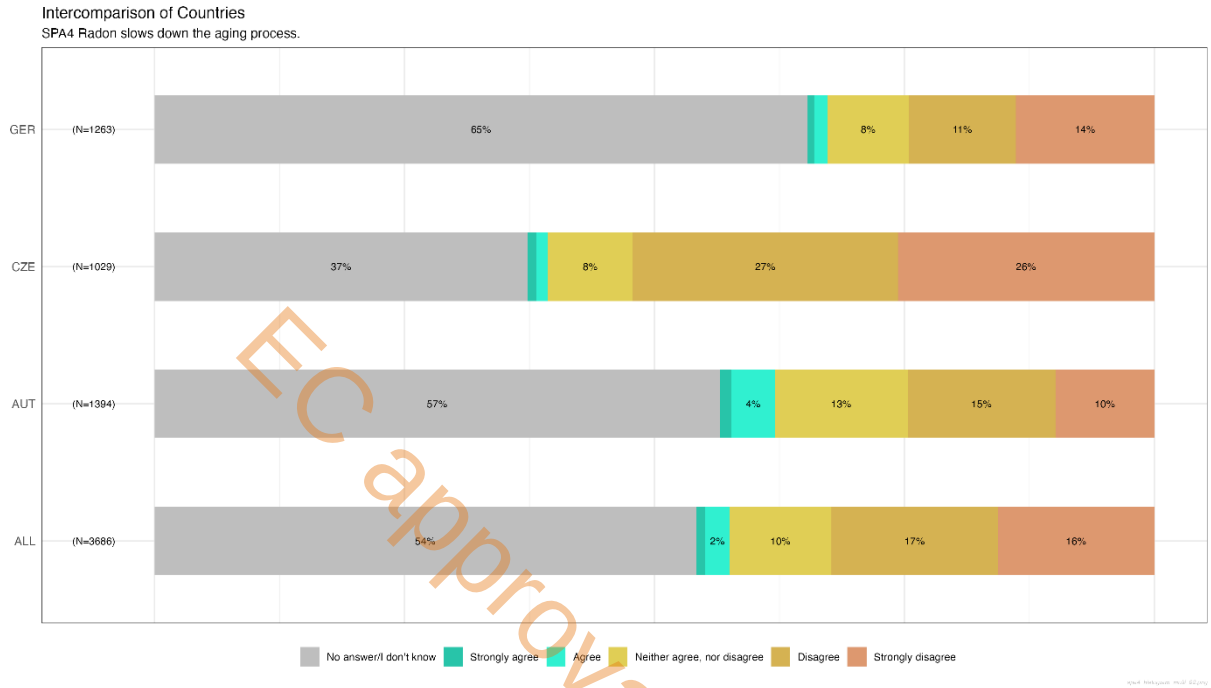

Figure 9: Perceptions of Radon's Effect on Aging

4.3.7 Public trust: Confidence, truthfulness and competences of stakeholders related to radon spas and healing caves

Trust is a multidimensional latent construct, meaning that it cannot be directly observed, but needs to be inferred from several observable indicators or dimensions, e.g. confidence, truthfulness, and competences (Hunt & Frewer, 1999). Poortinga et al. (2008) discovered that risk communication initiatives, which demonstrate the government's sincere commitment to addressing the health hazards associated with indoor radon, yield positive effects on trust in institutions responsible for risk management. In our study, the trust construct is measured using three dimensions: confidence, trustworthiness, and competence.

Confidence

As authorities are responsible for formulating and implementing radiation protection measures, it is crucial to assess the level of public confidence in these governing bodies (Perko et al., 2023). Confidence in authorities was evaluated specifically in relation to their actions in mitigating the risks associated with radon spas or caves with the following question "How much confidence do you have in the authorities for the actions they undertake to protect visitors of radon spas against potential risks from radon?". Respondents were also asked to express their confidence in authorities related to other types of risks, in order to provide a comparative perspective. Responses were collected using a 6-point Likert scale, ranging from (1) "none" to (6) "very high."

The results reveal that respondents who were familiar with radon spas expressed a relatively high level of confidence in authorities to protect visitors of radon spas against potential risks from radon, with a mean score of 4.05 in Austria. In fact, public confidence in the authorities' ability to protect against risks from radon spas was the highest among all measured domains. This was followed by confidence in the authorities' actions to protect the population from risks associated with the use of ionising radiation in medical treatments, with a mean score of 3.74 in Austria.

Notably, the lowest levels of confidence were observed in two areas. The first was in relation to the climate crisis, where the mean score in Austria was 3.15, indicating lower trust in authorities' ability to handle climate-related risks. Similarly, among radiological risks, respondents showed the least confidence in authorities' ability to address "indoor air pollution due to radon," with a mean score of 3.35 in Austria.

