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Comparative analysis of the perception of nuclear risk in two populations (expert/non-expert) in France

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ABSTRACT

In an effort to reduce CO₂ emissions, many countries throughout the world are initiating plans to transition to more sustainable forms of energy. Nuclear energy would appear to be a powerful contender to replace fossil fuels, or at least be an unavoidable option, from an energy-mix perspective. However, nuclear energy suffers from a poor image among certain populations, especially the young, who favor the development of renewable energies. We wanted to get a more accurate read of what was happening in France, one of the most nuclearized countries in the world, where the share of nuclear energy is greater than 70%. Since plans are underway to reduce this level to 50% by 2035, understanding popular perceptions on this matter is even more important. In order to gain a better understanding, we interviewed an “expert” population and compared the results obtained with a so-called young “non-expert” student population. The first group is composed of firefighters, about half of whom have attended training in radiological risks, and the other, a non-expert population, composed of students from Université Côte d'Azur (UCA), who are potentially influenced (for better or worse) by social media. The aim of this study is to compare and contrast any differences in perception that these two distinct populations may have on the subject of nuclear energy.

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Introduction

Since Antoine Henri Becquerel's discovery of the mysterious radiation from uranium salts in February 1896, which were later referred to as uranic rays emitted by “natural radioactivity”, the science of “radioactive nuclei” (unstable nuclei) has not ceased to be used by mankind. This sudden change in the history of science was largely due to the scientific advances of the first half of the 20th century and its development during World War II for military purposes. After the war, although the military objectives

have never been abandoned (especially during the “Cold War” period), the use of electrical energy produced by the nuclear power plants has been widely developed, mainly in the Northern Hemisphere.

Today in France, 58 reactors are in operation, 1 is under construction, and the proportion of nuclear-derived electricity was 71.6% in 2017.¹ Worldwide, at the end of 2016, 448 reactors were in operation, 61 under construction, and nuclear power accounted for about 11% of global electricity generation, while total electricity generation increased by 2.6% in 2016, with 2.1% coming from nuclear power (IAEA, 2017). At the same time, the significant development of the civil nuclear industry in the Northern

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¹ Data from EDF web site, www.edf.fr.

Hemisphere has raised new questions in terms of environmental impact, long-term management, defense and non-proliferation.

Moreover, whether it is being used as a source of energy or for other applications, it is subject to controversy: Nuclear energy tends to feed phantasmagories, fears and the most diverse and varied conspiracy theories (Brenot et al., 1996). However, among the various sources of electricity production, coal remains dominant despite significant growth in natural gas production.

The Chernobyl accident in April 1986, and more recently that of Fukushima Dai-ichi in March 2011, has had a major impact in terms of energy policy in various countries, mainly Western, because of the decline in the social acceptance of civilian nuclear energy. These social concerns, the perception of the public, and industrial development thus raise fundamental scientific, technical and sociological questions.

In the social sciences, perception has long been a useful concept for understanding risk situations by distinguishing “perceived risk (by the public) and real risk (according to experts)” (Brenot et al., 1996). The technological risk, and more particularly the risk associated with nuclear energy at the end of the 1960s, brought to the fore a perception from the “general public (...) disproportionate to the reassuring assessments of experts” (Brenot et al., 1996). It is clear that “knowledge influences public perceptions of issues like nuclear energy” (Hansen et al., 2003) and that the public’s lack of understanding may explain why the same issues are viewed in different manners (Kellstedt et al., 2008). This Knowledge Deficit Model (KDM)² suggests that experts understand issues better than the public (Stoutenborough et al., 2013).

Perception studies have sought to “determine how the public assesses the risks in order to understand, for example, the differences observed in the positioning of the various social groups”, “link perceptions to attitudes and behaviors”, and to move from “perceived reality” to an “objective reality” (Brenot et al., 1996). In the United States, the work of Slovic et al. (2004) referred to “perceived risks” of nuclear power. In France, the Institute for Nuclear Protection and Safety (IPSN)³ has, since 1977, studied the perception of risks with the assistance of the Commission of the European Community. Since then, IRSN has conducted a study based on a questionnaire entitled “Barometer on the perception of risks and security” (Baromètre IRSN, 2018). It is not possible to entirely recapitulate the questions asked in this barometer, since it has been published annually in this form since 1990 and it “traces the evolutions of the opinion of the French people on the social, environmental and technological risks” (Baromètre IRSN, 2018). However, the main objective of the IRSN is to “put the perception of nuclear risk in perspective” according to a representative panel of the French population.

Other organizations have also, in the past, conducted such investigations. Examples include those of the IFOP for *Dimanche Ouest France* in June 2013 on “The French and nuclear energy” (Ifop, 2013), then in April 2016 “for the conference #tcherno23” (Ifop, 2016). In 2013, the IFOP survey sought to establish “the opinion on the use of nuclear energy” and “the preference for the evolution of the proportion of nuclear power in France”, and that of 2016 concerned “support for the shutdown of nuclear power plants in France” including the reasons for these views.

In April 2011, at the height of the Fukushima event, and again in September 2012 and February 2015, a major survey (Ipsos Global Advisor, 2015) was conducted online in 16 countries

around the world⁴ “with a sample of around 18 000 people aged 18 to 64, on the basis of 500 to 1000 interviews per country”.⁵ It appeared that while “public opinion was favorable to nuclear energy in 7 countries out of 16”,⁶ “frank opposition toward nuclear energy” was observed throughout the period under consideration in all countries. It was thus noted that while “opponents to nuclear energy mainly associate it with the problems of waste, threat to civil safety, destruction of landscapes, too high costs and climate change”,⁷ it turned out that the proportion in favor of the technology nevertheless considered “waste, the safety of the population and costs to be problems” while “an obvious positive correlation between knowledge and support” emerged.

In 2010, the report produced by the Nuclear Energy Agency (NEA)⁸ of the Organization for Economic Co-operation and Development (OECD) found, after analysis of a number of surveys and opinion polls on nuclear energy, that “when the benefits of nuclear energy in relation to climate change are explained, the support for nuclear energy among respondents increased significantly. Similarly, if the question of the disposal of radioactive waste were to find a satisfactory solution, this support would also increase significantly” (OCDE, 2010).

