Potential Environmental Impact of the Fukushima Daiichi Nuclear Plant Accident: 4 Years Later

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Abstract

***Background and Purpose*:** The 2011 Fukushima Daiichi nuclear reactor incident in Japan resulted in the release of large quantities of radioactive material into the Pacific Ocean through deposition from the atmosphere and liquid discharges from the nuclear facility. Public misconceptions and the scarcity of radiation monitoring along the west coast of Canada have create doubt within the population regarding the safety of the ocean. A radiation survey along some of Vancouver's beaches was completed to determine whether radioactivity from Fukushima has reached our local shores.
Methods: Radiation surveys were conducted at three different locations; Sunset, Spanish Banks and Jericho Beach in Vancouver, British Columbia. Gamma radiation levels were measured using both the Radeye, GR 135 Plus EXPLORANIUM survey meters. At each beach, 30 samples of water, sand and various different artifacts including algae, stones and logs were each surveying. If the radiation detected exceed 0.05µSv/Hr the identification function of the GR 135 Plus EXPLORANIUM would be used to determine if it was from natural or artificial sources. The radiation levels were compared to the expected normal background levels (between 0.05µSv/Hr- 1.0 µSv/Hr) as well as to observed if there was any sufficient differences between the mediums under investigation.
Results: The radiation levels along all three beaches did not exceed normal background levels (between 0.05µSv/Hr- 1.0 µSv/Hr). Furthermore, characteristic radionuclides released from this incident, specifically Cesium 134 and Cesium 134, were not detected. There was no sufficient difference between the radiation levels observed from the sand, water and different artifacts (logs, stones, and algae)
***Conclusion*:** It was concluded that the radiation levels along the beaches, Jericho, Spanish Banks and Sunset Beach do not present an additional risk to the public visiting this area as a result of this incident.

Keywords: Fukushima Daiichi, Cesium 134, Cesium 137, gamma, radiation, Vancouver beaches

Introduction

The damage sustained by the Fukushima Daiichi nuclear power plant as a result of the March 11, 2011 tsunami that impacted the east coast of Japan caused an unprecedented release of radioactive material into the Pacific Ocean. Initially there was concern that the ocean currents may carry this material to the west Coast of North America. Present surveillance techniques indicate that only traces of radioactivity were detected, posing no threat to human health (WHOi, 2013). Following the Fukushima nuclear incident, Health Canada increased the frequency of its fixed air monitoring stations across the country. A small increase in radiation levels was detected in the air nationwide during the first few weeks following the incident but has since returned to normal background levels (Health Canada, 2014). Despite Health Canada's efforts to assure that ocean radiation levels are insignificant, many remain skeptical. Theories and speculations not supported by the scientific community are causing anxieties about the radioactivity of the Pacific Ocean. More specifically, there are public concerns about the safety of Canada's Pacific beaches and recreational waters as a result of radioactive material released from Fukushima Daiichi. With detection of trace amounts of the radionuclide, Cesium 134 off the coast of Vancouver Island, there appears to be confusion over what these results could mean for the rest of the west coast (WHOi, 2013). A lack of monitoring and information on the topic have contributed to fear that dangerous levels of radiation have impacted public safety and the environment.

This topic was proposed by Dr. Abderrachid Zitouni, Radiation Specialist at the BCCDC, as a continuation of two previous research projects completed by BCIT Environmental Health students concerning the effect that radioactive material released from Fukushima Daiichi may have on fish and imported foods from Japan (Luan, Takeuhiro 2013, 2014). This research aims to collect quantitative evidence to assess the impact that radionuclide migration may have on the beaches along the west coast as well as ease any misconception the public may still have concerning the radioactivity of the ocean. The survey will be carried out using sensitive radiation devices to detect gamma rays characteristically released from radionuclides like Cesium-134 and Cesium-137 associated with Fukushima Daiichi releases.

Literature Review

The basics of ionizing radiation

Radiation is ubiquitous in our environment as it can be found in various forms in all living organisms and their surroundings. Air, water, food and soil are all natural sources of radiation (EPA, 2015). Radiation transmits energy through the release of electromagnetic waves or particles. It exists in two distinct forms, ionizing and non-ionizing radiation. Ionizing radiation has enough energy to "ionize" matter while non-ionizing radiation does not possess sufficient energy to remove an electron out of orbit. Ionizing radiation poses more of a concern to public health because of its capability to affect the DNA (EPA, 2015). The loss of an electron through ionisation causes the molecules in the body to become charged and thus more reactive (CCOHS).