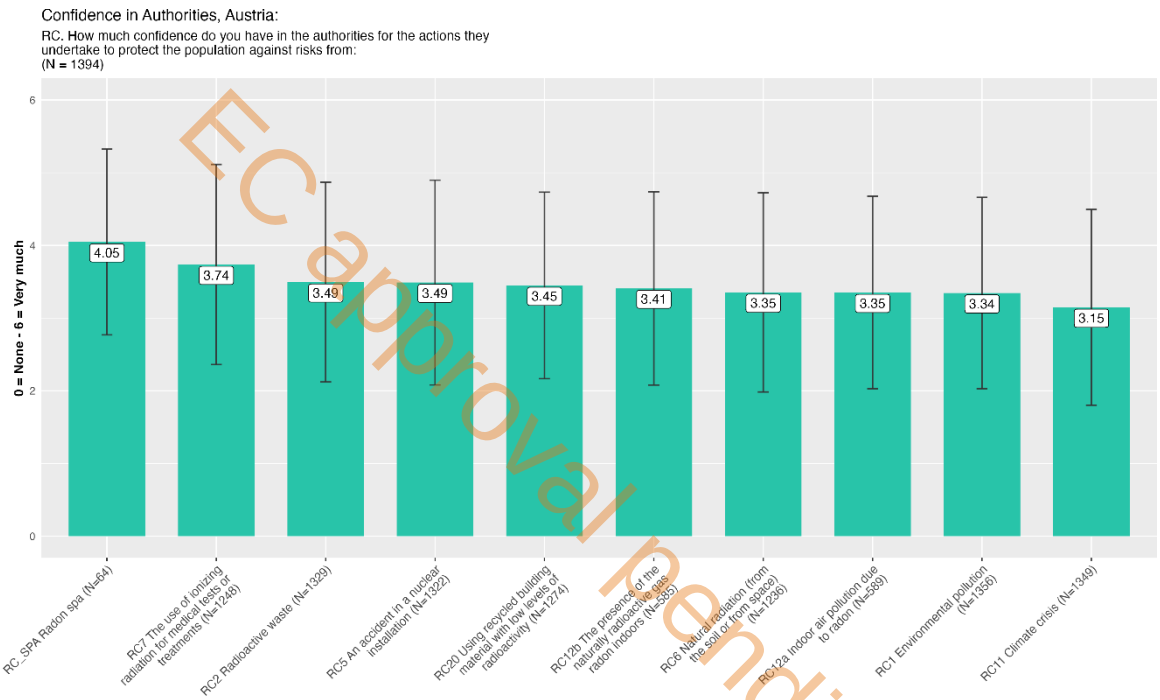

Figure 10: Mean and standard deviation for confidence in authorities in Austria

Trustworthiness and competence

In terms of truthfulness (i.e., telling the truth about radon) and competence in managing radon risks, the survey findings in Austria and Germany highlight that scientists from research institutes are the most trusted stakeholders in both countries, excelling in both truthfulness and technical competence. In Austria, the Radon Competence Centre is recognised as the most competent among all radon stakeholders and is also perceived as one of the most truthful. It is noteworthy that the Radon Competence Centre is among the most well-known stakeholders in Austria, as indicated by the size of the point in the figures below.

Interestingly, in both Austria and Germany, construction companies are seen as the least truthful, while public health authorities and doctors are perceived as the least competent in managing radon risks. Additionally, the owners and administrators of radon spas or caves are not widely known, but when respondents were familiar with them, they rated them as average, or mid-level, in terms of both truthfulness and technical competence. Respondents in Czech Republic were not asked to express their trust in owners and administrators of radon healing spas or caves.