In 2009, it was found that “in France, as elsewhere, the awareness of climate risk and vulnerability to the supply of hydrocarbons has reinforced pro-nuclear opinions and even brought some known ecologists to revise their opinion” (Lauvergeon and Barre, 2009). For its part, the Eurobarometer on “Europeans and Nuclear Safety” highlighted “that, in countries where nuclear power is in place, people perceive [nuclear risks] as lower than that of their counterparts in countries that do not have it”. This observation is explained by the communication and the information that is regularly transmitted to the population on the subject, by the relevant authorities and competent entities. A consequence of this same survey “shows that people, who think they are well informed about nuclear safety, tend to perceive a lower risk than those who do not feel informed”.

In the summary chapter of the “Barometer 2017 IRSN” (IRSN and Baromètre, 2017) Christelle Craplet points out that “it could be interesting to further push the analyses while distinguishing, among the people questioned within the framework of the Barometer, certain categories of population”. It is in this very general context that we carried out an on-line survey (from October 20 to November 20, 2018), on the knowledge and the perception of nuclear energy in representative populations with either expert opinion or non-expert opinion within the framework of a multi-disciplinary project of the “NR2P2”⁹ initiative of Université Côte d’Azur (UCA) Academy Space, Environment, risk and resilience.

1. Materials and methods

This survey, composed of multiple choice questions, was supported by the Limesurvey Internet platform and had the three following characteristics: it was “instantaneous”, in the sense that it provided a snapshot, at a precise moment, of the perception and

² The Knowledge Deficit Model attributes to the public a lack of understanding, resulting from a lack of information.

³ Merged in 2002 with the Office of Protection against Ionizing Radiation (OPRI) to become the Institute of Radioprotection and Nuclear Safety (IRSN) under the Decree n° 2016-283 of March 10, 2016, of several ministries including environment, defense and health.

⁴ India, China, Indonesia, the United States, Russia, Sweden, Great Britain, Saudi Arabia, Mexico, Germany, Poland, France, Brazil, Hungary, Spain and Japan.

⁵ Whose results have been weighted according to the degree of internet representativeness in each country (accessibility of technology according to the level of development of the country).

⁶ “The United States, Russia, Sweden, Great Britain, China, India and Saudi Arabia”.

⁷ So appears the mistaken belief “that nuclear energy is a cause of climate change”.

⁸ Created on 1st February 1958 under the name of the “European Agency for Nuclear Energy of the OECD” and which took its current name in 1972 “when Japan became its 1st non-European country with full membership”.

⁹ Nuclear risks of radioisotope (bio)chemistry to the public perception.

Table 1

The efficacy of the data used for the research.

	UCA students in 2018–2019	Firefighters in 2018
Number of	29 400	14150
Number of answers	1075	1240
Interval of confidence	95%	95%
Statistical error	2,93%	2,66%

knowledge of nuclear energy in France; it was “atomic” (Boudon and Fillieule, 2018), because it aimed for each individual surveyed to understand how he or she received information on nuclear energy (e.g. very trustful, trustful, not very trustful, not at all trustful, etc.) – these methods directly influencing perception and positioning (e.g. for, against, hesitant, etc.); it was also “contextual”, since this questionnaire made it possible to observe the perception and the knowledge of the individuals according to whether they were socially and individually identified as an expert or non-expert.

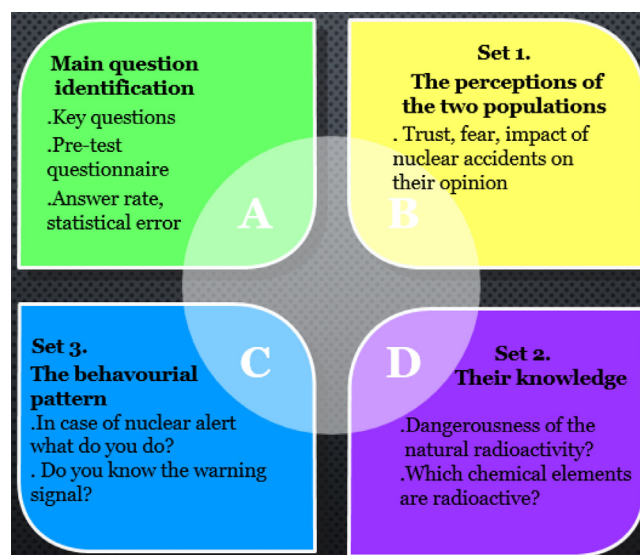
Two homogeneous groups of individuals formed the population sub-groups to respond to the evaluation criteria on information about nuclear energy “according to their level of expertise”. The first group was that of the “firefighters”, who constituted the expert group. The second group was that of “students” of UCA, who constituted the non-expert group. These two groups were of relatively uniform size, with 1240 and 1075 surveyed individuals, respectively.¹⁰ The figures and statistical errors associated to these groups are reported in Table 1.

Those two populations are not the most extreme in terms of profiles, indeed we could have interviewed nuclear actors and compared their opinion with those of the students, or general public. Instead, we preferred to consider the firefighters who have some knowledge by their training but who do not depend on the nuclear industry (dependency syndrome described by Wynne et al. (2007)) with those of the students.

The survey (see Appendix 1) was the result of several working meetings as we were a multidisciplinary team (composed of radiochemists, jurists, sociologists, experts in civil protection). We asked each discipline to provide us with a series of key questions, which were then selected by consensus. Before being put online using the Limesurvey platform, the questionnaire was tested with our respective students, which led to several modifications. We were able to initially differentiate, through thirty-three questions, the variables that characterized the reception and knowledge of experts and non-experts regarding nuclear energy.

Questions in the survey were ordered in such a way as to avoid any methodological bias that would disqualify the results of the perception survey, via an anticipated response of the individuals to questions relating to the survey of their knowledge. As such, the survey questionnaire was structured in three parts as described in Fig. 1. The first part was thus logically devoted to the perception of nuclear power in France with regard to its various security issues (technological and environmental risks, legislation implemented to address these, etc.). The second part investigated the knowledge of respondents about radioactivity and also aimed, through this, to inform them. The third and final part was a “snowball effect” (Boudon and Fillieule, 2018), which allowed us

¹⁰ This total corresponds with the complete and incomplete responses (people who did not complete the questionnaire right to the end). The complete responses were of the order of 720 for the students, and of 868 for the firefighters. All the analyses were carried out on the complete responses in order to maintain coherence between responses, the profiles of population, and to avoid automated responses that could have been submitted several times. Nevertheless, we show the % of the answers for the 2 populations (in appendix) and the % of incomplete answers, because this can give an indication of where the people dropped the questionnaire.