Radioactivity refers to changes in the nucleus that result in the spontaneous release of ionizing radiation (Pacchioli, 2013a). Isotopes are elements that have the same number of protons but differing number of neutrons and as a result will have varying degrees of instability (WHO, 2013). Radionuclides or radioisotopes are isotopes that are unstable and in order to achieve stability they must release energy. This energy is lost through the release of ionizing radiation in the form of gammas (photons), Betas (electrons), and Alphas (Helium nuclei). The process in which radionuclides lose energy is known as radioactive decay (Pacchioli, 2013a). The activity of radioactive material is determined by the number of decay events that occur within a specific time interval (WHO, 2013). Over time, the radioactivity of elements diminishes. Each radionuclide has its own decay rate and therefore has a distinct half-life (EPA, 2015). The half-life of a radionuclide is the time it takes for its activity to decrease by half. This can range from seconds to billions of years (CCOHS, 2015).

The activity of a radioisotope is measured in Becquerel (Bq) which is defined as the number of radioactive decay events each second. The biological effects induced by radiation are determined by a dose metric called the Effective Dose (E) in units of Sievert (Sv). The effective dose incorporates the amount of radiation energy absorbed in tissue, the effectiveness of the radiation, and the different sensitivities of organs and tissues (WHO, 2013).

Artificial vs Natural Sources

People are constantly being exposed to low levels of radiation. Every year it is estimated that Canadians on average receive 2-3 mSV of ionizing radiation as a result of normal background radiation from natural sources (Health Canada, 2009). Natural sources of radiation include cosmic rays from outer space and naturally occurring radioactive material (NORM) in the earth's crust. Radiation from nuclear bomb testing fallout, released from nuclear reactors or materials generated for nuclear medicine are all considered artificial sources. Health Canada estimates 80% of an individual's yearly exposure to radiation is from natural sources while the remaining 20% is from artificial sources. Exposure to natural radiation varies depending on the geographic location. Individuals will have higher exposure to radiation living in places at higher altitudes that are less protected from the sun's cosmic rays, as well as places where the bedrock contains higher concentrations of radioactive substances such as natural Uranium and decay products, natural Thorium and decay products, and Potassium-40. Furthermore, natural sources of radiation are present in our ocean; Potassium-40 and Uranium 238 in the ocean are found at levels 1000 to 10,000 times higher than artificial sources (Health Canada, 2008). Regardless of the exposure to both natural and artificial sources of radiation in the ocean, the average person swimming is only exposed to a minimal amount of radiation compared to a cross-Canada flight (WHOi, 2013a).

Significance to Public Health

The impact of ionizing radiation on the human body is dependent on the type and amount of radiation the individual is exposed to and the route of exposure. Ionizing radiation causes tissue damage through the transfer of energy to the cells. This transfer causes neutral tissues in the body to become charged, which could potentially result in changes to their molecular structures (Health Canada. 2009). Depending on the amount of exposure, the resulting change could cause damage directly to the molecules in the body or indirectly through the creation of free radicals. At low doses, the body is capable of repairing cell damage caused by radiation. However, when the exposure is high enough the damage can be irreparable (Pacchioli, 2013b). The DNA molecule will often become damaged as a result of radiation exposure. If it is unable to repair itself properly, it may result in cell death or continued cell proliferation leading to cancer. Certain cancers are more associated with ionizing radiation, such as cancers of the lungs, thyroid and skin; this is because of their sensitivity to radiation (Health Canada 2009).

Ionizing radiation emission as a result of nuclear decay is primarily found in three primary forms: alpha, beta and gamma radiation (Health Canada, 2009). Each type of ionizing radiation has differing capabilities in their potential to cause harm to the body. Alpha particles, composed of two protons and two neutrons, are generally unable to penetrate the skin due to their larger size. However, they can be very detrimental if they are inhaled or ingested (Pacchioli, 2013b). Through this mode of entry, alpha particles are able to transfer their energy, causing disruption in the molecules of the body's tissue. Beta particles are classified as fast moving and high energy electrons (Health Canada, 2009). They can penetrate few millimeters under the skin; due to their smaller size however, the tissue damage is fairly limited with each exposure. Lastly, gamma rays are released as high energy photons that have no charge or mass. Due to these properties, gamma rays are considered the most dangerous form of ionizing radiation externally as they are able to travel the farthest (long range) (Pacchioli, 2013a). As cesium 134 and cesium 137 decay they release a distinct pattern of both beta and gamma radiation (JAEA, 2013). Gamma radiation from Cesium-134 and Cesium-137 will be the focus of this research due to their long range in air and the easiness to detect them.