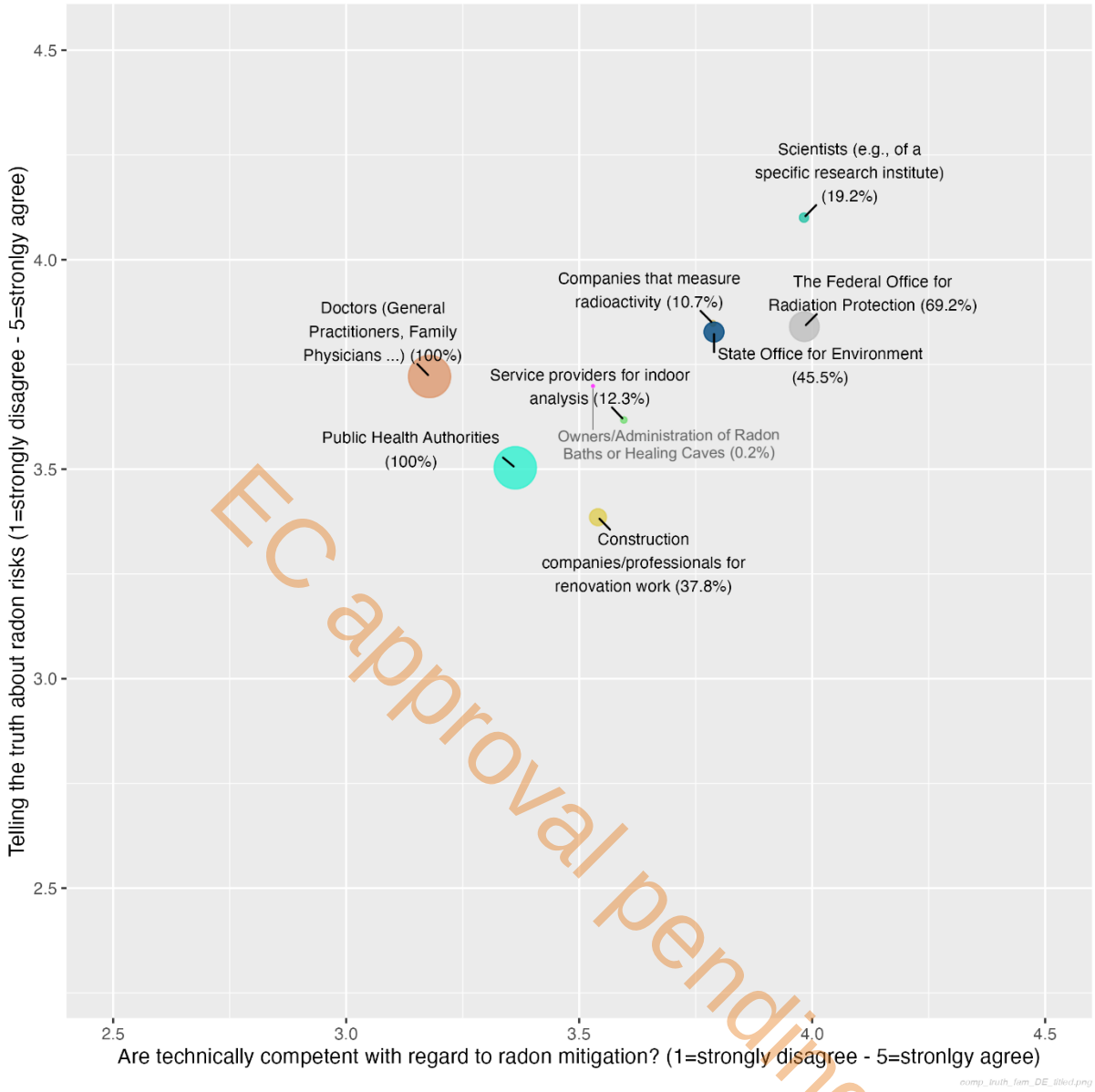

Figure 11: Trust in radon stakeholders in Germany

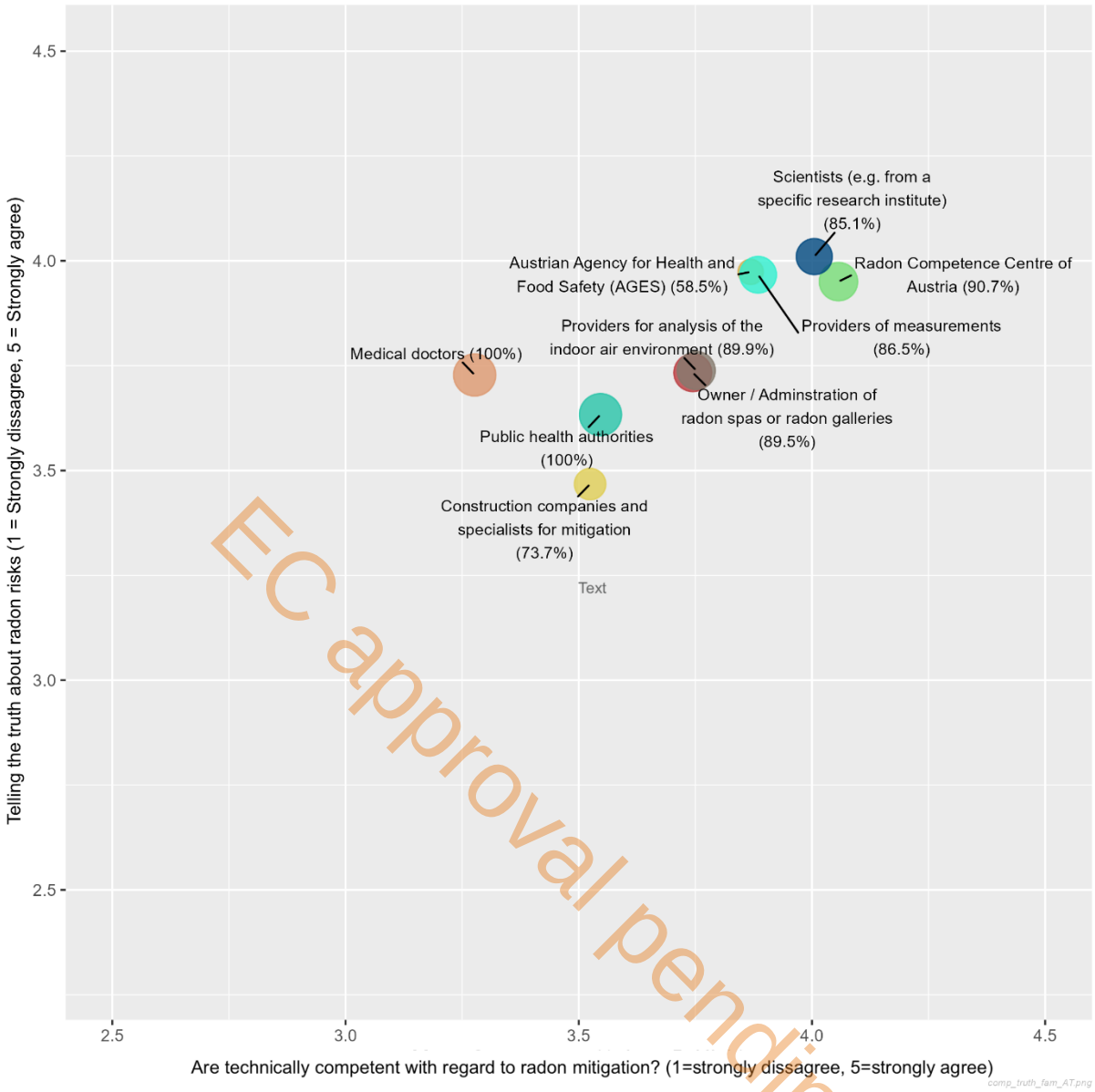

Figure 12: Trust in radon stakeholders in Austria

4.3.8 Public knowledge related to radon

In this study, the term "radon knowledge" is used to describe the information or understanding that a person has acquired through information campaigns, learning or study at schools, or gained through experience about the risks associated with radon exposure. This knowledge may be factual, theoretical, or practical, and can be acquired through various means such as communication campaigns, education, training, observation, or research (Perko et al., 2024). In essence, radon knowledge encompasses having a basic understanding of the risks associated with exposure to radon. Assessing the level of knowledge related to radon is of utmost importance, as increasing radon related knowledge and communicating scientific facts about radon have been the primary objectives of all communication interventions conducted by the radon management authorities in Austria, Czech Republic and Germany over the last decades.

In the frame of this survey, radon knowledge is probed by presenting 11 items to a specific group of respondents. Out of the population respondents were selected based on their response to a prior question that inquired whether they are aware of radon. Those who answered that they knew or heard something about it, were included in the group and were asked to respond to the 11 statements. These are: 1) radon causes headaches, 2) radon exposure is linked to lung cancer, 3) radon is radioactive liquid, 4) radon has a strong odour, 5) radon is invisible, 6) radon levels are usually higher in the attic than the basement, 7) testing is the only way to determine if a home has an elevated radon level, 8) radon can enter homes through cracks in walls and floors, 9) health effects of radon do not show for years, 10) the risks from radon exposure increase the longer you are exposed to it, 11) concentrations of indoor radon are expressed in Watts. The answering categories for the items were: “agree”, “disagree”, or “don't know/no answer”. The results for each country are presented in the figures below (*Figure 13Figure 14Figure 15*).

Overall, respondents who were aware of radon demonstrated mixed knowledge on radon-related topics. Notably, some participants across all countries not only held incorrect information about radon but also frequently admitted to not knowing the answers or being unfamiliar with radon in general. For example, in all three countries, only 15% to 17% of respondents correctly knew that radon does not cause headaches.

Figure 13: Radon knowledge in Austria

The figure below displays the correct and incorrect responses to radon knowledge statements among respondents in the Czech Republic.

