Department of Physics

Investigating radioactivity in everyday life

Maximilian Talberg

Supervised by
Dr. Carole Mundell

Project Partners
Funmi Looi-Somoye
Miles Pearce
Dominic Williams

May 6, 2022

Acknowledgment

I would like to thank my supervisor Dr. Carole Mundell, for her continued support and guidance throughout this project, Dr. Pete Bryant and Jonathan Hatton, for their valued help in providing power plant data and information about Sizewell C. I would also like to extend my gratitude to my project partners Funmi Looi-Somoye, Miles Pearce and Dominic Williams.

Contribution of Authors

- M.T. researched beer, CT scans and X-rays. M.T. developed the interactive radiation tool.
- F.L.S. researched coffee, radon and a holiday to Cornwall. F.L.S. developed the interactive radiation tool and constructed the research survey.
- M.P. researched long haul and short haul flights. M.P. developed the campaign poster and constructed the research survey..
- D.W. researched bananas and background radiation. D.W. developed the social media campaign.

Abstract

First popularised at COP21 Britain has set out to achieve 'Net Zero' by 2050, this will require moving towards nuclear energy. Despite this, there has been little research quantifying the risk attached to nuclear energy and public perceptions. The aim of this study was to compare the radiation dose received in nuclear power stations with everyday activities, as well as investigate the public perception of radiation. The study involved condensing radiation research into an interactive radiation tool, campaign post and social media campaign. Participants were asked a seven-question survey before and after reviewing these tools. The study found the radiation dose from nuclear power stations was comparable to everyday items. Additionally, participant feedback confirmed the tools were successful in developing the public understanding of radiation. The results of the survey revealed participant perceptions of nuclear power are tied to nuclear disasters, despite a lot of these participants considering nuclear power to be safe. No correlation was found between an improved understanding of radiation and the belief nuclear energy is key to a sustainable future. The findings indicate perspective communication is successful, although suggests 'Net Zero' is misunderstood. The implications of these findings are discussed.

Contents

1 Introduction

In 2019, Britain set a target to reduce greenhouse gas emissions to achieve net-zero emissions by 2050. This goal is referred to as 'Net Zero' and involves eliminating harmful carbon emissions. Achieving 'Net Zero' will involve switching from fossil fuels to other sources of energy, specifically nuclear energy. Sizewell C is set to be an important nuclear power station in Britain's journey to 'Net Zero', whilst creating thousands of jobs in the process. Sizewell C will supply energy to over six million homes while avoiding nine million tonnes of carbon emission every year of operation, whatever the weather [1].

In a world post-Chernobyl and Fukushima Daiichi, effectively communicating the risk of nuclear energy is challenging due to conflicting views from the mainstream media and social media. In this study, the radiation risk encountered in everyday activities and items has been researched, to assess how these items compare to workers in the nuclear industry and people living near nuclear power stations (Sizewell C). To investigate the public perception of radiation this research has been condensed into an interactive radiation tool, campaign poster and social media campaign. A survey has been created to analyse public response before and after interacting with the radiation tool and campaign poster. This investigation into radiation and communicating radiation risk could lead to important developments in Britain's journey towards 'Net Zero'.

1.1 Communicating radiation risk

Radiation and communicating radiation risk have been widely associated with medical procedures, nuclear weapons or nuclear power stations [2, 3, 4]. A study investigating risk communication in medical procedures revealed there is a lack of knowledge of radiation dose and a lack of experience in risk communication [5]. Another study, communicating with residents about risks following the Fukushima accident found people expressed big concern over radiation and distrust of the government [6]. In many cases, concern about radiation risk was associated with psychological distress [7]. It is important to remember the later studies findings are directly from people who have been massively affected by radiation, moreover, Japanese people had pre-existing concerns about the risk of radiation as a result of Hiroshima and Nagasaki [7, 8]; most people will not have such strong views about radiation. Although, these opinions will have some influence around the world as a result of news and social media. Both studies re-enforce the need for effective communication of risk and highlight a potentially larger problem: the mistrust of authority. The purpose of this investigation is to analyse radiation risk and public perception of radiation risk, with such scepticism around radiation and authority it is important the participants are appropriately informed to come to their own decision about radiation [9]. Despite the amount of research around medical procedures and nuclear plants, it is apparent there is a lack of research communicating the risk of radiation in day-to-day activities.

In a previous study to assess the level of public knowledge regarding radiation, participants selected nuclear power plants as the greatest risk; age, gender and education level did not influence radiation knowledge [10, 11]. In another study investigating perceived risk, nuclear power experts rated nuclear power as a much lower risk than laypersons. When asked to order the perceived risk for 30 hazardous activities, the three groups of laypersons ranked nuclear power as 1st, 1st and 8th. Whereas the nuclear power experts ranked it 20th. Conversely, the three groups of laypersons ranked X-rays as 22nd, 17th and 24th. Whereas the experts ranked it 7th [12]. These studies suggest people perceive nuclear power as having a higher risk than medical x-rays. Radiation experts view things differently, rating nuclear power as less risky than public perception and viewing x-rays and natural radiation as riskier than generally believed. This is known as the perception gap [13].

To achieve UK wide 'Net Zero' by 2050, nuclear power has an important role to play in UK electricity generation, as it is important to break down this perception gap and improve public understanding of nuclear power. This is done by carefully and effectively communicating risk. Risk communication is the dissemination of information to the public about health risks and events. Effective risk communication involves relating the message to the audiences' perspectives [14]. To the public comparisons are more meaningful than figures and probabilities [13, 9]. This suggests the most effective means of communication is placing the risks of nuclear power in perspective. Such perspective can be achieved by drawing comparisons with everyday activities and items.

This was investigated by developing an interactive radiation tool to measure and compare the associated day-to-day radiation dose of members of the public with radiation doses in the nuclear industry over a year, followed by a campaign poster and social media campaign. A survey was used to measure public response before and after interacting with the radiation tool and campaign poster.

1.2 Radiation

For the tool to be effective, it is essential comparisons are drawn from relatable everyday activities and items. A variety of activities involving ionising radiation were selected and researched: X-rays, CT scans, coffees, bananas, alcohol, geographic location, flights, a holiday to Cornwall and background radiation. As well as the radiation received from a nuclear power plant worker and someone living near a nuclear power plant (Sizewell C). This research and creative insight were transferred to an interactive radiation tool developed in python as well as a campaign poster and social media campaign created in Canva, a graphic design platform. Communication impact was measured by conducting an anonymous survey of participants before and after reviewing the radiation tool and campaign poster. The study aims to further understand and improve the public perception of radiation, which is essential for the critical journey of nuclear power adoption in society that enables 'Net Zero' by 2050 to be achieved. The selected activities and items are listed in Table 1 with their source of radiation.

