MSc Program
Environmental Technology & International Affairs

Radon, the silent killer: The neglected repercussions cause unforeseen environmental health risks in African countries

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 12.06.2019

Affidavit

I, **ALAN VOLDRICH, BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "RADON, THE SILENT KILLER: THE NEGLECTED REPERCUSSIONS CAUSE UNFORESEEN ENVIRONMENTAL HEALTH RISKS IN AFRICAN COUNTRIES", 75 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

This thesis focuses on raising public and political awareness regarding the consequences of radon in Africa and has two major purposes: the first is to provide an in-depth analysis of the position of institutions such as the EU and the AU and their role in respect to the lack of awareness of the consequences of radon exposure; the second is to find out whether and how can a better understanding of the consequences of indoor radon exposure in Africa be achieved. The hypotheses include that awareness of radon is dependent on the people's education concerning the environment and the consequences of radon. The data used and accessed through the database Factiva were obtained from EU and AU documents as well as scholarly literature dealing with radon exposure and lung cancer in Africa.

In the first part, the scholarly literature is discussed which deals with radon and lung cancer in developing countries as well as Africa's growing lung cancer problem due to environmental and occupational issues. In the second part, the situation in the EU and the AU is analyzed regarding the public's protection from radon exposure in workplaces and dwellings. Furthermore, possible and potential channels are discussed to raise public and political awareness of the consequences of radon in Africa.

The outcome of the thesis is that this lack of awareness has been manifested through the lack of education regarding health effects due to radon. However, the results suggest that education is not enough to acknowledge radon as a threat to public health. Thus, a more emphatic engagement that goes beyond education and scientific support is needed. The amplification of a political will to acknowledge radon as a threat to public health can lead to lengthy procedures.

This research serves as a basis to conduct a pilot project and fieldwork in Africa.

Keywords: *Radon, dwellings, lung cancer, Africa, European Union*

Table of Contents

Lists of abbreviations

AERA	Atomic Energy Regulatory Authority of Malawi
AHS	Africa Health Strategy
AU	African Union
BEIR	National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (USA)
CRIIRAD	Commission for Independent Research and Information on Radioactivity
CZ	Czech Republic
DE	Germany
EU	European Union
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
MW	Malawi
Rn	Radon (radioactive decay products of ^{222}Rn)
UNEP	United Nations Environment Programme
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization
ZA	South Africa

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I would like to thank my loved ones, who listened patiently to my thoughts even though not knowing the subject matter. I am fortunate to have you around.

1. Introduction: Radon

Numerous people think that all radioactivity is man-made and created in nuclear power plants, nuclear explosions or laboratories (Grupen & Rodgers, 2016). However, there is more to it. Since the formation of the planet earth, there has been radioactivity. Radioactivity surrounds us every day: It is in the food we eat, the water we drink and the air we breathe. Especially in the air we breathe, the radioactive noble gas radon is a constant companion. It is a companion that particularly affects our lungs (Grupen & Rodgers, 2016) and originates from the decay of Uranium-238. In detail, radon is natural radioactivity from the environment emitted by primary rock, such as granite, sandstone and Uranium-238. Most of the radiation exposure is natural, while some of it is artificial. The main contributor to radiation exposure is radon (see figure: 1). On the one hand, it is emitted as an internal dose (42% of total distribution of radiation exposure) due to radon in building material, hence infiltrating into houses. On the other hand, it is emitted as an external dose (16% of total distribution of radiation exposure) due to its existence in soil (UNEP, 2016). Thus, radon contributes to more than half of the total environment radiation exposure. As it has been proved that radon may cause cancer, particularly lung cancer (WHO, 2009), it poses a health hazard to humans if the right measures are not taken.

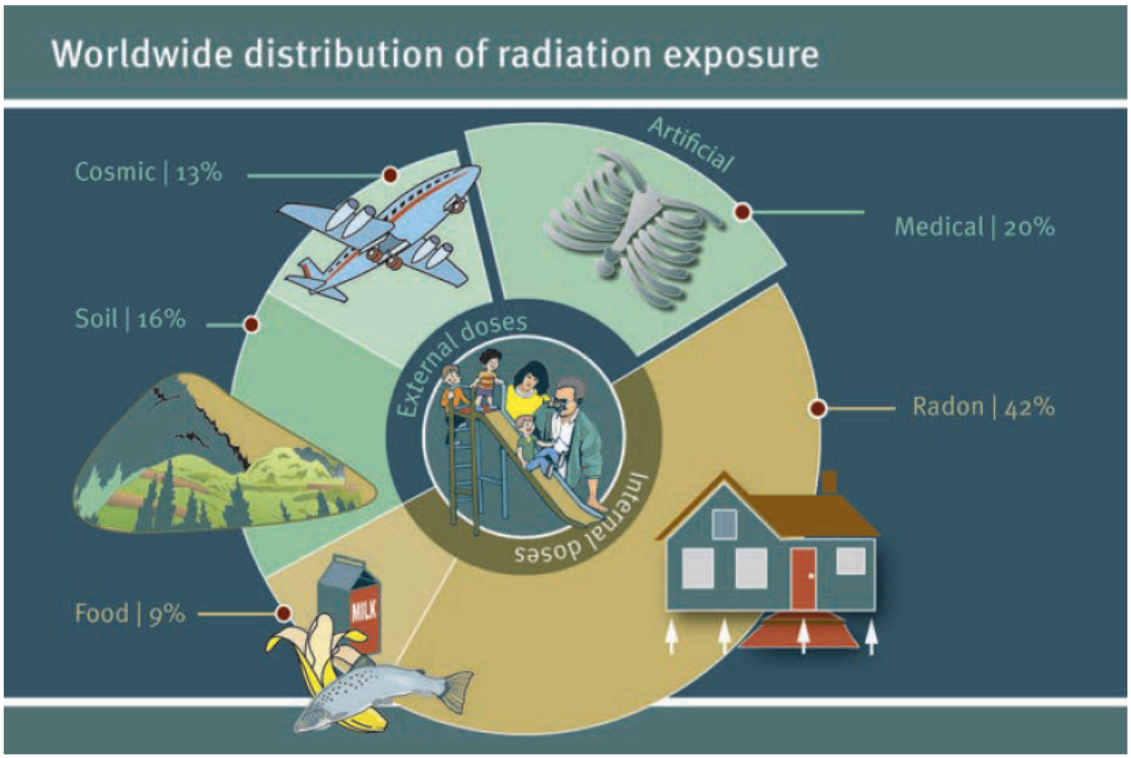


Figure 1: Worldwide distribution of radiation exposure UNEP (2016). Radiation Effects And Sources. p. 27

1.1 Radon's pathways into homes

Building materials used for any kind of house - whether mud-built houses, brick houses or concrete houses – emit radon to a variable extent and are an environmental source for radon progeny which are the short-lived radioactive decay products of ^{220}Rn (thoron) and of ^{222}Rn (radon). In the context of the project, radon will refer to any combination of isotopes of the element radon.

Radon enters a house from the ground and from the walls (see figure: 2). It must not be forgotten that two neighboring houses can have a different radon concentration level. It is found in the soil foundation of each house from where it seeps in through small cracks in the floor. Because of their penetrability, high radon levels specifically occur if houses are built on limestone and chalk (Dixon, 2005). When wet, clay can function as an effective barrier against gas movement; but if it dries out and cracks, the barrier effect vanishes (Dixon, 2005, p. 168). This is an enormous problem for traditional mud-built houses in Africa. Another pathway for radon to get into the house is through the shower. However, the amount of radon in water is much smaller than in the air (UNEP, 2016). Radon gas will always find a way to enter buildings if they are not shielded it gets into the house due to air pressure. The pressure level is often lower inside the house than in the soil around the foundation of the house; hence, radon is sucked into the house because of the pressure difference (Field, 2018). If a house is frequently ventilated by opening a window, exposure to radon is reduced for the moment – however, the air pressure difference will draw in new radon. Hence, a special ventilation is needed which transports the radon via a tube from the basement to the rooftop; but this type of ventilation is rarely available in developing countries.

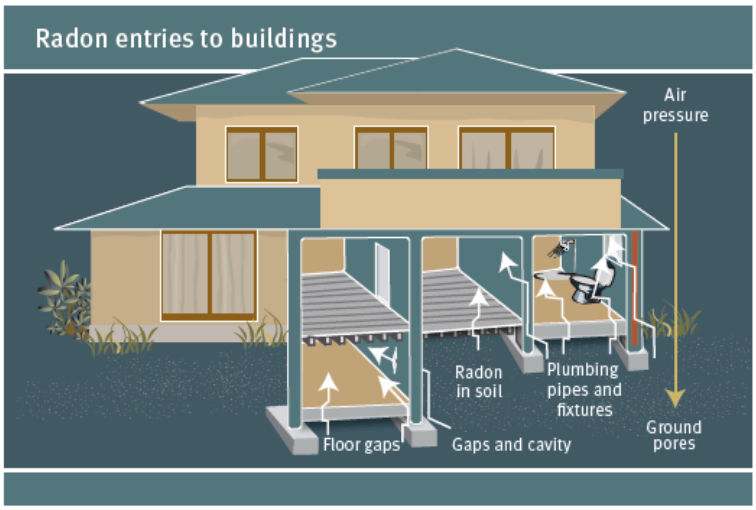


Figure 2: Radon entries to buildings UNEP. (2016). Radiation Effects And Sources. p. 31

1.2 Radon health effect

Radon is a severe health hazard. In the IARC Monograph (1988), it was highlighted that radon may cause lung cancer in humans. Not only the IARC stated that radon causes lung cancer, but also the Committee on the Biological Effects of Ionizing Radiation within the US National Research Council confirmed that finding (BEIR IV, 1988). Radon is the largest source of radiation exposure for most people and has clearly been proved to be responsible for an increased risk of lung cancer (Dixon, 2005, p. 164). The decay products of radon are solid atoms that act as airborne particles. These airborne particles are attached to dust, to carbon or to other small particles that ionize in the lung tissues when inhaled (Yamada et al., 2004; Grupen & Rodgers, 2016). In other words, when the particles with the radon decay products on it are inhaled, it deposits itself in the lung tissues and causes lung cancer (see figure: 3).

It has been known for a long time that radon is carcinogenic. Moreover, for the general population, the WHO (2009) identified radon as the second most common cause of lung cancer following smoking (p. 1). For smokers, the risk of lung cancer is 25 times greater than for non-smokers. Nevertheless, radon can also cause lung cancer in non-smokers – only the risk is lower. In Europe, for example, radon is accountable for 9% of all deaths from lung cancer (out of 20,000 lung cancer deaths) and for 2% of all deaths from cancer (Darby et al., 2005). The figures on deaths from lung cancer in Africa are not precise; they often are not available at all. Hence, as the influence of radon exposure and lung cancer is unidentifiable, radon is a silent killer in Africa.

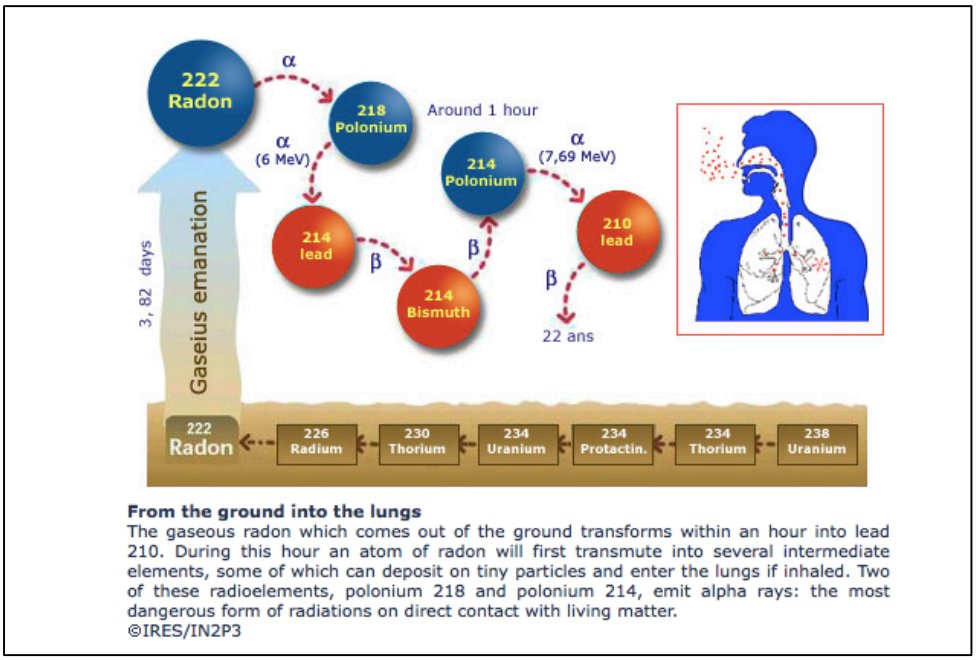


Figure 3: From the ground into the lungs http://www.radioactivity.eu.com/site/pages/Risks_Radon.htm

2. Purpose of the project

The lack of standards and regulations regarding radon left the African continent in a situation in which the lack of knowledge created a vacuum of unawareness. The aim of the project is to highlight the potential of reducing radon exposure and to emphasize the issue of radon in Africa. Most of the people in the African countries do not know anything about hazardous health effects of radon. So far, countries in Africa have not acknowledged the health risks, nor have the countries taken any measures to deal with the consequences of radon exposure. The repercussions of radon have an adverse effect on the economy, on politics, on public health, on the housing situation and also the social life. The underlying problem is that people living in Africa are simply not aware of the health hazard due to radon.

In general, African countries lack standards and regulations regarding radon but also consciousness as described above. In addition, most of the countries in Africa have not yet created a radon risk map of their territories like most of the European countries have done. Zielinski & Chambers (2008) conducted a mapping of residential radon in the world showing that just a few Africa countries, Egypt, Algeria and Ghana, possess a radon risk map (see figure: 4). These three countries (out of 53) represent 12% of the total surface of Africa. By contrast, 34 European countries (out of 46) have available data (Zielinski & Chambers, 2008), which represents 96% of the total surface of Europe. This fact proves that developed countries have already successfully identified radon as a health risk, while developing countries have not done so.

It is obvious that these continents are difficult to compare based on their total surface area, but it is important to realize that the European countries have put much more effort in raising public awareness of radon than African countries. The research will focus on different aspects of how radon exposure causes unforeseen problems on the African continent. The research will not simply state that radon is a silent killer as the research will propose effective measures and mitigation measures. Hence, the research will recommend suitable standards and regulations to be adhered to by the authorities. The recommendations will be embedded in a simplified regulation. However, the research still considers creating a radon risk map of Africa as an important step to identify radon-prone areas. An African radon risk map can help to systematically implement standards and regulations where they are mostly needed. In the words of Zielinski & Chambers (2008), radon maps are a clear and easy to understand way of presenting the issue of radon to the public and policy makers, just

as they are essential for persuading people to take that issue seriously (p. 6). A radon risk map of the African continent is also helpful to allocate public and private funds more efficiently in areas where the level of radon exposure is intolerable.

