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Research Article

Diverse Risk Perceptions of Low Dose Radiation of People Living Near Nuclear Power Stations in Ontario, Canada

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Abstract. Through survey and focus group this research explored the perceptions of residents in Ontario, Canada surrounding risk, trust, knowledge and benefits of radiation. Results were analyzed in relation to those living in proximity to Nuclear Power Stations (NPS) and those who did not, and those who worked with radiation, and those who did not. People living in proximity to NPS in Ontario are not ambivalent to its benefits; radiation workers in this area have statistically significant positive emotions to radiation and trust in the nuclear regulator; and there is not a significant minority living near a NPS that are distrustful of the nuclear industry. While radiation workers living proximate to NPSs have higher perceptions of being at risk for cancer and radon risk than people not living in this proximity, the public living in this zone has less perception of these risks. Two focus groups conducted in communities with NPS also corroborated some risk concerns regarding cancer and radon, but a lack of concern for Low Dose Radiation (LDR). This research has important policy implications surrounding interest and understanding of people in relation to radiation and further research and work to address misperceptions.

Keywords: Nuclear power, Energy Technology, Nuclear Power Stations, Risk Perceptions

Introduction

How people think about risk and benefits of climate change and clean energy technology is important in relation to the acceptance of clean energy technology including nuclear power and SMRs [1,2]. The greater one's perceptions of the benefits of nuclear energy, the more accepting a person is of its use [3].

There is a substantive body of literature relating to risk perceptions and nuclear energy and radiation. Many studies have documented people's risk perceptions concerning nuclear power generation post Fukushima or Chernobyl [4,5], experts versus non-experts perceptions of radiation and nuclear power generation risk [6], perceptions of nuclear energy risk in relation to risk surrounding climate change [7-9], and specifically the perceptions of those living near Nuclear Power Stations (NPS) [10-12]. However fewer studies have compared risk perceptions of people living next to power generating stations with those who do not, specifically including those who have experience working in a job with radioactivity and those who do not have that experience. This research aims to fill in such a gap by answering the following question: What are the risk and benefit perceptions, emotions, and levels of trust among people living near nu-

clear power stations and how do they differ from those who do not, and with people who work or have worked with radiation (and arguably have some familiarity with radiation)?

After reviewing the literature on risk perceptions and radiation, the method will be described, followed by an analysis of results and a discussion.

Nuclear Science Knowledge and Risk Perception Literature

In the past, the communication of science was based on an assumption that by developing a better understanding of science, societal support for issues in science and technology would improve, a model known as the knowledge deficit model of science communication [13]. This model made intuitive sense, given studies document that people with more knowledge in respect of an issue have reduced perceptions of associated risks [2,14]. However, in the context of science communications, empirical research has largely discounted this model, studies document that simply providing information from technical experts to people does not make people more accepting of science and less concerned about risks [15].

However, the deficit model persists [16,17]. Various reasons have been identified including scientific communicators preoccupation with the belief in rationality, their lack of formal training in public communication, a view by most scientists that the public is a variety of 'others,' and its simplistic allure [13]. In order to move beyond thinking of the public as information deficient, what is needed is training in positive communication methods grounded in social science research to develop in depth scholarship about how people process information and form opinions. However, an important precondition is also engaging community members around scientific issues they are inherently interested in (Simis, Madden, Cacciatore and Yeo) [13] and engaging in methods of information sharing, listening, learning and building relationships [18]. These practices underscore alternate models including the lay expertise model (wherein knowledge is based on lives and histories of a community) [15] or the contextual model (wherein the context, personal psychological issues, and personality affect the way information is received) [15]. Each will be discussed in turn.

Social science research documents that in relation to scientific issues, emotion, affect and political understanding and knowledge is important in learning [14]. Emotion or affect is a defining characteristic determining how people think about scientific issues including climate change, LDR, and nuclear energy, rational decision making is informed by dual modes of thinking that are a complex interplay of emotion and reason [19]. Fast decision making, including responding to survey questions, is greatly influenced by affect or emotion [19].