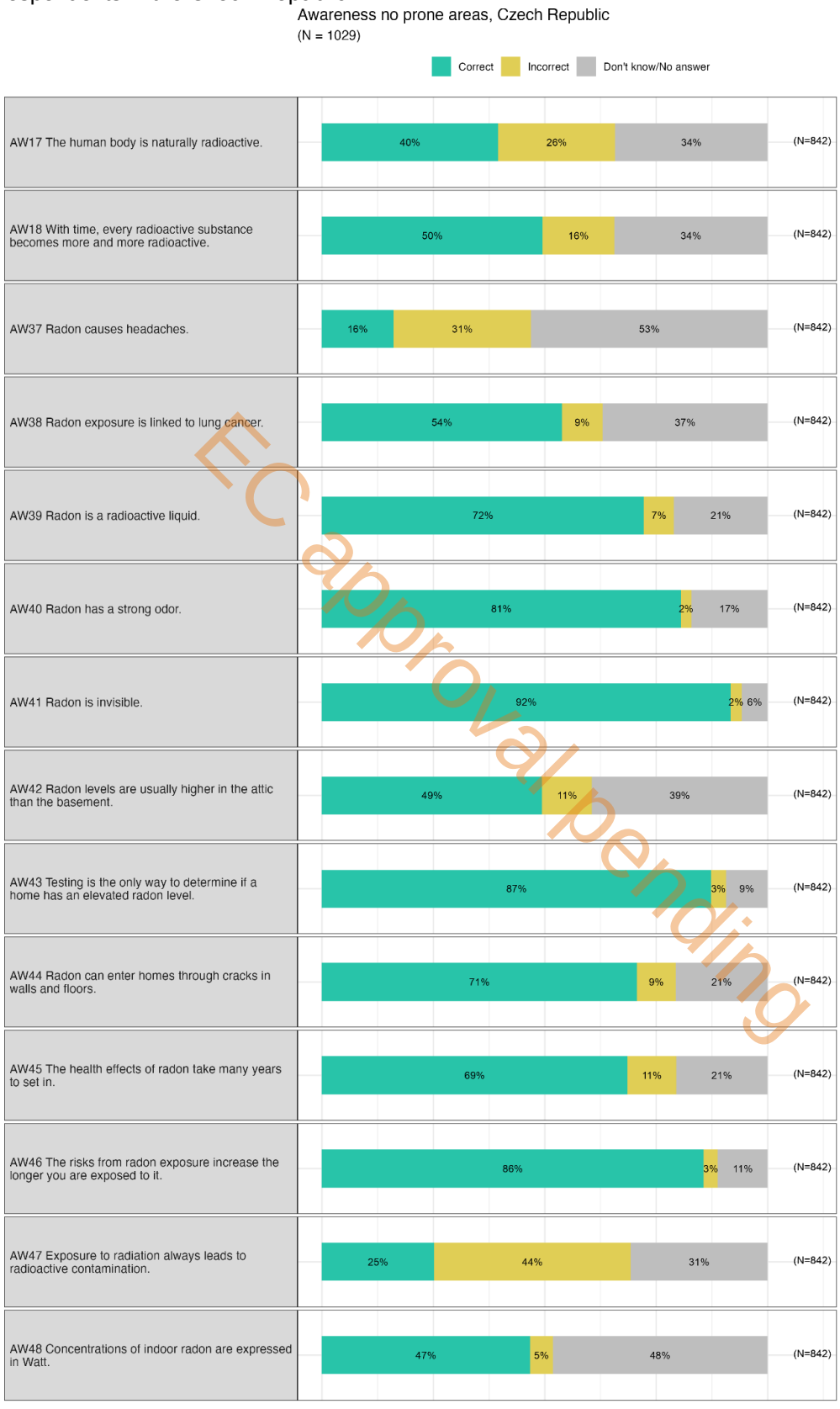

Figure 14: Radon knowledge in Czech Republic

The figure below displays the correct and incorrect responses to radon knowledge statements among respondents in the Germany.

Figure 15: Radon knowledge in Germany

5. Discussion

This section presents a discussion of the research activities conducted in RadoNorm Subtask 6.4.3. The structure follows the individual research activities.

5.1 Framing analysis of radon spa websites[5]

In public health campaigns, a dominant way of framing radon is in terms of health risks and hazards. For example, a recent content analysis of 173 public authority websites in eight European member states found, among others, the following messages: “take the test to protect yourself”, "radon: an enemy in your house"; “the radon risk”; “Test. Fix. Save a Life” (Perko & Turcanu, 2020).

At the same time, RadoNorm Subtask 6.4.3 has found that radon spas provide alternative or even contradictory radon frames on their websites, and hence can potentially impact radon communication campaigns. Having analysed 26 websites of European radon spas, this analysis shows how these websites make information on radon available to the public and communicate about radon as a cure (instead of a carcinogen) in a consistent and engaging way. More specifically, five distinct radon frames were identified, which present radon as a) a source of health, b) a natural gas, c) a (non) risk, d) a luxury and e) a fountain of youth. Comparing these frames with how public authorities tend to communicate on risk, feeds the impression that we are in fact dealing with two different substances. While radon spas frame radon as a source of health, health campaigns try to convey the message that radon “is an important public health issue that requires action” (WHO, 2009). Furthermore, the extensive attention spa websites put on radon’s natural origins and characteristics stands in contrast to recent advice formulated for those designing health campaigns. This latter advice builds on the notion that people “perceive technological threats to be more risky than natural threats” (Hevey, 2017), and hence stresses that “risk communicators need to draw attention to radon” not as a natural gas, but rather as a major cause of “indoor air pollution” (Bouder et al. 2021). Thirdly, radon spa websites mostly provide implicit and non-visual references to radon risk (if any), while health campaigns contain numerous explicit references to the lung cancer risk associated with radon, often supported by various visuals (see e.g. the websites of the 2021 US radon awareness week www.cdc.gov/radon/awareness.html, the 2021 European radon week www.radoneurope.org/event/european-radon-week-2021/ , or the 2020 UK radon awareness week www.radonweek.co.uk/). And fourth, spa websites present radon as a rare and exceptional element, which can be encountered at unique locations, while health communication stresses the abundance of radon by emphasising that “it can enter any building: homes, offices, schools” (Federal Agency for Nuclear Control, no date). Highlighting the existence of these different frames demonstrates that radon communication can be controversial.