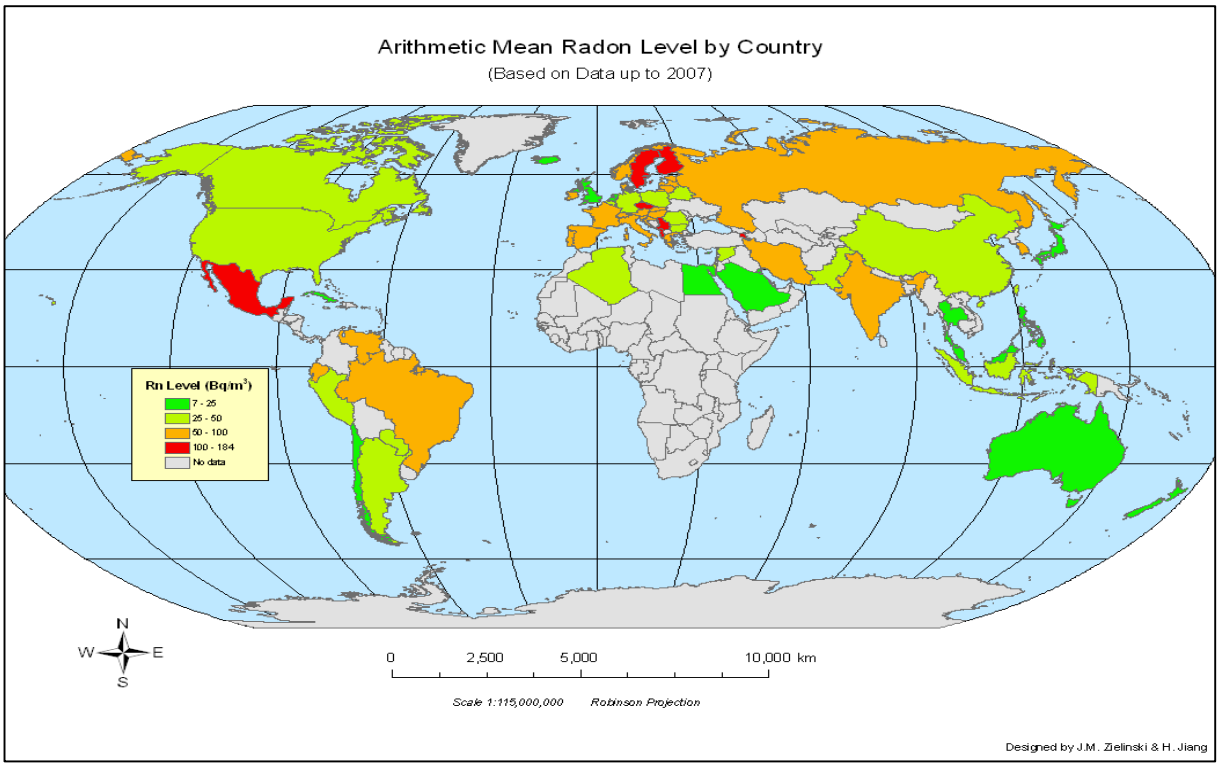


Figure 4: Availability of indoor radon data in the world: whole world (Zielinski & Chambers, 2008, p. 6)

Although the immediate purpose of the project is not to create a radon risk map of the African continent, it is important to highlight the need for such a map. This map simply illustrates that European countries have conducted research on radon, while African countries have not done so yet. Thus, the final purpose of the project is to raise public awareness regarding the consequences of radon which is fundamental for further research.

3. Overall objectives of the project

3.1 Objectives

The overall objectives of the project are:

- The position of institutions and their role in respect to awareness building regarding the consequences of radon exposure.
- How can it be achieved to better understand of the consequences of radon in developing countries? Which stakeholders should be involved in communicating the risk of radon inhalation?

By pursuing these two objectives, the role of institutions as well as the questions of how can a better understanding of the consequences of radon in developing countries be achieved as well as which stakeholders should be involved in communicating the risk of radon inhalation shall be investigated. The first objective deals with the position of institutions like the EU and the AU and their obligation to inform the public about the consequences of radon. The position of the EU is that it is aware of the consequences of lung cancer risk associated with radon inhalation and tacks action to reduce the exposure to radon. The position of the AU is it lacks education and knowledge concerning the consequences of lung cancer risk associated with radon inhalation. Moreover, it will be investigated what their responsibilities are in respect to protect the population from radon exposure. The second objective deals with the possible stakeholders that should be involved in raising awareness regarding the consequences of radon as well as the question of how the consequences of radon can better be understood in developing countries. For example, simple messages can be the key – as it is the case in developed countries where they worked effectively – to transfer the message that radon causes lung cancer.

The aim of the project is to raise public and political awareness regarding the consequences of radon in Africa. Moreover, neglected repercussions of radon cause unforeseen environmental health risks in developing countries. The research is limited by the fact that no data is available on radon in dwellings in Africa and no data exists on lung cancer cases due to radon inhalation.

3.2 Research Questions

The research questions are:

- Why have developing countries not identified radon as an issue?
    - Is this due to lack of awareness? Or due to insufficient financial resources? Or due to the low level of education and knowledge in Africa concerning the consequences of lung cancer risk associated with radon inhalation?
- Why is there a different approach to radon in developed and developing countries?
    - Is this due to missing regulatory bodies? The absence of public awareness regarding the health hazard of radon exposure? Or is there a combination of both?
- How can the knowledge be transferred from the European Union to the African Union?
    - How can the standards that were developed in the EU be transferred?
- What can be done to make the consequences of radon exposure a pressing issue?
    - Are international organizations the answer to advocate on behalf of the issue?

3.2.1 Hypothesis

The hypothesis is that one's awareness of radon is dependent on the knowledge of one's environment and the consequences of radon. The underlying notion of the hypothesis is that the lack of standards and regulations are interchangeably linked with lack of awareness.

4. Methodological approach

4.1 Literature review

4.1.1 Radon and lung cancer in developing countries

In the literature, a way is sought to explain not only the growing burden of lung cancer in developing countries (Lam, White & Chan-Yeung, 2004; McCormack, Schüz, 2011), but also a way to understand why developing countries have not yet identified radon as an agent that causes lung cancer.

A wide range of literature on radon has yielded a detailed understanding of radon and lung cancer in developed countries but the topic has been neglected in developing countries so far. Therefore, works of literature dealing with radon are necessary. In other words, the research foci dealing with radon as a cause of lung cancer have only been on developed countries and not on developing countries. Moreover, safety and health risks which arise due to the exposure to radon, indoor like outdoor, have been identified and communicated in industrialized countries but not in developing countries. The reason for this awareness gap may be too little education regarding safety and health risks of radon. In developed countries, lung cancer is the prevailing type of cancer among males, and it also growing among females (Lam et al., 2004). For a long time, lung cancer has been identified as a major health risk in industrialized countries. Radon, the agent causing lung cancer in underground mines and in dwellings, has been well known since the 1940s when it was termed a health risk (Committee on the Biological Effects of Ionizing Radiation, 1999). The Committee on the Biological Effects of Ionizing Radiation (1999) points out epidemiological studies which were conducted in the 1950s to assess the dose-response relationship between radon exposure and lung cancer. These studies were carried out in the United States, in Canada and in several European countries. Since the late 1980s, radon has been categorized as a carcinogenic agent (BEIR IV, 1988; IARC, 1988). Winde, et al. (2017) emphasize that the knowledge gained from this research showed that uranium ore contains many different radioactive elements and chemical toxins. Works of literature like the a forenamed, however, show that there are several other risks due to exposure to U-ores besides radon and lung cancer. These include types of cancers from exposure to radium and ionizing radiation, cancer because of arsenic exposure, kidney, genetic and developmental effects from uranium, and silicosis from breathing fractured sand particles (Winde et al., 2017, p. 760).

This scientific knowledge is not available in developing countries. That is, it does exist to some extent, but it is not accessible to improve the situation and to create awareness. In developing countries, lung cancer has not been identified as a major health risk; not even a conclusion regarding radon and lung cancer has been drawn yet. The problem of radon causing lung cancer has not been verbalized in developing countries. Particularly due to the fact that radon can be found anywhere on this planet, it should also be an issue in developing countries.

In Africa, lung cancer is not on the list of the most common diseases – as it is in developed countries –, but it becomes more and more frequent (Lam et al., 2004). In other words, the commonness of lung cancer is still low but steadily increasing. The rate of smoking in Africa is generally thought to be low, but there are also great changes (Lam et al., 2004, p. 1046). Given the fact that people in Africa smoke less than people in Europe, the risk of lung cancer might be lower, statistically speaking. Radon is now recognized as the second most common cause of lung cancer after smoking in the general population (WHO, 2009, p. 1). In the handbook on indoor radon, the WHO (2009) emphasizes that radon is much more likely to cause lung cancer in people who smoke, or who have smoked in the past, compared to lifelong non-smokers. However, radon is the primary cause of lung cancer among people who have never smoked (p. 3). Most studies in developed countries differentiate between lung cancer cases related to smokers and to non-smokers while only a limited number of studies conducted in developing countries show this particular differentiation. In detail, no study conducted in Africa deals with the difference of cases of lung cancer due to smoking and due to radon inhalation. In general, the issues of indoor radon has not been propagated to the public on the African continent. Indoor radon comes from the soil, building material and groundwater from drilled wells (Lam et al., 2004, p. 1049). Lam et al. (2004) stress the fact that only a few studies of indoor radon exposure and lung cancer have been conducted on the African continent. They conclude that epidemiological data on lung cancer are lacking in many Asian and African countries, while studies on risk factors, environmental or genetic, are patchy and scarce (p. 1052). Moreover, the use of different data sets as well as various approaches to the data sets make it difficult to address the issue of lung cancer in a coherent way in Africa.

In the report “Estimates of worldwide burden of cancer in 2008: GLOBOCAN 2008”, published 2010, for example, the authors Ferlayet et al. (2010) conclude that “already

the majority of the global cancer burden now occurs in developing countries, these proportions will rise in the next decades if rates remained unchanged" (p. 2916). Many authors agree with this conclusion while at the same time, some disagree with the methods and data used for modeling lung cancer deaths.

Beck and Winkler (2011), for instance, approve of the deduction but oppose the selected data. In figure 5, their disagreement is clearly emphasized by the different colors used. The color coding shows the different estimates regarding male and female lung cancer mortality on the African Continent. Ferlay, et al., 2010 and Beck & Winkler agree and are certain that the demographic transition in developing countries yields rising absolute numbers as for lung cancer in the future (Ferlay, et al., 2010; Beck & Winkler, 2011). In other words, there is no doubt about the increase of deaths from lung cancer in Sub-Saharan Africa (SSA); but data on lung cancer are not available – aside from South Africa – to develop a clear scenario (Beck & Winkler, 2011). Beck and Winkler (2011) believe that the local registries which the GLOBOCAN estimates are based on are not sufficiently reliable at present and are the main cause of the observed differences (p. 1538). By contrast, Ferlay, et al. (2010) claim that their method which is based on reported cancer registry data has adequately been chosen. It seems that some scholars underestimate the data, while the others overestimate it, which can be seen in the dramatic change of colors as used in figure 5 Maps a) and b) present the data provided by Beck and Winkler (2011). The data provided by Ferlay et al. (2010) are shown in maps c) and d).

Figure 5– map of estimated age – classified lung cancer mortality rates in Sub-Saharan Africa by sex according to GLOBOCAN (method by Ferlay, et al. (2010), see points c) and d)) and the method used by Beck and Winkler (2011).

a) According to Beck and Winkler (2011), Malawi has an ASR[1] of 26.0 to 27.9 in males and of 8.0 to 9.9 in females. This means that the estimated male lung cancer mortality in Malawi is relatively high in general; the more the color red is depicted for a country on the map the more people are estimated to die from lung cancer and the more yellow is depicted on the map the fewer people are estimated to die from lung cancer. In other words, 26.0 to 27.9 per 100,000 males suffer from lung cancer, which is depicted in dark red.

[1] ASR is the adult sex ratio. ASR is defined as the proportion of adults in a male population. ASR is described as cancer incidence rate.

c) In comparison, the estimated male lung cancer mortality in Malawi according to Ferlay et al. (2010) is yellow. Thus, the estimated male lung cancer mortality in Malawi is relatively low in general. The estimated lung cancer mortality in Malawi are about 2.0 to 3.9 in males and 0 to 1.9 in females. In

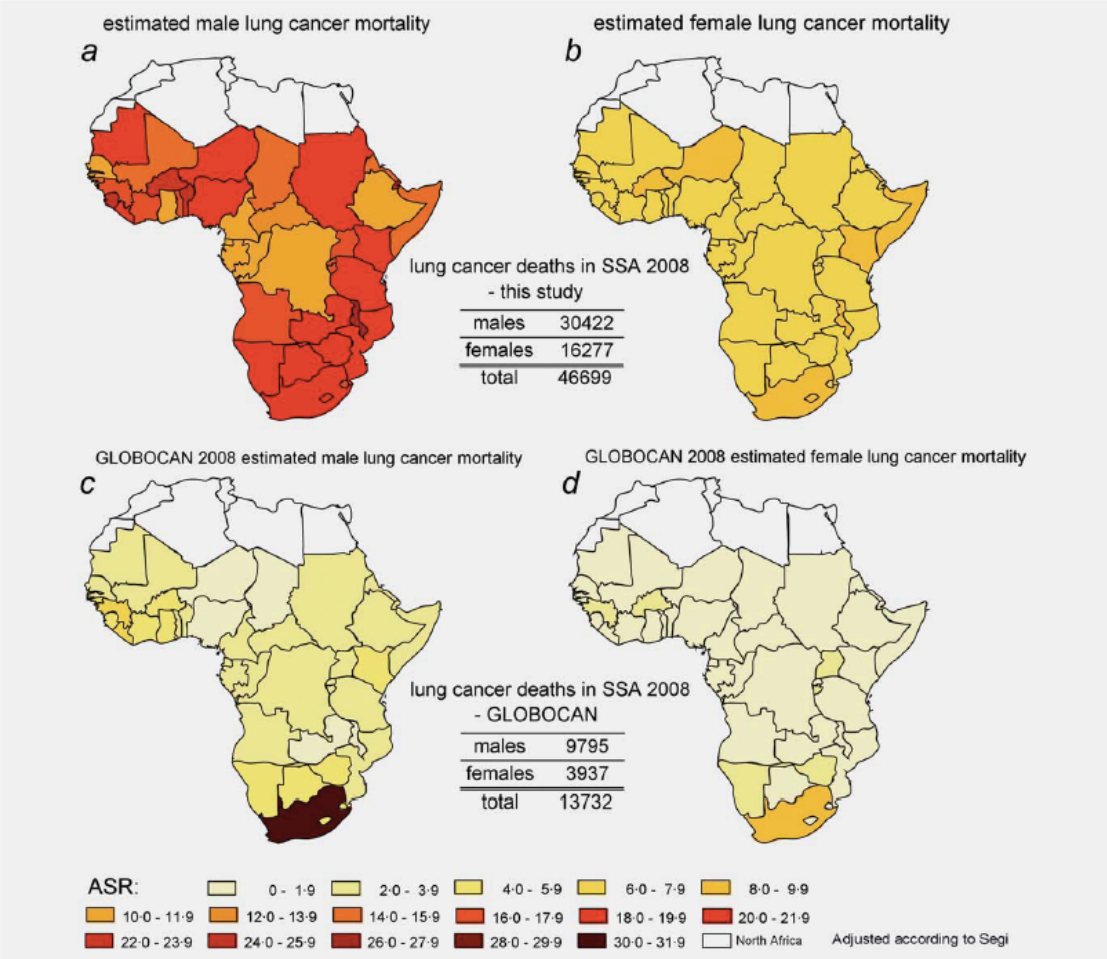


Figure 5: Map of estimated age-adjusted lung cancer mortality rates in Sub-Saharan Africa by sex according to GLOBOCAN and the method by Beck & Winkle (Beck & Winkler, 2011, p. 1537)

In maps a) and b), Malawi is shown at very high risk to be a country with a large share of lung cancer patients, regardless of males and females.

One major cause of lung cancer is the radioactive gas radon, which is found in the dwelling of the people. Particularly those people who live close to uranium mines are exposed to a rising radon level. The French non-governmental organization called Commission for Independent Research and Information on Radioactivity (CRIIRAD), under the lead of Bruno Chareyron (2015), conducted a study in Kayelekera Village, Malawi, which is located near the largest uranium mine in Malawi. In detail, the mean radon 222 activities in the buildings tested by CRIIRAD in Kayelekera ranged between 72 Bq/m^3 (private house in Nkhachira, Malawi) and 123 Bq/m^3 (community hall in

Kayelekera, Malawi). Chareyron (2015) points out that these results indicate radon inhalation is a non-negligible contributor to the dose received by the population (p. 54). The inhalation of radon is an increasing threat in Africa. The findings in Malawi collected by Chareyron (2015) will be further analyzed in this research.

Regarding South Africa, all four maps (a), b), c) and d)) show an exceptional picture. The cancer mortality rate is very high. As lung cancer is one of the more common types of cancer in South Africa (15.4% of all deaths from cancer in men and 6.9% in women in 2008), the environmental contribution to lung cancer alone would represent 2 and 4% of total cancer mortality in men and women respectively (McCormack & Schüz, 2011, p. 2). Thus, the environmental health risk that adds to lung cancer which also arises from inhaling radon gas makes for 2% of total cancer mortality in men and 4% of total cancer mortality in women. The environmental and occupational exposure to radon gas shall gain more attention by African countries and the African Union because its contribution to death from lung cancer is significant.

Despite the fact that some African states are under pressure of an increasing lung cancer mortality in the future, the particular area of interest is that radon gas inhalation in dwellings causes lung cancer and the question of how to mitigate its deadly effect. In detail, the primary focus of the research is radon gas emitted by rocks which are used as building material for dwellings in Africa. Nevertheless, the research still needs to consider Africa's growing issue with cancer as the growing cancer burden can to some extent be linked to the building material used for the people's dwellings.