The lay expertise model includes issues of belonging to a community, which has aspects of both geography and expertise [20]. Nuclear experts perceive risks to LDR and nuclear power generation very differently than the general public, assigning higher levels of risk to medical X-rays and natural radiation than the general population, but lower levels of risk to nuclear waste or an accident at a nuclear installation [6,7,21,22]. Nuclear experts accept the risk and uncertainty of nuclear science and are generally more positive in respect of radiation, but for the general public radiation gives rise to or means anxiety [23]. People with more negatives attitudes to nuclear power have higher perceptions of risk and less trust in the nuclear industry, government and governance institutions [24]. Risk perceptions generally require a better understanding of an issue than simply measuring general attitudes of support or endorsement [25].

Nuclear experts have more calculated perceptions of risk, especially in relation to nuclear science [26], and as a consequence, nuclear experts believe that public perceptions of risk in relation to nuclear power plants are irrational [27]. Social science documents how uncertainty, fear or dread, and distant long term risks impact people's perceptions of risk [28]. Experts simply providing information to people and filling an 'information deficit' has resoundingly been

disproven as a successful mechanism of addressing affect or emotional responses to science issues [19,26,29].

Trust is a mediating factor between scientific knowledge and risk perceptions. Those who have an increased level of trust in the nuclear industry, government and governance institutions have lower perceptions of risk to nuclear power and more positive attitudes with increased benefit perceptions and decreased risk perception [30,31]. Sjoberg and Drottz-Sjoberg found that the greater nuclear power plant employee's knowledge is of radiation, the lower their expressed risks [32]. Low knowledge about a specific risk (so people with less knowledge and understanding of nuclear power) positions 'trust' as more salient in people's perceptions about the severity or risk, especially in relation to technologies combined with other psychological and contextual variables [10]. Oltra, et al., founded the trust which is varied by community living in 100 km proximity to nuclear facilities, positive attitudes towards nuclear energy were the strongest with correlates of trust.

There is much research that documents that people living in proximity of nuclear facilities are less likely to express negative attitudes and concerns about nuclear energy [33-37]. and one study in North America confirmed greater support for nuclear power [38]. Cale and Kromer found that people living in proximity to nuclear power stations have been found to have increased levels of awareness about nuclear power overall, but their general attitudes toward the use and perceived safety of nuclear energy were not impacted [39]. Two studies concluded the level of support for a nuclear power plant in communities close to these plants was generally ambivalent, but there is a significant minority of people who expressed strong mistrust of both the industry and the government [10,40]. A study of people living near to nuclear power plants in Taiwan, conducted one year after the Fukushima disaster in Japan, found 77.6% of respondents perceived a higher relative risk of cancer incidence for those who live within 30 km from a NPP than those who live outside 30 km [11].

In sum, risk and attitudes toward technologies vary, one's perceptions of risk or 'non endorsement' of a technology, regardless of their location, can be very different than what is expressed in general attitudes about a technology and require better understanding [25]. In contrast to studies of 'support' for nuclear energy and plants in the preceding paragraph, people living in proximity to nuclear power stations have been found to have heightened concerns surrounding nuclear radiation risk [11,12] (both studies occurring after Fukushima).

Methodology

This study used two main sources: A telephone survey (88 questions clustered into ten sections) with a total of 1,008 participants from Ontario, conducted between January 2020 and July 2020 and 2 focus groups (6 people) with general population and radiation workers in the communities of Darlington and Chalk River which are close to NPS. Survey respondents reflected the population in respect of gender and geography. In terms of age, most of the respondents belonged to the group of 65 to 75 years old, followed by the group of 55 to 64 years old, while younger respondents were less represented. Respondents were asked if they have experience with radioactivity. Specifically, "Do you have personal experience working in a job that involves the use of radioactivity (e.g., in a nuclear power plant, in industry or in a hospital using radioactive sources, or from exposure to natural radioactivity in ores and other materials)?" Workers with such experiences are referred to as 'Radiation workers'. Approximately 18% answered in the affirmative in Ontario. The characteristics of the survey and focus group participants are included in the Supplementary Materials.

