

Testing for presence of radioactivity in BC Pacific Ocean's seafood supply

Amy Luan¹, Bobby Sidhu², and Abderrachid Zitouni³

¹Lead Author, B. Tech Student, School of Health Sciences, British Columbia Institute of Technology, Burnaby, BC.

²Supervisor, School of Health Sciences, British Columbia Institute of Technology, Burnaby, BC.

³Contributor, Environmental Health Services, BC Centre for Disease Control, Vancouver, BC.

Abstract: Due to the Fukushima Daiichi Nuclear power plant incident in March 2011, large quantities of contaminated water were released to the Pacific Ocean in Japan. The severity of contamination on the marine environment is unclear, therefore, the public is concerned with the possible internal radiation exposure from ingesting contaminated seafood products caught in the Pacific Ocean. This study was aimed to investigate the presence or absence of gamma radioactivity in commonly consumed seafood products from B.C. In total, ten different species of fish and three different species of shellfish were selected for analysis. For each species of fish, two samples were collected and each sample was from a different local seafood market. For each species of shellfish, ten samples were collected from three different sources. Using the portable GR-135 Plus gamma ray spectrometer, the samples were tested and analyzed for the presence of Fukushima radionuclides, particularly Cesium-137 (Cs-137) and Cesium-134 (Cs-134). Based on the analyzed fish and shellfish, no gamma radiation was detected. The detector did not identify any gamma radiation over the normal background readings.

Key words: fish, shellfish, Fukushima, radiation, gamma, Pacific Ocean, Cesium-137, Cesium-134

Introduction

Radiation is a subject of rising relevance in the 21st century due to the increase of nuclear applications in the world and the lack of concrete understanding of the associated health effects from low levels of radiation exposure. Since the Fukushima Daiichi Nuclear power plant incident in 2011, the world has watched large amounts of radionuclides being released into the Pacific Ocean with great concern and fear of the detrimental effects to the environment and public health. Although Health Canada has reported that the concentration of radiation in Canada's environment and air is far below the national acceptable limits, the unsettling fact of radioactive contamination continues to drive the public into a state of disbelief and distress. There appears to be a gap between the reality of risk and the public's perception of risk. This may be due to media speculations, theories with unproven findings, and mainly, the shortage of radiation testing in response to the aftermath of the Fukushima incident. In order to mitigate the concerns of the public, the objective of this research was to test for presence or absence of

radioactivity in fish and shellfish harvested from the Pacific Coast.

This research topic was formulated by Lorraine McIntyre, the Food Safety Specialist at BC Centre for Disease Control. She was inspired by an Environmental Health Officer who spoke about the numerous telephone calls received by their Health Authority with regards to the public's concerns on radiation in seafood products harvested from the Pacific Ocean.

What is radiation?

There has been a substantial growth of knowledge and research in the field of radiation. Due to the burst of new technologies in our society, as well as the nuclear disasters of Chernobyl (26 April 1986) and Fukushima (11 March 2011), radiation has generated sparks of interest and attention from the general public. Radiation is understood as energy emitted by sources that are either naturally occurring in our environment or from human-made materials (EPA, 2013). It is divided into two categories, ionizing and non-ionizing. Ionizing radiation is the most energized

form between the two types of radiation because it has the ability to strip electrons and create highly reactive ions. Ionizing radiation is emitted by radioactive materials (in the form of particles or electromagnetic waves) that have atoms with unstable nuclei or by radiation-generating machines (e.g. X-rays). It is through the process of radioactive decay that radionuclides disintegrate and emit ionizing radiation (EPA, 2013). Each radionuclide is specifically categorized by the type of radiation emitted, the level of energy, and its half-life (WHO, 2012).

There are three main types of ionizing radiation emitted by radioactive material: alpha particles, beta particles, and gamma rays. All of which have the innate ability to deposit energy in tissues at different depth levels. Depending on the form of radiation exposure and the type and energy of the ionizing radiation, health effects will vary (WHO, 2012). In external exposure, gamma radiation is the most hazardous form due to its ability to penetrate beyond the skin to damage tissue and cells while alpha and beta radiation do not possess that level of penetrative ability. In contrast, if alpha and beta emitters are exposed internally through ingestion, inhalation, or skin contact, the radioactive particles can severely damage organs, tissues, or bones as they can release larger amounts of energy due to their low penetrative ability (WHO, 2012). Each radionuclide has a specific physical half-life, which is the time it takes to disintegrate to half of its original activity. However, in the case of internal exposure, the biological half-life is used to determine the amount of time it takes the body to eliminate half of the original amount.

How frequently are we exposed to radiation?

Naturally, radiation is present at low concentrations in the environment and their levels will vary depending on the geographical location. Radioactive materials are naturally occurring in the biosphere, geosphere, atmosphere, and hydrosphere with radon as the most prevalent natural radioactive gas found today (EPA, 2013). Due to their natural abundance in the ocean, radionuclides are commonly present in the tissues of marine organisms. Additionally, depending on the habitat, diet, and species of the aquatic organisms, different types of radionuclides and concentration will be found in their bodies. In a study by Carvalho et al (2011), Polonium-210, Uranium isotopes, Potassium-40, Radium-226, and Lead-210 are several examples of natural alpha, beta, and

gamma emitters found in marine life from the North Atlantic Ocean. Consequently, when monitoring radioactive contamination, it is important to understand that radiation is naturally present in aquatic organisms; therefore, if radiation is detected in any specie, one must take into consideration of the natural occurring radionuclides in the ocean before making a positive association with human-made factors.