4.1.2 Africa's growing burden: Environmental and occupational lung cancer

A research gap in the existing literature shows very few scholars have considered that Africa's cancer burden is becoming a real threat to the population on the African continent. An even smaller number of scholars have addressed the environmental and occupational contributions to lung cancer (McCormack & Schüz, 2011).

In 2008, 715,000 new cases of cancer and 542,000 deaths from cancer were totaled (Ferlay, Shin, Bray, Forman, Mathers and Parkin, 2008; McCormack & Schüz, 2011). These numbers are expected to be doubled by 2030 (McCormack & Schüz, 2011), which will solely be due to demographic change. Africa's population has risen constantly in the last 25 years. As of 2017, the population consisted of approximately 1.3 billion inhabitants (United Nations Department of Economic & Social Affairs, 2017), which amounted to 17% of the current global population. The projection for the year

2030 is 1.7 billion. In other words, Africa's population is anticipated to double between 2010 and 2030. According to the United Nations Department of Economic and Social Affairs (2017), the population in Africa will reach 2.5 billion inhabitants by 2050, which is nearly one-third of the world's population in 2050. Thus, the African continent has the highest population growth rate worldwide. As a high population growth rate goes along with a higher cancer burden, the future cancer burden is thus projected to double from 0.7 million to 1.3 million between 2008 and 2030 (McCormack & Schüz, 2011, p. 2).

McCormack & Schüz (2011) highlight the scarcely studied contributions of environmental and occupational exposure to Africa's cancer burden (p. 2). Hence, the authors focus on the neglected environmental health risks which cause lung cancer. The exposure to radon in the air, indoor like outdoor, is a serious health hazard which is most of the time overlooked in developing countries. In Africa, for example, the exposure to the radioactive radon gas in dwelling has completely been ignored. Considering the rapid population growth in Africa and the consequential need for more housing, also the rate of lung cancer will rise eventually. As mentioned before, this is mostly due to the building materials which normally contain the carcinogen radon (Straif, Cohen, & Samet, 2013). In detail, the building material generally used for traditional housing is mud which contains uranium. With the decay of uranium, the building material emits radon; this type of radiation exposure can be mitigated.

An adequate adaptation method needs to be considered when a house is built in Africa as well as a suitable adaptation method needs to be found for existing buildings. The environmental and occupational exposure to radon needs to be contemplated because they are often preventable and adaptable. The lack of awareness considering radon situation in many African countries gives rise to circumstances with unnecessary and avoidable exposures, sometimes at high levels, in many African countries (McCormack & Schüz, 2011). Nevertheless, Africa's data deficit makes it difficult to evaluate how many people are affected by radon exposure. In detail, without constant monitoring, it is almost impossible to apprehend the risk of radon exposure in Africa (Wichmann, Yael & Garland, 2016). The lack of quantifying the risk makes it hard to mobilize resources to tackle the problem. McCormack & Schüz (2011) bluntly state that "suboptimal implementation and monitoring of environmental protection and of occupational health standards, including in the informal sector, use of outdated

technologies in industry and lack of awareness of potential hazards in the specific employment structure give rise to high levels of exposures" (p. 1).

The environmental impact on the cancer burden may possibly increase. As prosperity in Africa is expected to increase in the future, it entails also a longer life expectancy. Given a longer life expectancy implying that carcinogenic diseases have long latency periods, the cases of lung cancer will increase. By now, a dramatic increase in lung cancer cases has not been experienced yet. The motive behind can be that the competing risk from HIV-related deaths that is predominate in the discussion and the reason for ignorance of worsening the situation surrounding lung cancer. (Kielkowski, Nelson, Bello, Kgalamono, & Phillips, 2011; McCormack & Schüz, 2011).

The lack of data concerning the environmental exposure and the risk to suffer from cancer are crucial aspects in the current research and policy making. There is presently large uncertainty regarding how viable it is that a major proportion of all cancer is caused by environmental and occupational exposure (WHO, 2011a). In this context, the WHO arranged the so-called International Conference on Environmental and Occupational Determinates of Cancer: Interventions for Primary Prevention in Asturias, Spain, from 17th to 18th of March 2011. The scientist of the IARC (International Agency for Research on Cancer) who participated in this conference work closely with colleagues at the WHO. The IARC acknowledges that the impact in scarcely researched countries is difficult to evaluate. Moreover, the tools to exactly measure environmental carcinogens are insufficient to study the relationship with cancer risk in exposed population (WHO, 2011a). Therefore, the IARC supports the Asturias Declaration to address this neglected topic. During the conference, the scientists from the IARC drafted the Asturias Declaration to foster research regarding the environmental causes of cancer (WHO, 2011a). The scientists from the IARC are aware that the benefit of primary prevention will only emerge in the future as cancer develops slowly and often decades after exposure. This is why it is very urgent to become active now regarding the modifiable risk factors (WHO, 2011a, para. 3).

The gap in data collection, evaluation and research which was identified during the International Conference on Environmental and Occupational Determinates of Cancer led to the 2011 Asturias Declaration. The Asturias Declaration aims at the primary prevention of environmental and occupational cancer throughout the world (WHO, 2011b). The declaration pronounced in Asturias calls for a primary prevention to save lives and a lot of money (WHO, 2011b). The key recommendations by the scientists of

the IARC are, amongst others, that all countries adopt and enforce legislations for protection of populations, especially the most vulnerable populations, against environmental and occupational cancers. In addition, all countries develop communication campaigns that educate populations regarding environmental and occupational causes of cancer and preventive strategies (WHO, 2011b, p. 1).

This proclamation sounds very promising for Africa's growing cancer burden in terms of environmental and occupational contributions. However, without available and adequate data, the issue becomes simply irrelevant. There is a need for a new method to approach the issue of the persistent data deficit in Africa. In other words: How can the lack of data be overcome in Africa?

4.2 How to overcome the lack of data on radon in Africa

As some authors have pointed out, it is difficult to extrapolate cases of lung cancer in Africa (Lam et al., 2004; Beck and Winkler 2011; Ferlay et al., 2010; McCormack & Schüz, 2011). Similarly, it is almost impossible to draw conclusions about lung cancer cases from radon inhalation without enough and suitable data regarding these cases in general and the consequences of radon exposure.

Africa's data deficit poses a challenge to draft sound policies and to recommend useful implementation technologies. Although it is difficult to overcome the obstacle of data scarcity, this research came up with an alternative approach to tackle this difficulty. In table 1, the risk assessment of radon gas in developed countries and the proposed approach to that assessment in developing countries are shown.

Table 1: Risk assessment of radon gas in developed countries and potentially in developing countries

Risk Assessment of Radon	Current Approach in Developed Countries	Proposed Approach in Developing Countries
Approach	• Standards are established • Surveys are conducted	• Sociology of health and illness (impact pathway) • Surveys are conducted
Data Used	• Radon flux is measured in radon-prone areas • Sampling in dwellings	• Life expectancy • WHO database: burden of disease and Globocan (Global Cancer Observatory); • Citizen science

Method	• Quantitative → mapping	• Interviews • Quantitative method → identify areas of exposure
Policy	• Recommendation for dwellings • Mining safety standards	• Mitigation measures are expressed for dwellings and mining activities → Data-driven policy making

The approach currently used in developed countries has already been used for a long time; it emerged because many European countries kept track of radon measurements for a long period of time and adequate remediation could be drawn. The equipment is state of the art, and the public awareness regarding radon gas and lung cancer is relatively well established. The improvements to be made are very small and require just a nuance of adjustment, the chain of information is well founded. In addition, the farmworker used by EU has been proven to work properly most of the time.

The approach in developed countries (i.e. in the European Union) can be the following:

- Regulations and standards are established.
- Surveys are conducted to understand radon emissions in depth; geological data, health data (about lung cancer), housing styles

The data used in developed countries can be the following:

- Radon flux is measured in radon-prone areas to obtain the radon level.
- Sampling is done in dwellings because the radon level can differ from house to house. Although a radon risk map is a map of radon-prone areas and a tool for planning, it does not predict indoor radon concentration.

The method used in developed countries can be the following:

- Most of the time, scientists use quantitative methods for mapping.
- The mapped quantity, for instance, can be chosen to be long-term mean Rn-concentration in ground-floor living rooms (Bossew, Tollefsen, Gruber & De Cort, 2013, p. 2).

The policy advice in developed countries can be the following:

- Recommendation for dwellings and houses are suggested. What kind of building materials should be used, and which should be avoided?
- At work places where works are exposed to radon, specific measures are implemented.

- A synergy of health and safety standards are adopted to mitigate the effects of radon.

The general situation is different in developing countries. Regulations and standards do not exist, just like public awareness. As a topic, radon has reached neither the public nor policy makers, while people are suffering from its consequences. Hence, there is a need for a fast and at the same time a cost-effective response to radon. Thus, it has been thought about an alternative approach to assess the risk of radon emissions.
The approach in developing countries (i.e. in Africa) can be the following:

- The sociology of health and illness deals with the interplay of society and health. In detail, this approach aims at finding out how social life affects mortality rate and vice versa (Timmermans, & Haas, 2008), and it acknowledges social sciences as an important part in studying health patterns. The field of sociology considers the fact that diseases are influenced by the socioeconomic status of individuals, their ethnic traditions or beliefs, and other cultural factors (White, 2016). It also takes different aspects into account, like lifestyle, family, workplace and the environment. As the individual lifestyles might change in Africa in the upcoming decades, the sociology of health and illness seems to be a useful approach to study health patterns.

The data used in developing countries can be the following:

- Life expectancy rates
- Database for Environmental Burden of Disease by the WHO and Globocan, the Global Cancer Observatory database by the International Agency for Research on Cancer: These databanks can help to estimate cases of lung cancer in Africa. However, for many African states, the datasets are limited.
- The use of citizen science can compensate the data deficit. The people themselves will acquire the data on radon flux with simple tools before the data will be evaluated by scientists.

The method used in developing countries can be the following:

- Interviews with people are conducted to raise their awareness and to find out what the interviewees think about the risk due to radon gas.
- Quantitative method is used to identify areas of high, middle and low exposure.

The policy advice in developing countries can be the following:

- Mitigation measures are expressed for dwellings and mining activities.

- The main difference to policy advice in developed countries is that a data-driven policy making seems more suitable in developing countries. In detail, based on the data collected, a policy will be drafted. If an area shows a high radon level, a different mitigation will be proposed than in an area with a low radon level.

The presented alternative approach to radon risk assessment in developing countries is a guideline for further research on the African continent. The lack of data in Africa requires new approaches to the topic of environmental health risk and the consequences due to radon gas. One of the key aspects is data-driven policy making. Esty and Rushing (2007) claim that data-driven policy making creates great opportunities to quickly identify problems and highpoint effective solutions; this is the ideal case of the usage of data-driven policy making. However, Esty and Rushing (2007) also mention that data on the environment, like air, water pollution and chemical pollution, is seldom available, which is why it is difficult to prevent public harm. A complementary method to data-driven policy making can be citizen science. The concept of citizen science is that non-scientists participate in scientific work (Hand, 2010). A layman, for example, will have a simple device which measures radon gas in his house. The device sends constantly data to a laboratory which evaluates the data anonymously. The obtained data is then projected on a geography map Thus, an interactive radon map of the whole world could be made using citizen science. Such a kind of radon map already exists; it was launched in 2011 by the Norwegian company “Airthings” (Airthings, 2008). This company produces radon detection gas devices for private homes.

4.3 Questionnaire on radon in developing countries

The questionnaire is an element of the research to understand better the public opinion on radon and the people’s awareness of the topic. The questionnaire is on the topic: radon in developing countries meaning that the questions are linked to radon and the African continent. The purpose of the opinion poll is to survey what people think, do not believe, what they know and do not know about radon in Africa. The questionnaire was designed to gather information on the neglected repercussions caused by radon gas and the unforeseen environmental health risks it poses in developing countries. In developed countries like in European countries, a number of regulations have been adopted and efforts have been made to identify radon-prone areas and establish radon risk maps. As this is not the case in many developing countries, the environmental health risk caused by radon on the African continent will be assessed in the following.

The opinion poll is divided into two parts. The first part consists of quantitative questions and the second part of qualitative questions. The ten participants were asked to answer both parts but did not agree to the disclosure of their names. In the study, they will be referred to as “the participants” or “the participant”.

The first section, the quantitative part, contained five questions related to radon. All participants answered the questions by putting down a cross to indicate if they strongly disagreed, disagreed, slightly disagreed, slightly agreed, agreed, strongly agreed or whether the question was not applicable. The reason to choose a scale ranging from “strongly disagree” to “strongly agree” was due to the notion to maybe achieve a higher degree of sensitivity (see table 2). The second part, the qualitative part, consisted in total of six questions (see annex). However, only one participant answered all six questions while the other nine participants replied to just five. The questions were answered by giving statements related to radon (see figure 6). The answers below were left unchanged and are fully authentic.

4.3.1 Overview of the result from the quantitative questions

The five questions were as follows (see table 2):

1. Is radon a cause for lung cancer?
2. Is radon an environmental health risk?
3. Do you think that developing countries are more affected by radon than developed countries?
4. Do you think a radon map shall be created for the African continent?
5. Do you think that education on the environment can help create awareness regarding the health risks caused by radon?

As for the first question whether radon causes lung cancer, all ten participants agreed. All partakers of the questionnaire were fully aware that radon causes lung cancer. It is true that radon is the second most frequent cause for lung cancer after smoking (WHO, 2009).

Regarding the second question whether radon is an environmental health risk, all ten partakers agreed again. The respondents thought that radon is an environmental health risk meaning that measurements should be taken to reduce the health risk coming from naturally occurring radon emission of primary rocks.

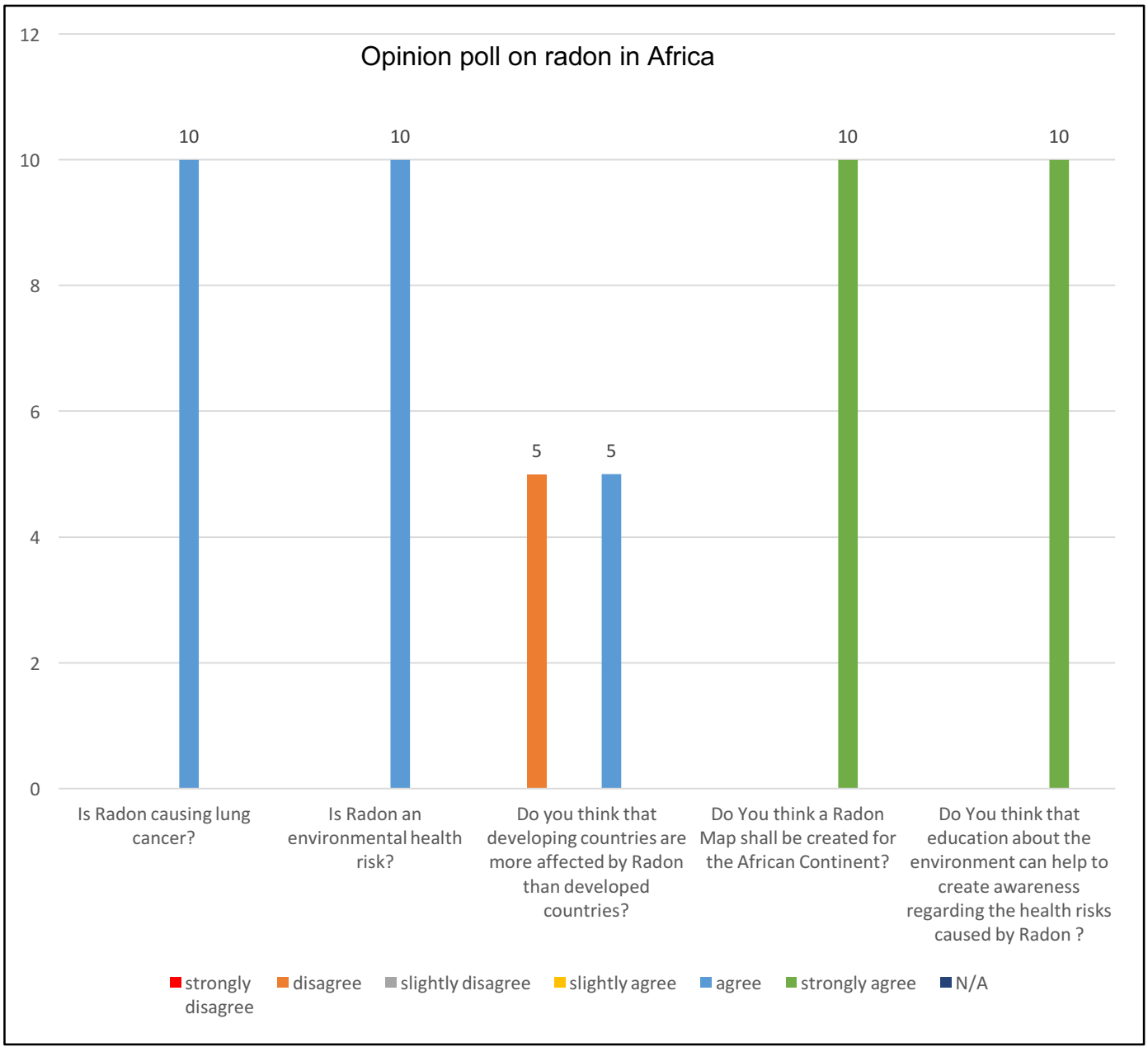
Regarding the third question whether the participants thought that developing countries are more affected by radon than developed countries, half of the partakers

disagreed with the statement, while half of the participants agreed. That meant that five respondents thought developing countries and developed countries are equally affected by radon exposure. It is true that radon exposure occurs globally; however, five interviewees thought that developing countries are more affected by radon than developed countries. Hence, developing countries might be less aware of the consequences of radon and have fewer financial resources to mitigate the effects of radon exposure. The disagreement shows that there is need for action to raise public awareness of the consequences of radon and to invest in different mitigation and adaptation methods to reduce the risk of radon exposure.