Table 1: The selected activities and items for the interactive tool, the campaign poster and the social media campaign. With the respected sources of ionising radiation.

Activities and items	**Source of radiation**
X-rays (Dental, Wrist)	Electromagnetic radiation
CT scans (Head, Chest, Abdomen)	Electromagnetic radiation
Coffees	Radionuclides ^{40}K, ^{214}Pb, ^{214}Bi, ^{212}Pb
Bananas	Radionuclides ^{40}K
Alcohol (Beer)	Radionuclides ^{210}Po, ^{234}U, ^{238}U
Geographical Location (UK)	Naturally occurring radon gas
Flights (Long, Short)	Cosmic radiation
Holiday to Cornwall	Naturally occurring radon gas
Cosmic background radiation	Cosmic radiation
Nuclear power plant worker	Gaseous radionuclides
Living 1km from a nuclear plant (Sizewell C)	Aqueous and gaseous discharge

The activities and items mentioned in Table 1 emit ionising radiation. Ionising radiation is the energy produced from natural or artificial sources and consists of electromagnetic waves that have enough energy to ionise atoms by removing an electron from an atom. This radiation can damage cells and DNA. The relevant amount of exposure due to ionising radiation is known as the radiation dose. There are three kinds of doses in radiological protection. The absorbed dose, equivalent dose and effective dose. Absorbed dose is the amount of energy deposited by radiation per unit mass

$$D = \frac{\Delta E_D}{\Delta M}, \tag{1}$$

where E_D, M and D are energy, mass and absorbed dose respectively [15]. An equivalent dose is an absorbed dose to an organ, adjusted to account for how damaging the type of radiation is [10, 11]

$$H_T = \sum_R W_R D_{T,R}, \tag{2}$$

where W_R is the weighting factor and H_T is the equivalent dose. The effective dose is the tissue-weighted sum of the equivalent dose in all tissues and organs of the human body

$$E = \sum_T W_T H_T = \sum_T W_T \sum_R W_R D_{T,R}, \tag{3}$$

where W_T is the tissue weighting factor.

The effective dose represents the stochastic health risk to the whole body and is used to assess potential long-term effects of radiation, making it suitable for comparing risks from different sources. In the interactive radiation tool, the effective dose is used to reflect the overall risk of the activities and items, this is expressed in sieverts (Sv). The unit of activity is the becquerel (Bq), a becquerel is one decay per second. In instances where the activities and items involve radionuclides, the effective dose is calculated by the summation of the radionuclide dose

$$E = \sum_i I_i D_{Ci} = \sum_i A_i M D_{Ci}, \tag{4}$$

where I_i is the intake (Bq), D_{Ci} is the dose coefficient $({}^{Sv}/_{Bq})$, A_i is the specific activity $({}^{Bq}/_{Kg})$ and M is the mass (Kg) [10, 11] . The relevant isotopes from Table 1 are listed below in Table 2.

Table 2: Relevant radionuclides and corresponding dose coefficients from ingestion [16, 17]

Radionuclide	Dose coefficient $({}^{Sv}/_{Bq})$
^{40}K	6.2×10^{9}
^{214}Pb	1.4×10^{10}
^{212}Pb	5.9×10^{9}
^{214}Bi	1.1×10^{10}
^{210}Po	1.2×10^{6}
^{234}U	4.9×10^{8}
^{238}U	4.5×10^{8}

2 Methodology

This study used a qualitative approach using surveys to review the public perception of radiation. The participants were presented with the interactive radiation tool and campaign poster. Responses were recorded before and after engaging in these tools using a Likert scale to measure attitudes. Before creating these tools, research was conducted around the activities and items listed in Table 1. The activities selected must be relatable to the general user. The activities and items have been tailored to people living in the UK. The interactive radiation tool, campaign poster and social media campaign are built with the power plant Sizewell C in mind which is set to be built in Suffolk, England.

2.1 Selected activities and items

2.1.1 Medical scans

X-rays and CT scans are included in the tool to investigate the "perception gap" [13] . These medical scans produce radiation in the form of electromagnetic waves, the specific medical scans have been selected because these are the most common [18, 19]. For X-rays this consisted of wrist X-rays and dental X-rays, corresponding to an effective dose of 1.0 μSv and 0.002 mSv respectively for one scan [20, 21]. Similarly, for CT scans this consisted of a head CT scan, chest CT scan and abdomen CT scan, corresponding to an effective dose of 1.4 mSv, 6.6 mSv and 10 mSv respectively for one scan [22].

2.1.2 Food and drink

Coffee, bananas and beers are included as relatable everyday food and drink items. Bananas are the classic example of a radioactive food with radiation sourced from potassium ^{40}K. One study calculated the effective dose using the percentage of ^{40}K content in a banana. Given the radioactivity of a large banana is 18 Bq and the ingestion dose coefficient for ^{40}K in adults in Table 2. The effective dose per banana is 0.1116 μSv. Another study used Gamma-ray spectroscopy to detect specific activity ($^{Bq}/_{Kg}$) in bananas and arrived at a similar conclusion [23, 24].

Coffee and beer have been selected as these are popular drinks, that will aid participant engagement. A radioactive study researched the average activity (Bq) of radionuclides present (Table 1) in coffee. Using Equation 4, these values were multiplied by the respective dose coefficients (Table 2) to give an effective dose of $2.99 \times 10^{-5} \pm 6.51 \times 10^{-6}$ mSv per cup of coffee. Where a cup of coffee is 300 ml [16, 25, 26]. Another study used gamma-ray spectrometry and arrived at a similar conclusion [27]. The radiation present in beer is mostly from radionuclides (Table 1) in the water, a study measured multiple types of radiation in samples of beer with an alpha spectrometer over 3-10 days. This study gave the activity of radionuclides present in beer. Using the same method as with coffee gave an effective dose of $3.45 \times 10^{-6} \pm 7.42 \times 10^{-20}$ mSv per pint of beer [17]. Where an imperial pint is 568 ml.

It is worth noting that the food and drink items have been selected with the audience in mind. Brazil nuts are a relatively highly radioactive food, with an annual effective dose of 1 mSv which is 45 times the annual dose of coffee [28]. Although, Brazil nuts are not as relatable or suitable for this study when compared to bananas or coffee.