Health effects from radiation can be classified as either deterministic or stochastic. According to Health Canada, a high radiation threshold of 500mSV over a short period of time (hours) must be met in order for acute deterministic effects to manifest. Symptoms have an acute onset and include nausea, vomiting, diarrhea, hair loss, immunosuppression, nervous system damage and even death. After the threshold of 500mSV is reached, the side effects become dose-dependent. This means the severity of the symptoms will begin to correlate with the increase in the overall radiation dosage absorbed. Stochastic effects are side effects associated with radiation exposures that do not exceed the threshold. Cancers and birth defects are considered the main concern for these low dose exposures (Health Canada, 2009). There has been shown to be correlation between exposures to radiation above 100 mSV and an increased risk of developing cancer. However, exposures under 100 mSV show little evidence of this dose-dependent relationship. It appears that low dose exposure and an individual risk of cancer are dependent on the number of exposures (Pacchioli, 2013b). Since cancers caused by radiation are indistinguishable from those caused by other origins and some have a long latency period that can extend for decades before detection, epidemiological studies must be conducted between groups that have relatively high exposures, such as atomic bomb survivors, and those that do not (Health Canada. 2009). A long-term cohort study conducted by Radiation Effects Research Foundation (RERF) has been assessing the health effects of survivors of Hiroshima and Nagasaki since 1950. As a result of this research, they have concluded that exposures to high levels of radiation increases the risk of cancer mortality throughout a lifetime. Furthermore, the risk has been shown to be dependent on the initial dose received. Exposures at younger ages lead to a greater risk of lifelong cancer mortality, showing that children are indeed more sensitive to exposure to radiation. However, this study was unable to determine a correlation between low dose exposure and negative health effects as a result of radiation exposure (Kotaro, 2012). Similarly, children and adolescents exposed to radiation, specifically Iodine 131, following the nuclear accident in Chernobyl were at the greatest risk of developing thyroid cancer. Other age groups did not show as definitive a correlation between exposure and the development of thyroid cancer as this group. Moreover, this study conducted by Cardis et al stated the workers involved in the cleanup after this accident have shown an increased risk of leukemia. It was also suggested there may be a relationship between an increased risk of cardiovascular diseases and the exposure to low dose radiation (2011). The International Commission on Radiological Protection estimates there is about a 5% per sV increase in lifetime excess of cancer and heritable effects, assuming the linear low dose model (Buesseler, 2012). However, there seems to be inconsistencies with current evidence that this model accurately reflects the risks at low radiation exposure.

The importance of Cesium detection

Cesium 137 and Cesium 134 are the main radionuclides of concern released from the Fukushima Daiichi Nuclear Power Plant accident (Buesseler, 2012). From the seawater samples collected, Cesium is relatively easy to detect using high resolution gamma ray spectroscopy (Bandstra, 2014). A study conducted by Buessler et al. shortly after the incident detected highly elevated levels of ^{137}Cs and ^{134}Cs near the shoreline of Japan. Prior to this, ^{137}Cs was found in the ocean mainly due to nuclear weapons testing that occurred in the 1950s and 1960s. For this reason, ^{134}Cs is a better indicator of the degree of contamination caused Fukushima Daiichi since it only has a half-life of 2 years compared to ^{137}Cs which decays more slowly and has a half-life of 30 years (Buesseler, 2012). When ^{134}Cs is detected in conjunction with ^{137}Cs, this is an indication of radionuclides released from the Fukushima Daiichi reactors.

In addition to the release of ^{137}Cs and ^{134}Cs, Iodine 131 and Tellurium 132 were detected shortly after the incident in the water surrounding the reactor (Bandstram 2014). Research conducted at Simon Fraser University few days following the accident at the Fukushima Daiichi plant detected traces of Iodine- 131 in seaweed and rain water from samples collected within Metro Vancouver. These levels did not pose any concern health concern (Starosta, 2011). Nevertheless ^{131}I and ^{132}Te have a relative short half-life, 8 days and 3 days respectively, and are no longer detectable in Vancouver four years later. Furthermore, the release of Strontium-90, with a half-life of 29 years, has the potential to be a marker of Fukushima Daiichi contamination as well. Moreover, strontium isotopes are difficult to measure directly using conventional techniques as they emit only beta radiation, in contrast to radiocesiums which emit gamma rays (Bandstra, 2014).