Regarding the fourth question whether the interviewees thought a radon map should be created for the African continent, the unanimous answer shows that all partakers raised their voice in favor of establishing a radon risk map in Africa. In support, a radon risk map in Africa would be beneficial for the scientific community and for the people who live in areas with high radon emissions.

Regarding the fifth question whether the respondents thought that education on environmental topics can help create awareness regarding the health risks caused by radon, all ten participants strongly agree with the statement. All interviewees were convinced that this kind of education is a vital element to raise awareness of the consequences of radon exposure.

Table 2: quantitative opinion poll on radon in Africa (source: data acquired through a questionnaire, see annex)



4.3.2 Genuine result from the qualitative questions

The five questions were the following (see figure: 6):

1. When was the first time you heard something about radon, and in which context?
2. Why might radon cause a greater problem in terms of a health risk for developing countries than for developed countries?
3. What can be effective tasks to raise public awareness in developing countries?
4. Why is it difficult to get people to take action on radon?
5. Who should take the lead in raising public awareness of radon?
6. Do you have any other thoughts on the issue?

Regarding the first question about the first time the interviewees heard about radon, one participant answered as follows: “In the late 1980s, we used radon as test tracer to evaluate transport processes in the atmosphere.” Hence, this participant has been intensely involved in using radon as a tracer to assess transport processes in the atmosphere. This answer showed that radon can be used in different ways and not just be associated with lung cancer. The other participants claimed to have not heard something about radon before this survey.

Regarding the second question whether radon might cause a greater problem in terms of a health risk for developing countries, one participant answered that “indoor exposure depends on the radon source strength and on the construction of your house. The research does not see why the risks should in principle be higher in less developed than in developed countries. However, the application of a ventilation system reduces the radon exposure significantly. Such investments might be more common in wealthier countries.” This elaborated answer illustrated that the lack of financial resources is an important issue if radon exposure shall be mitigated. Another participant highlighted that “lack of awareness and a lack of proper building codes in rural poor areas” means a greater health risk for developing countries. Especially in rural areas, there is a lack of information, a building code is missing, and there is only little to none awareness regarding the consequences of radon inhalation. This participant comprehended that most of the radon emissions come from building materials.

Regarding the third question asking about effective tasks to raise public awareness in developing countries, all participants suggested that information should be made

available and education in schools should be promoted. Moreover, communities should be made conscious of different building materials emitting radon.

Regarding the fourth question whether it is difficult to get people to take action on radon, all participants almost answered with one voice that “radon is an odorless, tasteless and invisible gas which does not immediately lead to health damage” and “radon is invisible and its effects are slow to take effect”. Hence, the participants already knew that radon is a silent killer meaning that the health damage is not acute but chronical. In other words, lung cancer due to radon inhalation does not come into being immediately after inhaling it, but the risk of lung cancer is high when one has been exposed to radon over a long time.

Regarding the fifth question who should take the lead in raising public awareness of radon, the participants recommended local medical providers and construction companies as they are close to the people. Local medical providers can inform the people of the consequences of radon like lung cancer, while construction companies can explain the different building materials and adequate adaptation methods for the houses. Other participants proposed that scientists, the European Union and governments should be responsible for raising public awareness. Institutions like scientific institutes, the European Union and different regulatory bodies within the governments gather reliable data and bring forth expertise to implement certain standards and regulations concerning radon. In other terms, trustful people should raise awareness regarding the mortal consequences of radon exposure.

Qualitative Questions and answers about radon health risk and awareness

When was the first time you heard something about radon, and in which context?	• "In the late 1980s, we used radon as test tracer to evaluate transport processes in the atmosphere." • Through Alan Voldrich's research
Why might radon cause a greater problem in terms of health risks for developing countries than for developed countries?	• "The indoor exposure depends on the radon source strength and on the construction of a house. I do not see why the risks should in principle be higher in less developed than in developed countries. However, the application of a ventilation system reduces radon exposure significantly. Such investments might be more common in wealthier countries." • "Lack of awareness and lack of proper building codes in rural poor areas" • Due to control mechanisms; therefore, developed countries have a more elaborated regulation and mechanisms to regulate exposure to radon
What can be effective tasks to raise public awareness in developing countries?	• Information • Education in schools, communities • Through policy development and awareness in developing countries
Why is it difficult to get people to take action on radon?	• Radon is an odorless, tasteless and invisible gas that does not immediately lead to health damage. • Radon is invisible and its effects are slow to take effect. • Failure to understand its long-term effects on human health
Who should take the lead in raising public awareness of radon?	• Local medical providers and construction companies • Scientists, European Union, governments • The government through the Ministry of Health
Do you have any other thoughts on the issue?	• Sensitization on the issue is critical, hence, the effects of radon exposure and its control need to be understood as well.

In conclusion, the questionnaire on radon in developing countries illustrated that the participants are aware of radon in general, but only little aware of radon in Africa. However, the participants suggested that public awareness should be raised about radon in Africa. The general outcome is that public awareness should also be raised in developed countries regarding the problem of radon in Africa. The extrapolated results support the hypothesis that awareness of radon is dependent on the individual knowledge about the environment. Also, the participants thought that education may help raise awareness regarding health risks caused by radon.

4.4 Case study

The case study will focus on radon standards which have been introduced at many different levels. The different levels for the case study are the international level and the respective levels of the United Nations, the European Union and the African Union. In detail, the different radon standards will laid down which have been agreed on at an international level. At a national level, selected cases are the Czech Republic and Germany to show how EU-Members deal with radon standards. These two cases show a practice in setting radon standards in general, and radon standards in dwelling in particular. Although the Czech Republic and Germany demonstrate well how radon standards can be implemented and radon risk maps can be produced, these cases will not be further elaborated. The EU, the Czech Republic and Germany will be compared to understand better the lack of awareness in of the AU, South Africa and Malawi. The aim of the research is the neglected repercussions of radon in developing countries. Thus, the focus will mainly be on two member states of the African Union, namely South Africa and Malawi. The cases were selected because no radon standards in general, and radon standards in dwelling in particular have been researched so far. In South Africa, awareness regarding the environmental health risk of radon is present to some extent and shall be strengthened. Even though South Africa can be used as a blueprint for other countries, the case will be treated as an exception rather than an example to follow. In this respect, the case of South Africa has a potential for generalizability beyond national interest. In the case of Malawi, awareness concerning the environmental health risk of radon is not at all existent. Thus, awareness regarding radon needs to be built from the start.

This selection was made based on several factors like accessibility, relevance and publication date. Moreover, these are important cases because they have a current relevance to radon standards. Both countries have a mining industry,

and their populations represent two different types regarding lack of awareness. The first case (South Africa) needs strengthened awareness regarding the environmental health risk due to radon inhalation, while the second case (Malawi) has no awareness at all. Although the case selection seems to be contradictory, it is assumed that these cases will help us understand the situation in general. Both cases suggest a potential for generalizability beyond national interest. Other criteria for the case selection include the availability of information and the lack of awareness considering radon on the African continent can be overcome.

4.4.1 Data source

The applied method to collect the data is a qualitative approach. Archival data was used, like official documents, policy proposals and academic literature. The data was gathered based on a systematic research of file names, keywords, key players and peer-reviewed articles and documents that were accessed through the database Factiva. The chosen texts were mainly related to indoor and outdoor radon, radon in developing countries, lung cancer in Africa, lung cancer and radon, the IAEA, the African Union, the European Union. These texts included scholarly articles, scientific publications and official documents published by the EU, AU as well as the IAEA and other international organizations.

The texts were analyzed because it was assumed that these articles, journals, EU directives showed a significant influence of radon standards A specific timescale was used to show the influence of the EU on radon standards. Most of the archival data came directly from the European Union archives and was gathered by experts, scientists and scholars who have done fieldwork to provide the EU with suitable information and data.

Although the data deficit in the African Union regarding radon must be considered, the research tries to compensate this lack by introducing the possibility of data transposition. In detail, the possibility of transposing radon standards will explored which were introduced in the European Union and could be initiated by the African Union

5. Empirical analysis

In the empirical analysis, a process-tracing approach is applied to demonstrate that the lack of standards and regulations regarding ionizing radiation are interchangeably linked with lack of awareness regarding radon. Moreover, the research takes into consideration that the African continent is facing a growing cancer burden due to environmental and occupational contributions. The research will address the possible lack of awareness through the hypothesis that awareness of radon is dependent on the level of knowledge about the environment and the selected cases. The carefully chosen cases will help measure the influence of the aforementioned standards and regulations regarding. In other words, if standards and regulations regarding ionizing radiation are introduced in a country or an international organization, the hypothesis expects the awareness of radon to be high. If these standards and regulations are not introduced, the hypothesis expects the opposite.

The structure of an empirical analysis means to systematically study different standards and regulations related to radon at an international and a national level by encompassing a set of research questions as well as the hypothesis. The cases will be discussed and a connection will be established. Furthermore, facts will specifically be used not prior to the year 1959 and not after the year 2020. At an international and a national level, this time span is not equal to all standards and regulations related to radon. The year 1959 marks the first time that the topic of radon and ionizing radiation appeared in a regulation or standard, while the year 2020 was chosen because a regulation or standard needs to be implemented by that time. More precisely, the European Economic Community presented the Basis Safety Standard Directive in 1959. In accordance with the German Radiation Protection Act, the federal states have to determine in what areas a high amount of radon in buildings has to be expected by 2020. Although these two points of reference show the continuality of the European Community, it must not be overlooked what happened in the African Union, which was established in 2002 as a successor to the Organization of African Unity (OAU) (OAU Charta, 1963). Thus, the selected time span demonstrates a comprehensive framework for the research over the course of 60 years.

The process-tracing approach is divided into different levels of analysis. The fist level is the international level and split in three main sections: guidelines by the United Nations regarding radon, regulations and standards on radon in the European Union and regulations and standards on radon in the African Union. The second level is the

national level. Based on the regulations and standards on radon in the European Union, the research will analyze the measures taken in Germany and the Czech Republic. In addition, based on the regulations and standards on radon in the African Union, the research will analyze the measures taken in South Africa and Malawi. These levels of analysis will guide us to examine whether the lack of standards and regulations regarding ionizing radiation are interchangeably linked with lack of awareness. The channels to profoundly understand the lack of standards and regulations regarding ionizing radiation and the link to lack of awareness shape the research questions. Within the framework of this research, these research questions will be supported by the hypothesis.

The research questions are as follows: Why have developing countries not identified radon as an issue? Is it due to the absence of awareness or the deficiency in financial capabilities or the insufficient or even non-existent knowledge about the consequences resulting from radon exposure? Why is there a different approach to radon in developed and developing countries? How can the knowledge be transferred from the European Union to the African Union? How can the standards which were developed in the EU be transferred? And: What can be done to present the consequences resulting from radon exposure as a pressing issue? At the same time, the research will also ask: Are international organizations the answer to advocate on behalf of the issue?

Hence, the empirical analysis is based on a process-tracing approach with a time span of over 60 years to systematically trace the lack of standards and regulations regarding ionizing radiation (like radon) which is interchangeably linked with lack of awareness of radon.

5.1 Guidelines by the United Nations

The United Nations (UN) and their specialized agencies as well as related organizations have a long history of publishing guidelines and key reports related to ionizing radiation and radon (see figure 7). In the late 1970s, the WHO and the European Community were the first organizations to draw attention to the health effects of residential radon exposures while collaborating in a working group on indoor air quality (WHO, 2009). Since then, the consequences of radon exposure have gained more of scientific interest. A decade later, in the late 1980s, the IARC (International Agency for Research on Cancer) classified radon as a human carcinogen (IARC, 1988). The IARC, which is part of the WHO, detected the environmental health risk caused by radon. In other words, the International Agency for Research on Cancer categorized radon as a leading cause for lung cancer as a result of smoking. A few years later, in 1993, the ICRP (International Commission on Radiological Protection) published a report with recommendations on protection measures against radon exposure (ICRP, 1993). One of the recommendations, for example, was that the radon strategy should be simple and realistic (same approach for smokers and non-smokers), integrated (consistent for all buildings), graded (according to the situation and the legal responsibilities) and ambitious (choice of the reference level; addressing both highest exposures and global risk) (ICRP, 1993, p. 10). The advice by the ICRP helped to set the tone for the upcoming guidelines drafted and agreed by the United Nations and their specialized agencies as well as related organizations. In 2004, the IAEA introduced the Programme of Action for Cancer Therapy (PACT) with the aim to address cancer as a health risk in middle and low income IAEA member states. Although the PACT has the objective to combat cancer it has failed to underline the health risk causes by the radon, a carcinogenic agent.

In 2005, the WHO launched a project to minimize the risks causing radon. The so-called International Radon Project was designed to reduce the health risk linked to radon (WHO, 2005). This project tried to raise awareness regarding the risk of lung cancer due to radon around the world. The WHO facilitated this international collaboration with many working groups. The different working groups met frequently to exchange data and to further organize the project. During the third meeting of the WHO International Radon Project, the scientific working groups drafted a table of contents for the WHO radon handbook which included, for example, chapters on the radon health effect, radon mitigation and prevention, exposure guidelines and risk

communication (2007). This ambitious project lasted from 2005 to 2007. The main outcome of the International Radon Project was the *WHO handbook on indoor radon: A public health perspective* (WHO, 2009). To explain in detail, the *WHO handbook on indoor rado*n is a detailed guide on how to deal with the environmental health risk caused by indoor radon exposure. The main recommendation in the guidebook includes that countries adopt a reference level of 100 becquerels per cubic meter (Bq/m^3) and not exceed 300 Bq/m^3 (WHO, 2009). These proposed reference levels are used as a benchmark by countries. In addition, other booklets on radon exposure mention these reference levels as a suggested standard.

In 2006, the IAEA published the so-called *Fundamental Safety Principle*, in which it is stated under principle 10 that protecting actions to decrease existing or unregulated radiation risk must be justified and optimized in situations concerning radiation of essentially natural origin. Such situations include exposure to radon gas in dwellings and workplaces, e.g., for which remedial actions can be taken if necessary. However, in many situations, there is little that can practicably be done to reduce exposure to natural sources of radiation (IAEA, 2006, p. 15). In the course of time, the International Atomic Energy Agency changed its position in some ways from barely can be done to decrease exposure to radon gas to emphasize the health risk of radon exposure and homogenizing the process of radon measurements in dwellings. In 2013, the IAEA tried to standardize the procedure of radon measurements in dwellings by publishing the *National and Regional Surveys of Radon Concentration in Dwellings.* This publication still serves as a guideline on how to design a survey for radon measurements in dwellings. In the same year, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) issued the 2013 report on sources, effects and risks of ionizing radiation. Volume two goes into detail about radon exposure, cancer and the fact how children are even more affected by radon exposure. This report opened up the discussion and showed the serious problems caused by radon. However, until this point in time, no study had been published about a state in Africa or about the problematic situation of radon exposure in developing countries.