Moreover, while indeed the impression might arise that we are dealing with two entirely different radon realities, these realities share social and physical spaces, affecting overlapping audiences. Our analysis hence provided a first step towards recognising that different and sometimes contradicting frames on radon exist and offers a plea to recognise the potential role of radon spas in shaping people’s awareness, perceptions and actions with regard to radon. There are indications that some public authorities already demonstrated such recognition in legal frameworks for radiation protection. The German radon action plan, for example, states how a measurement obligation exists for specific workplaces, explicitly listing radon baths as a place where workers need to be protected from radon. Similarly, public health campaigns need to at least be aware of these spas, the ways in which they frame radon, and the potential effects these alternative framings might have on their audiences. One of these effects might be that citizens perceive the threat of radon as insignificant, hence making it less likely that

[5] This text has previously been published in Geysmans et al., (2022)

they act upon the issue by testing and/or remediating their homes (Bouder et al. 2021). The 2013 BSS Directive stipulates that all EU member states are legally required to design a public communication strategy to increase awareness on radon risk, and hence decrease lung cancer rates due to radon in dwellings, public buildings and at work (Directive, C. 2013). We argue that especially in regions where radon spas are present, a successful public communication strategy would require a reflection on how to deal with the radon communication offered by these parties.

5.2 Semi-structured interviews in Austria and Germany

In this part of the study, we wanted to gain more insight into how radon spas are perceived by people working in the environment of the facility (respondent group 1) and on the other hand by representatives from health authorities, radiation protection authorities and scientists (respondent group 2). Therefore, 16 semi-structured interviews were conducted in radon spas in Austria and in Germany to investigate - inter alia- respondents' perceptions about radon and radon spas.

It turned out that respondents of group 1 represent a heterogeneous group in terms of their perceptions about radon and radon spas. Interestingly, respondents that are working in spas with de-radonised water refer to radon spas as a place of leisure whereas respondents working in spas with radon baths and/or tunnels refer to radon spas much more in terms of treatments and medical therapies. The emphasis is on medical treatment, with the nice and comfortable atmosphere as an add-on.

The respondents of group 1 generally stated having little self-reported knowledge of radon but emphasised having knowledge to an extent that corresponds to their professional activities. When asked what they knew about radon, radon is mostly referred to as a natural gas. Here, we see a parallel to results of the framing analysis, as almost all of the analysed spa websites also refer to the natural origin of radon, whereas information campaigns by authorities avoid this wording/phrase, as people generally perceive technological threats more risky than natural threats (Hevey, 2017).

One key finding is that respondents of group 1 perceived radon to have healing capacities. Anecdotal evidence plays an important role here. The perceived health benefits in the interviews range widely from high success rates and positive experiences that the interviewees have had themselves or have witnessed among their spa clients. Furthermore, health benefits are considered by some respondents to be demonstrated by scientific studies. However, disagreement on this latter aspect existed, as views were expressed that emphasised uncertainties related to the "scientific" basis of health claims.

The opinion of the interviewed representatives from health authorities, radiation protection authorities and scientists (stakeholder group 2) on the healing effects of radon is very cautious. Nevertheless, they pointed out that positive effects can occur in some cases or under certain circumstances.

Another interesting insight is that radon used in treatments is considered to be a controllable risk by several respondents. This controllability (through measuring the dose to which clients of spas expose themselves, time limit of how long and how often clients can undergo treatments or restrictions for certain people such as cancer patients or pregnant women) is one factor that gives respondents a sense of safety. Another factor is that radon therapies must be prescribed by doctors. It is interesting to refer here to the results of the RadoNorm survey (4.3), which also show that doctors and scientists in Austria and Germany are perceived as competent to protect from radiological risks and enjoy a high level of trust compared to other parties (Figures 12, 13).

As published in an article of Erickson (2007a), respondents in group 1 and 2 (under certain conditions) believed that radon therapy could be an acceptable treatment choice for arthritis. They perceived benefits such as more effective pain relief, avoidance of medication side effects, lower costs and improved quality of life (Erickson, 2007a). Paracelsus' quote "the dose makes the poison" was referred to particularly often in interviews with both stakeholder groups to emphasise the importance of dosage when considering radon benefits and risks. Furthermore, in some cases (e.g. for older people and/or

those severely affected by certain medical conditions) the potential benefits of radon were considered to be of a more acute nature in some cases than the potential negative effects of radon on the longer term.

When asking about their opinion regarding public communication on radon risks, some respondents of stakeholder group 1 indicated that risk-emphasising communication might be justified and also in this context referred to the adage “the dose makes the poison”. In this sense, a balanced communication should be aimed for according to some of the respondents, which also leaves room for potential health benefits. Especially respondents of stakeholder group 1 took a sceptical position towards communication and information campaigns pointing out health risks of radon. Emphasising the risk of radon is as a threshold for potential clients to come visit the radon spa. Interestingly, none of the respondents expressed a conscious/possible connection between the locality of the radon spa and potentially elevated indoor radon levels in this area.

Finally, it is noteworthy that several respondents of stakeholder group 2 indicated that communication about radon spas is challenging, as the existence of radon spas makes it challenging to explain to the broader public that radon offers a health risk at home or at work.

5.3 Public attitudes and beliefs related to radon in spas investigated by the RadoNorm survey

First, survey results indicate that in the three countries, – Germany, Austria and the Czech Republic – the respondents' knowledge about radon varies greatly. Only respondents who indicated that they had at least already heard about radon received the radon knowledge questions. For some statements, only very few people gave the correct answer. This may be explained by the fact that these are aspects which because they are not correct, are not part of radon risk communication. Other aspects, such as the fact that radon is a natural radioactive gas or that it can cause lung cancer, were more widely known. Particularly striking is that only slightly more than half of the people gave the correct answer that radon is linked to lung cancer.

The results of the RadoNorm online survey show that the majority of respondents in Austria, the Czech Republic, and Germany are aware of radon spas or caves. The highest level of familiarity was found in Austria and the lowest in Germany.

The five frames identified in the Radon spa website analysis are also present among the respondents, which was indicated spontaneously by an open-ended question. A closer look at the results from the online survey with respect to these frames reveals interesting details. For example, it is striking that a significant proportion of respondents answered the question in an affirmatory way that radon has healing powers. Although one third (Czech Republic) to just over half of respondents (Germany) said “I don't know”, between 18% (Germany) and 27% (Austria) believe in the healing effect of radon. This could be interpreted as alarming in view of the harmful effects of indoor radon, a risk that affects large parts of the population. However, it is also noticeable that even more respondents affirm the therapeutic effect of radon – 30% on average across all three countries (compared to 23% for healing power in general).

With regard to the interpretation of radon as a natural gas, it is noticeable that in the specific query (“due to its natural origin, radon gas is not dangerous”) a large proportion of respondents either disagree with this statement, do not commit themselves or do not give an answer / do not know. On the one hand, this contradicts the general assumption that people consider radon to be harmless because it is natural. On the other hand, it is also possible that the wording of the question prompted the respondents not to confirm the statement in its absoluteness.