Our assumption for this study was that residents living close to a Nuclear Power Station (NPS) may have different perceptions about Low Dose Radiation (LDR) and nuclear technology. Our

hypotheses (based on the findings of the literature in section 2) were: 1)Radiation workers, and people living in proximity to a NPS are ambivalent to the benefits of radiation and have heightened perceptions of risk, and 2) Greater knowledge of nuclear science increases positive emotional reactions and trust and reduces risk perceptions. To test our hypotheses, we selected residents living within five different radii: 10 km, 20 km, 30 km, 40 km, and 50 kilometers away of any of the three nuclear power stations in Ontario.The total number of respondents are presented in Supplementary Materials.

The three nuclear stations from Ontario Power Generation (OPG) are:

• Bruce Power

• Darlington Nuclear Generating Station

• Pickering Nuclear Generating Station

The province of Saskatchewan does not have any nuclear power stations. It has, however, mines and mills of uranium U_3O_8 [41,42].

While the survey was a representative sample size, limitations of the study include the predominance of the older age group respondent. Further, the number of focus groups participants was not statistically significant (which is a general shortcoming of qualitative research).

Results

Studying the risk perceptions of people specifically living near a NPS, and contrasting them with the risk perceptions of those who live throughout the entire province, together with further perceptions of respondents who have a higher level of knowledge (as they are radiation workers), offers interesting insights. These insights relate to affect or emotion and the word radiation, the benefits verses the risks of radiation, trust, risk perceptions, and nuclear knowledge.

Benefits of Radiation and Positive Perceptions

When asked if the benefits of radiation outweighed the risks, those living in the NPS areas had the greatest divide between those that were strongly in agreement and those that were in disagreement. Overall, more people were in agreement or strongly in agreement that the benefits of radiation outweighed risks. More radiation workers living in proximity to a NPS 'strongly agreed' that the benefits of radiation outweighed the risks than those radiation workers living throughout Ontario. However, there were also a few more radiation workers living in proximity to a NPS who 'disagreed' than radiation workers living throughout the province. Overall more people were in agreement or strongly in agreement that the benefits of radiation outweighed risks. A significant number (Radiation workers (11%) and Public (24%)) were undecided as depicted in Figure 1.

When asked what their first reaction was when they heard the word 'radiation,' respondents who had experience working with radiation had a higher rate of positive reactions and a lower rate of negative reactions than non-radiation workers. Proximity to a NPS revealed other trends, including that a range of 19-25% of radiation workers living in proximity to a NPS chose 'mainly positive' compared to 10% of radiation workers living throughout the province. A reverse trend occurred among non-radiation workers (the 'public') in the category of 'mainly negative' where a higher number of those living in proximity to a NPS chose this answer compared to the public living throughout Ontario. However, more non-radiation workers living both in proximity to a NPS and throughout the province chose either 'a mix of positive or negative' or 'neutral' as their answer to this question see in Figure 2.