2.1.3 Travel and locations

Location, holidays to Cornwall, cosmic background radiation and travel are the remaining items for the interactive radiation tool and campaign poster. Location is an important option as this makes the tool personal to the user and accounts for almost all day to day activities such as running or walking. In the UK depending on location, one will receive varying amounts of naturally occurring radioactive radon gas [29]. Radon gas comes from the breakdown of naturally-occurring radioactive elements such as uranium and thorium in soils and rocks [30, 31]. Some areas of the UK have naturally much higher levels of radon, for instance, residents in Cornwall receive an annual effective dose about 5 times that of the average person in the UK [29]. Cornwall is built largely on granite and igneous rock which is responsible for the high levels of radon [32]. Given Cornwall is a popular holiday destination for the British public it seemed suitable to include it in the app [33].

Cosmic background radiation is radiation from space. The Sun and other stars are constantly emitting a stream of cosmic radiation hitting the Earth. As such this is radiation everyone experiences based on altitude, in the UK cosmic radiation equates to an annual effective dose of 0.68 mSv [34]. At high altitudes, the air is thinner resulting in less shielding effects from air molecules. Therefore travelling in planes at high altitudes exposes you to greater amounts of cosmic radiation from the sun. Long-haul flights and short-haul flights have effective doses of 0.065 mSv and 0.0015 mSv respectively [35, 36].

2.1.4 Nuclear power

A nuclear power plant produces very small amounts of radiation [37]. Plant workers receive radiation from gaseous radionuclides in the form of gamma irradiation. Those who live near a nuclear power plant receive radiation in the form of gases and liquids, although this number is incredibly low [38, 39]. The annual dosage of a nuclear worker and the annual dosage of someone living 1km from a power station (Sizewell C) is 0.5 $^{mSv}/_{year}$ and 0.013 $^{mSv}/_{year}$ respectively [40, 38]. These values will be compared to all the activities and items from Table 1 in the interactive radiation tool and campaign poster. The UK limit for an occupational worker and the lethal dose of radiation for a human has been included in the tool to provide context to the numbers. The UK limit for an occupational worker is 20 mSv in any calendar year [41]. A lethal dose of radiation for humans is 4000 - 5000 mSv in a month (this dose gives a death rate of 50%) [42, 43]. To assess how these activities and items compare to workers in the nuclear industry and people living near nuclear power stations the average annual dose is calculated for each activity and item. This is done by finding out how much an average person in the UK consumes [34, 35, 36, 40, 44, 45, 46, 47, 43].

2.2 Interactive radiation tool

The interactive radiation tool was developed in Python using a library called Dash, an open-source framework for building data visualisation interfaces. Dash helps data scientists build analytical web applications without requiring advanced web development knowledge, making it a useful library for this project. The framework of the tool consisted of a frontend and a backend. The frontend is the part of the tool the user interacts with, this consists of everything the user experiences: text, colours, graphs, buttons and images. The frontend follows a minimal design throughout, with clear images and a chronological structure to aid user intuition. The colours used are EDF's blue and orange brand colours. The results show an easy-to-understand comparison of the user's annual effective dose, relative to an annual dose of living near and working in a nuclear power plant. Below this is a graphical breakdown in the form of a bar chart and pie chart. The backend is the part of the tool the user cannot see, this consists of the code that accesses the database and processes input data. The backend incorporates callback functions, which are functions that produce different outputs based on the user inputs as illustrated in Figure 1.

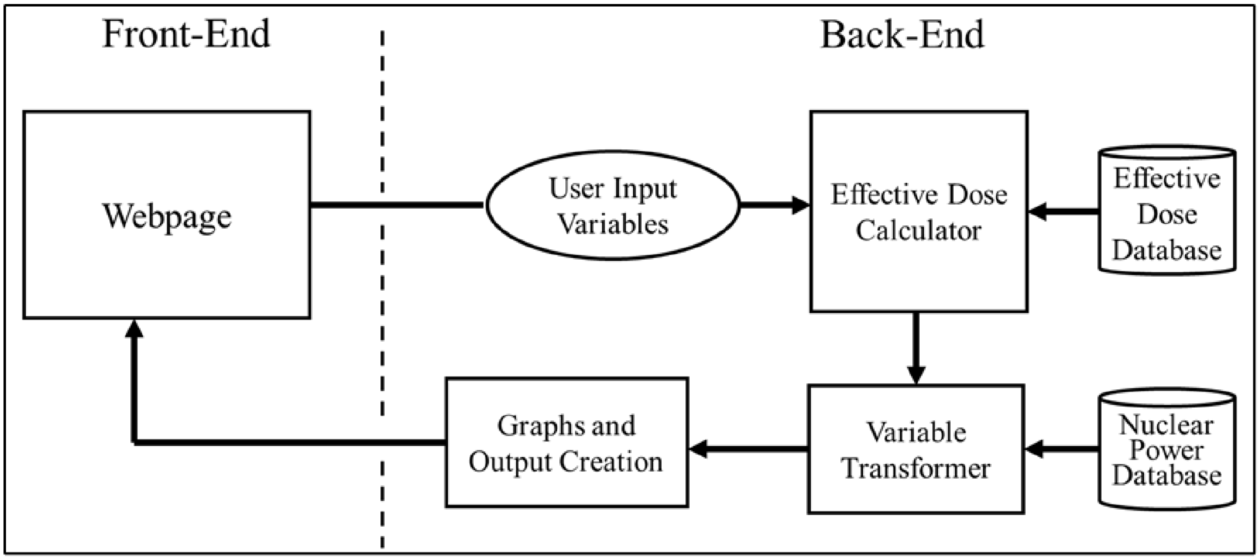

Figure 1: High-level visualisation of the integration between the frontend and the backend of the interactive radiation tool.

2.3 Campaign poster

The campaign poster was developed in Canva, a graphic design platform used to create visual content. The poster compared the annual dose of everyday activities to working and living near a nuclear power station for one year. The designs are kept consistent with those used in the interactive radiation tool, with the primary colours as blue, dark blue and purple. These colours increase subjective attention and have been shown to increase trustworthiness [48].

2.4 Social media campaign

The social media campaign was developed in Canva. The social media campaign aims to engage people's emotions through simple attention-grabbing images. These images used interactive messaging, which has been shown to improve public engagement [49]. The social media campaign was launched on Twitter and Instagram, these apps include interactive features to aid with user engagement. This also targets a younger demographic (18-30), which is important as this study aims to change attitudes towards nuclear energy moving forward.