In 2014, the IAEA released the report *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards.* In relation to the requirement (number 50) regarding public exposure indoors due to radon, the report states that the government shall provide information on levels of radon exposure indoors and the associated health risks as well as, if appropriate, an action plan for controlling public

exposure shall be established and implemented (IAEA, 2013, p. 99). This was an important signal for policy makers around the world. Nonetheless, an action is still missing regarding the neglected topic of radon exposure and health risks posed on developing countries and the reminder that developing countries shall have a special support on this issue.

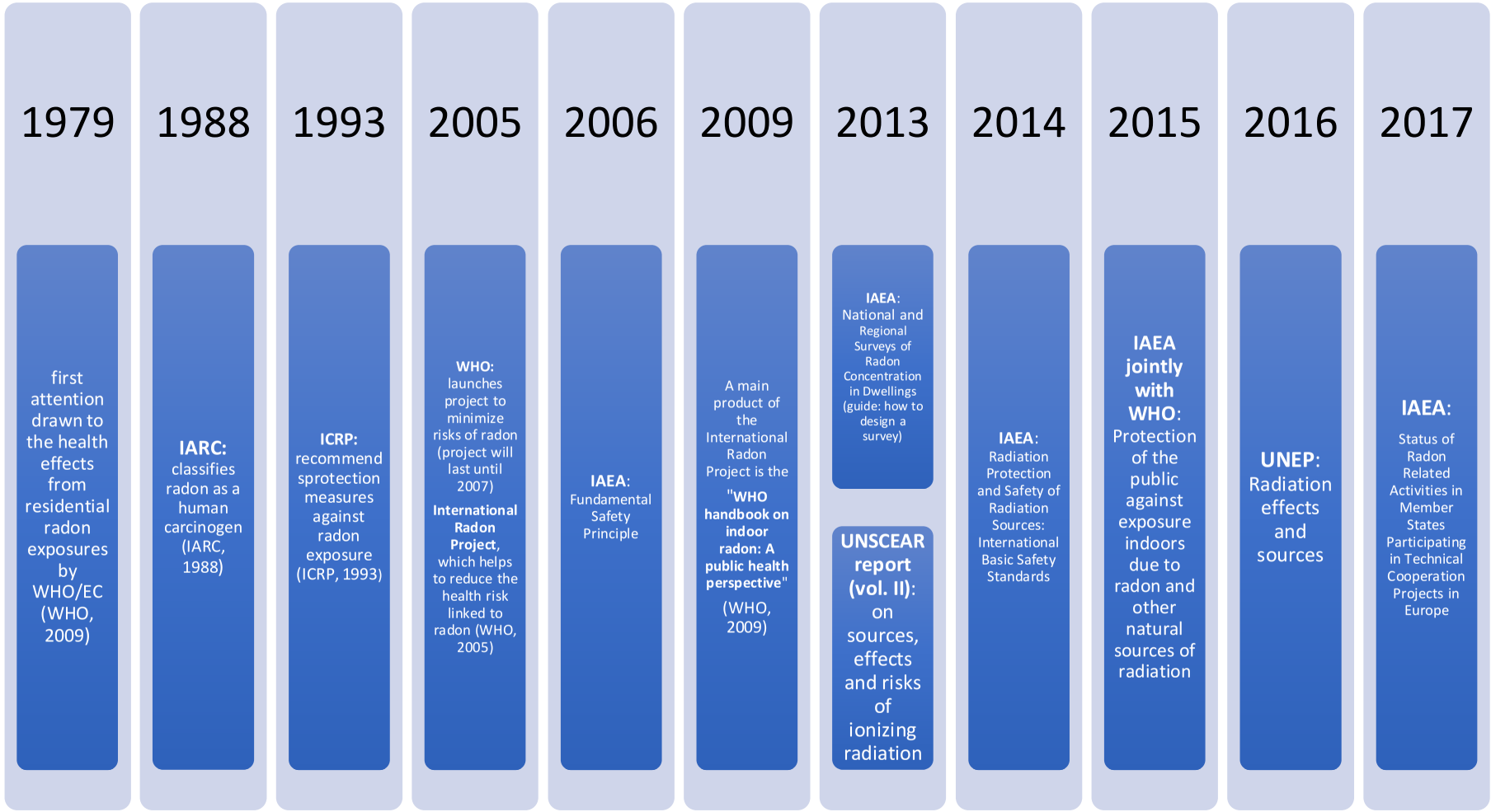
In 2015 and in 2016, two efforts were made to address the issue of radon exposure. In 2015, the IAEA worked together with the WHO to release the report *Protection of the public against exposure indoors due to radon and other natural sources of radiation.* This publication specifically targeted radon and its repercussions on human health. In this report, the IAEA and the WHO expressed the serious environmental health risk caused by radon exposure. Since then, the IAEA has strongly been advocating the health risk caused by radon, which helps the people in the end. However, this report does not expose the potential health risk for developing countries due to radon. In 2016, the United Nations Environmental Program (UNEP) became active regarding the topic of radon by publishing the booklet entitled *Radiation effects and sources.* This booklet is a conglomerate of the UNSCEAR reports published in the past 25 years. Its purpose is to enhance the public awareness of ionizing radiation. The booklet was published in ten different languages to make it accessible to a wider audience. In 2017, the IAEA initiated a survey on the undertakings by members states in relation to radon and released a booklet on the *Status of Radon Related Activities in Member States Participating in Technical Cooperation Projects in Europe.* The booklet offers an extensive overview of the national regulations and standards of some member states. However, the African continent was not represented is this publication.

In conclusion, the United Nations has made a great effort to raise people's awareness of ionizing radiation in general, and of radon exposure in particular. The concentration and continuity of standards and regulations regarding ionizing radiation are high in numbers as is the awareness of radon at an international level. The United Nations, their specialized agencies and related organizations are highly aware of the consequences of radon that are posed on human health and, moreover, aims at amplifying the level of knowledge about the environment and natural radiation. Thus, the level of awareness regarding radon has been heightened due to the number of standards and regulations as the level of knowledge about the environment has been well-established due to a wide range of agencies, organizations and programs of the UN involved in this matter. However, the research is concerned that the UN has not

managed to address the topic of radon as a silent killer in developing countries. Hence, the UN acknowledges the repercussions of radon while neglecting the unforeseen environmental health risks in developing countries. In this respect, the United Nations should be a driving force to address the neglected repercussions of radon causing unexpected environmental health risks in developing countries. The international organization is part of the solution because there is an extensive outreach to advocate on behalf of the issue. The United Nations should clarify and publish the consequences of radon exposure as an urgent issue in developing by introducing public health as a key element for a health society and by improving the data collection in Africa on radon and lung cancer as well as radon exposure in dwellings.

Guidelines and key reports related to Radon published by specialized agencies and related organizations to the United Nations

The WHO Handbook on indoor radon recommends that countries adopt reference levels of 100 Becquerel per cubic meter (Bq/m3) and not exceeding 300 Bq/m3.



Sources: IAEA. (2006). Fundamental Safety Principle. Safety Fundamentals No. SF-1.; IAEA. (2013). National and Regional Surveys of Radon Concentration in Dwellings. IAEA Analytical Quality in Nuclear Applications Series (No. 33).; IAEA. (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA Safety Standards Series No. GSR Part 3.; IAEA, (2015). Protection of the public against exposure indoors due to radon and other natural sources of radiation.; IAEA. (2017). Status of Radon Related Activities in Member States Participating in Technical Cooperation Projects in Europe, IAEA-TECDOC-1810, IAEA, Vienna IARC.; (1988). Working Group on the Evaluation of the Carcinogenic Risk to Humans. IARC Monographs on the Evaluation of the Carcinogenic Risk to Humans, Man-made Minerals Fibers and Radon (Vol. 43). IARC.; ICRP, (1993). Protection Against Radon-222 at Home and at Work. ICRP Publication 65, Ann. ICRP 23(2).; UNSCEAR (2013). Sources, effects and risks of ionizing radiation. volume II Scientific Annex B.; UNEP. (2016). Radiation effects and sources.; WHO, (2005). WHO launches project to minimize risks of radon. [online] Retrieved from: https://www.who.int/mediacentre/news/notes/2005/np15/en/, Accessed 9 Feb. 2019.; WHO. (2009). WHO handbook on indoor radon: a public health perspective. 2009.

Figure 7

5.2 Regulations and standards regarding radon in the European Union

In the late 1950s, the European Union first acknowledged the danger emerging from ionizing radiation and natural existing exposure to radon. In the European Union, the problem of lung cancer and radon inhalation was recognized in the late 50s; hence, sound and stable regulations and standards followed (see figure: 8). The regulations and standards were strong and based on the will of the member states to respect these rules and control mechanisms.

In 1959, the member states of the European Community approved the first directive on *Basic Safety Standard (BSS).* This landmark directive preserves the highest possible safety of workers, patients and the public against the risk resulting from exposure to ionizing radiation (Article 30 BSS, 1959). In the decades to come, this directive will continually be amended to satisfy the latest scientific findings and suggestions. The protection of the public, for instance, means that the society shall be protected from radon in buildings. The forward-thinking attitude in addition to the new scientific findings led to several amendments of the *Basic Safety Standards* directive. In 1980, the directive was amended by putting the development of scientific knowledge concerning radiation protection in line with the recommendations of the ICRP and on the basis of operational experiences (1980).

Moreover, the directive included a dose limit for whole-body exposure of workers which shall be 50 mSv (5 rems) in a year, which is approx. 850 Bq/m^3 (in this case: 0.017 mSv/y for 1 Bq/m^3). The dose limit for the lens of the eye shall be 300 mSv (30 rems) per year (Article 9, BSS, 1980), while in the case of whole-body exposure, the dose limit shall be 5 mSv (0.5 rem) in a year. The dose limit for the public in the case of whole-body exposure shall be 5 mSv (0.5 rem) in a year, which is approx. 100 Bq/m^3 (Article 12, BSS, 1980). These reference values set a high standard which was partly motivated by the WHO. In 1990, the European Union's *Commission Recommendation on the protection of the public against indoor exposure* to radon was introduced. The advice by the commission regarding reference levels for existing buildings was to be an effective dose equivalent of 20 mSv per annum which is understood as equivalent to an annual average radon gas concentration of 400 Bq/m^3 (Article 2. b), EC, 1990) In addition, for future constructions, the design should be an effective dose equivalent to 10 mSv per annum which is understood as equivalent to an annual average radon gas concentration of 200 Bq/m^3 (Article 3. b), EC, 1990). The suggestions by the European Commission were based on scientist data to protect the human being at the

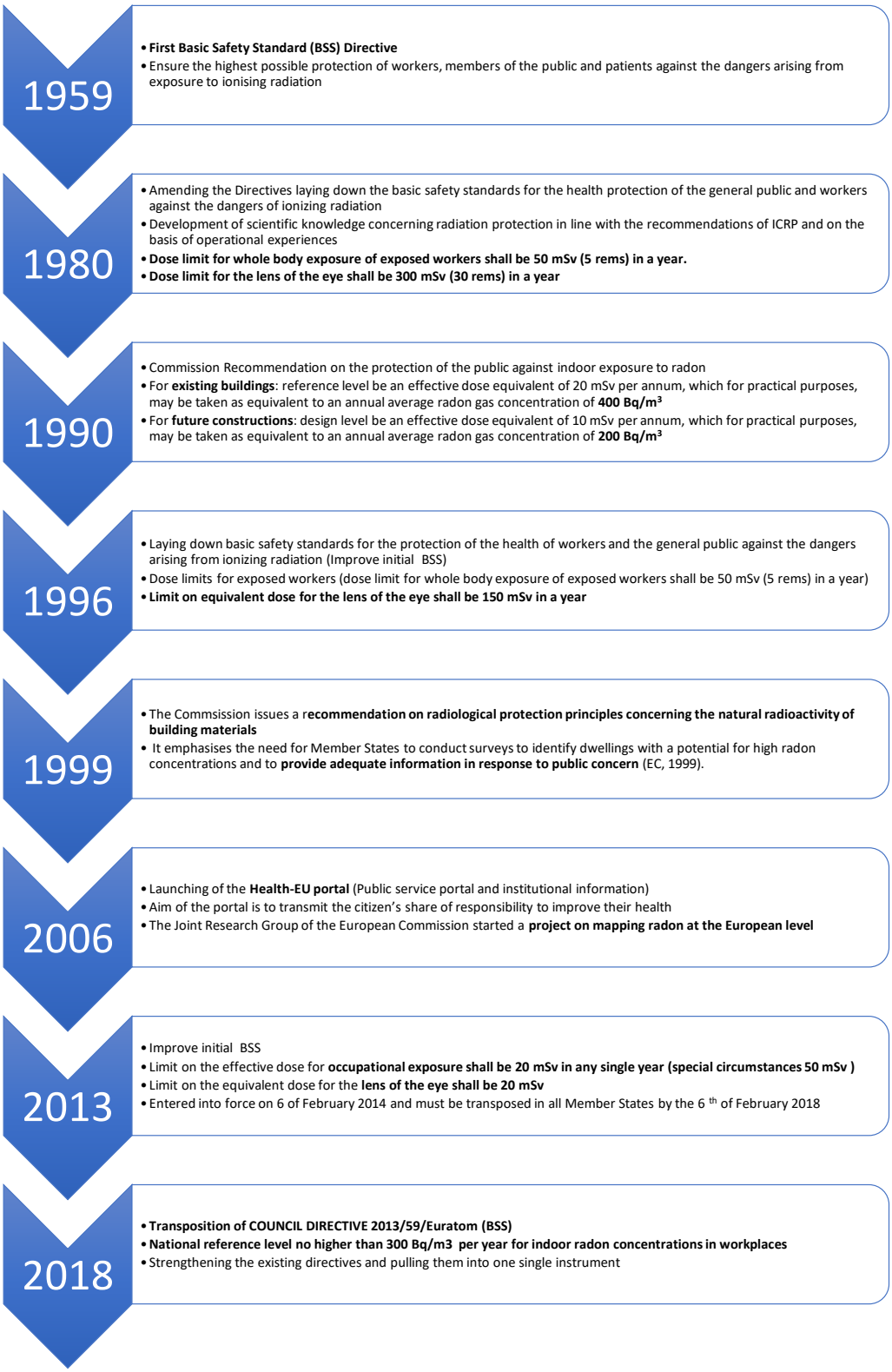
best possible rate. These recommendations show that the European Union is fully aware of the consequence of radon and willing to apply the best available data when suitable. It is the willingness to learn and to share the knowledge with the public which make the European Union to some extent a pioneer in the field of radon exposure.

In 1996, the EU amended once again the directive on *Basic Safety Standard.* Although the dose limits for exposed workers remained at the same level (50 mSv in a year), the limit on equivalent dose for the lens of the eye was reduced by half to 150 mSv in a year (COUNCIL DIRECTIVE 96/29/EURATOM). A few years later, in 1999, the European Commission published a guideline called *Radiological protection principles concerning the natural radioactivity of building materials.* The recommendations followed and supported the Directive mentioned above in terms of the reference levels; moreover, the European Commission fostered the application of the radiation protection principles (EC, 1999). The principle of protections is guided by the principles of justification, optimization and dose limitation (ICRP, 1985) and it was emphasized that member states should provide enough information to the concerned public. In 2006, the EU envisaged its educational role, and due to the necessity of raising public awareness regarding the consequences of radon exposure, the *Health-EU portal* (EU public health portal) was launched. This portal is a public service portal on health risks in general, and on radon exposure in particular. The overall aim of the *Health-EU portal* is to transmit the citizens' responsibility to improve their health. This means, the EU encourages the public to become informed about different health risks so that the society may take on the recommendations to live a healthy life. Public awareness will not rise automatically because of the portal's existence, but there is data available to receive information. Also, in 2006, The Joint Research Group of the European Commission started a project on mapping radon at a European level (Bossew et al., 2013). In 2013, the directive on *Basic Safety Standard* was amended regarding the lens of the eye and the occupational exposure. In greater detail, the limit on the effective dose for occupational exposure ought to be 20 mSv in one year (special circumstances: 50 mSv), while the limit on the equivalent dose for the lens of the eye was set to be 20 mSv (COUNCIL DIRECTIVE 2013/59/EURATOM). The directive is largely consistent with the IAEA Basic Safety Standards; especially the numerical values were harmonized.

In general, the Directive required EU member countries to establish a national reference level no higher than 300 Bq/m^3 per year for indoor radon concentrations in

workplaces. Member states of the EU like Germany and the Czech Republic must adhere to the occupational reference level of not higher than 300 Bq/m^3 per year. Despite this regulation, member states of the EU could go beyond this value and introduce more stringent reference levels. This amended directive entered into force on February 6th, 2014 and had to be transposed in all member states two years later, by February 6th, 2018. The reason for amending the directive on *Basic Safety Standard* was to strengthen the existing directives and to turn them into one single instrument. In conclusion, all members of the EU need to develop a legal framework for radon concentration in dwellings.