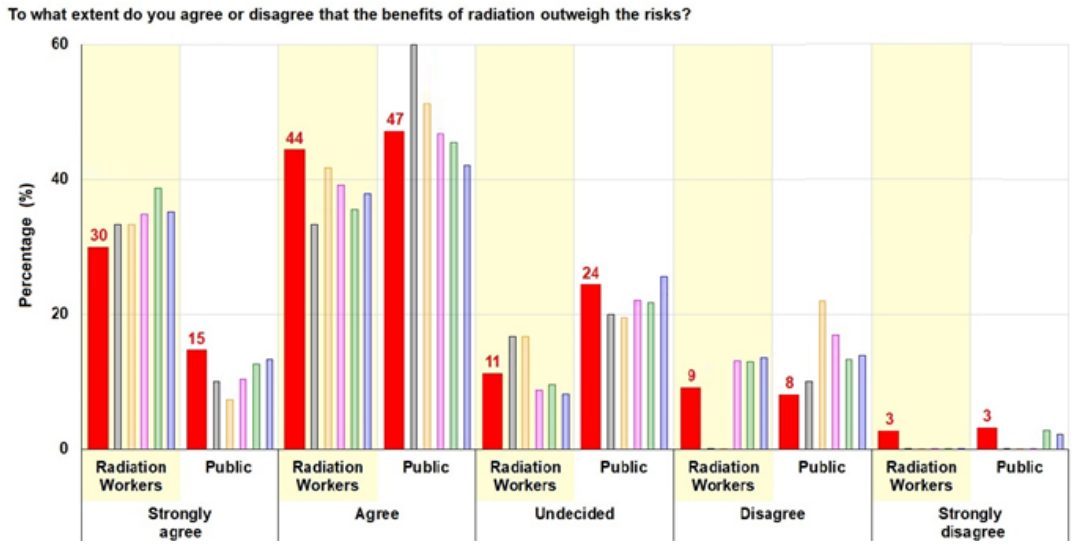

Figure 1: Percentage of respondents' perception on benefits of radiation. **Note:** (■) Ontario, (■) NPS =20 Km, (■) NPS=40 Km, (■) NPS=10 Km, (■) NPS=30 Km, (■) NPS=50 Km.

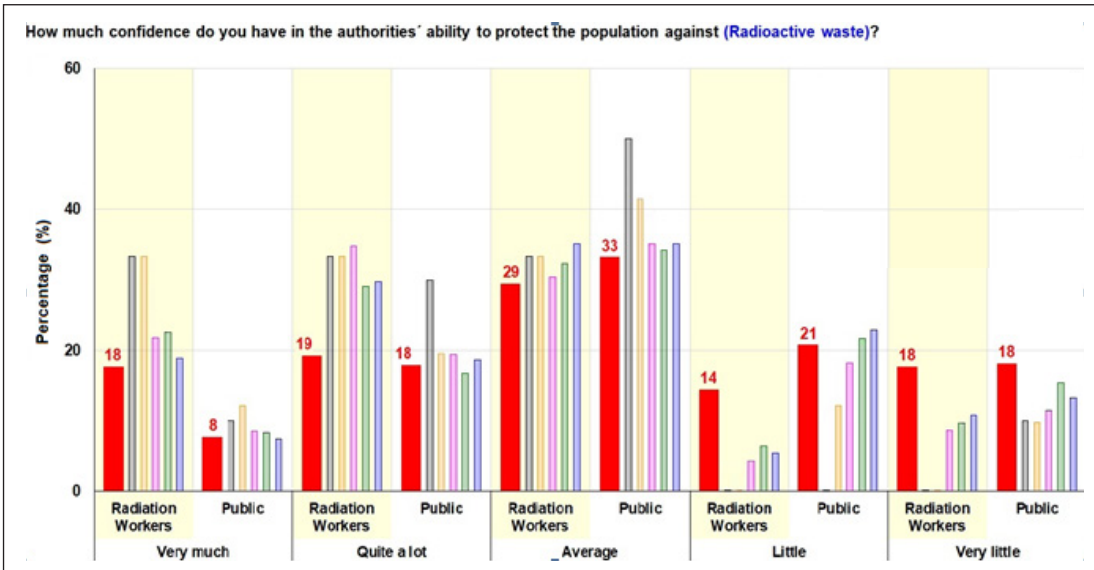

Figure 2: Percentage of respondents' perception on confidence in the authorities' abilities to protect population against radioactive waste. **Note:** (■) Ontario, (■) NPS=10 Km, (■) NPS=20 Km, (■) NPS=30 Km, (■) NPS=40 Km, (■) NPS=50 Km.

Focus group participants confirmed that overall; perceptions were that the benefits of radiation outweighed the negatives and risks. In Darlington, the focus group identified the benefits of radiation in cancer treatments, its use in inspecting bridges, buildings for structural safety and electricity generation. The majority of Darlington respondents identified the medical benefits of LDR, one described it, "Well it can tell if I have a broken bone or not… decay in my teeth etc." Respondents also identified uses including In Chalk River, sterilizing medical equipment, Cobalt 60 treatments, and irradiation of produce were also identified. One respondent stated, "Currently the benefits outweigh the risks. I would eat strawberries irradiated to prevent them going bad after a week, extend it to three weeks, for example".