2.5 Survey

The survey consists of seven questions to gather information about the user's familiarity with nuclear energy and attitudes towards nuclear energy in the future. The user interacts with the radiation tool and the poster, before answering the same seven questions again. This style of quantitative research is known as the Likert scale, the Likert scale is a psychometric scale commonly used to measure perceptions and attitudes [50]. This survey measures the impact of the interactive tool and campaign poster, whilst giving insight into public perceptions around radiation. The descriptive statistics of the survey were obtained using statistical software called SPSS [51].

The following section details the outcome of the interactive radiation tool, campaign poster and social media campaign, as well as the recorded outcomes of the survey.

3 Results

3.1 Activities and items

Table 3 shows a summary of the research into activities and items. The annual dose from each activity and item has been calculated for an average person living in the UK. Where annual dose cannot be calculated easily, suitable substitutions have been made.

Table 3: The corresponding average effective dose received per capita, from the list of activities and items originally researched in Table 1 plus additional dose values from existing literature [34, 35, 36, 40, 44, 45, 46, 47, 43]

Activities and items	**Effective dose**
Wrist X-ray	1.0 μSv per scan
Dental X-ray	2.0 μSv per scan
Head CT scan	1.4 mSv
Chest CT scan	6.6 mSv
Abdomen CT scan	10 mSv
Coffee	20.7 μSv per year
Banana	10.3 μSv per year
Beer	0.38 μSv per year
UK average radon dose	1.3 mSv per year
Average long haul flight	0.13 mSv per return flight
Average short haul flight	0.003 mSv per return flight
Holiday to Cornwall	0.038 mSv per 3 days
Cosmic background radiation	0.68 mSv per year
Nuclear power plant worker	0.5 mSv per year
Living 1km from a nuclear plant (Sizewell C)	0.013 mSv per year
Lethal dose	4000 mSv received in a month
UK workers exposure limit	20 mSv per year
UK average dose	2.7 mSv per year

Figures 2 to 5 respectively show the outcomes of the interactive radiation tool questions, interactive radiation tool outputs, the campaign poster and the social media campaign. Figure 6 and Table 4 show the survey results. The results indicate that the radiation tool and poster were effective, with a 13% increase in familiarity with nuclear energy.

3.2 Interactive radiation tool

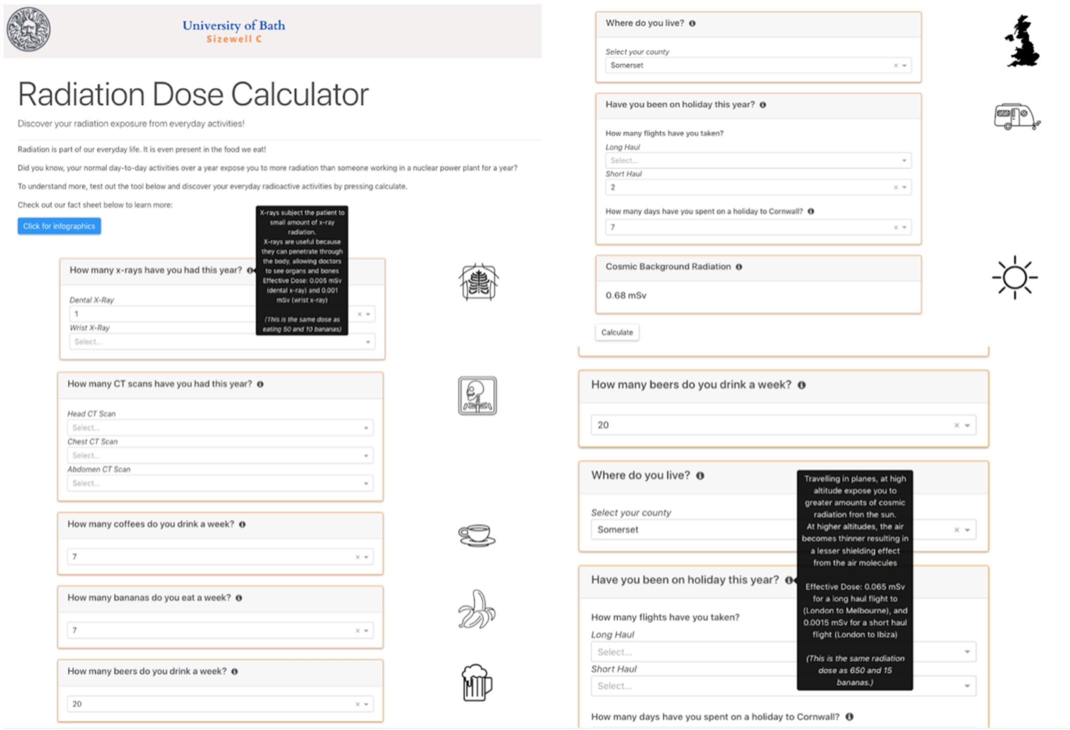

Figure 2: The question section of the radiation tool, with a demonstration of the information button. The code repository (github) for the tool is in Appendix A

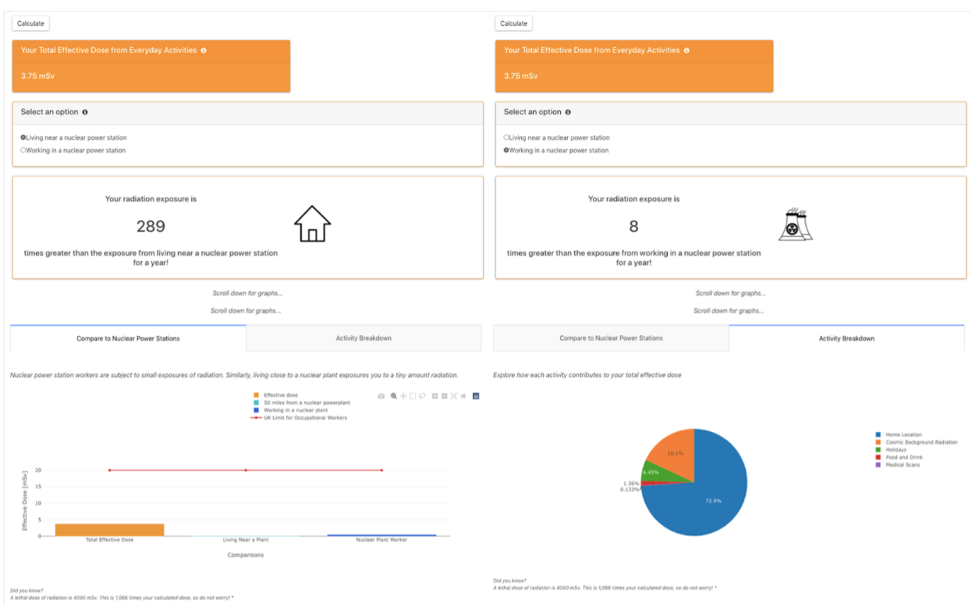

Figure 3: The answer section of the radiation tool. **Top Panels:** Easy to understand comparison of the user's annual effective dose, relative to an annual dose of living near and working in a nuclear power plant. **Bottom Left Panel:** A bar chart visually comparing the user's annual dose. This also includes the UK limit for an occupational worker. **Bottom Right Panel:** A pie chart breaking down the distribution of the user's annual dose.