**Fig. 1.** Sketch of the survey structure.

to expand the interdependent relationships – between knowledge and perception – characterized for our population sample on nuclear issues. Here, it was finally a question of establishing causal relations between the perception and the knowledge of our two sub-groups of individuals, in particular with their sources of information, their behavior in the event of a nuclear alert, their state of mind, their age, and their education.

The responses have undergone several statistical analyses (simple sorting, cross sorting, word cloud, principal component analyses), which we address below.

1.1. The first section of the questionnaire – the perceptions of the two subpopulations

First analyses show great differences between the two sub-populations: students and firefighters. Indeed, firefighters were more confident in their future than students whose professional future can be anxiety-provoking, meanwhile the firefighters were already settled in life.

Q1: Overall, are you confident about the future?

Confident	Firefighters 51%	UCA students 26%
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We also noted this difference in terms of trust in the nuclear industry, with firefighters being twice as likely as students to trust the industry:

Q2: What is your degree of trust in the nuclear industry in France?

I have confidence	Firefighters 50%	UCA students 22%
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This can be explained by the fact that half of the firefighters surveyed had undergone training in radiological and nuclear risks as established a national reference guide. This guide identifies four levels of training (RAD1 to RAD4) for specialized teams, and four levels of employment (initiated, specialist worker, chief of response unit, and technical advisor). In addition, non-specialist firefighters receive awareness training during their integration. The specialized teams, besides their initial training, are required to complete a quota of hours in learning retention in order to remain on the operational lists that are the subject of a prefectural

order. The RAD4 training (technical adviser) is more focused on advising and supporting the prefecture in the event of a major crisis.

For the question: “Are the terms *nuclear* and *radioactivity* linked from your perspective?”, the firefighters were more readily associating these two words compared to students.

Q3: Are the terms “nuclear” and “radioactivity” linked from your perspective?

Yes	Firefighters 69%	UCA students 59%
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Note respondents had the opportunity to answer “partially” for that question, and students were more numerous than firefighters in choosing this option. Despite the fact that the survey was in no case presented as an evaluation, this is perhaps an indication of their cautiousness. It is worth recalling that the two words are indeed related, because they relate to properties of atomic nuclei. **Radioactivity** is a phenomenon that is produced by the unstable nuclei of some atoms. These unstable atomic nuclei tend to transform into other nuclei. This transformation is accompanied by the emission of radiation, i.e., particles, which may be of different types: alpha (α), beta (β), gamma (γ) or neutron (n). While the adjective **nuclear** means “relative to the nucleus”, in this case the nucleus of the atom. Following the development of the nuclear industry, the term “nuclear” now refers to all civil and military activities that use the phenomenon of radioactivity for the production of energy (“energy” in the broad sense).

The perception gap between the two subpopulations tends to narrow when it comes to answering the question: “Does the nuclear industry scare you?”, as we can see below:

Q4: Does the nuclear industry scare you?

Yes	Firefighters 49%	UCA students 68%
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The reasons that motivate fear were sometimes similar (radioactive waste, long-term contamination, aging of the power stations), and sometimes divergent because of the better knowledge of the firefighters who had undertaken radiological training: out of control, fear of the effects of radioactivity. They were also much less likely than students to be in favor of a partial exit from nuclear energy, thinking that the French authorities are transparent in terms of nuclear power, the power stations are safe, and they felt they were sufficiently informed with respect to nuclear energy. They were also less likely than students to indicate that they might change their minds if they had more knowledge on the subject, which is logical since they have already, through their training or activity, more “objective” knowledge than students (see below). For the same reasons, they know how to protect themselves from radioactivity (73%, compared to only 22% for students). Students were also in need of information on the subject. For instance, only 28% of them knew the warning signal in the event of a nuclear accident (which is no different from the other warning signals in France), and which corresponds to a modulated siren, rising and descending for three sequences of 1 min with a 5-second interruption between each sequence. This signal warns the public of imminent danger and the need to shelter, regardless of the nature of the event in question. This question had a pedagogical purpose and was intended to remind them of its significance.

Q6: Are you in favor of a partial exit from nuclear energy?

Yes	Firefighters 50%	UCA students 67%
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Q8a: In general, do you think the authorities are transparent in terms of nuclear power?

Completely/Somewhat agree	Firefighters 40%	UCA students 20%
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Q8b: In general, do you think that French nuclear power stations are safe?

Completely/Somewhat agree	Firefighters 75%	UCA students 51%
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Q8c: In general, do you think you are sufficiently informed with respect to the nuclear energy sector?

Completely/Somewhat agree	Firefighters 38%	UCA students 18%
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Q8d: In general, do you think that you would change your mind about the nuclear energy sector if you had more knowledge on the subject?

Completely/Somewhat agree	Firefighters 53%	UCA students 62%
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Q25. Do you know how to protect yourself from radioactivity in the event of an accident?

Yes	Firefighters 73%	UCA students 22%
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Perception of nuclear risk has changed in about the same proportions (60%) since the Fukushima accident, which was still on people's minds (Fig. 2). This impact was a little less for the accident of Chernobyl (54% for the firefighters, who were older, and 45% for the students who had not been born at the time), while the Three Mile Island accident which occurred in the USA in 1979, was even less known.

Q5b: Has your perception of nuclear risk changed since the [Chernobyl] nuclear accident?

Yes	Firefighters 54%	UCA students 45%
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It appeared that the nuclear operators were poorly recognized by students, with the exception of the historic operator, EDF (Electricité de France), which produces electricity in France from nuclear power plants (88%), followed by the army (84%, the link between nuclear energy and nuclear weapons was made by the students), nuclear medicine services (48%) and AREVA (ORANO today, 46%). The other operators were only known by 35%. Of course, the firefighters, given their activity, were more connected to these operators than the students, they were *de facto* more aware of them (see the Appendix 2). Note that all the organizations mentioned in the questionnaire were indeed French nuclear operators, or international agencies.

Legislation relating to the nuclear field in France was also little known by students, this may be due to the difficulty in accessing and understanding this information¹¹ for non-specialist students, since in response to the question: “Do you agree with the following assertion: information on the law applicable to nuclear risks is accessible to all?” more than 39% of the students indicated “somewhat disagree”, and 21% “disagree”. However, there are indeed standards that regulate Basic Nuclear Installations (BNI),

¹¹ These difficulties are not unique to the nuclear field they are inherent in the legislative framework itself.