Current Guidelines

Health Canada estimates that one third of an individual exposure to ionizing radiation is external, such as the absorption of gamma rays through the skin. The remaining amount is attributable to internal exposure through inhalation and ingestion (Health Canada, 2009). In order to approximate and limit an individual's annual dose, guidelines have been established by the Canadian government for drinking water and foods.

Exposure to sources of ionizing radiation are closely monitored in occupational settings for the protection of radiation workers. The International Commission on Radiological Protection recommends that the annual occupational exposure limit for the general public should not exceed 1mSV (Rossi, 2013). The radiation safety standards generally follow the linear no-threshold (LNT) model for radiation exposure, stating that any exposure to radiation increases the risk of cancer. Although there is little evidence to support this theory, it is best to take a conservative approach as the accumulating effects of low dose radiation still remains unclear (Pacchiolim, 2013b).

In accordance with the Canadian Drinking Water Quality Guidelines, the water supply is routinely monitored for the concentration of radionuclides from artificial and natural sources. Determining the maximum acceptable concentration (MAC) of radionuclides are based on the annual dose received and the increase lifetime risk of cancer. The dose level of 0.1 mSV/ year is considered the acceptable radiation exposure through the ingestion of drinking water; this accounts for only 5% of an individual's total annual exposure from natural background levels. This exposure dose is only estimated to increase an individual's lifetime risk of fatal cancer or other serious health effects to less than 1 in 100,000 cases.

The Maximum Acceptable Concentration (MAC) is calculated as following:

$$MAC\ (Bq/L) = \frac{0.1mSV/year}{730\ L/year \times DC \times 1000mSv/Sv}$$

0.1 mSV/ year = annual dose level
730 L/year = yearly water consumption for an adult
DC = dose coefficient based on 50 years' accumulated dose that would result in an intake of 1Bq of a given radionuclide (Health Canada, 2009)
Although ^{137}Cs is readily absorbed by soft tissue, it does not persist for long in the body as it is removed relatively quickly through metabolic processes. Consequently, the calculated maximum acceptable concentration for ^{137}Cs is 10 Bq/L (Health Canada, 2009).

Predication of the arrival of the plume

A radioactive plume was released into the Pacific Ocean through direct discharge from the Fukushima Daiichi reactor and through atmospheric deposition. High levels of the radionuclides, ^{137}Cs and ^{134}Cs from water samples taken near the damaged reactor were detected soon after the accident. Shortly thereafter, a study conducted by Buessler et al, detected ^{137}Cs off the coast of Japan to be in an excess of 50 million Bq/m^3. Levels this high are associated with negative health effects. As the source of contamination was contained, ^{137}Cs levels recorded in June 11, 2011 were sufficiently lower. Levels around the reactor still remain around 1000 Bq/ m^3 (Buessler, 2012). The Kuroshio currents are responsible for carrying a certain amount of these radionuclides to North America west coast. As predicted by the model created by Rossi et al., by 2012 the radioactive plume was halfway across the Pacific Ocean. Cesium is water soluble, therefore, as it travels farther away from the reactor, the concentration will rapidly dilute. Beginning in 2013, a slight increase in radioactive cesium became detectable across the west coast of North America. Multi-decadal projections predict the ^{137}Cs will reach approximately 10-30 Bq/m^3 between 2014 and 2020 (Pacchioli, 2013b).

Purpose

The purpose of this experiment was to determine the environmental impact if any, that the Fukushima Daiichi Nuclear power plant accident in Japan has had in British Columbia along some parts of the West Coast in Vancouver. This was accomplished through a survey of gamma radiation and identification of specific radionuclides (Cesium 137, Cesium 134) along some popular Vancouver beaches. Sand, water, and various sample media, including stones, algae and driftwood were screened due to their differing abilities to retain radioactive material. The two hypotheses that were investigated during this research were as follows:

Hypothesis #1
Null Hypothesis: The radiation levels along the beaches will not exceed the local background levels, ranging from 0.05 µSv/hr to 1 µSv/hr.
Alternative Hypothesis: The radiation levels along the beaches will exceed the universally accepted background levels

Hypothesis #2
Null Hypothesis: There will be no differences observed between the radiation levels from sand, water, and different artifacts found on the beach (stones, algae, drift wood)
Alternative Hypothesis: There will be differences observed between the radiation levels from sand, water and different artifacts found on the beach (stone, algae, drift wood)