With regard to the effect of radon on ageing, the quantitative data also show that the vast majority of respondents do not agree with this statement. What is striking here is the negligible proportion of people

who agree with this assumption. It is pleasing to see that the vast majority do not succumb to this misconception and do not attribute this effect to radon.

Considering risk perception related to radon spas in comparison to other potential risks, it can be stated that in Germany and Austria, radon spas are perceived as posing the least potential risk to one's own health within the next 20 years. On the one hand, this can be explained by the fact that although the people who answered this question knew that radon spas or caves exist, the majority had not yet visited them and would be only personally affected if they visited a radon spa. On the other hand, this again confirms the perception of the positive effect of radon spas on health.

It is interesting to note that the group of respondents who received the statement "indoor air pollution due to radon" to express their risk perception, perceived the radon risk to be slightly higher than the group of respondents who received the statement "presence of the naturally radioactive gas radon indoors".

The high proportion of "don't know" answers in Germany and Austria as reaction to radon statements compared to the other possible risks again shows the large gaps in knowledge about radon and the uncertainty associated with the possible risks. Also, for Germany and Austria, the perception is very comparable: both statements – "indoor air pollution due to radon" and "presence of the naturally radioactive gas radon indoor" – attract the lowest risk perception compared to other risks, apart from the risk perception in relation to "natural radiation from the ground or from space". This comparative enquiry displays climate crisis and environmental pollution as with the highest risk perceptions in both countries, followed directly by the risks from radioactive waste and a potential accident in a nuclear facility. This result is in line with the knowledge about risk perception of radioactive waste and nuclear accidents.

The positive perceptions that the respondents have regarding the health effect of radon and, above all, with regard to the therapeutic effect of radon, fits in with the fact that the respondents expressed a relatedly high level of confidence in authorities to protect visitors of radon spas against potential risks from radon. This arguably aligns with the results from several semi-structured interviews, where the respondents expressed views that the controlled setting in radon spas and caves leads to a high trust in the use of radon as a remedy.

6. Recommendations for public health communication

The general framework recommendations addressed in this section are based on the research results dealt with in Section 4. In parallel, they aim to account for all relevant specificities in their contexts, as discussed in Section 2; including adherence to the current state-of-the-art in ethical risk communication, outlined in Section 2.2.

In this context, the authors of this report recommend that in light of the existence of different 'radon realities', public health communication activities, strategies and tactics, should consider the following:

- The existence of two "radon realities" must not be a contradiction per se. But it is of importance for good communication to recognise both realities. This also entails communicating about the specific characteristics of both radon realities, so people can comprehend why it could be possible to use radon as a cure and at the same time the importance to protect oneself against elevated exposure to radon indoors at home, school, and/or the workplace.
- It is important to bring the different radon realities together. The public should be enabled to deal competently with radon in both forms. Information should therefore be offered together and in a transparent manner. Transparency in communication is ethically important and can furthermore lead to higher trust. Furthermore, short and clear messages can contribute to a better understanding (Bouder et al. 2021).
- Also, the difference between these two radon realities should be well and clearly communicated, especially when pointing out the main contexts in which radon is enacted as a remedy, and those in which it is enacted as a carcinogen.
- Furthermore, we advocate for stakeholders such as doctors, general practitioners and health authorities to take the opportunity to provide information about health protection where people encounter radon. These stakeholders play an important role as communicators and multipliers and should therefore provide holistic information about health protection.
- Finally, institutions working in both radon contexts should work together to give holistic information on radon. It may require some reflection and effort to communicate about both sides of radon in a balanced matter, without distracting from the main messages relevant in a particular radon context. But a more harmonised approach of the stakeholders involved would send a clear signal that both radon realities should be clearly distinguished. In the end, joint communication can lead to better health.

The situation observed in the Czech Republic (Annex 1) may suggest that consideration of the above outlined recommendation is feasible, at least in some contexts.

7. Limitations and roads for future research

The research presented in this Deliverable offers pioneering insights into a previously under-researched and potentially controversial topic. Nevertheless, several limitations, which are discussed in this section, must be acknowledged. Some of these open clear roads towards future research.

First of all, the research primarily focused on radon spas in EU countries (framing analysis), with a specific focus on Germany (interviews and survey), Austria (interviews and survey) and Czech Republic (survey). While this geographical focus provides in-depth insights, it may limit the applicability of the findings to other areas or countries where radon spas operate in different contexts, as partially discussed in Section 2.2. Future research could hence be considered which would focus on other countries in which radon spas operate, also beyond the EU.

Also, the methodological choices made for data gathering and analysis impose certain boundaries on what this study could and could not achieve. For example, framing analysis, even if applied in a thorough and robust way, has inherent limitations, such as the impossibility to fully exclude some potential bias in frame identification and/or interpretation. Also, only English and German language websites were included, hence excluding websites which are only available in another language. Semi-structured interviews, in turn, allowed to gain insights into knowledge, perceptions and opinions regarding radon spas, but did not allow to observe the enactment of radon-related practices in radon spas. For such insights, observations would provide a useful methodology, that was considered at the start of this study. However, due to ethical, practical (COVID-19) and budget constraints, it was not possible to extend the semi-structured interviews with observational methodologies. Furthermore, future studies could aim to conduct also interviews with patients or visitors of radon spas, as well as with a higher number of spa employees and management, and radon authorities and scientists. However, as the efforts in this study clearly show, it might also be difficult in a future project to find enough voluntary interviewees.

The surveys in Austria, Germany and Czech Republic were conducted with the aim of gaining valid and comparable data. Comparability between different countries is influenced by various factors, such as type of sample, type of survey instrument, type and training of interviewers. Due to translation processes from English into Czech and German, however, there might have been some minor differences between the Czech and the German versions. Furthermore, surveys in different countries are always subject to a certain variability, especially when implemented by different clients and contractors.

Finally, we aimed to demonstrate a strong commitment to ethical research practices, as exemplified e.g. by including the early open-access publication of research intentions and internal training. However, the sensitive nature of the radon spa controversy – the central and overarching research topic – may have influenced the willingness of potential respondents to participate in the research, particularly given the time investment required on their part.