3.3 Campaign poster

Figure 4: The campaign poster. **Left Panel:** Comparisons of everyday items with the radioactive dose of working in a power station for a year. **Right panel:** Comparisons of everyday items with the radioactive dose of living within 1 km of a nuclear power station.

3.4 Social media campaign

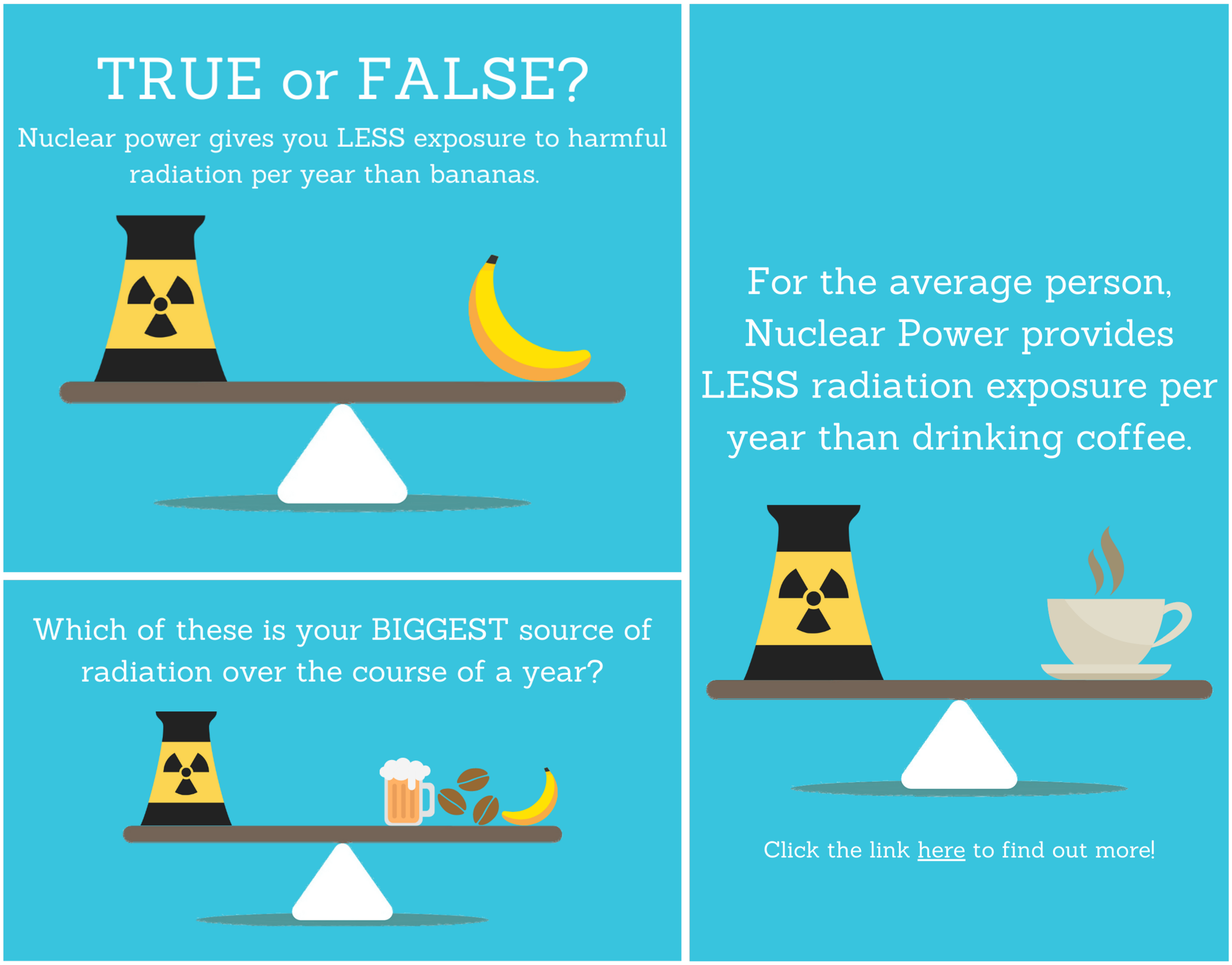

Figure 5: The social media campaign. Consisting of interactive emotionally engaging messages.

3.5 Survey

The user's response before and after using the interactive radiation tool and the campaign poster has been recorded through a seven-question survey. Six of the questions follow the Liker scale, 1 to 5 where 1 is strongly disagree and 5 is strongly agree. The remaining question required a written response. 87 participants' results were recorded for this data set. Figure 6 is a graphical representation of the responses, whereas Table 4 represents the mean and standard deviation.