Standards adopted by the European Union against the dangers emerging from ionizing radiation and natural existing exposures, e.g.: Radon



Sources: Council Directive 2013/59/ Euratom; Council Directive 80/836/Euratom; EC. 90/143/Euratom: Commission Recommendation on the protection of the public against indoor exposure to radon; Council Directive 96/29/Euratom; EC, (1999). Radiological protection principles concerning the natural radioactivity of building materials. https://publications.europa.eu/en/publication-detail/-/publication/293b4d07-74fd-11e8-9483-01aa75ed71a1/language-en/format-PDF; http://www-ns.iaea.org/tech-areas/communication-networks/orpnet/documents/cn223/1-mundigl-euratom.pdf; https://ec.europa.eu/health/home_en, accessed 9 February 2019; http://radoneurope.org/index.php/activities-and-events-2/working-groups/radon-regulation/, accessed 9 February 2019.

Figure: 8

5.2.1 Germany

Already in 1978, Germany started a Radon program to test the radon concentration in 6,000 homes. This program was designed to obtain data and to identify where the concentration in soil is the highest in Germany. Moreover, it was intended to detect the source of radon exposure in dwellings (WHO, 2007). This shows that Germany has already been aware of the radon problem for a long time (see figure: 9) In 1992, measurements for a radon map were taken, namely 2,346 geologically representative measurement points were used. These measurements were concluded in 2003, and the main outcome was the *Radon concentration in the soil* map. In 2016, Germany published the *Handbook on Nuclear Safety and Radiation Protection,* and one year later, the *Radiation Protection Act* was adopted. This act was the transposition of the Council Directive 2013/59/Euratom and encompassed a comprehensive protection against harmful radiation in medicine, protection against radon in dwellings and better provisions in case of an emergency. It adhered to the given reference level of 300 Bq/m^3 for working spaces by the EU directive. In addition, Germany went one step further and claimed that regions exceeding the reference level had to develop a plan for protective measurements, while measures had to be taken concerning newly constructed buildings to prevent the accumulation of radon (Radiation Protection Act, 2017). The threshold value to reduce the radon level was set to is 100 Bq/m^3 for dwellings. However, if the threshold value of 100 Bq/m^3 is reached action are only to be taken on a voluntary basis (Bartzis et al., 2012a)

In 2018, a bilateral meeting of the *Nuclear Regulatory Bodies* of the Czech Republic and the Federal Republic of Germany took place within the framework of the *Intergovernmental Agreement on Issues of Common Interest in the Field of Nuclear Safety and Radiation Protection*. By 2020, in accordance with the *Radiation Protection Act,* the federal states of Germany will have to determine in which areas a great deal of radon in buildings has to be expected.

5.2.2 Czech Republic

In 1997, the Czech Republic introduced the *Atomic Act,* which determined the regulation and control of all possible radon sources (see figure: 9). Two years later, in 1999, the radon program was launched in the Czech Republic. This program established preventive remedial measures in new buildings and interventions to reduce exposure to radon in existing buildings, and moreover, it was also designated for surveying the situation. A decade later, in 2009, the Radon program was improved. An

important aspect of the amended Radon program is the assistance to people owning houses with higher indoor radon levels. In special cases, the program offers a state financial support.

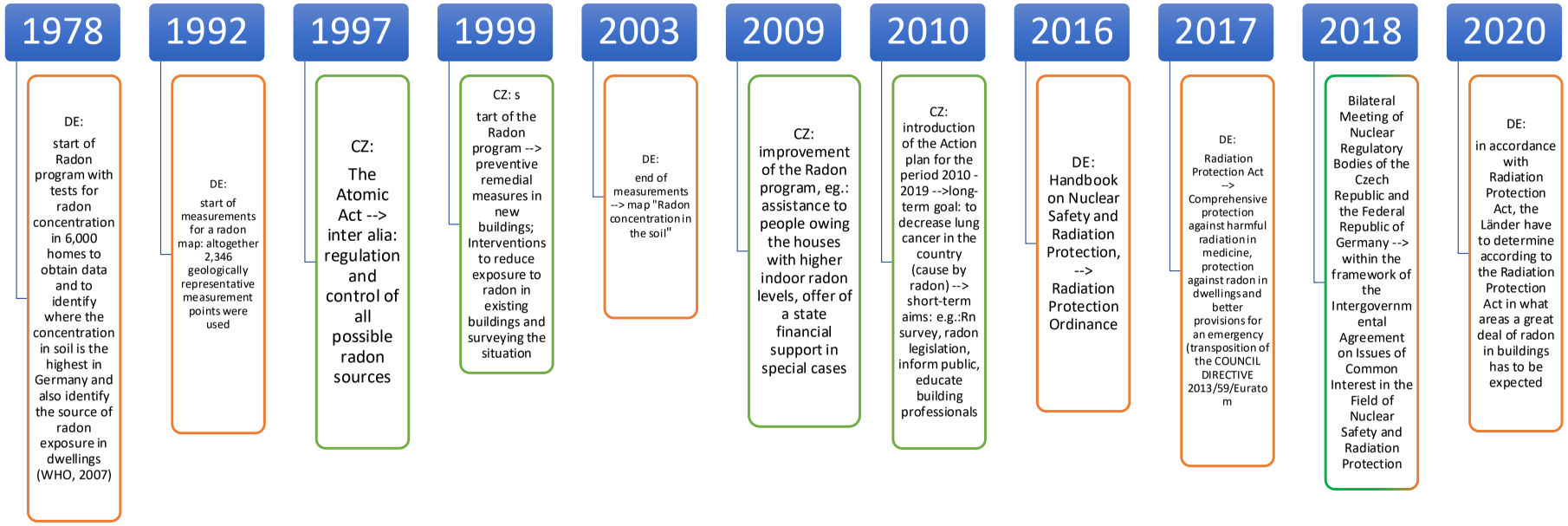
In 2010, the Czech Republic introduced the radon action plan for the period 2010 through 2019. The long-term goal of this action plan is to decrease the rate of lung cancer caused by radon in the country. The short-term aims are an extensive radon survey, a radon legislation as well as to inform the public and offer education for building professionals. The action plan contains an awareness strategy, a radon prevention strategy, a strategy of regulating the existing exposure, scientific experts and technical support of the implementation (IAEA, 2017). Besides the EU Directive, the Czech Republic provides its own radon action plan as well as a state financial support for people possessing houses with higher indoor radon levels. The action level for dwellings in the Czech Republic amounts to 400 Bq/m^3 (Bartzis et al., 2012a), while the limit value is 4000 Bq/m^3 (IAEA, 2017).

In conclusion, both EU-member states Germany and the Czech Republic have conducted extensive measurements on radon and have produced comprehensive material as well as data on the consequences of radon exposure over the years. Germany and the Czech Republic, hence, seem to take the issue of radon and lung cancer very seriously. The amount of regulations and standards is coherent and the level of awareness regarding radon is high in these two countries which attaches the importance of education in the field of environment health. Germany and the Czech Republic have identified radon as a health hazard because the consequences of radon would pose a threat to public health. In addition, there is an interest in conducting research on radon as well as available financial resources to mitigate the radon exposure.

Regulations related to Radon in Germany and the Czech Republic

Directive 2013/59/Euratom requires EU member countries to establish a national reference level no higher than 300 Bq/m3 per year for indoor radon concentrations in workplaces by February 6, 2018.

CZ (Czech Republic): the action level for existing buildings: 400 Bq/m3; New buildings: 200 Bq/m3
DE (Germany): reference level for existing buildings is 100 Bq/m3 on a voluntary basis; if the radon concentration at workplaces is above 300 Bq/m3, measures must be taken to reduce the radon concentration inside the building.



Sources: http://www.bfs.de/EN/topics/ion/environment/radon/regulations/law.html, accessed 11 February 2019.; https://www.bfe.bund.de/EN/bfe/laws-regulations/hns/A1/a1_node.html, accessed 11 February 2019.; The Federal Office for Radiation Protection (BSF), 2016. Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Radiation Protection Ordinance); http://www.bfs.de/EN/topics/ion/environment/radon/maps/soil-air.html, accessed 11 February 2019.; http://www.bfs.de/EN/bfs/laws-regulations/radiation-protection-act/radiation-protection-act_node.html, accessed 11 February 2019. http://www.radon.eu/ca1.html, accessed 11 February 2019.; https://www.suro.cz/en/prirodnioz/rnprogram, accessed 11 February 2019.; https://www.sujb.cz/en/news/detail/clanek/bilateral-meeting-of-nuclear-regulatory-bodies-of-the-czech-republic-and-the-federal-republic-of-ger-1/, accessed 11 February 2019.; https://inis.iaea.org/collection/NCLCollectionStore/_Public/45/079/45079253.pdf, WHO, 2007. International Radon Project Report of the 3rd meeting.; https://www.oecd-nea.org/law/legislation/czech-republic.pdf International atomic energy agency (2017). Status of Radon Related Activities in Member States Participating in Technical Cooperation Projects in Europe, IAEA-TECDOC-1810, IAEA, Vienna.

Figure: 9

5.3 Regulations and standards regarding radon in the African Union

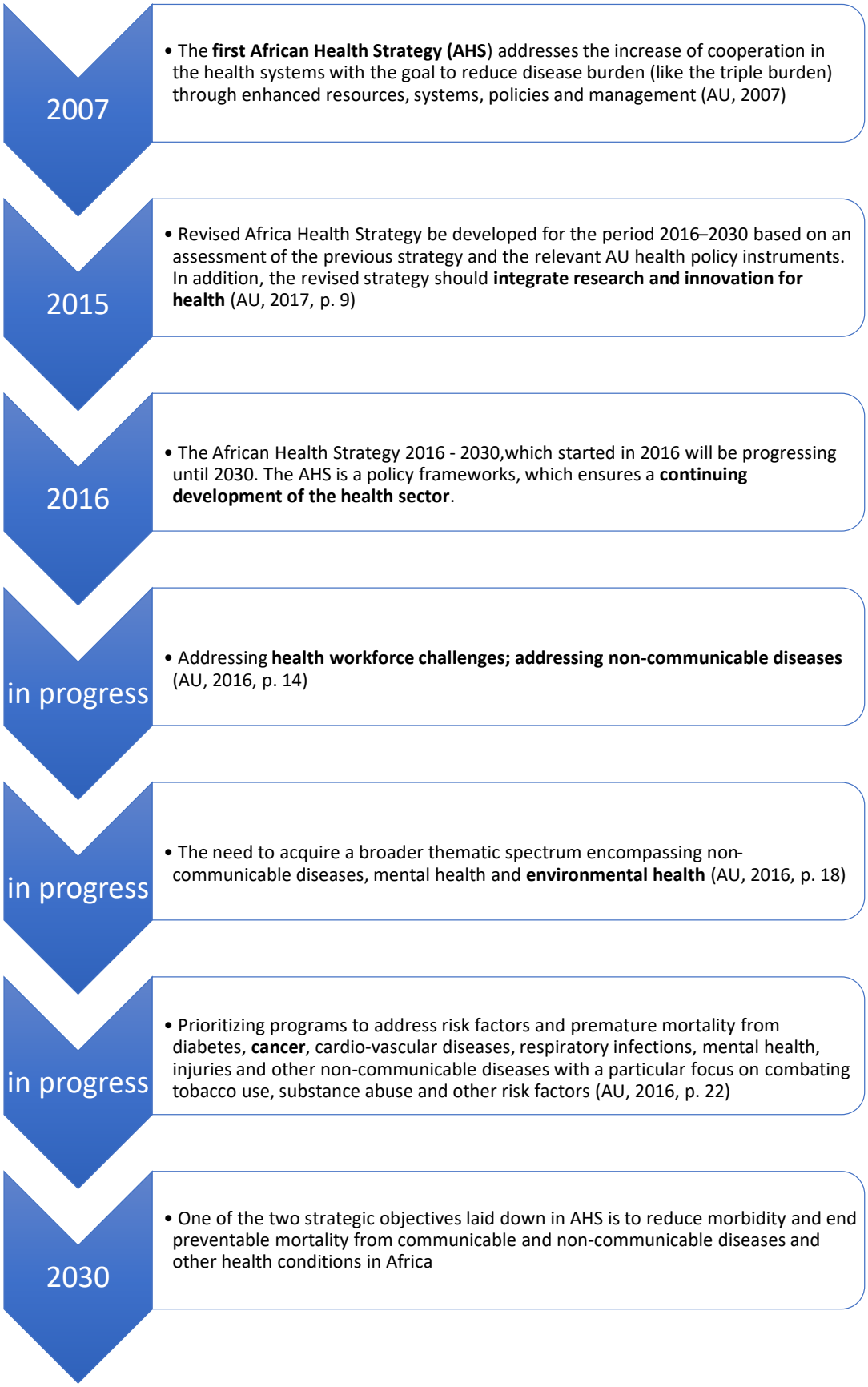
The African Union has adopted standards related to public health and non-communicable diseases (see figure: 10). However, no regulations and standards on radon exposure have been assumed so far.

In 2007, the African Union implemented the first *African Health Strategy (AHS),* which addressed the increase of collaborations in health systems with the goal to reduce diseases through enhanced resources, systems, policies and management (African Union, 2007). The *African Health Strategy* is an action plan coordinating efforts to reduce the rate of diseases. In the long run, a better and healthy life on the African continent shall be enhanced. In 2015, the African Union revised the *AHS* and developed another strategy for the period 2016 through 2030 based on an assessment of the previous strategy and the relevant AU health policy instruments. In addition to the first *AHS,* the revised strategy should integrate research and innovation for health (African Union, 2017, p. 9). One year later, in 2016, the African Union launched the *African Health Strategy 2016 through 2030.* The new *AHS* is a policy framework which ensures the continuing development of the health sector. Although this new *AHS* was presented as a great effort, no real outcome has been published of how the AU is going to implement the objectives. Moreover, the topic on the environmental health risk due to radon exposure has not even been touched yet.

In the years to come, the *African Health Strategy* will address health workforce challenges and non-communicable diseases (African Union, 2016, p. 14). In addition, the AU acknowledges through the *AHS* the need to acquire a broader thematic spectrum encompassing non-communicable diseases, mental health and environmental health (African Union, 2016, p. 18). The notion about a possible environmental health risk due to radon exposure arose in the *AHS* but was not explicitly stated. Until 2030, priority programs will be in progress to address risk factors and premature mortality due to diabetes, cancer, cardio-vascular diseases, respiratory infections, mental health, injuries and other non-communicable diseases with a particular focus on combating tobacco use, substance abuse and other risk factors (African Union, 2016, p. 22). What is important: The AU recognized the emerging challenge arising from different diseases like lung cancer. One of the two strategic objectives laid down in the *AHS* is to reduce morbidity and end preventable mortality from communicable and non-communicable diseases and other health conditions in Africa by 2030 (African Union, 2017).

In contrast to the EU, the AU has not addressed the environmental health risk coming from radon exposure. The neglected repercussions were considered in the *African Health Strategy* but no health program was dedicated to radon as it was the case in the EU strategy. The situation in the AU shows that the lack of standards and regulations are interchangeably linked with lack of awareness of radon. Hence, the AU needs to raise public awareness regarding radon and set accurate standards and regulations to tackle the issue of radon.