Trust

People living near a NPS had the greatest support and confidence in Canada's regulator, the

Canadian Nuclear Safety Commission. In respect of respondents' confidence in the authorities' ability to protect the populations against radioactive waste, radiation workers living in proximity of a NPS consistently expressed stronger confidence than radiation workers throughout the province. Thirty three percent (33%) of radiation workers living within 20 km of a NPS chose 'Very much' compared to 18% of radiation workers living in the whole province. The option 'Quite a lot" was chosen by 19% of radiation workers throughout the province compared to 30% and above for those living in the proximity of a NPS. Even the categories of 'little' and 'very little' were chosen by less radiation workers living in proximity to a NPS than by those throughout the province.

When respondents were asked about their confidence in the authorities to protect against a nuclear accident at a nuclear installation, the distribution of answers was slightly different than when asked about radioactive waste. Although radiation workers within the NPS zones once again expressed more confidence in the authorities than radiation workers living throughout the province, slightly more respondents living near a NPS who are not radiation workers (the public) chose 'little' or 'very little' than in the previous question, indicating lower levels of confidence in the authorities regarding protection from an accident than from waste, even though this number was still lower than the public throughout the province who chose 'little' or 'very little' confidence for this question.

Focus group results confirmed that participants had high levels of trust in the Canadian regulator and believed proper rules and regulations were in place to protect citizens from high levels of radiation. They referred to checks and balances, sensors on and around the NPS, obligations in the nuclear license, emergency measures and regular practice drills.

Radiation Knowledge of People Living Near NPS

After reviewing our data, two particularly interesting characteristics of people living near NPS related to the level of knowledge about radiation and the perceived involvement of the nuclear industry in the community. When asked if there were two types of radiation (ionizing and non-ionizing) for which the answer is 'true', the greatest difference in answering correctly was between radiation workers and the general public. While approximately 65% of radiation workers answered correctly, 51% of the general public also did a difference of 14%. Also, the percentage of respondents answering 'don't know' almost doubled when comparing radiation workers with general public (14% versus 27%). Radiation workers answered this question correctly only approximately 4% more often if they lived within proximity of a NPS.

In the focus groups, there was good knowledge surrounding nuclear science and LDR, but this question wasn't generally answered any differently than our survey results. Only one participant in the Chalk River group identified as working with radiation and knew the specifics relating to this question. In the Darlington focus group, when asked 'What unit is used to measure amounts of radiation?" people were uncertain (one guessed a Geiger counter). Respondents expressed a diverse range of where or when people might be exposed to LDR (including a nuclear plant, dentist offices, X-rays, the sun, or that this might occur where raw materials containing radiation are mined). Participants believed high doses might occur with nuclear weapons, industry, mining, if a nuclear power plant exploded, during an X-ray, or cancer treatment. The Chalk River radiation worker participant said they had read in peer review literature that LDR could possibly be beneficial.

In the Darlington focus group, only one person mentioned a measurement of radiation (a Geiger counter) and only one knew what ionizing radiation was. However, the participants in this focus group were generally knowledgeable about LDR in relation to medical uses and nuclear power plants, and differences between LDR and higher doses. One participant in particular referred to nuclear power generation radiation information obtained from friends working in the NPS. In Chalk River one person was well acquainted with radiation knowing the measure-

ments was rads, Rems or Sieverts and the definition of ionizing radiation. In Chalk River when asked, 'how often do you hear about LDR' one participant responded, "every month we have emergency sirens go off and it puts into place where you live and the possibility of disasters." This participant also mentioned receiving iodine pills in case of emergency exposure and not absorbing Iodine-131. Another Chalk River participant mentioned they lived north of the site and warnings were received about twice per year and reported receiving coloring books for kids with information about four times per year. When asked what the most important things that needed to be communicated to the public these focus group participants confirmed how safe NPS were and that LDR was not something to worry about.

People living near a NPS believed that the nuclear industry was active in their community. Survey data showed that 100% of radiation workers living within a ten km radius of a NPS believed the nuclear industry was active in the community in which they lived. Within the 20 km and 30 km zones this percentage dropped to 82%, and further dropped to 68% among radiation workers living within a 40 and 50 km radius. This contrasts with 42% of Ontario radiation workers living throughout the entire province. Similar findings were made in relation to the public living in proximity to a NPS at 90%, 80%, 61%, 44%, and 41% (from 10 to 50 Km zones) compared to 26% of the public living throughout the province.