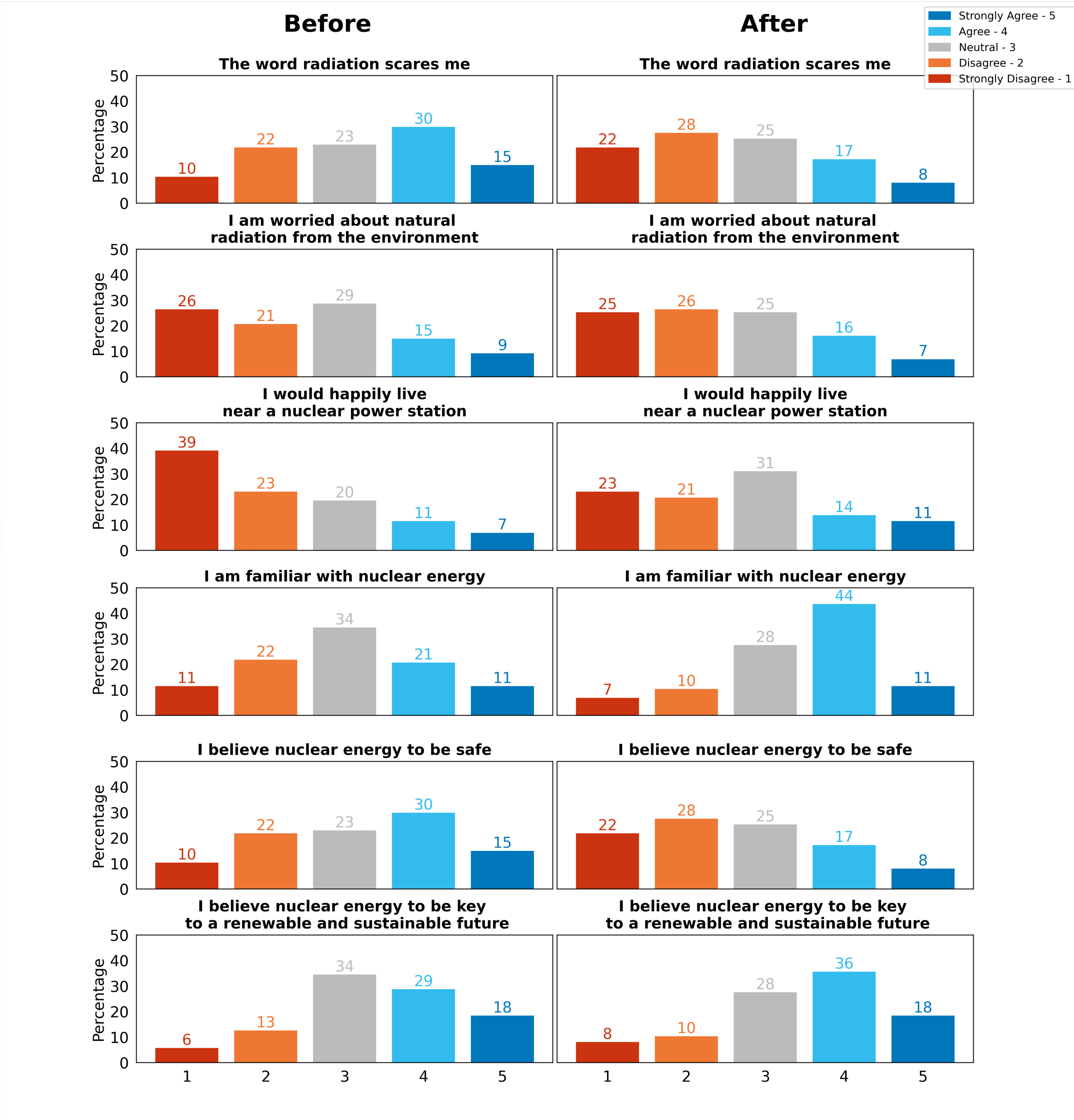

Figure 6: A graphical summary of the survey results following the Likert scale. Where Strongly Disagree (1) corresponds to red and Strongly Agree (5) corresponds to blue. The colours in this graph follow a qualitative vibrant colour scheme, that is colour blind safe [52].

Table 4: The mean and standard deviation of the survey results, before and after the user has interacted with the radiation tool and campaign poster.

	Question	Before		After	
		Mean	Standard deviation	Mean	Standard deviation
1	I am familiar with nuclear energy	2.99	1.17	3.43	1.05
2	I believe nuclear energy to be safe	3.05	1.18	3.47	1.10
3	I believe nuclear energy to be key to a renewable and sustainable future	3.41	1.11	3.46	1.15
4	I am worried about 'natural radiation' from the environment	2.60	1.28	2.53	1.23
5	The word 'radiation' scares me	3.17	1.23	2.62	1.23
6	I would happily live near a nuclear power station	2.24	1.28	2.70	1.29

4 Discussion

4.1 Activities and items

The data in Table 3 (section 3 results) shows that the radiation risk from working and living near a nuclear plant is comparable to the radiation received from day-to-day life. The dose from working in a power station and living 1km from a nuclear plant for a year is 18.5% and 0.48% of the UK average annual radiation dose respectively. Re-enforcing that the harmful radiation from nuclear energy is low relative to other sources of radiation.

4.2 Interactive radiation tool, campaign poster and social media campaign

Responses from the survey were encouraging and suggested the radiation tool and campaign poster effectively developed public understanding of radiation, whilst providing interesting insights into public perception. Before viewing the tools 32.2% of participants agreed or strongly agreed with the statement 'I am familiar with nuclear energy, after viewing the tools this percentage increased to 55.2%. The written feedback from users consisted of positive comments, several comments mentioned being better informed about radiation. Suggesting the success of the interactive radiation tool and campaign poster. Future changes would involve adding more activities and items to the tool, as well as expanding on the existing options in the tool. For instance, provide more options for different types of x-rays.

4.3 Survey

Of the 87 participants 43.7% agreed or strongly agreed with the statement ‘I believe nuclear energy to be safe’, while 47.1% of participants disagreed or strongly disagreed with the statement ‘I am worried about ‘natural radiation from the environment. These numbers enforce the idea underpinned by the perception gap, that people perceive nuclear power as having a higher risk than other forms of radiation [13]. Previous literature does however expect a larger perception gap. A possible reason for this is most of the participants are in higher education, which could account for an above-average knowledge of nuclear energy. Another factor to consider is the age range, 55.2% of the participants are between the ages 18 to and 28. Studies have shown older generations experience more psychological distress around radiation. This is a result of subsequent ’nuclear anxiety’, which has stemmed largely from the nuclear threat throughout the Cold War and nuclear disasters (Chernobyl) [7, 4, 53, 54]. None of the younger participants will have experienced these events, suggesting a reason for the smaller than expected perception gap.

In the future, a wider and more varied pool of participants will help investigate this claim. After interacting with the tools, participants in favour of nuclear energy as being safe increased to 54% whilst the participants comfortable with ‘natural radiation’ increased to 51.7%. This outcome supports the success of the tool and supports the perception gap theory: Experts view things differently, rating nuclear power as less risky than public perception and viewing other forms of radiation as riskier than generally believed.

Research of course reveals natural radiation from radon has an effective dose of 2.6 times that of a nuclear worker.