Methods and Materials

Material and Equipment Used

The *RadEye personal Survey meter* and *the portable gamma spectrometer GR135 Plus EXPLORANIUM* were used to detect and analyze gamma radiation emissions along the beaches.
RadEye Survey meter (Figure 1): This device is a personal dosimeter designed to directly detect radiation levels. A programmed alarm will alert the researcher if radiation levels exceed 1 µSV/ Hr. The detection limits of the RadEye survey meter range from 0.01 µSv/h to 250 µSv/h. This low level detection is accomplished through the amplification of the absorbed radiation through a scintillation detector with a miniature photon multiplier (Thermo Scientific, 2012). This instrument is able to detect the presence of gamma radiation and was used for initial screening. However, further measurements would have to take place in order to identify if the detected gamma radiation is from natural or artificial sources. In the interest of this study, the researcher focused on the identification of artificial radionuclides including Cesium 134 (Cs-134) and Cesium 137 (Cs-137) as they are associated with the radioactive material released from the Fukushima Daiichi power plant after the accident. During the experiment the RadEye device was placed in a pocket until the designated GPS locations were reached; at these sites the readings were recorded. If the alarm sounds prior to reaching a surveying location further analysis took place immediately using the portable gamma spectrometer *GR-135 Plus*.

GR135 Plus EXPLORANIUM (Figure 2): This device was used simultaneously with the RadEye survey meter. In addition to being more sensitive to radiation levels than the RadEye, the *GR135 Plus* EXPLORANIUM survey meter is able to identify the radionuclides responsible for emitting radiation. Each radioactive isotope creates a unique signal at specific gamma energies, which is compared with data stored in the libraries of the device. The instrument can detect radionuclides with an energy range between 20keV to 3.0MeV (Leidos, 2014). The lowest detectable dose rate of the *GR-135 Plus* is 0.01 µsV/Hr (SAIC, 2006).

Figure 1: RadEye survey meter (Thermo Scientific, 2012)

Figure 2: GR135 EXPLORANIUM survey meter (Leidos, 2014)

Standard Method Used

The following three beaches were included in this study: Sunset Beach, Spanish Banks and Jericho Beach. Upon arrival at the site, the temperature, date and weather conditions were noted. The presence of stones, algae, driftwood were recorded at each beach; pictures were taken to document this.

Additional pre-tests were regularly performed during the field surveys to ensure that the meters were always functioning properly. Prior to taking gamma readings, both devices were tested to verify that the batteries were full. The RadEye survey meter displayed dose rates in units of µSv/hr or count rates in counts per minute (cpm). The *GR135 Plus* EXPLORANIUM survey meter displayed dose rates in units of µSv/hr and a gamma spectrum. When switched to identification mode, the *GR135 Plus* was able to perform a sample analysis after 60 seconds. Initial readings away from the beaches were used as a control to establish the natural background radiation levels at each specific location and were later used to compare with the levels recorded along the beach.

With both meters on, the survey of the beach began. As radiation absorption is dependent on the medium under investigation, different variables are included in this survey. Measurements were taken along the sand at a set distance from the water, along the water's edge as well as near different artifacts (stones, algae, driftwood). A total of 30 readings were collected from each of these categories.

Sand

The first survey conducted assessed the radiation levels of the sand along the beach. Walking at a normal pace, 10 to 15 metres away from the water, the dose rate was recorded from the RadEye survey devices every 10 metres. The GPS coordinates were also recorded at this time. The procedure was repeated until 10 readings had been collected from each beach.

Water

Similar to the survey conducted along the sand, an analysis of the dose rate along the water's edge took place. This determined the radioactivity of the water. Using the RadEye meter, the dose rate was recorded every 10 meters as well as the GPS coordinates until 10 readings had been collected from each of the three beaches.

Stones, Algae, Driftwood

At each site, different sample medium were identified including stones, algae, driftwood of varying distance from each other and from the water's edge. The beaches had a different composition of each medium. These features were noted in the site description. The measured dose rate from the RadEye survey device and GPS coordinates were recorded until 10 readings had been collected from each of the three beaches (total of 30 readings).

If at any time the radiation levels exceeded 1.0 µSv/Hr, the pre-programmed alert on the RadEye survey meter would alarm. At this point, the GR135 Plus EXPLORANIUM survey meter would have been used to search for the highest dose rate at that location. Once this location had been established, the GR135 EXPLORANIUM Plus survey meter would then be switched to identification mode in order to determine if the elevated levels are due to natural or artificial radiation. If cesium 137 and cesium 134 were discovered, this would be an indication of Fukushima Daiichi contamination (Zitouni, A 2015 personal communication, Nov 2).