Risk Perceptions

The responses of people living in the NPS zones provide some interesting insights that offer background into risk perceptions surrounding radiation. First there is the highest ranking of risk for chest X-rays among radiation workers. Conversely, non-radiation workers have the least fear of chest X-rays, radon, and cancer.

Chest X-Rays

In respect of chest X-rays, generally the distribution of answers given by radiation workers and the public was similar as depicted in Figure 3. The option with the highest number of selections was 'moderately dangerous' with 27% of non-radiation workers and 28% of radiation workers choosing this as their answer. An equal 8% of radiation workers and 8% of non-radiation workers ranked X-rays as 'dangerous.' Radiation workers living in proximity to a NPS chose 'slightly dangerous' more than those throughout the province (especially in the 20 km NPS radius where almost 60% of this group chose 'slightly dangerous' as their answer), whereas the public living in proximity to a NPS chose 'moderately dangerous' more than the public living throughout the province. However, generally the distribution of answer tended to the not dangerous to slightly dangerous.

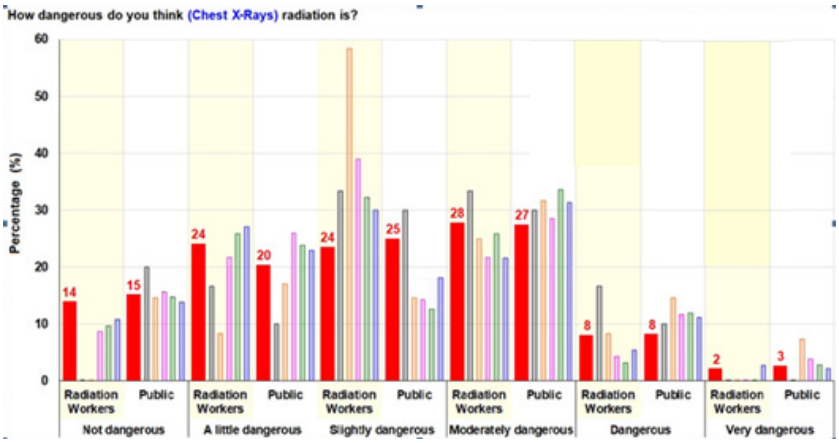

Figure 3: Percentage of respondents' perception about radiation from chest X-rays. **Note:** (■) Ontario, (■) NPS=20 Km, (■) NPS=40 Km, (■) NPS=10 Km, (■) NPS=30 Km, (■) NPS=50 Km.

Radon

In relation to LDR from natural sources, specifically radon, the rankings of 'dangerous' and 'very dangerous' were chosen by radiation workers to a greater extent than non-radiation workers (25% and 15% versus 23% and 14%). In the extreme category of 'very dangerous' the effect of proximity was especially noticeable among radiation workers where the percentage of responses increases with proximity to a NPS, while the opposite happened with the general public living in proximity to a NPS (Figure 4). It is interesting to highlight that the percentage of respondents who chose the option 'don't know' was the highest for radon (17%) followed by an average 8% for both cosmic rays and air travel.

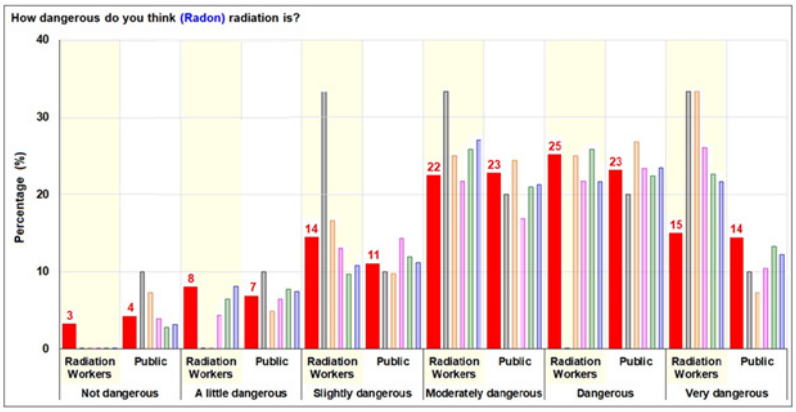

Figure 4: Percentage of respondents' perception about radiation from radon. **Note:** (■) Ontario, (■) NPS=20 Km, (■) NPS=40 Km, (■) NPS=10 Km, (■) NPS=30 Km, (■) NPS=50 Km.