Effective communication of radiation and risk is important in the journey towards ’Net Zero’. When asked if nuclear energy is the key to a renewable and sustainable future 47.1% of participants agreed or strongly agreed before and 51.7% after. This of course shows an improved understanding of nuclear energy does not correlate to the belief nuclear energy is important in a sustainable future, despite previous predictions. A possible reason for this is a general lack of information about Britain’s journey to ’Net Zero’, perhaps this is to reduce public fears of radiation. The radiation tool and campaign poster also did not include information about the role nuclear power would play in a sustainable future, further investigation into the importance of nuclear energy would provide interesting insight. Participants also stressed a disinterest in living near a nuclear power station, with 62.1% disagreeing or strongly disagreeing before and 43.7% after. Although this percentage has decreased, the comments highlight that one would not want to live near a nuclear power station for reasons other than radiation concerns. One participant commented about the scenery living near a power station. Further research should be conducted to determine these other reasons.

When talking about radiation risk it is impossible to avoid incidents such as Chernobyl, Fukushima and Hiroshima. As predicted, many of the responses to the statement ‘Why do you believe it (nuclear energy) to be safe/unsafe?’ mentioned these disasters. Before reviewing the tools 44.8% of participants acknowledged one of these disasters or mentioned the possibility of a meltdown/accident, despite a lot of these responses deeming nuclear energy as safe. After reviewing the tools the percentage of participants mentioning meltdowns/accidents decreased to 13.8%. Despite the percentage decreasing, it is apparent that ‘radiation’ and ‘nuclear energy’ still hold onto these connotations even among those who are well informed. Although the United Kingdom is not a country that has been negatively affected by nuclear energy, it is clear the impact mainstream media, as well as popular social media, have on public perception. Perhaps there are deeper issues concerning distrust of the government. Studies have shown this is prevalent in Fukushima [6, 7], it is within reason people in the UK share that mindset. These disasters will prove to be a big obstacle for the UK (and the rest of the world) moving forward with nuclear energy, a combination of time and correct information will prove fundamental to achieving a sustainable future. Other concerns revolved around the disposal of radioactive waste. Some participants suggested the risk of nuclear energy is in the disposal of waste. This was not covered by this investigation; further research should be conducted. The remaining comments mentioned nuclear weapons, and one comment mentioned nuclear energy ”reminds me of nuclear weapons ”. The dread of nuclear weapons has been evidenced [12, 3]. Whilst nuclear power plants and nuclear bombs can be distinguished, there exists a difficult connotation to escape.

The survey assessed a range of areas surrounding radiation and risk. The level of public knowledge regarding different types of radiation supported the concepts of the perception gap. Age had a slight correlation with positive attitudes towards nuclear energy, although the sample size was not extensive enough to conclude. The number of participants who believed nuclear energy to be key to a sustainable future did not correlate with an improved understanding of nuclear energy. Moving forward more emphasis on the bigger picture and ‘Net Zero’ is recommended to be adopted. Some participants’ perceptions of how safe nuclear energy remains tied to nuclear disasters (Chernobyl, Fukushima, etc), despite a lot of these participants believing nuclear energy is safe. An improved understanding of nuclear energy reduced the number of participants mentioning disasters. A few participants expressed concern over nuclear weapons and radioactive waste.

5 Conclusion

Britain’s target to achieve ’Net Zero’ by 2050 will involve moving towards nuclear energy. Accepting radiation as an energy source is imperative in this journey. To investigate public perception and improve opinions towards radiation, the relative risk of nuclear energy was researched and compared to everyday activities and items. This research was condensed into an interactive radiation tool and campaign poster. A survey using the Likert scale measured attitudes towards nuclear energy, before and after participants interacted with the radiation tool and the campaign poster.

Research showed the risk from nuclear energy is comparable to everyday items and activities. Survey results confirmed the interactive radiation tool and the campaign poster successfully improved public understanding of nuclear energy and confirmed the perception gap [13]. Analysis of the survey data corroborated that although participants acknowledge the safety of nuclear energy, there is a perpetual awareness of nuclear disasters. An increased understanding of nuclear energy showed no relation to the belief that nuclear energy is important for a renewable and sustainable future.

The importance of nuclear energy's contribution to achieving 'Net Zero' is a significant opportunity which has all the environmental and sustainability benefits but still has to address concerns and misconceptions surrounding nuclear radiation. Direct messaging through the use of comparisons proved an effective way to educate people who had negative connotations surrounding nuclear energy. Perhaps there should be more focus on this model and approach by age groups to build an expansive data set of comparisons. From here a wide range of comparative communication tools and strategies would be developed as part of the long term journey of adopting and accepting nuclear power.

References

[1] EDF. Sizewell c nuclear power station project update. 2022.

[2] Lawrence T Dauer, Raymond H Thornton, Jennifer L Hay, Rochelle Balter, Matthew J Williamson, and Jean St Germain. Fears, feelings, and facts: interactively communicating benefits and risks of medical radiation with patients. *AJR. American journal of roentgenology*, 196(4), 2011.

[3] Joseph P Ring. Radiation risks and dirty bombs. *Health Physics*, 86:S42–S47, 2004.

[4] Ross H Pastel. Radiophobia: long-term psychological consequences of chernobyl. *Military medicine*, 167(suppl_1):134–136, 2002.

[5] Anita F Reitan and Audun Sanderud. Communicating radiation risk to patients: Experiences among radiographers in norway. *Journal of medical imaging and radiation sciences*, 51(4):S84–S89, 2020.

[6] Michio Murakami, Akiko Sato, Shiro Matsui, Aya Goto, Atsushi Kumagai, Masaharu Tsubokura, Makiko Orita, Noboru Takamura, Yujiro Kuroda, and Sae Ochi. Communicating with residents about risks following the fukushima nuclear accident. *Asia Pacific Journal of Public Health*, 29(2_suppl):74S–89S, 2017.

[7] Yuriko Suzuki, Hirooki Yabe, Seiji Yasumura, Tetsuya Ohira, Shin-Ichi Niwa, Akira Ohtsuru, Hirobumi Mashiko, Masaharu Maeda, and Masafumi Abe. Psychological distress and the perception of radiation risks: the fukushima health management survey. *Bulletin of the World Health Organization*, 93:598–605, 2015.

[8] Reiko Kanda, Satsuki Tsuji, and Hidenori Yonehara. Perceived risk of nuclear power and other risks during the last 25 years in japan. *Health physics*, 102(4):384–390, 2012.

[9] PA Bryant. Communicating radiation risk: The role of public engagement in reaching alara. *Journal of Radiological Protection*, 41(2):S1, 2021.

[10] ICRP. Calculating doses from intakes of radionuclides. 2019.

[11] F Paquet, George Etherington, MR Bailey, RW Leggett, J Lipsztein, W Bolch, KF Eckerman, and JD Harrison. Icrp publication 130: Occupational intakes of radionuclides: Part 1. *Annals of the ICRP*, 44(2):5–188, 2015.