8. Concluding remarks

In conclusion, the results reaffirm the limited awareness about radon, not only among the general public but also among stakeholders in the radon spa industry[6]. While some groups recognise the dichotomy between radon as a health risk and radon as a therapeutic agent, there is sometimes limited understanding of the exposure-related differences that distinguish these two radon realities. Communication in this area faces several challenges, including the contrasting narratives: the positive framing of radon in spa settings versus the negative framing in public health messaging related to indoor radon exposure. As a result, these two communication approaches – one emphasising wellness and health, the other focusing on risk and caution – follow divergent paths, making cohesive communication on the subject difficult.

The presented results therefore not only demonstrate that the seeming controversy between these two radon realities has a strong communication component but also outline framework recommendations to address potential communication challenges. As such, this Deliverable can inform public health authorities in EU member states that host radon spas about the potential ways in which these spas could impact (public) perceptions and behaviours regarding radon, while also supporting these authorities in ensuring that their communication activities consider:

- Principles in ethical risk communication,
- Perceptions of different stakeholders related to radon spas,
- The various ways in which radon is enacted in different health contexts.

Additionally, this Deliverable provides an overview of desk research results relevant to the 'radon spa controversy'. This includes addressing various contexts such as differences in legal frameworks (Section 2.4), ethical challenges (Section 2.5), and the correct use of academic language (Section 2.6).

This Deliverable also, though only implicitly, acknowledges that the 'radon spa controversy' is a complex issue spanning multiple academic disciplines, including medical, social, and natural sciences, as well as the humanities. The medical, biological and technical aspects of the health-related issues were intentionally not addressed in this study. It is therefore important to emphasise that the research presented in this Deliverable could not and did not evaluate the actual effectiveness and/or safety of radon treatments.

[6] This situation might be different in specific localities, such as e.g. the Czech town of Jáchymov, as discussed in Annex A

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Appendix A. Radon spas in Czech Republic

Historical Context

The town of Jáchymov in the Czech Republic is renowned not only for its former uranium mines, but also for its radon spa, [most probably] the first of its kind globally. Established in 1906, Jáchymov's spa marked the initial conscious utilisation of radon-rich water for therapeutic purposes. The spa sources its water from the Svornost mine, operational since 1518, which continues to provide radon-laden water for treatments. The spa gained fame for treating musculoskeletal disorders, rheumatic diseases, and other health issues through radon therapy, attracting international visitors.

The Jáchymov town's history is deeply intertwined with mining, particularly silver and later uranium, which also played a role in early nuclear research. Notably, Jáchymov was the source of radium for Marie Curie's Nobel Prize-winning work.

Due to extensive mining and other specifics, radon levels at Jáchymov are among the highest in the Czech Republic. Therefore, in the first half of the 1990s, Jáchymov undertook the first extensive radon measurement project of its kind, involving mandatory radon level measurements at all houses and flats in the town.

Desk research and observations

The preparatory desk research resulted in these key initial findings:

- Jáchymov houses the sole radon spa in the Czech Republic, in contrast to the multiple facilities found in Austria and Germany.
- Jáchymov's radon spa operates under legal requirements overseen by the Czech State Office for Nuclear Safety. This authority issues a public certificate declaring compliance with safety regulations for both clients and employees.
- The spa management might address the so-called 'radon controversy related issues' exclusively by referencing the aforementioned certificate.
- A radon educational trail, installed in Jáchymov in the spring of 2011, provides detailed information about radon and its health impacts. This trail is approximately three and a half kilometres long and connects the historical centre of the town with the radon spa, primarily following a route through the forest. According to the Czech media, might be the first and oldest radon educational trail globally.

During his visit to Jáchymov in 2021, and within subsequent internet search (including the archived original version of the website of the Radon educational trail), the Slovakian RadoNorm researcher noted:

- The municipal tourist information centre lacked promotional materials for the radon spa, and was informed that the spa had opted for self-promotion.
- The spa complex included a 'Visitor Information Centre' advertised with the slogan 'All about radon'.
- The initial information board of the radon educational trail referred above, which originally included information on lung cancer risks, was replaced with a new board that did not include a drawing of lungs and lung cancer.

The framing research of marketing narratives used in advertising materials for the radon spa in late 2020 and early 2021 found that it centred around the slogan "Radon is Energy, and Energy is Life." Supporting narratives emphasised:

- The evolutionary connection between living organisms and environments with ionising radiation.
- The importance of baseline radioactivity in life's genesis and current ecosystems.
- Human physiology's capacity to respond to ionising radiation by activating regenerative processes.

In summer 2021, the Jáchymov radon spa was acquired by Alí Fardán, an entrepreneur from the United Arab Emirates. Following this change in ownership, further modifications to the educational trail were observed. The revised trail, installed in 2023, adopts a more balanced approach, centring on the adage "Radon: the good servant and the bad master". It now includes interactive elements, such as a children's quiz, to enhance engagement and understanding. In contrast with the original radon educational trail, the radon spa joined the project team, and became one of the official partners in this project (www.radonovastezka.eu/o-projektu/).

Analysis and Hypothesis

The RadoNorm researchers hypothesise that changes in the content of the Radon educational trail reflect attempts by the National Nuclear Safety Authority to strike a balance in presenting radon-related information. The complete transformation of the educational trail's content in 2023 suggests a shift from the former narrow focus on homeowners and lung cancer risks to a more holistic educational resource appealing to a broader demographic. This evolution might underscore a concerted effort to provide balanced information about radon while redefining the educational trail's purpose. The revised approach moves away from serving solely as a public health campaign platform towards a more inclusive educational resource.

The mandatory radon level measurements in the 1990s most probably significantly raised awareness among the Jáchymov town's residents about radon and its associated health risks. Consequently, the entire population became well-informed about the town's unique radon situation. Following these compulsory measurements, numerous anti-radon measures were implemented, with varying degrees of success. Whilst many interventions proved effective, there were also several unsuccessful attempts to reduce radon levels below the reference threshold in some properties. The radon issue in Jáchymov has thus come to be regarded primarily as a problem related to the specifics of house construction. The prevalence of numerous external natural sources, along with the frequent use of building materials with high radium content, has made reducing radon levels in certain structures exceedingly challenging and financially burdensome.