Standards adopted by the African Union related to public health and non-communicable diseases (like cancer, which is also caused by Radon)



Sources: African Union, 2016. Africa Health Strategy 2016-2030. AUC,2016.; African Union, 2007. Africa Health Strategy 2007-2015. AUC, 2007.; https://au.int/sites/default/files/pages/32895-file-africa_health_strategy.pdf

Figure: 10

5.3.1 South Africa

South Africa has a long history in mining. Due to the legacy of mining activities, the health problem regarding radon became so such a major problem that people's awareness of the health risk of radon also reached people's houses. The spillover effect made some people think that radon might be in their house, too. In 1988, a survey on indoor exposure to radon in South Africa was conducted. This research outcome suggested that the enhanced exposure had been caused using mine waste as underfill or building material. Furthermore, natural geological features in association with construction practices might have also resulted in an indoor concentration creating unacceptable health risks (Leuschner, Van As, Grundling & Steyn, 1988, p. 5). This study made clear that the exposure to radon stemmed from the lack of standards and regulations. People living in South Africa used waste from mine as building material for their homes – this showed that public awareness was limited. However, a decade later, in 1998, the *National Environment Management Act* was announced (see figure: 11). The act enabled an environmental impact assessment, which was a great effort, but no specific environmental quality standards regarding radiation were established. Nevertheless, the civil society in South Africa was active in bringing up the issue regarding radon. One year later, in 1999, the *National Nuclear Regulator Act (NNR)* was introduced. Even though the *NNR* focused on radiation resulting from human intervention during mining, the act did not contain any dose limits on radon in dwellings. South Africa has a dose limit for occupational exposure which is authorized by the National Nuclear Regulator (Pule & Speelman, 2016). The annual worker dose limit is 20 mSv (approx. 800 Bq/m^3, if 5 mSv is 200 Bq/m^3); this equals the standard in the Czech Republic and Germany. However, the Czech Republic and Germany have reference levels for radon in dwellings, which is not the case in South Africa. South Africa adheres to the principle that all radiation dose should be "as low as reasonably achievable" (ALARA) (South African Government - NRR, 1999). Nevertheless, the issue regarding radon in dwellings still has not entered a policy making stage. Most of the South African society is aware of the consequences due to radon, while the regulatory bodies neglect them. The authorities have not implemented any standards or regulations dealing with radon exposure. In 2016, during the *National Nuclear Regulator Information Conference,* Pule & Speelman (2016) highlighted typical radon exposure situations: houses built by using radioactive uranium ore and houses built in radon-prone areas (p. 15-16).

In the first scenario, radon can be found anywhere because the dwelling consists of material containing radioactive uranium ore which is mostly coming from mine waste. The Beaufort West farm in Karoo, South Africa, for example, where many uranium mines are located was built using dumped radioactive uranium ore. It shows an average concentration of 476 Bq/m^3 (approx. 11.99 mSv/a if 5 mSv are approx. 200 Bq/m^3) and a maximum value of 536 Bq/m^3 (approx. 13.5 mSv/a) (Pule & Speelman, 2016). These values prove that the population will certainly benefit from a radon action plan recommending which building material shall be used. Pule & Speelman (2016) also took a measurement in Tshepisong, a township in Soweto. In the second scenario, radon comes from the ground when buildings were built in a radon-prone area. The average concentration in this area amounts to 211.9 Bq/m^3 (approx. 5.32 mSv/a), and the highest value measured is 1728.5 Bq/m^3 (approx. 43.5 mSv/a). A radon action plan cloud be useful to suggest different remediation methods. Moreover, these values show that a radon program to take nationwide measurements is urgently needed to identify radon-prone areas and to produce a radon risk map for the whole country of South Africa. People are not aware of radon exposure in rural poor areas, and they live with a health risk which will constantly have an effect on their respiratory system. The regulatory body must advice the government to adopt a regulatory control regarding radon in dwellings. In the future, the *NNR* will advise governments to include mandatory radon measurements in housing regulations and building codes (Pule & Speelman 2016, p. 22). As for South Africa, scientists are already pushing for a regulatory framework to protect the civil society from the harm of radon inhalation.

In summary, awareness regarding radon risks is low in South Africa even though the situation is not very well, economically and socially speaking. Despite the lack of a legal document for indoor radon exposure, the civil society actuates general awareness of radon risks without the help of the government.

5.3.2 Malawi

Malawi has no large mining activity, and awareness of radon is very low. Thus, the question arises how awareness can be raised and how the public can be sensitized regarding radon and lung cancer.

In 1996, the Malawi government introduced the *Environmental Management Act* (see figure: 11). This act enabled people to carry out an environmental impact assessment. In detail, it authorized people to prescribe environmental quality standards generally and particularly for air, water, soil, noise, vibrations, radiation, effluent and solid waste.

In 2011, the government introduced the *Atomic Energy Act 2011* (No. 16 of 2011), through which the *Atomic Energy Regulatory Authority (AERA)* was founded. The *AERA* acts under the Ministry of Natural Resources, Energy and Environment and has the mandate to protect people and the environment from the harmful effects of ionizing radiation (Chirombo, 2019; Phiri, 2019). In 2015, the journalist Collins Mtika pointed out that the AERA has not yet been established. Also, in 2015, an environmental impact assessment was made in the village Kayelekera, which is located near the biggest uranium mine in Malawi. The outcome was that the mean radon 222 activities in the buildings tested by CRIIRAD in Kayelekera were ranging between 72 Bq/m^3 (private house in Nkhachira) and 123 Bq/m^3 (community hall in Kayelekera). According to Chareyron (2015), these results showed that radon inhalation is definitely contributing to the dose received by the population (p. 54). The CRIIRAD research group advised the village chief of Kayelekera to advise the community not to use this sand for building purposes taking into consideration the risk of exposure to gamma radiation and the risk of enhanced concentration of radioactive radon isotopes (Chareyron, 2015. p. 60).

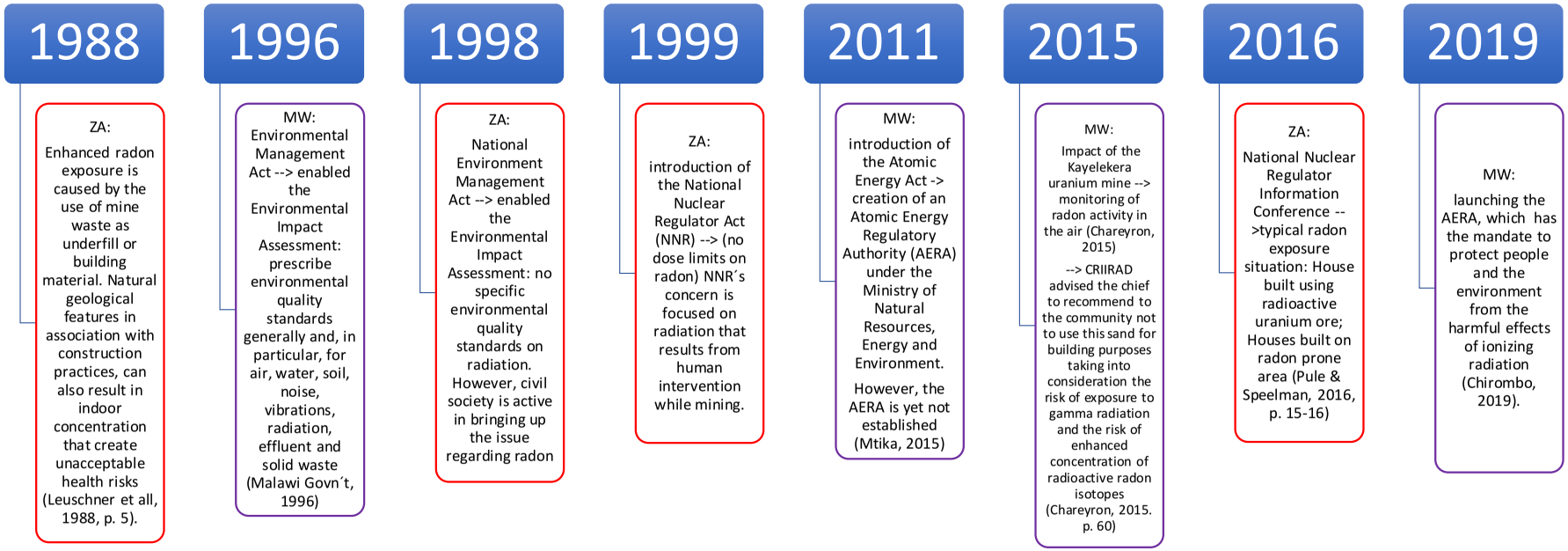
In 2019, the Principal Secretary of the Ministry of Natural Resources, Energy and Mining, Patrick Matanda, stated that during the launch of the *AERA* and in accordance with the provisions of the *Atomic Energy Act,* the Ministry of Natural Resources, Energy and Mining was urging all institutions, organizations, companies and any person possessing or using any nuclear or radioactive material to notify *AERA* so that the material could be licensed for the protection of the users, the public and the environment from any harmful effects of ionizing radiation (Chirombo, 2019, para. 7). The Malawi government takes the lead in raising public awareness of ionizing radiation but the awareness of the health risks due to radon exposure has been neglected. Hence, the *AERA* should put an emphasis on the consequences of radon exposure.

In conclusion, the main question arises why there is a different approach to radon in developed and developing countries. Only regulatory bodies for ionizing radiation have been established, but no measurements have been taken to raise public awareness of health hazard due to radon exposure. In other words, the regulatory bodies only deal with ionizing radiation and do not emphasize the problematic of radon exposure. Developing countries have not identified radon as an issue because the missing data on radon and lung cancer in combination with the absence of knowledge about the

consequences make African countries unaware of the lung cancer risk associated with radon inhalation.

Regulations related to Radon in South Africa and the Malawi

ZA (South Africa): not embodied in a regulation but the annual average activity concentration should not exceed 1000 Bq/m3; Public Exposure not exceed 300 Bq/m3
MW (Malawi): no regulation in place



Sources: Malawi Government. (2011). Atomic Energy Act.; Chareyron, B. (2015). Impact of the Kayelekera uranium mine, Malawi (No. 21, p. 77). EJOLT Report; https://mininginmalawi.com/2015/02/24/independe monitoring-at-paladins-kayelekera-uranium-mine-in-malawi/, accessed 11 February 2019.; Malawi Government (1996). Environmental Management Act.; Mtika, C., (2015). Paladin's uranium waste 'wars', Malawi villagers up in arms. Nyasa Times, Malawi.https://fatalextraction.investigativecenters.org/2015/07/10/paladins-uranium-waste-wars-malawi-villagers-up-in-arms.html, accessed 11 February 2019.; South African Government. (1999). National Nuclear Regulator Act 1999, Act 47 of 1999, and Regulations.; Leuschner, A. H., Van As, D., Grundling, A., & Steyn, A. (1988). A survey of indoor exposure to radon in South Africa. *In Proceedings of the international conference on residential air pollution*.; Pule, J., Speelman, W. (2016). South African Perspective for Radon in Dwellings and the Anticipated Regulatory Control Measures. Departme Environmental Affairs Republic of South Africa. (1997). National Environment Management Act, 1998 (Act No. 107 of 1998). https://www.health24.com/Lifestyle/Environmental-health/Environmental-disasters/kil gas-why-homes-in-sa-are-not-tested-for-radon-20160223, accessed 11 February 2019. https://www.health24.com/Lifestyle/Environmental-health/Environmental-disasters/radon-is-a-silent-killer-could-it-be-in-yo home-20160201,, accessed 11 February 2019.; Chirombo, R. (2019, March 5). Government ready for atomic energy regulator launch. The Daily Times Malawi. Retrieved from https://www.times.mw/government-ready-for-atomic-energy-regulator-launch/

Figure: 11

5.4 Comparison of the situation in EU and AU

The situation in the EU is very different compared to the situation in the AU. Both regional integrational organizations have a different approach to the environmental health risk caused by radon exposure. In short, the EU does have an approach, while the AU has none. The approach of the former is that the European Union, as a supranational entity, tries to establish dialogues with INGOs & local communities, enhance self-driving forces to support scientific findings, collaborate with private entities to set standards for the exposure of radon and to ensure open access to information on the consequences of radon inhalation which is a mainly contributing to lung cancer. In the EU, standards on radon exposure are mandatory. The European Union sets standards and regulations at a European level which are obligatory for member states of the EU. Nevertheless, EU member states can go beyond and implement stringent standards and regulation.

By contrast, the AU has no standards and regulations on radon exposure which shall be followed by member states. The AU neither possesses a mandatory nor an advisory system which could support member states how to tackle environmental health risks. The AU touches upon the terms environmental health and cancer but the AU does not state in what way these terms are connected to the society. They are loose terms have link to action or measurements. These two terms indicate that radon is a problem, but it is locked in text that it is not explicitly states that radon is a health risk. The member states of the AU can simply rely on individual actions and estimations regarding how dangerous radon exposure is for the population. A first step to better the situation would be to accept the radiation protection principles as it is the case in the EU. The principle of protection is guided by the principles of justification, optimization and dose limitation (ICRP, 1985). The radiation protections principles can be explained as follows: The practice to set standards and regulation must be justified, and the protection of the individual should be optimized; furthermore, no practice should exceed a specific dose limit. The principle of optimization underlies the standard that radiation exposure must be kept as low as reasonably achievable, taking economic and social factors into account (IAEA, 2010, p. 3).

The existing knowledge gap between the AU and the EU is the most important reason why the AU has not published any document about the consequences of radon exposure. It is as simple as that: Information on radon is missing in Africa. The AU needs to adapt to and extend the knowledge gap regarding the consequences of radon

exposure. The EU can support this undertaking by offering scientific support. The AU and the EU can use science as a catalyst to promote the radiation protection principles at an international level. The knowledge gap can be reduced through a scientific cooperation and by introducing joint research programs on the topic of radon exposure in mud-built houses in Africa. This top-down approach can support member states of the AU with knowledge about radon and can assist the AU when implementing a radon action plan. This means, the European standards can be transferred to the African Union by an interaction of different stakeholders from the public and private sector supported by the EU and the AU.

Thus, the AU needs credible commitments to be taken into account by the member states. However, credible commitments by the AU are not enough to be acknowledged as an active actor by the member states. The member states need to consider the consequences of radon exposure in-depth, going beyond scientific support by the AU. Only the political will of the AU member states to do so is decisive.

6. Findings and recommendations

The main finding is that the impact of the EU directive *Basis Safety and Standard (BSS)* improves the lack of knowledge of radon in many EU member states. The directive requires member states to develop a regulatory frame to actively work on reducing radon exposure not only of workers, but also of the general public, and on lowering the reference level for the annual average activity concentration in the air to a maximum value of 300 Bq/m^3 (European Radon Association, 2014). The European Union has not established a legal framework for radon concentration in houses. Thus, different approaches have been used in EU member states to develop a national strategy. This multitude of national strategies and reference levels for radon concentrations in homes has led to an uncoordinated broad range of different practices and regulations across the European Union. A legal framework for radon concentration in homes would help coordinate actions in a more consistent way.

The empirical analysis disclosed that the Czech Republic and Germany, both members of the EU, adhere to the legal framework for radon exposure in workplaces, while the EU lacks a regulation for radon exposure in homes. Hence, individual national action plans have to compensate that deficiency. For example, the action level for dwellings in the Czech Republic is 400 Bq/m^3 (Bartzis et al., 2012a), while the limit value amounts to 4000 Bq/m^3 (IAEA, 2017). In Germany, the action level for dwellings is 100 Bq/m^3 on a voluntary basis (Bartzis et al., 2012a). On the other side, South Africa has a dose limit for occupational exposure, which is authorized by the National Nuclear Regulator (Pule & Speelman, 2016). The annual worker dose limit is 20 mSv (approx. 800 Bq/m^3, if 5 mSv is 200 Bq/m^3), which equals the standard in the Czech Republic and Germany. South Africa possesses a regulation which manages occupational exposure to radon but has no reference level of radon exposure in homes. In other words, South Africa is aware of the fact that radon causes harm in workplace but people also suffer from radon exposure in homes where a legal framework to protect the people is still missing. The civil society has to step in to take radon measurements as the government does not offer support. Malawi, a developing country, has only just taken the first step to establish the *Atomic Energy Regulatory Authority,* which oversees radiation protection measurements; however, the regulatory body, just like the civil society, is still not aware of the consequences of radon.

Based on the findings, the following recommendations will be made for the EU in general, the AU in general, the Czech Republic, Germany, South Africa and Malawi.

The key recommendation for the European Union is that a radon policy and strategy need to be launched. In greater detail, the radon policy and strategy consist of a comprehensive approach which shall be developed with various stakeholders and is promoted in coordination with other actives, like energy saving and cigarette smoking (Bartzis et al., 2012a). The combination of energy saving measures and a radon policy has the potential to become a conflict of interest. Energy saving in buildings and radon exposure reduction have different purposes. In the field of energy conservation, the house has to be sealed to keep the heat in the house. Regarding radon exposure reduction, fresh air needs to be circulated to reduce radon exposure. In a sealed house, however, the air conditioning will only recirculate the radon-contaminated air.

The key recommendation for the African Union is to adopt the radiation protection principles and raise public awareness of the consequences of radon exposure.

The key recommendation for the Czech Republic and for Germany is to encourage the civil society to test their homes. An incentive to test a house for radon exposure can triggered by a state-led financial support in case the radon value is too high. A financial compensation will be offered if the radon level is too high. This is the case in the Czech Republic where a financial support is offered if the radon level is too high. Hence, other states can or could adopt this method to promote radon tests.