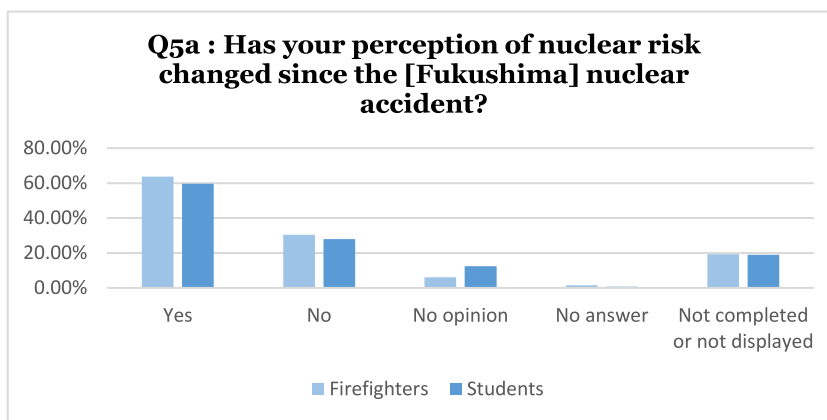


Fig. 2. The perception change of nuclear risk since the Fukushima accident, in %, for the two populations.

radiation protection (legal regime of health protection), the transport of radioactive substances, materials and waste, or emissions and extractions in nature (Jaeger et al., 2017). In France, it is the law of June 13, 2006 (n° 2006-686) (Legifrance, 2006) on the transparency and safety in nuclear matters, known as “law TSN”, which clarified the legal framework for nuclear activities. Before this law, the standards were scattered across different texts. The provisions relating to transparency in nuclear matters are set out in Articles L. 125-12 et seq. of the Environmental Code (Legifrance, 2012): “Transparency in nuclear matters consists of all the measures taken to guarantee the public’s right to reliable and accessible information on nuclear safety”. This transparency is ensured, in particular, by the obligation for the operators of basic nuclear installations, to establish an information report each year that is communicated to the public. Local information commissions ensuring representation of the relevant interests are instituted in the facilities (Article L. 125-17 C.) (Legifrance, 2012b). Basic nuclear installations are subject to a strict authorization and supervision regime set out in articles L. 591-1 et seq. of the Environmental Code (Legifrance, 2012c). These rules determine, in particular, the creation and commissioning of an installation, its operation, as well as its shutdown and dismantling.

Regarding the management of radioactive waste (as we saw in the introduction, this issue could change the opinion of respondents, especially if it were better addressed), the difference between the two populations was 24% (70% for firefighters, and only 46% for students), this difference was reversed when the question of the management of nuclear waste in deep geological zones was broached, the majority of the students being against it. Indeed, radioactive waste is very diverse because of the very wide variety of radionuclides it contains, as well as its volume and physical nature. Each type of waste requires appropriate treatment and management, in order to control the associated risks, especially the radiological one. In France, each category of waste is managed in a particular sector that includes a series of operations such as the sorting, treatment, packaging, stockpiling and storage of the final waste. France has set up a National Plan for the Management of Radioactive Materials and Waste (ASN FR, 2016a), which regularly reviews the radioactive waste management policy to evaluate new requirements, and to determine the objectives to be met in the future.

We also asked respondents if they considered that the risk was greater between living near a chemical waste storage facility, radioactive, industrial or domestic waste storage facility? The students responded nearly 57% “to live close to a site for

storage of radioactive waste”, while for the firefighters, it was the possibility of living near a chemical waste site that they would find concerning (47%). Actually, the risk depends on the nature of the waste, its physical form, its quantity and the method of storage. It is not possible to define the risk associated with a waste simply in relation to its origin (chemical, radioactive, industrial or household waste). Household or industrial waste may, for example, contain chemicals that are hazardous to health and/or the environment.

After having sought, in this first part to understand the perception of these two populations, the second section sought to evaluate their general knowledge of the nuclear field.

1.2. The second part of the questionnaire – the knowledge of the two populations

First of all, the respondents, whether they were students or firefighters, mainly responded that they do not feel exposed to radioactivity in their daily lives (more than 60%), with the nearest nuclear power plant being 150 km from Nice (where Université Côte d’Azur is located). In France, in 2018, the number of nuclear power stations was 19, with 58 nuclear reactors having powers between 900 and 1450 MWe (see Fig. 3 below).

When we asked how radioactivity could affect them, firefighters respond more accurately than students (86% correct answers for firefighters, compared to 75% for students). Radioactivity can affect organisms via two exposure modes: external (exposure to radiation without contact), or internal (following contamination by radioactive particles internalized by inhalation, skin contact or ingestion).

When it comes to knowing “Which organs can be affected by radioactivity?”, the two subpopulations placed the thyroid at the top, followed by skin, lungs for students, and blood for firefighters. All organs can in fact be affected by radioactivity since ionizing radiation,¹² which is very energetic, has the capacity to pass through matter. Each organ has a sensitivity to radioactivity of its own and this depends on the nature of the radiation. Note: The Sievert (Sv) is the unit used to give an assessment of the impact of radiation on living tissue. It represents the quantity of ionizing energy (in joule) received per unit of mass (in kg). To summarize, our sensitivity to radiation is a very complex issue

¹² The ionizing radiation associated with radioactivity: alpha, beta and gamma, do not all have the same energy and are not all capable of penetrating matter in the same manner. The most penetrating radiation (and therefore that which causes the most damage to internal organs) is gamma rays.

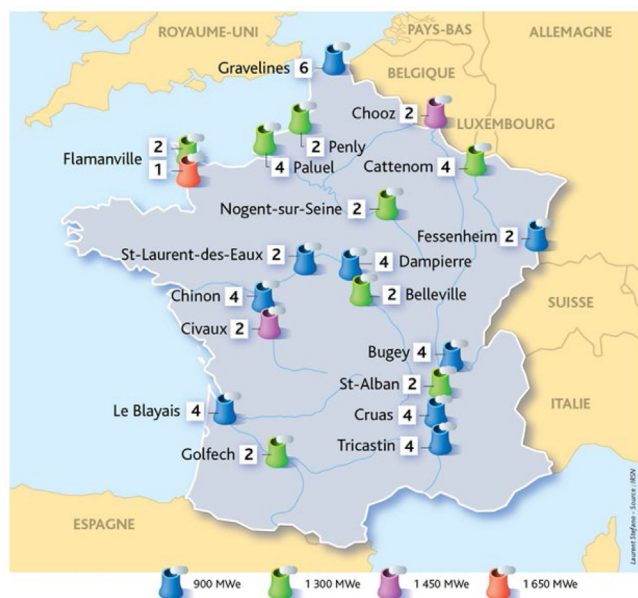


Fig. 3. The EDF reactor park map in operation in France in 2018 (Source: IRSN (IRSN FR, 2020a)). EPR Flamanville 1 650 MWe under construction. Numbers represent the number of reactors per power station.

that depends on the nature of the radiation, the integrated dose, the dose rate, the duration of exposure, the exposed organ and its age.