Concluding remarks

In 2023, it seemed that under the new proprietor, the spa management discontinued the previous marketing strategy focused solely on radon's positive health impacts, which had centred on the slogan "Radon is Energy, Energy is Life". It therefore appears that not only the public authorities (nuclear regulator and other relevant bodies) but also the new spa management have shifted their positions from conflicting to complementary, and not only concerning the project team and the content of the radon educational trail. After learning about this specific context, the RadoNorm research team decided not to conduct interviews in the Czech Republic, as they considered such interactions to be an implicit intervention in how the spa management and authorities should address the radon spa controversy. This was deemed unnecessary and, moreover, might bear risks of potential counterproductivity due to interference in sensitive issues where such interference would not be welcomed.

Appendix B. Protocols semi-structured interviews

Stakeholder group 1

Introduction

- Can you shortly introduce yourself, particularly with regard to the function that you have here at [spa name]?
    - Probe on: education, time in the organisation, how/why they obtained function at spa

General info spa

- Can you describe what sort of facility [name spa] is?
    - Probe on: what kind of services are provided?
- Why do you think your clients visit [name spa]?

General radon

- Are you familiar with radon gas?
    - [If no (- not expected)] Radon is a gas, which is invisible and odourless. It is a radioactive gas that is naturally occurring, it comes out of the soil.
        - Check whether this rings a bell. If not → end of interview…
    - [If yes] Can you please describe in your own words what radon gas is, as if you needed to explain it to someone who has never heard of it?

Radon @ spa

- On the website of [name facility] radon is also mentioned. Can you describe in which context radon is used or present in [name facility]?
- What would you consider the main benefits (if any) of using radon in [name spa]?
- What would you consider the main challenges (if any) of using radon in [name spa]?
- Is the presence/use of radon at [name facility] something that you communicate about? If yes: in which contexts? And with which message(s)?
    - With your clients?
    - With your (fellow) employees?
    - With the general public?
    - With others?
- Do you ever receive any enquiries or questions regarding radon?
    - From your clients?
    - From external actors?
- Many health authorities highlight that radon has certain risks for human health, if being exposed to it over longer time periods or in high concentrations at home or at work. Have you ever heard (about) such messages? What do you think of such messages?
    - (How) do you connect such messages to the ways in which radon is used/present at [name facility]?

Closure

- [short summary of main messages] Is there anything you would like to add or which has not sufficiently been addressed?

Stakeholder group 2

Introduction

- Can you shortly introduce yourself, particularly with regard to the function that you have at [name organisation]
  - Probe on: education, time in the organisation
- Can you describe a bit what [name organisation] is, and what it does?
  - Probe on responsibilities, mandates, objectives of the organisation

General radon

- Are you familiar with radon gas?
  - [If no (- not expected)] Radon is a gas, which is invisible and odourless. It is a radioactive gas that is naturally occurring, it comes out of the soil.
    - Check whether this rings a bell. If not → end of interview…
  - [If yes] Can you please describe in your own words what radon gas is, as if you needed to explain it to someone who has never heard of it?
- Can you describe the tasks you have at [name organization] regarding radon gas?
  - Probe: are there any other activities conducted at [name organisation] regarding radon gas

General info spa

- Have you heard of the term 'radon spas'?
  - If yes: Can you shortly describe your understanding of this term?
    - Probe on perceptions regarding role of radon in such facilities
  - If no: These are facilities which offer services based on claimed health benefits of radon gas.
    - Check whether this rings a bell
- What is your opinion on such spas?
  - Probe on whether they perceive any benefits or disadvantages to the spa
- Are you familiar with such facilities in [name country]?
  - If yes: can you give some examples?
  - If no → end of interview
- Does [name of organisation] conduct any work/activities connected to these spas?

Radon @ spa

- What would you consider the main benefits (if any) of using radon in these spas?
- What would you consider the main challenges (if any) of using radon in these spas?
- Is the presence/use of radon at these spas something that you communicate about at [name organisation]?
  - If yes: in which contexts? And with which message(s)? Internal/external communication?
- Do you ever receive any enquiries or questions regarding radon spas?
  - Probe: From who? What sort of enquiries?
  - From external actors?
- Often it is emphasised that radon has certain risks for human health, if being exposed to it over longer time periods or in high concentrations at home or at work. What do you think of such messages?
  - (How) do you connect such messages to the ways in which radon is used/present at radon spas?

Closure

[short summary of main messages] Is there anything you would like to add or which has not sufficiently been addressed?

Appendix C. Radon spa related questions from the European Radon Behavioural Atlas Questionnaire

(Perko T. et al, (2024): RadoNorm European Radon Behavioural Atlas, RadoNorm, No 900009)
***INTRO:** To what extent do you agree or disagree with the following statements?*

Attitude radon spa: RANDOMISE *(don't show this title to respondents)*		
SPA1	Radon taken at specific doses relieves symptoms of some diseases.	1.Strongly disagree 2.Disagree 3.Neither agree, nor disagree 4. Agree 5. Strongly agree 9. I don't know/NA
SPA2	Radon has healing powers.	
SPA3	Due to its natural origin, radon gas is not dangerous.	
SPA4	Radon slows down the aging process.	
SPA5	Do you know anything about radon spas or caves?	1.Yes 2. I have heard something about them 3. No 9. I don't know/NA
SPA6	IF SPA5 = 1 or 2: Can you describe in a few words what you have heard about radon spas or caves?	… [Open]
SPA7	IF SPA5 = 1 or 2 : Some people who are important to me visited a radon spa or cave.	Yes No Prefer not to say I don't know /NA
SPA8	IF SPA5 = 1 or 2 : Have you ever visited a radon spa/cave?	1 Never 2 Once 3. Two to five times 4. More than five times 5. Prefer not to say 6. I don't know/NA

SPA9	IF SPA7 = 2, 3 or 4 Could you tell us was the main motivation for your visit of a radon spa or cave?	… [Open allow to skip]
RP SPA	IF SPA7 = 2, 3 or 4 How do you perceive the potential risk to your health within the next 20 years from a radon spa?	1. No risk at all 2. Very low 3. Low 4. Moderate 5. High 6. Very high 9. I don't know/NA
RC SPA	IF SPA7 = 2, 3 or 4 and RP SPA = 2, 3, 4, 5, 6 How much confidence do you have in the authorities for the actions they undertake to protect visitors of radon spas against potential risks from radon?	1. None 2. Very little 3. Little 4. Moderate 5. Quite a lot 6. Very much 9. I don't know/NA