Standard operating procedure for the RadEye survey meter was derived from the Health Canada: Emergency Preparedness and Response Division Nuclear Emergency Preparedness and Response Division's procedure designed to monitor tsunami debris along the coast of British Columbia following this incidence. Techniques concerning operation, wearing the device, loading batteries and set up were followed using this guideline. (Health Canada, 2013).

Inclusion and exclusion

The beaches, Sunset Beach, Spanish Bay and Jericho Beach, were selected based on a google search of Vancouver's most popular beaches (Lacusta, 2013). As they are the most frequently visited, these beaches would pose the most concern if there is indeed elevated levels of artificial radiation. Different environmental locations, different medium including driftwood, stones and algae were considered during this survey due to their differing capacities to radioactivity. The focus of this survey was the detection of artificial gamma radiation, more specifically Cesium 134 and Cesium 137, which are the main radionuclides of concern released from the Fukushima Daiichi Nuclear Power Plant after the nuclear accident of March 11 2011.

Results

Of the 90 locations surveyed, none exceeded normal background radiation levels (between 0.05- 1.0 Sv/Hr). Furthermore gamma radiation from Cesium-134 and Cesium 137 from Fukushima were not detected. Therefore it can be concluded that there was no detectable increase in radiation level as a result of the incident at Fukushima Daiichi Nuclear Power Plant. Hence the beaches can be considered safe.

Descriptive Statistics

The mean dose rate was determined to 0.0168µsV/hr with a standard deviation of 0.006. Since none of the samples exceeded 0.05 µsV/hr it can be concluded at this point that the null hypothesis cannot be reject.

Table 1.1. Descriptive Statistics of dose rate reading of all three locations

Dose Rate (µsV/hr)	
Mean	0.0168
Median	0.02
Mode	0.02
Standard Deviation	0.006
Range	0.02
Minimum	0.01
Maximum	0.03
Count	90

Calculated by Microsoft Excel 2007 (MS Excel, 2013)

The means for sand, water and artifacts (stones, algae and driftwood) were 0.0163, 0.0167 and 0.0173 respectively. The standard deviation ranged from 0.00480 to 0.00615.

Table 1.2: Descriptive Statistics for the data collected from each category (sand, water, artifacts).

	Sand	Water	Artifacts
Mean	0.0163	0.01667	0.0173
Standard Error	0.00112	0.000875	0.00106
Median	0.02	0.02	0.02
Mode	0.02	0.02	0.02
Standard Deviation	0.00615	0.00479	0.00583
Range	0.02	0.01	0.02
Minimum	0.01	0.01	0.01
Maximum	0.03	0.02	0.03
Count	30	30	30

Calculated by Microsoft Excel 2007 (MS Excel, 2013)

Inferential Statistics

It is predicted that radiation levels between locations will be negligible, thus the dose rate readings will only be compared between categories (sand, water, artifacts). In order to determine if there is really no difference between the variables a one-way ANOVA will be conducted. The data was shown to be normally distributed through the NCSS analysis ($p>0.05$, goodness of fit test). This indicates that parametric tests should be used. The p value of 0.78 indicates that the data is not significantly different. Therefore the null hypothesis should not be rejected and it can be concluded that there is no difference in radiation levels between sand, water and artifacts at Vancouver beaches.

Discussion

As a result of this study, it was concluded that none of the beaches, Spanish Banks Beach, Jericho Beach and Sunset Beach surveyed exceeded the expected natural background levels of 0.05-1.0µSv/hr. Additionally, no Cesium 134 or Cesium 137 sources were identified, indicating the absence of Fukushima Daiichi contamination. Thus, it can be extrapolated the radiation levels along the beaches of Vancouver present no risk to public health. The average dose rate observed from the measurements of the sand, water and various artifacts (driftwood, algae, and stones) were 0.0163 µSv/hr, 0.0167 µSv/hr and 0.0173 µSv/hr respectively. A p-value of 0.78 indicates that these differences are not statistically significant.