1.3. The influence of the disciplinary field of study for the students

We subsequently intended to know if the disciplinary field of the students could play a role in their knowledge and responses to certain questions. For example, whether they systematically associated radioactivity and cancer, or whether it actually depended on the dose received. At 45%, it was the students enrolled in the Faculty of Science who gave the correct response (depending on the dose), far ahead of other non-scientific courses. The effects of radioactivity are effectively dose-dependent (ASN FR, 2016b). A French person receives an average total annual amount of about 3.75 mSv corresponding to natural radioactivity (radon, terrestrial radiation, cosmic radiation), medical exposure and exposure to the artificial radionuclides (IRSN FR, 2015).

In another question, we wanted to know if the students were informed of the existence of natural radioactivity (due in particular to radon gas, Rn), which is less well known than radioactivity of artificial origin. Again, many more scientific students responded that radioactivity can be of artificial origin, but also of natural origin (45%).

The various sources of radioactivity exhibit a large variability all around the world. In France, average values have been estimated and may be summarized as follows (IRSN FR, 2020b; Anon, 2015).

The various sources of *natural radioactivity* (about 65% of total average exposition, 2.9 mSv/year in France) come from:

- Cosmic rays from galaxies and the Sun (7% about 0.32 mSv/year in France);
- Terrestrial radiation (14%, from 0.36 to 1.1 mSv/year) emitted by radioactive elements present in the Earth's crust, such as uranium and thorium or primordial radionuclides (mostly 40-K and 87-Rb);

- Cosmogenic radionuclides (such as 14-C for example, of the order of 0.01 mSv/year);
- Airborne radioactivity (32%) due to 222-Rn in gaseous form, itself derived from 238-U from the Earth's crust (1.4 mSv on average in France with large variabilities);
- Radioactivity of the human body and food, in the order of 120 Bq/kg (8400 Bq for a person of 70 kg), due to ingestion of food containing radioelements or inhalation of radioelements from the air (about 12%).

The sources of *artificial radioactivity* (about 35% of total average exposition, about 1.6 mSv/year) relate to:

- Medical field (medical examinations, radiotherapy, 34%, 1.6 mSv/year);
- Rays emitted by TV and computer screens, and smoke detectors (<0.03 mSv);
- Repercussions of the nuclear energy production (chronic accidents or emissions) and military tests (about 1%, 0.02 mSv/year).

In summary, in France, the average total exposure amounts to about **4.5 mSv/year**. The dose to natural radioactivity sources amounts to **2.9 mSv** per year per inhabitant, which corresponds to **65%** of the total exposure dose per year per inhabitant. The average exposure dose to sources of artificial radioactivity amounts to **1.6 mSv** per year per inhabitant, which corresponds to **35%** of the total exposure dose per year per inhabitant. Let us recall that the effects of the ionizing radiation do not depend on their natural or artificial origin, because the physico-chemical phenomena of interaction remain the same in both cases.

The scientific students were also distinguished from the other students by favoring a partial exit from nuclear power (50%, around 12% for the other education disciplines), and while more frequently evoking the possibility of changing opinion if they had more knowledge on the subject (43%). Independence between these two last questions (partial exit and change of opinion) was verified by a Chi-squared test. Given that the calculated *p*-value (0.985) is greater than the level of significance alpha (0.05), we cannot reject the null hypothesis, and there is therefore independence between these two questions.

We subsequently wanted to probe the students' knowledge of radioactivity more precisely, by asking them, for example, which chemical elements from a pre-established list they associated with radioactivity. It appears that uranium and plutonium were well known to be associated, but the other elements were much less so (Fig. 4). All the elements listed below have radioisotopes, i.e., radioactive isotopes.¹³

1.4. The third part of the questionnaire — the behavioral patterns of the two populations

In terms of behavior, the differences between the two populations were, as expected, large. Fewer than half of the students (44%) would take the appropriate measures (move to a confined space, block up vents), 55% would prepare for an evacuation and 84% would keep informed, not via social networks as we might have thought, but via a state body responsible for the management of the nuclear sector. Fig. 5 reports the main sources of information in case of a nuclear event and trust from both populations.

Remember the instructions to follow in order to protect yourself from radioactivity:

¹³ Isotopes are nuclides with the same number of protons, but in which the number of neutrons differs. For example, carbon has 3 isotopes: C-12 (with 6 neutrons), C-13 (with 7 neutrons), C-14 (with 8 neutrons). C-12 and C-13 are stable (non-radioactive) isotopes, whereas C-14 is a radioisotope (unstable and therefore radioactive).

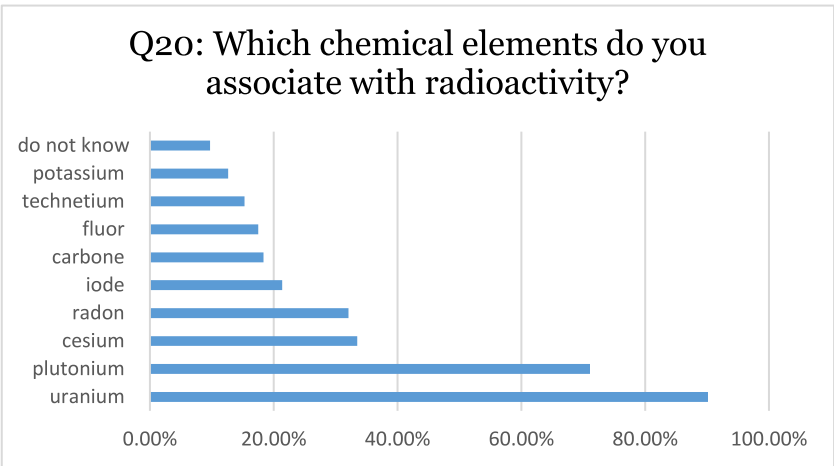


Fig. 4. The UCA science students' responses, in %, to the question "Which chemical elements do you associate with radioactivity?".