The key recommendation for South Africa and Malawi is to raise public awareness regarding lung cancer and radon exposure. South Africa should conduct more tests on radon exposure in dwellings and create a radon risk map of the country, while Malawi is advised to adopt the “ALARA” principle. The abbreviation “ALARA” means that all radiation doses should be “As Low As Reasonably Achievable“.

6.1.1 Radon risk communication channels

The main objectives of this communication strategy are to raise awareness of radon health effects, to stimulate radon testing and, where necessary, remediation of existing dwelling and to encourage preventative measures in future dwellings (Bartzis et al., 2012b, p. 36). These aims pertain to both developed and developing countries.

The radon risk communication strategy is grounded on the concept of double benefits. Every person involved creates a value-added element to the overall communication. Populations as well as the government and construction companies vastly benefit from a proper risk communication (see table 8). The communication strategy should involve

different stakeholders, like local construction companies and local authorities. The risk communication should involve the civil society in the process and listen to the people.

Table 8: Communication with stakeholders on radon risk and their expected responses

Stakeholder	Communication	Expected response
Civil Society	Double Benefit → health and safety for the families and access to information	The people appreciate that the government cares about their health and they also gain access to information
Government (local authority)	Double Benefit→ reduce environmental health issue and cost-effective measure to reduce radon exposure	Providing support for the people, care about their health and safety
Local construction companies	Double Benefit→ employment rate is raised and profit is generated due to remediation of radon	Promoting social responsibility among other companies. Being more popular due to their participation in radon remediation.

6.1.2 Building public awareness

Public awareness in developed countries like the Czech Republic and Germany is well-established. In the Czech Republic, about 50 to 75% of the population know about radon and its effects (Bartzis et al., 2012a), while in Germany, only about 0 to 25% of the population have that consciousness (Bartzis et al., 2012a). The reason for the higher value in the Czech Republic might be that the level of radon concentration in the rocks in the Czech Republic is high, and people simply know more about that than people in Germany. Raising public awareness is not essential in developed countries – it only needs to be maintained.

By contrast, public awareness in developing countries like South Africa and Malawi needs to be generated because there is a great lack. An approach to alter the situation, for example, is to create a strategy for communication to increase public awareness and inform local decision makers of the risks of radon in relation to smoking (Bartzis et al., 2012b, p. 93) as the risk of lung cancer is higher when someone is a smoker. A simple qualitative message may, moreover, be that radon increases the already high risk of lung cancer in smokers. However, whether one smokes or not, radon exposure

increases one's lung cancer risk in any case (WHO, 2009, p .78). A qualitative message should be used because the lack of data in Africa makes it impossible to address the population with quantitative messages.

Thus, an effective way to raise public awareness, for example, is through clear messages. A selection of direct messages was presented in the *WHO handbook on indoor radon: a public health perspective:* "Radon causes lung cancer", "Radon is a radioactive gas present in homes", "Radon is easy to measure" and "You can easily protect your family from radon" (WHO, 2009, p. 78). Once public awareness and public acceptance will have been established, politicians will invest more in policies which mitigate the consequences of radon.

6.2 Pilot project in a developing country

The objective of the proposed pilot project is to improve the housing conditions in Africa. The aim of that pilot project in a developing country is to remediate the adverse effects of radon exposure in dwellings, like mud-built homes. Although this pilot project can be realized in most of the developing countries, the focus was primarily on the African continent.

The challenge is to remediate the exhalation of radon from building material used for the typical mud-built homes in Africa. In general, low-cost housing construction in developing countries often relies on the use of local soil or clay that is compacted and dried to form the walls of the dwellings. Depending on the local geological context, soil and clay may contain enough thorium and uranium to produce significant exhalation of radon isotopes (Schimmelmann et al., 2017, p. 139). Hence, the radiation health hazard arises due to the building material used to build homes. However, the health hazard does not only result from radon but also from daughter products of radon, like thoron (WHO, 2009).

In the area of Nkhachira in Malawi, for example, sand is accumulated by draining sandstone on the way to the village of Kayelekera, which is close to the Paladin uranium mine (Chareyron, 2015). As the sand shows a high concentration of radiation, CRIIRAD (Commission for Independent Research and Information on Radioactivity), which conducted the research, advised the village chief to recommend the community not to use this sand for building purposes considering the risk of exposure to gamma radiation and the risk of enhanced concentration of radioactive radon isotopes (Chareyron, 2015, p. 60). Currently, the inhabitants of Kayelekera use the sand with

elevated concentration of radon and thoron to build their traditional mud houses. Arndt Schimmelmann (2017), who conducted research in Vietnam regarding the environmental health risk of radon in mud walled houses, points out that that people living in these mud-built houses place their beds near the walls where the thoron concentration is much higher than anywhere else in the room. He claims that in contrast to thoron (^{220}Rn) with its short half-life of ~55 seconds, the longer-lasting ^{222}Rn with a half-life of ~3.8 days is rarely of concern in mud houses because their typically drafty construction allows for fast ventilation of room air. An inhaled atom of ^{222}Rn will likely be exhaled over the next day before it decays in a human body. In contrast, an inhaled atom of thoron that has readily dissolved in the lung's fluid will almost certainly decay in the human body and contribute to radiation damage in tissue (Schimmelmann et al., 2017, p. 139). Neither population nor the government, however, are aware of this environmental health risk in the homes. The simple thought that an improved ventilation may help tackle this problem does not apply in this case because the concentration of radon near the mud surface will never decrease due to more ventilation. The reason for that is that the houses are built of compact soil and have small rooms which cannot be ventilated (Dang Thi Phuong Thao et al., 2016). Hence, a solution is needed to improve the people's lives in their homes.

A solution, however, is not easy to find. Yet, a research group called EOS Geoscience Research Group, led by Arndt Schimmelmann, tried to find remediation strategies to mitigate radiation geohazards in mud-built homes in Vietnam (Schimmelmann et al., 2017). The research group found out that a promising strategy is a diffusion barrier on inside walls to delay the escape of ^{220}Rn until the short half-life of ~55 seconds has caused safe decay within the porous mud wall (Schimmelmann et al., 2017, p. 140). The research group conducted different tests in mud-built houses in northern Vietnam. For example, they used sheets of paper as radon emits alpha radiation, and this type of radiation does not penetrate paper. The paper sheets, wall paint, foil pinned to the wall nor tapestry proved to be the adequate solution. The deep cracks in the wall prevented an acceptable sealing by paper sheets or foil, and the high cost for paint did prove to be the best solution (Schimmelmann et al., 2017). After further tests, the research group found an alternative solution which can also be applied in Africa today. By adhering a solution to the walls, the thoron concentration close to the wall can be reduced from above 1000 Bq/m^3 to below detection limit (Schimmelmann et al., 2017). The research group EOS Geoscience (2017) claimed that the applied diffusion barrier

is inexpensive, non-toxic, non-flammable, resistant to biodegradation and easily applicable using regionally available materials (p. 141). This dissolved chemical may protect the mud-built homes in Africa without high costs and without any side effects due to the chemical. The solution is a spray which is simply applied to the walls.

In conclusion, this pilot project presented a simple solution for developing countries. A ventilator, as it is frequently used in developed countries, might appear to the best solution, but a steady grid connection and an appropriate maintenance support for a ventilator might not be available. In other words, the infrastructure and the financial resources may not be given in some developing countries. In Malawi, for instance, in the city of Lilongwe, the installation of ventilators will become possible with the help of the UN-Habitat. The United Nations Human Settlements Program and the city of Lilongwe have shared projects in the area of *Participatory Slum Upgrading Program* and *climate change risk* (UN-Habitat, 2011). However, the environmental health risk of radon has not yet been addressed in this report. In the rural areas of Malawi, the installation of radon ventilators will not be possible because of the missing infrastructure. Thus, the spray developed by the research group EOS Geoscience is a simple remediation method to reduce the environmental health risk of radon. The spray has the potential to decreases the risk of lung cancer in the rural area of Malawi as the non-toxic chemical which is simply applied to walls presents an easy way to improve the housing conditions.

6.3 Simplified regulations

The notion behind a simplified regulation is that dwellings which are constructed with radon-contaminated building materials pose an environmental health risk. Sometimes, building material like sand is illegally obtained from uranium mines, and the people using this material are simply not aware of the health hazard. Thus, a simplified regulation will encourage better health and safety for dwellings in Africa. The aim is to raise consciousness that illegally obtained materials for the construction of buildings cause an environmental health risk.

The simplified regulation is designed as a guideline which is both easy to implement and to understand. The guideline consists of for key elements which make up the building code for better health and safety in developing countries (see figure: 12). The first key element is a radon risk communication with different stakeholders, like local construction companies, local authorities and the public that illegally obtained building

material. The population shall be aware that radon causes lung cancer. The second step is that people take action and start testing their homes for radon. The reference level for dwellings should, on a mandatory or voluntary basis, be set to less than or equal to 400 Bq/m^3 to reduce the risk of lung cancer due to radon. The reference level for workplaces should, on a mandatory or voluntary basis, be set to less than or equal to 1000 Bq/m^3. The third key step is that affordable and reasonable remediation is proposed to house owners in rural and urban areas in Africa. In rural areas, the non-toxic anti-radon stray can be recommended, while the installation of ventilators or of a bottom sealing can be suggested in urban areas. Likewise, the remediation method has to be socially acceptable to ensure a successful implementation. The last element for better health and safety is to continue risk reduction. Hence, radon exhalation rates for building materials are quantified, made publicly accessible and suitable building materials with low radon exhalation rates (Bq/m^2/h) are recommended.
At the end, all these measures contribute to the overall goal of improving public health. Through that goal, the building code for better health and safety will meet with approval.

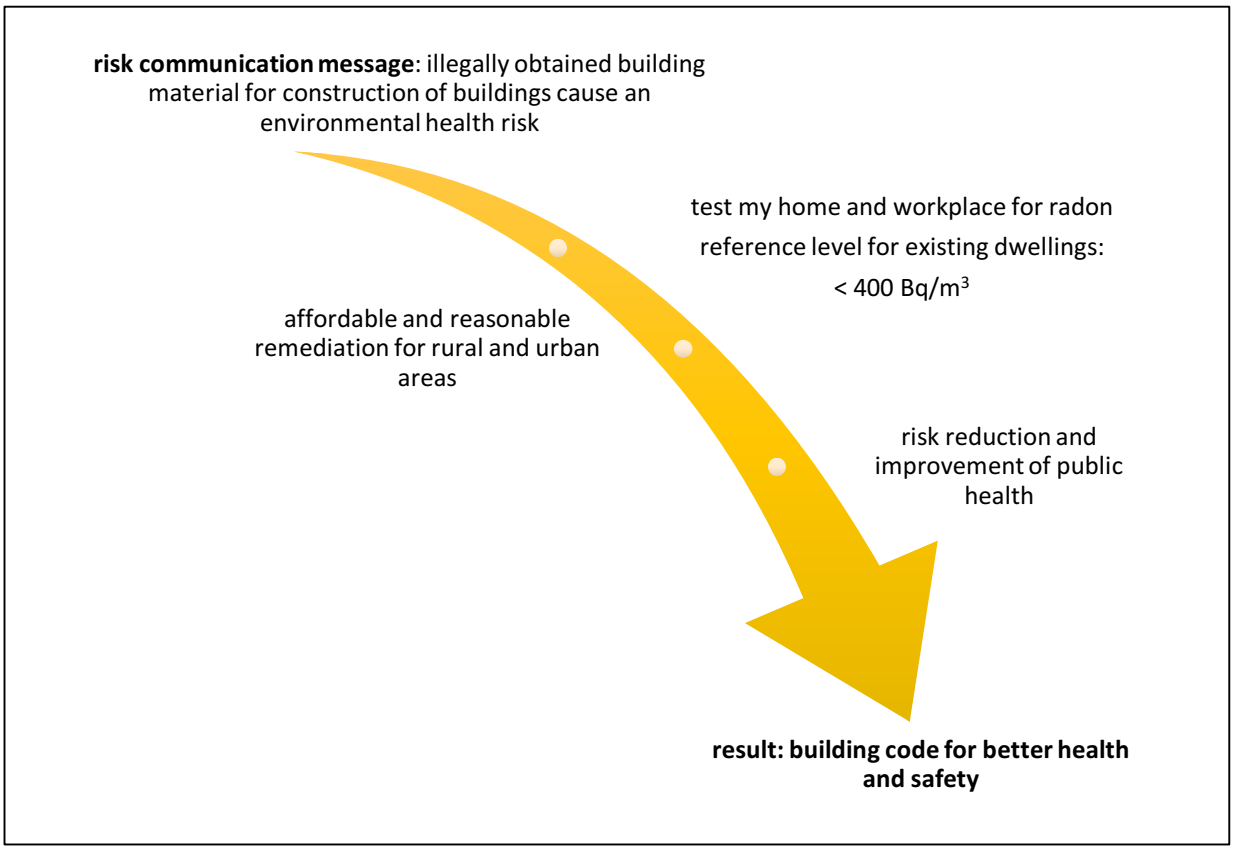


Figure 12: Simplified regulation for African countries

7. Conclusion

Lessons learned include that developed countries have identified radon as a threat to public health because people suffer from the consequences; furthermore, financial support is available to protect the people from unnecessary exposure. The European Union has implemented occupational dose limits but has failed to implement dose limits in dwellings. However, the Czech Republic and Germany have independently established national reference and action plans for radon concentration in dwellings. Lessons learned regarding the African Union are that the African Union, unlike the EU, has not identified radon as a threat to the public. The AU is simply not aware of the consequences of radon exposure and the risk of lung cancer. The lack of awareness of radon combined with the absence of financial support for research projects on radon leave the consequences of radon exposure undetectable. In other words, no attention is drawn on the consequences of radon by the AU because people in African countries suffer silently of radon yet, but they will probably suffer more soon, and the poorest will even be more affected if the AU does not act. The main recommendation for the African Union is to adopt a simplified regulation which should be embedded in the radiation protection principles. These principles are justification, optimization and dose limitation (ICRP, 1985). At a national level, Malawi and South Africa have recognized that occupational dose limits are important; however, they have not identified radon as a threat in dwellings yet. In addition, both countries do intend to conduct a national radon action plan. The lack of awareness regarding the consequences of radon exposure in dwellings and the absence of financial resources to conduct research are the main factors preventing them from acting. A national radon project is needed in Malawi to raise awareness of the consequences of radon. In the case of South Africa, reference levels for radon concentration in dwellings are necessary. Thus, lessons learned are that public awareness needs to be raised through education at a national level in African countries, namely of consequences of radon exposure and of the consequences of radon exposure in dwellings.

The findings confirm and contradict the hypothesis at the same time. The hypothesis stated that awareness of radon depends on people's education regarding the environment. The findings confirmed the hypothesis to that extent that education is a helpful vehicle to raise public awareness regarding radon inhalation. Likewise, the findings contradict the hypothesis insofar as education is not enough to acknowledge

radon as a threat to public health. Hence, there is need for a more dedicated engagement that goes beyond education and scientific support.

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Annex

Questionnaire on Radon in Developing Countries

Note about the project:

The project is designed to gather information about the neglected repercussions caused by Radon gas and the unforeseen environmental health risks it poses on developing countries. In developed countries, e.g. European countries a number of regulations have been adopted and large efforts are being done to identify radon-prone Areas and establish radon risk maps. This is not the case in many developing countries. In detail, we will assess the environmental health risk caused by Radon on the African Continent

Quantitative questions (mark your answer by X)*
*if the question is not applicable, please, write N/A (not applicable)

Questions	Rating						
	1 strongly disagree	2 disagree	3 slightly disagree	4 slightly agree	5 agree	6 strongly agree	N/A
1. Is Radon causing lung cancer?							
2. Is Radon an environmental health risk?							
3. Do you think that developing countries are more affected by Radon than developed countries?							
4. Do You think a Radon Map shall be created for the African Continent?							
5. Do You think that education about the environment can help to create awareness regarding the health risks caused by Radon?							

Qualitative questions:
*if you need additional space, please, use the back of the page by indicating the number of the question. If the question is not applicable, please, write N/A (not applicable)

1. Questions When was the first time you heard something about radon and in which context?
1.1. Answer
2. Questions Why might Radon cause a bigger problem in term of a health risk for developing countries than for developed countries?
2.1. Answer
3. Questions What can be effective tasks to raise public awareness in developing countries?
3.1. Answer
4. Questions Why is it hard to get people to take action on Radon?

4.1. Answer
5. Questions Who should take the lead in raising public awareness about Radon?
5.1. Answer
6. Questions Do you have any other thoughts on the issue?
6.1. Answer