In the Chalk River focus group there was no discussion of radon. However, in the Darlington focus group one participant stated that they aired their basement because of the potential damage radon gases could do. This participant did so because of news reports on the dangers of radon.

Radiation Induced Cancer

When asked to rate the level of risk of cancer for a person living in Ontario, the high and very high percentages for radiation workers and the general public were similar for those living throughout the province as depicted in Figure 5. More radiation workers living near a NPS ranked the risk of cancer as 'high' or 'average' than radiation workers and the public living in the province as a whole. Of the public living in proximity to a NPS, more ranked the risk of cancer as 'low' and less ranked the risk as 'high' than the public living throughout Ontario Figure 5.

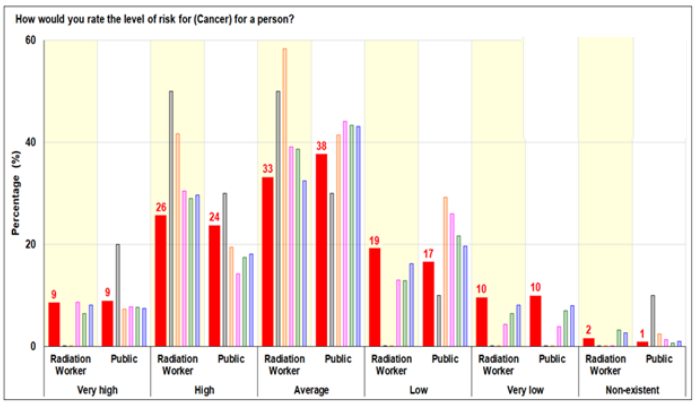

Figure 5: Percentage of respondents' perception on the level of risk for cancer for a person. **Note:** (■) Ontario, (■) NPS=20 Km, (■) NPS=40 Km, (■) NPS=10 Km, (■) NPS=30 Km, (■) NPS=50 Km.

Focus group participants' discussions reflected survey results with many speaking to risks of cancer, a couple participants speaking of the risk of radon, and generally an acceptance of exposure during chest and dental X-rays. In the Darlington focus group there was consensus that LDR were doses that were not harmful and a fact of life that couldn't be escaped, but when discussing risk, the group was not ambivalent to radiation. One stated, "I think any dose of radiation is scary". "If I need to get a few X-rays and take a few flights, I'm not going to worry about it. You could drive yourself crazy!" Another stated, LDR was "risky but unavoidable." In Darlington participants identified LDR from natural sources (areas rich in Uranium), nuclear power plants, X-rays, aircraft travel, bone mass scans at hospitals, and the sun. Chalk River discussions were similar; these participants also identified higher doses from nuclear medicine (like Barium for heart function), chemotherapy, or working in a power plant, nuclear lab.

Focus group participants were generally appreciative of the discussion and thought providing information about LDR was important. They found the dialogue informative and most stated they learned a few things. There was no stated increase in concern from participants and most stated more information about LDR should be provided to people. In closing the session focus group participants concluded with words of 'still nothing,' 'not much' bothered them about LDR and one stated, "I don't let it worry me too much."

Discussion

This is the first study to our knowledge surveying radiation workers (experts) and the public both in proximity to a NPS, and outside a 50 km range of a NPS. Findings that there is a positive reaction to the word radiation for radiation workers is consistent with literature [6,23]. It is not surprising that radiation workers who live in proximity to a NPS may be employed at the NPS have different perceptions due to factors including receiving a wage and economic benefits [43]. However, the positivity of people living within 50 Kms of the NPS differs from literature finding people living near a NPS to be ambivalent in relation to benefits [10,44]. This study found people to be relatively positive while living near a NPS, and a majority considered the benefits of radiation to outweigh the risks.