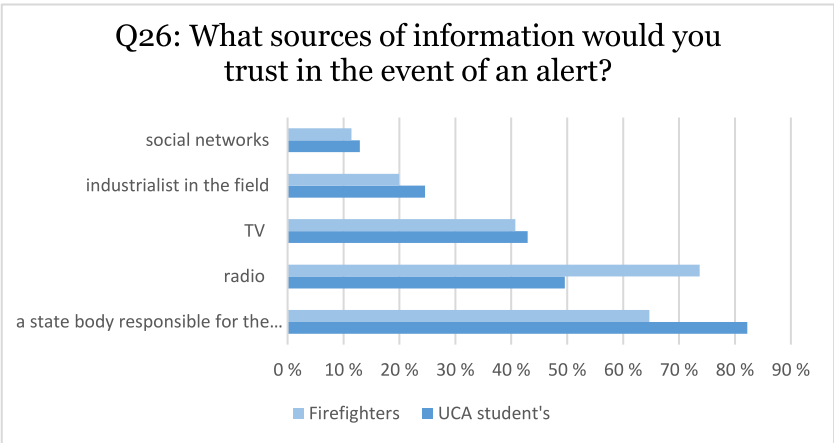


Fig. 5. The responses, in %, to the question "What sources of information would you trust in the event of an alert?".

- Take shelter in a structurally sound building, close doors and windows and stop the ventilation.
- If you are in a vehicle, return to a shelter (building, accommodation) as soon as possible.
- Do not touch objects, food, water.
- If it rains, leave everything outside that could have become wet (umbrella, shoes, coat, raincoat, etc.).
- Take iodine, for the resident population, or those working near a nuclear site (radius of 20 km), or upon instruction of the prefect.
- Keep informed.

"In the event of a nuclear alert, respect the public protection guidelines broadcast by the media (France Bleu, France Info, France Télévisions, etc.), the website and the accounts of your prefecture on social networks. Remember to have a battery-powered radio and spare batteries beforehand".

Source: <https://www.gouvernement.fr/risques/accident-nucleaire>

If an alert were to occur, students report that they would be anxious (42%), frightened (12%) or even panicked (25%), unlike the firefighters who would behave as expected, be more reasoned, much less panicked (difference of 21%), even if half of them specified that they would still be anxious.

1.5. Lexical analysis of the comments on the questionnaire

Respondents had a free field to respond to the question *Do you have any suggestions for this questionnaire?* This was the case for 10% of them (similar percentage in both populations). These comments have been extracted and integrated into the



Fig. 6a and 6b. The 100 most frequent words used in the comments: students left; firefighters right (words in French, translation in the text).

TagCrowd <https://tagcrowd.com/> lexical analysis tool, which highlights the 100 most frequently used words in these free comments.

This analysis is illustrated in Fig. 6a for students and 6b for firefighters. The questionnaire was well received by the students. They appreciated being consulted on this subject, found the questionnaire¹⁴ interesting, and encouraged us in this study of perception of nuclear risk. It made them aware of their limited knowledge in the field of radioactivity, they were eager to have the “correct” answers to the questions that we asked them, which they will receive at the same time as this article. The words most frequently used by firefighters were similar and related to the very purpose of the study: nuclear, questionnaire, question (s), answers. Sometimes, they were specific to their field of activity: risk management, population(s), they highlighted the lack of information and knowledge of citizens on these questions. The state of power plants and fears about the aging of the French nuclear plants were also mentioned.

2. Discussion

2.1. Comparison of the profiles of the two populations

Finally, we wanted to understand if, in terms of a few questions, the overall profile of the UCA students differed from that of firefighters. For this, we used a Principal Component Analysis (PCA). The selected five questions relate to the perception of the nuclear risk strictly speaking, the trust in French nuclear energy (Trust), favorability of an exit from nuclear power (Exit), considering artificial radioactivity being dangerous (dangerousness), the link between radioactivity and cancer (R & C), and the possibility of changing one's mind if the respondent had more knowledge in that area (Opinion).

Students: The two factorial axes F1 and F2 shown in Fig. 7 summarize 49.21% (28.17 + 21.04) of the information for these five questions for the UCA student population (left). The introduction of a 3rd factorial axis (right) did not increase this score (47.25%).

The Pearson correlation matrix, as well as the correlation between the variables and the factorial axes of Table 2, help us to find the significance of the latter two. Fig. 8a shows the projection of all UCA students who completely answered these 5 questions, on the 2 factorial axes F1 and F2. The horizontal axis F1 extends toward the perceived dangerousness of the artificial radioactivity (correlation of 0.720 of this variable with this axis, correlation of 0.537 between the variable R & C and the axis F1) and the trust in this type of energy (−0.630). The vertical axis F2

Table 2

Correlation Matrix (Pearson (n)), correlation between variables and factors for the five questions that relate to the students' nuclear risk perception:

Variables	Trust	Exit	dangerousness	R & C	Opinion
Trust	1	−0.125	−0.201	−0.106	0.049
Exit	−0.125	1	0.133	0.020	−0.026
dangerousness	−0.201	0.133	1	0.199	0.049
R & C	−0.106	0.020	0.199	1	0.023
Opinion	0.049	−0.026	0.049	0.023	1

Correlations between variables and factors:

	F1	F2	F3	F4	F5
Trust	−0.630	0.257	0.054	0.655	0.324
Exit	0.453	−0.410	0.631	0.442	−0.181
dangerousness	0.720	0.184	0.019	−0.018	0.669
R & C	0.537	0.382	−0.506	0.424	−0.360
Opinion	0.012	0.798	0.545	−0.183	−0.179

Values in bold are different from 0 to a level of significance $\alpha = 0.95$.

is marked by the variables Opinion (0.798) and Exit (−0.410), it expresses the changeover that can take place from the moment the person surveyed has sufficient knowledge, and if free from presuppositions, his or her opinion may evolve. Thus, only 22% of students have confidence in nuclear energy. But a positive change about their perception of the links between radioactivity and cancer could tip their opinion, and their desire to get out of nuclear power.