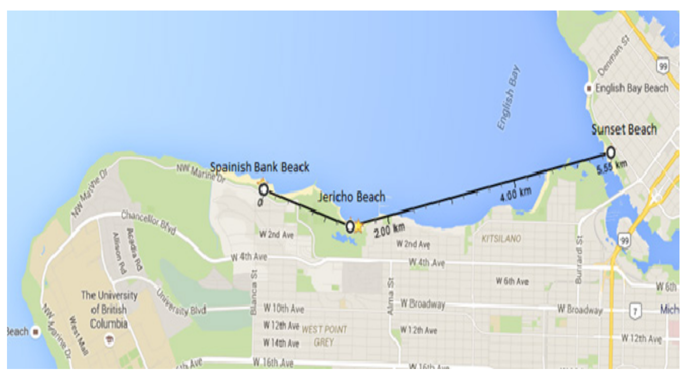

Figure 3 Location of Survey Sites: The following map shows the location of the sites surveyed during this study. Spanish Banks Beach, Jericho Beach and Sunset Beach in Vancouver British Columbia, Canada were chosen based on their popularity and their differing characteristics.

Each site had distinct environment conditions and characteristics. At Sunset beach, some algae was present along the shoreline and large stones were found both in the water and sand. In comparison, at Jericho Beach there was no algae present but driftwood was highly prevalent. The presence of small pebbles and shells were noted along the shore. Finally at Spanish Banks Beach, stones were found along the perimeter of the water's end. Algae was present on some on these stones.

The risk associated with the observed dose at the different beaches, 0.0168 µSv/hr, is negligible in regards to their effect on human health when compared with more significant exposures received during other activities, such as a cross-Canada flight or medical imaging using a Computerized tomography (CT) scan (WHOi, 2013). According to the World Health Organization an elevated risk of cancer is associated with doses above 100 mSv (WHO, 2012). This is almost 5,000 times greater than the levels recorded along the beach. In order to assess the influence of the radiation from the beaches, background levels were established at locations away from the site prior to conducting the survey. The dose rate measured by the RadEye survey meter at Sunset beach, Jericho beach and Spanish Banks beach were 0.03 µSv/hr, 0.02 µSv/hr and 0.02 µSv/hr respectively. Due to the many variables involved in measuring ionizing radiation, it is common for the dose reading to fluctuate slightly depending on the conditions. Background levels of radiation can vary greatly depending on the topography and geographic location. As previously mentioned, the exposure to natural ionizing radiation can be greater at higher altitudes that are less protected from cosmic rays, as well as places where the bedrock contains a higher composition of radioactive substances. (Health Canada, 2008). As predicted, the radiation levels between locations were inconsequential, thus the dose rate readings were only compared between the different categories of sand, water and artifacts. The ability of certain medium to concentrate and accumulate certain radionuclides has been well documented. For instance certain species of seaweed are known to absorb Cesium, Strontium and Iodine (Manley, 2014), while algae species, such as *Chlorella* vulagaris, have a high tolerance to gamma radiation and in turn will reflect the radiation. (Mavi, 2014).

The results from this study are in agreement with research conducted by other groups. Wood Hole Oceanographic Institution (WHOi) and the Integrated Fukushima Ocean Radionuclides Monitoring (InFORM) Program analyzed sea water samples collected along the West Coast of the United States and Canada and have only detected trace amounts of ^{134}Cs and ^{137}Cs. None of the samples contain radioactivity that would be a concern to the public (Rossi, 2013). Prior to this incidence ^{137}Cs levels across the west coast were between 1-2 Bq/cm^3, reflecting the radioactive fallout that occurred during the 1950s and 1960s nuclear testing, while ^{134}Cs remained below detectable amounts. Currently, the ^{134}Cs level present in seawater, which is used as a fingerprint of Fukushima Daiichi radioactivity, remains below 2 Bq/cm^3. These levels are more than 1000 times lower than the EPA accepted level for drinking water and therefore pose no concern to human health (WHOi, 2013). On February 19, 2015, ^{134}Cs was detected for the first time along the West Coast of Canada in Ucluelet, British Columbia. The sample analyzed by InFORM detected 5.8 Bq/cm^3 Cs^{137} and 1.4 Bq/cm^3 of Cs^{134}. This detection was not unexpected based on the modelling studies predicting the arrival of the plume released from Fukushima Daiichi (InFORM, 2015). Based on these models, the levels are predicted to remain very low in comparison to international standards (Rossi, 2013). The ^{134}Cs levels remain below detection in all other locations monitored in British Columbia, including Bowen Island, Salt Spring Island and the four sampling sites along the Vancouver coastline. This is due to the rapid dilution of the radioactive material that occurred in the Pacific Ocean following the incident (WHOi, 2013). It should also be noted that Health Canada's Radiation Monitoring Stations located throughout the country did detect a slight increase atmospheric concentration of Iodine 131, Cesium 134, Cesium 137 and Xenon 133 along the West coast that were attributed to the incident at the Fukushima Daiichi nuclear power plant. A dose assessment using the "worst case" scenario estimates the maximum increase of exposure to be 4.4 µSv (0.0044 mSv). This is minimal in comparison to the normal background level of 2-3mSV individuals are exposed to every year. There are no negative health effects related to such a small increase in exposure (Health Canada, 2014).