[12] Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein. Perceived risk: psychological factors and social implications. *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences*, 376(1764):17–34, 1981.

[13] Paul Slovic. The perception gap: Radiation and risk. *Bulletin of the atomic scientists*, 68(3):67–75, 2012.

[14] National Research Council et al. Improving risk communication. 1989.

[15] Warren Sandberg, Richard Urman, and Jesse Ehrenfeld. *The MGH Textbook of Anesthetic Equipment E-Book*. Elsevier Health Sciences, 2010.

[16] K Eckerman, John Harrison, HG Menzel, CH Clement, et al. Icrp publication 119: compendium of dose coefficients based on icrp publication 60. *Annals of the ICRP*, 41:1–130, 2012.

[17] Mayeen Uddin Khandaker, Nur Khairunnisa Zainuddin, DA Bradley, MRI Faruque, FI Almasoud, MI Sayyed, A Sulieman, and PJ Jojo. Radiation dose to malaysian populace via the consumption of roasted ground and instant coffee. *Radiation Physics and Chemistry*, 173:108886, 2020.

[18] Ai-Min Wu, Catherine Bisignano, Spencer L James, Gdiom Gebreheat Abady, Aidin Abedi, Eman Abu-Gharbieh, Robert Kaba Alhassan, Vahid Alipour, Jalal Arabloo, Malke Asaad, et al. Global, regional, and national burden of bone fractures in 204 countries and territories, 1990–2019: a systematic analysis from the global burden of disease study 2019. *The Lancet Healthy Longevity*, 2(9):e580–e592, 2021.

[19] NHS. Provisional monthly diagnostic imaging dataset statistics. 2022.

[20] United Nations Scientific Committee on the Effects of Atomic Radiation et al. *Sources and effects of ionizing radiation, united nations scientific committee on the effects of atomic radiation (UNSCEAR) 1993 report: report to the general assembly, with scientific annexes*. United Nations, 1993.

[21] ACR. Radiology safety. 2022.

[22] HM Government. Patient dose information: guidance. 2022.

[23] David W Ball. How radioactive is your banana? *Journal of chemical education*, 81(10):1440, 2004.

[24] P Tchokossa, JB Olomo, FA Balogun, and CA Adesanmi. Assessment of radioactivity contents of food in the oil and gas producing areas in delta state, nigeria. *International journal of science and technology*, 3(4):245–250, 2013.

[25] Carla Roselli, Donatella Desideri, A Rongoni, D Saetta, and Laura Feduzi. Radioactivity in coffee. *Journal of Radioanalytical and Nuclear Chemistry*, 295(3):1813–1818, 2013.

[26] C. Shearlock and J Irons. The boat galley cookbook. *Camden, Maine: International Marine/McGraw-Hill*, 2013.

[27] Mayeen Uddin Khandaker, Nur Khairunnisa Zainuddin, DA Bradley, MRI Faruque, FI Almasoud, MI Sayyed, A Sulieman, and PJ Jojo. Radiation dose to malaysian populace via the consumption of roasted ground and instant coffee. *Radiation Physics and Chemistry*, 173:108886, 2020.

[28] Maria José Aguirre Armelin. Activity levels of gamma-emitters in brazil nuts. *Brazilian Journal of Radiation Sciences*, 4(1), 2016.

[29] UK Health Security Agency. Uk maps of radon. 2022.

[30] Anssi Auvinen and Göran Pershagen. Indoor radon and deaths from lung cancer, 2009.

[31] Where does radon gas come from? 2021.

[32] Radiation mapping in cornwall. 2022.

[33] Pocket Wanderings. Most popular holiday destinations with brits. 2022.

[34] WB Oatway, AL Jones, and S Holmes. *Ionising radiation exposure of the UK population, 2010 review*. Centre for Radiation, Chemical and Environmental Hazards, Public Health England, 2016.

[35] IAEA. Cosmic radiation exposure of aircrew and space crew. 2016.

[36] S Bailey. Air crew radiation exposure. 2000.

[37] Abel J Gonzalez and Jeanne Anderer. Radiation versus radiation: Nuclear energy in perspective. *IAEA Bulletin*, 31(2):21–31, 1989.

[38] Sizewell c project radioactive substances regulation (rsr) permit application appendix d support document d1 - human radiological impact assessment.

[39] Frequently asked questions about radiation protection. 2020.

[40] HSE. statistics ionising radiation. 2017.

[41] Alison King. An insight into digital radiography use in small animal practice in the uk. *The Veterinary Record*, 182(8):222, 2018.

[42] Claus Grupen and Mark Rodgers. What are radioactivity and radiation? In *Radioactivity and Radiation*, pages 7–25. Springer, 2016.

[43] HM Goverment. Ionising radiation: dose comparisons. 2011.

[44] N Wunsch. Average purchase per person per week of fruit and nuts in the united kingdom (uk) in 2019/20. 2022.

[45] M. Ridder. Average number of cups of coffee consumed per person per day in the united kingdom (uk) in 2018, by generation. 2018.

[46] Global beer consumption by country in 2019. 2022.

[47] KANTAR. Great britain tourism survey. 2019.

[48] Andrew J Elliot. Color and psychological functioning: a review of theoretical and empirical work. *Frontiers in psychology*, 6:368, 2015.

[49] How to build an ad that grabs attention in 2 seconds or less. 2016.

[50] Ankur Joshi, Saket Kale, Satish Chandel, and D Kumar Pal. Likert scale: Explored and explained. *British journal of applied science & technology*, 7(4):396, 2015.

[51] Tae Kyun Kim. T test as a parametric statistic. *Korean journal of anesthesiology*, 68(6):540, 2015.

[52] Paul Tol. Colour schemes and templates. 2021.

[53] GP Beehler, JA Baker, K Falkner, T Chegerova, A Pryshchepava, V Chegerov, M Zevon, E Bromet, J Havenaar, H Valdismarsdottir, et al. A multilevel analysis of long-term psychological distress among belarusians affected by the chernobyl disaster. *Public Health*, 122(11):1239–1249, 2008.

[54] Jian Tong and Tom K Hei. Aging and age-related health effects of ionizing radiation. *Radiation Medicine and Protection*, 1(1):15–23, 2020.

[55] F. L. Somoye M. Talberg. Interactive radiation tool, 5 2022.

A Appendix: Interactive radiation tool

https://github.com/MaxTalberg/PH30096 [55]