The majority of individuals appear to be distributed around the central quadrants (0 to −2 and 0 to +1 for the horizontal F1 axis and 0 to −2 and +2 for the vertical F2 axis). This is explained by the fact that for the F1 axis, 90% of the students considered artificial radioactivity to be dangerous, and 44% associated radioactivity and cancer, while for the F2 axis: 62% of the students were ready to change their opinion if new knowledge was brought to them (open-minded).

Firefighters : The Pearson correlation matrix, as well as the correlation between the variables and the factorial axes of Table 3. In the Principal Component Analysis for the firefighters, again, the first 2 factorial axes are sufficient to explain the variability of the information (Fig. 9).

But it is at the level of the projection of the variables that things seem to change (Fig. 8b). Indeed, it is the variables “dangerousness” and “Trust” that change quadrants compared to the PCA carried out on the student population. Recall that firefighters were more than twice as likely to trust nuclear power in France (50%) compared to students (22%), and that they were slightly less likely than students (82% compared to 90%) to think that artificial radioactivity is a danger. This results in a displacement of individuals toward the “north-west” quadrant a little wider

¹⁴ Underlined words are those that appear most in the word clouds in French.

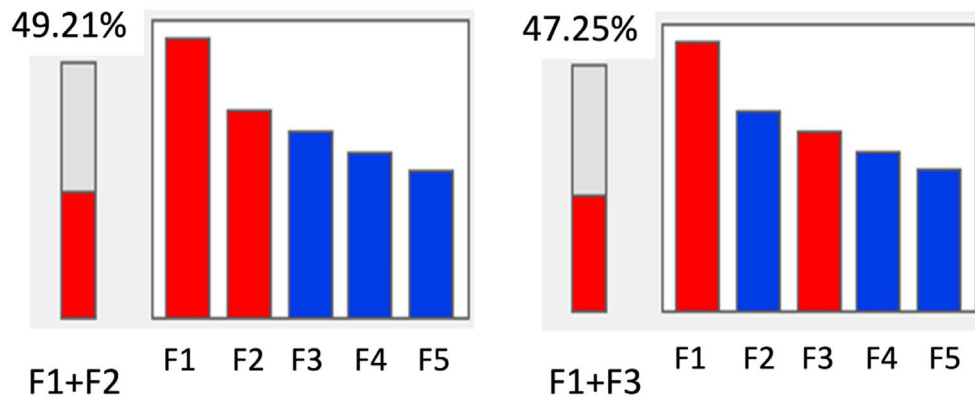
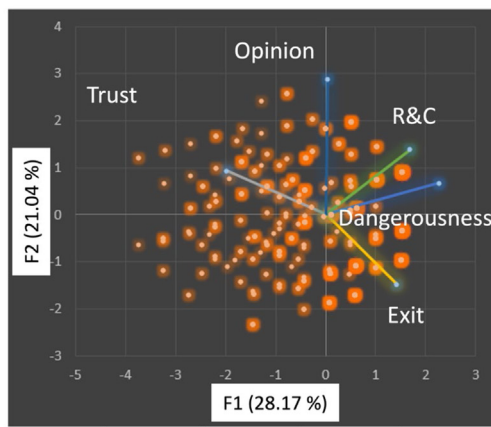


Fig. 7. Proportion of the information synthesized by the first 2 factorial axes (F1, F2) for students.

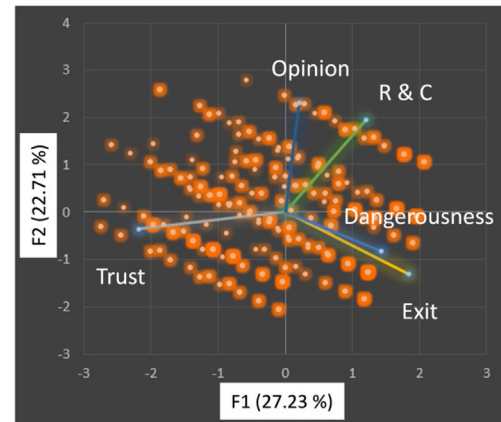


UCA student's

F1 horizontal axis: dangerousness and Trust (28.17%)

F2 vertical axis: Opinion (change) and Exit (21.04)

F1+F2 = 49.21% of the variability (answers) is explained by these 2 axes



Firefighters

F1 horizontal axis: Exit and Trust (27.23%)

F2 vertical axis: Opinion (change) (22.71)

F1+F2 = 49.94% of the variability (answers) is explained by these 2 axes

Fig. 8a and 8b. Projection of the individuals and the 5 variables on the F1 and F2 factorial axes: students left; firefighters right.

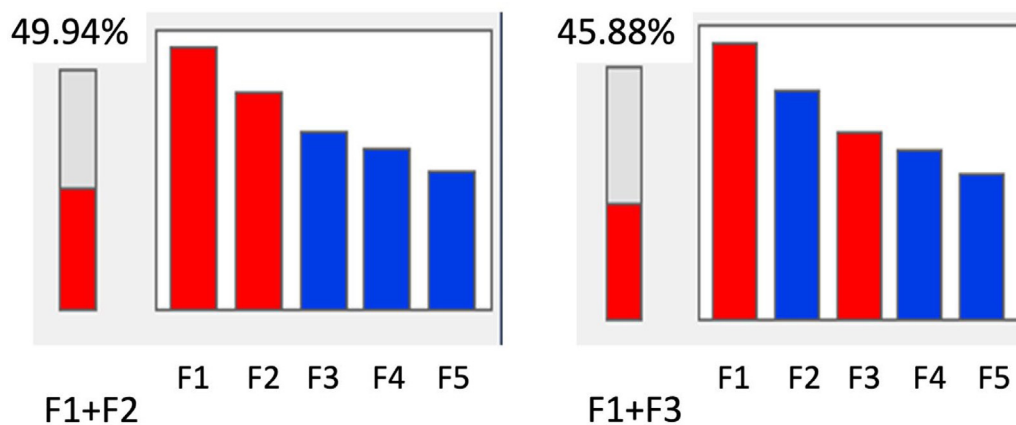


Fig. 9. Proportion of the information synthesized by the first 2 factorial axes (F1, F2) for firefighters.

compared to the projection of the students in Fig. 8a. "Exit" belongs to the horizontal axis F1 as we can see on the Table of the correlations between variables and factors line (correlated at

0.629), like "dangerousness" well represented with the F1 axis too (0.488), while F2 is defined by the "Opinion" variable (0.720) and R & C (0.608). It means the firefighters are less numerous than

Table 3

Correlation Matrix (Pearson (n)), correlation between variables and factors for the five questions that relate to the firefighters' nuclear risk perception:

Variables	Trust	Exit	dangerousness	R & C	Opinion
Trust	1	−0,219	−0,119	−0,170	−0,044
Exit	−0,219	1	0,132	0,014	−0,075
dangerousness	−0,119	0,132	1	0,012	−0,002
R & C	−0,170	0,014	0,012	1	0,101
Opinion	−0,044	−0,075	−0,002	0,101	1
	F1	F2	F3	F4	F5
Trust	−0,744	−0,111	0,189	0,168	0,609
Exit	0,629	−0,410	−0,155	−0,408	0,496
dangerousness	0,488	−0,258	0,712	0,434	0,012
R & C	0,411	0,608	−0,351	0,494	0,306
Opinion	0,071	0,720	0,493	−0,468	0,122

Values in bold are different from 0 to a level of significance $\alpha = 0.95$.

students to consider radioactivity is dangerous, that is why they are less in favor of a exit from the nuclear, but they would change their mind according their knowledge about the link between radioactivity and cancer.

3. Study limitations and conclusions

In view of the different analyses, we can say that the two populations (students, firefighters) have a rather different perception of nuclear risk, which is largely explained by the knowledge acquired by firefighters in this area through their training, and by the fact that they are mostly older than the students, they grew up with nuclear energy. In the same way, differences exist according to the field of study for the students (literary/scientific).

Perception surveys by population category shed additional light on studies conducted in the general population. They can lead to new information or even prevention messages that are targeted depending on the group. It would be particularly interesting to conduct a simultaneous comparison between different countries and populations. Of further interest is “understanding why some within the public support nuclear energy, and why others do not (Van der Pligt, 1992), [because it] is an important step toward navigating the divide between the experts and public” (Stoutenborough et al., 2013). Indeed, the “landscape of beliefs” about local nuclear power should not be viewed in simplistic bipolar terms (Venables et al., 2009). According to Stoutenborough “Risk perceptions differ from general attitudes like support or non endorsement because they require a better understanding of the issue than general attitudes” (Stoutenborough et al., 2013). In fact, “the complexities of nuclear power suggest that attitudes cannot be easily summarized in terms of partisanship and/or political ideology” (Stoutenborough et al., 2013).

Furthermore, “there are many facets to nuclear energy that must be considered” (Stoutenborough et al., 2013). Sapolsky (1968) argues that when there is a perception of uncertainty about the risks associated with an issue, the public is more likely to support policy actions that have the least direct impact on them, which in the case of nuclear energy would likely be any policy option that limits the use of nuclear power plants. The lack of information and more accurate knowledge on nuclear energy for the population in general, and nuclear risk in particular, has an influence on individual's perceptions, while we know that improved knowledge leads overall to a better acceptance of this form of energy. If the Knowledge Deficit Model (KDM) cited by Stoutenborough is correct, “we should expect to see that the public and experts will begin to coalesce around similar policy options as the public becomes better informed” (Stoutenborough et al., 2013).

The authorities have made information available to the French public particularly accessible and comprehensible (laradioactivite.com, www.irsn.fr, etc.) but in the absence of news related to nuclear energy (for example, an accident), it seems that there is a lack of interest in this form of energy from the French public, which could be a form of denial. This occurs now when we are more than ever at the center of an ecological transition with the use of more and more electric vehicles whose power supply raises fundamental questions of energy strategy.

Moreover, during the European elections of May 2019, the debate did not address these issues, and there was even a consensus between the different parties not to question (at least for now) nuclear energy, which has allowed France up until now to benefit from electricity that is cheaper than elsewhere in Europe (−22% in comparison to Germany). This occurred even while the socio-economic context was tense, and the price of petrol increasing too rapidly, by a few cents per liter, which contributed (among other factors) to the demonstrations in France over the winter of 2019. These questions highlight the particularly strong impact of a country's energy choices on its society (Stirling, 2014).

The main objective was to understand the differences of perception between an expert and non-expert population on the controversial nuclear issue, and on which aspects these differences could be the most important. But we cannot deny that the act of questioning people on the subject of nuclear power may be inherently biased due to the very nature of the subject and that fears surround it are often stigmatized. We are aware of this and as the study continues, we will call upon psycho-sociologists to help us understand this induced bias.

The objective was also to assess the knowledge of the students, and especially about the measures to be taken in the event of a nuclear accident. Students who do not live near a nuclear power plant were chosen because it is not certain where they will live throughout their lifetime and that it may be assumed that people living within a 20km perimeter of a nuclear power plant are aware of emergency procedures. Indeed, it could also be interesting to study how the perception of nuclear risk evolves according to a gradient of distance from a power plant “The significance of spatial proximity and “sense of place” are also important mediating factors in perceptions of local hazardous facilities” (Venables et al., 2009).

Likewise, the questions on perception implicitly dealt with the feeling of safety and of confidence of the interviewees toward nuclear power, whereas in part 2 the focus was put on their knowledge and the risk associated with an exposure. However, these two terms (safety, risk) deserve to be used wisely. It would have been more relevant to use a scale for these two concepts, because there is unfortunately no absolute safety, just as the multidimensionality of the risk gives it an uncertain dimension (Hansson, 2012, 2009).

At the current time, new nuclear power plants operate in countries where this energy was not previously available and where the study could be transposed (China (Shanyong et al., 2019), United Arab Emirates, Saudi Arabia). Indeed, in these countries, the culture of risk remains to be built, and this requires an assessment of the population's knowledge on the topic.

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CRedit authorship contribution statement

Sandra Perez: Conceptualization, Methodology, Writing - original draft. **Christophe Den Auwer:** Supervision, Project Administration, Funding acquisition. **Thierry Pourcher:** Validation. **Sandra Russo:** Investigation, Writing - original draft. **Cyril Drouot:** Formal analysis. **Maria Rosa Beccia:** Investigation, Writing - original draft. **Gaelle Creff:** Investigation. **Franck Fiorelli:** Resources. **Audrey Leriche:** Resources. **Frédéric Castagnola:** Resources. **Pascale Steichen:** Resources. **Georges Carle:** Funding acquisition. **Hervé Michel:** Investigation. **Nicolas Glaichenhaus:** Funding acquisition. **Denis Josse:** Resources. **Nicolas Pottier:** Investigation, Software. **Damienne Provitalo:** Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at <https://doi.org/10.1016/j.egyr.2020.08.015>.

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