Previous research conducted by Environmental Health students at British Columbia Institute of Technology have reached similar conclusions regarding the minimal impacts this incident has had on the residents of Vancouver, British Columbia. A study conducted by Luan et al. analyzed the radioactivity of certain species of fish and shellfish from the Pacific Ocean to determine the effects of the migrating radionuclides from Fukushima Daiichi Nuclear Power plant may had have on the marine life. It was determined that ^{137}Cs and ^{134}Cs was not present in these seafood products indicating no signs of contamination from this event. Thus, it was concluded that the West Coast was minimally impacted by the contaminated waters due to the rapid dilution that occur in the Pacific Ocean. Furthermore if migratory fish were indeed exposed to this radioactive material, they were able to metabolize the radionuclides prior to reaching the West Coast (Luan, 2013). In addition to this research, a study conducted by Takeuchi et al. analyzed the presence of radioactivity in food products imported from Japan. Similar conclusions were met as none of the products examined indicated the presence of ^{134}Cs and ^{137}Cs (Takeuchi, 2015).

Surveillance of radionuclides released from this incident is important in order to mitigate public anxieties about the radioactivity of the Pacific Ocean. Many misconceptions still exist mainly due to the theories and speculations in the media that are not based on scientific evidence. Lack of monitoring and quantitative evidence about the safety of Vancouver's beaches has created doubt within some members of the community. By quantifying radiation levels along three Vancouver beaches, it is possible to dispel some of those doubts and misconceptions by providing additional evidence that the beaches of Vancouver are indeed safe. While it is important for individuals to be aware of their exposure to ionizing radiation, it is also important for the public to be able to properly assess their risk.

Conclusion

Of the 90 locations surveyed, none exceeded normal background radiation levels and there were no observable differences between the various media surveyed. The radiation levels along the beaches did not exceed the universally accepted background levels, ranging from 0.05 µSv/hr.to 1 µSv/hr and there were no differences observed between the radiation levels of sand, water, and different artifacts (driftwood, algae and stone). Additionally the presence Cesium 137, Cesium 134, the signature radionuclides indicating Fukushima contamination, were not detected. Therefore it can be concluded that there is no observable increase in radiation levels along Vancouver beaches as a result of the Fukushima Daiichi Nuclear Power Plant accident. Hence the public should not be concerned about their exposure to ionizing radiation at these locations.

Limitations

Mainly due to the lack of time and resources only three beaches along the West Coast were surveyed. Other techniques for detecting radiation are more sensitive, such as the high resolution gamma ray spectroscopy method. Current research groups, such as the Wood Hole Ocean Institution (WHOi) and Integrated Fukushima Ocean Radionuclide Monitoring (InFORM) use this technique to analyze water samples collected along the West Coast. However this method is much more costly and beyond the scope of this study. The main goal of this research was to determine if the radiation levels could present harm to the public visiting these beaches. As trace amount of these radionuclides does not present any risk or additional health concerns, the utilization of such precise measuring techniques was not required.

Recommendations

This event was unprecedented and further research would help develop a better understanding of the migration patterns of radioactive material in the ocean. Thus it would be beneficial to the public if more monitoring was in place to relieve any anxieties and correct misconceptions about the incident. It would be advisable to continue conducting radiation surveys along popular beaches in British Columbia and publish the results on the British Columbia Center of Disease Control Website. This would ensure the public would have access to them.

Future Research

The standard method developed for this study could be used to survey beaches across the West Coast of North America, including the other Vancouver beaches, such as Iona Beach, Kitsilano Beach and Wreck Beach, which were excluded from this study due to time restraints. Future research could include examining how the implementation of additional radionuclide monitoring programs, while providing more scientific research about this event, does in fact help change the public perception about the ocean's radioactivity. Essentially, does additional exposure and assess to research provide reassurance to the public fears?

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Competing Interest

The authors declare that they have no competing interest

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