Study results show that knowledge of people living in proximity of a NPS was higher, and trust in the regulatory authorities was also higher. In fact, the statistical data did not show a 'significant' minority living near a NPS to be distrustful, as did Oltra et al. and Pidgeon et al. [10,40]. People living in proximity to a NPS were less likely to rank their trust in the regulator as 'very little' or 'little.'

While literature links increased knowledge and increased trust with reduced perceptions of risk [30,31], increased knowledge and trust exist for those living in proximity to a NPS, but generally with higher perceptions of risk for radiation workers (in relation to chest X-rays, radon, and cancer). While findings that people living in proximity to NPS have heightened perceptions of risk have been documented since Fukushima [11,12], this study offers new insights into different perceptions between radiation workers and the public living in proximity to NPS.

Radiation workers living in proximity to a NPS were more likely to rank the risk of cancer as 'high' or average than radiation workers and the public living throughout the province. Among the public (non-radiation workers) living in proximity to a NPS, there was less concern for cancer than the general public and radiation workers living throughout the province. Although radiation workers demonstrated heightened awareness of cancer risk, similar to heightened awareness of risk found in other studies [11,12], this heightened risk wasn't found in the general population in respect of cancer, or in respect of radon.

In respect of radon, more radiation workers living in proximity to a NPS chose 'very dangerous' (albeit the same number of people living within a 10 km of a NPS chose 'slightly dangerous'

as those that chose 'very dangerous'). However, showing ambivalence again, the public living within proximity to a NPS was less likely to choose very dangerous as the public throughout Ontario. Levels of concern surrounding radon for radiation workers living near NPS are surprising, given the NPS sites in Ontario are located in Canadian areas with relatively low home radon measurements [45,46]. This research raises questions about why it is radiation workers and not the general public that has concerns surrounding cancer and radiation from radon when living in proximity to a NPS. Areas for future research, or questions arising from our findings include: Are other factors (age, gender, education, and income) potentially also significant determinants? Or given the increased perception of the nuclear industry being active in the community, is there information being shared with those living in proximity of the NPS that is the cause of this? But why the difference between radiation workers and the general public?

Perhaps because Chest X-rays are voluntary exposures to LDR, perhaps because of increased positive emotional response to the word radiation, and increased knowledge for those living in proximity to NPS, there weren't significant differences in our findings surrounding Chest X-ray risk. The distribution of risk perception in respect of Chest X-rays were similar amongst radiations workers and the public and all were on the lower end of the 'dangerous' ranking. There were only a few more of the radiation workers living in proximity to a NPS who chose 'slightly dangerous' than radiation workers in general (Supplementary Table 1).

Conclusion

One thousand and eight individuals responded to 88 questions clustered into ten sections about LDR, nuclear health technology and nuclear energy technology in Ontario, Canada. Five groups were created based on their living in proximity to a NPS in radii of 10 km, 20 km, 30 km, 40 km, and 50 km and analyzed based on risk perceptions, emotional response to radiation, knowledge of LDR, work with radioactivity, trust and benefits of LDR. These results were compared and contrasted based on those living throughout the entire province, and people who had experience working with radiation and those who did not.

In contrast to previous studies, people living near Nuclear Power Stations (NPS) in Ontario, Canada and especially those who have worked or are working with radioactivity, have greater knowledge about radioactivity, more positive reaction to the word radiation, and greater trust in the Canadian regulator to protect against nuclear accident. Radiation workers could be important communicators and ambassadors for NPS. However, people working with radiation in this area had heightened cancer and radon risk perceptions while the public had depressed perceptions of cancer and radon risk. Ensuring access to information from credible scientific sources is warranted to resolve any misperceptions.

These findings confirm those of Venables et al. that determined people living in proximity to NPS do not hold simplistic bipolar ideas of good, bad, risk and benefits. And while Wynne et al. concluded people living in proximity of NPS are more realistic about risk than the nuclear industry and regulatory authorities realize, we discovered there are discrepancies between those working with radiation and the public that warrant further research.

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