In addition to the natural radiation, people are exposed to human-made radiation sources from industrial applications, nuclear medicine, diagnostic x-rays, and other medical devices. In 1980s, the United States National Commission for Radiological Protection (NCRP) estimated that 83% of radiation exposure is from natural sources while the other 17% is from artificial sources (NCRP, 2009). However, a more updated study revealed that 50% of radiation exposure in America is from natural occurrences while anthropogenic radiation constitutes for the other 50%. In merely 20 year, there seems to be a substantial increase in human's exposure to artificial radiation.

Aside from the widespread human-made radioactive sources on land, artificial radionuclides exist in the marine environment as well. Since the development of nuclear weapons, nuclear activity has continued to contaminate the oceanic water. Factors such as radioactive fallout (radioactive residual following a nuclear explosion), improper disposal of radioactivity wastes, and nuclear related accidents (Chernobyl and Three Mile Island nuclear incidents) are all contributing factors to the radioactive contamination present in the world today. Livingston and Povinec (2000) identified ^{90}Sr , ^{137}Cs , ^{239}Pu , ^{240}Pu , and ^{241}Am as the more prevalent radionuclides in the marine environment. Although evidence shows a clear indication of nuclear contamination, the author estimates that the level of ^{137}Cs in the ocean water and in marine organism will have negligible impact to the world. Relating to the recent Fukushima accident, while the ocean water is polluted, contamination may be negligible, therefore, should have little impact to the Pacific Ocean and the seafood harvested in British Columbia.

Associated health effects with radiation exposure

With the many surrounding natural and anthropogenic radiations in the world, it is necessary to evaluate the potential effects of ionizing radiation to the health of the human body. Due to the highly

energized state of radionuclides, the ionizing radiation has the ability to damage DNA molecules which can lead to injuries in human tissues and organs. Under natural conditions, the body can facilitate the repair of the damaged cells. However, if the dosage of radiation is over a certain threshold, the damage cannot be repaired and cells will die. Although cells have the capability to repair themselves, abnormalities can occur sporadically. This stochastic effect of ionizing radiation will result in cell mutations which may lead to cancer formation or other negative alterations to the body (WHO, 2012).

While the biological effects from high level radiation exposures are well documented, it is difficult to predict the health risks associated with exposure to low doses. However, from the extensive research and epidemiological study of Japanese atomic bomb survivors and people exposed through means of medical, occupational, and environmental reasons, the knowledge of radiation risk has significantly improved (Tomonaga, 1962). Radiation exposure is classified into two main categories: deterministic and stochastic effects. The deterministic effects occur when a certain threshold of exposure dose is reached, resulting in damage to tissues that can cause acute radiation syndrome (ARS) or death. On the contrary, stochastic effects have no threshold level but rather are based on random probability, which can result in cancers or genetic modifications (WHO, 2012). Scientific investigations have collected data that strongly associated radiation exposure to leukemia (Tomonaga, 1962) and cancers of thyroid, lung, and breast (Gillbert, 2009). In a study by Goto et al (2011), the cancer mortality ratio of the Japanese atomic bomb survivors (children between the ages of 0-14 during the time of the bombing) was compared to the cancer mortality ratio of the unexposed Japanese population. Their notable finding concluded that people who were exposed as children had a

significantly higher number of death from cancer when compared to people who were not exposed. Additionally, Scholz (1994) reported that newborns and fetuses who are exposed to radiation are at a higher risk to develop cancer and can accumulate radionuclides in their bones more than adults. This clearly indicates that children are more likely to be at risk from radiation exposure due to their body's rapid cell division; therefore, radiation protection is more crucial for this specific population than the general public. On the whole, it is clear that radiation exposure can cause detrimental effects and certain populations are more vulnerable to exposure than others. From all the studies on radioactive exposure, it is crucial to monitor our surroundings for radiation and have protective measures for the purpose of eliminating the chances of adverse health effects experienced by those in Japan during the atomic bombing.

Food and water safety

Ingestion is a major pathway of radiation entry in the human body due to traces of natural and artificial radionuclides found in our food chain. The common radionuclides naturally found in food products are Potassium-40, Polonium-210, and Radium-226. For example, the level of Potassium-40 is estimated at 3520 pCi/kg (130 Bq/Kg) in bananas, 4450 pCi/kg (165 Bq/Kg) in sweet potatoes, 5600 pCi/kg (207 Bq/Kg) in Brazil nuts, and 6500 pCi/kg (241 Bq/Kg) in raw spinach (Brodsky, 1978). Although the numbers appear to be alarming, the level of radionuclide concentration is negligible to pose any health risk.

To prevent people from ingesting a hazardous amount of radionuclides in food, beverages, and water, different organizations and governments have set national and international guidelines on the maximum allowable safety level for each category.

Table 1: Radionuclide limits in food from various government agencies		
	Cesium-137 (Bq/kg)	Cesium-134 (Bq/kg)
Japan (standard limit)	100	100
Canada (actionable limit)	1000	1000
Food and Agriculture Organization of the United Nations (guideline levels)	1000	1000
United States (derived intervention level)	1200	1200

Note: Data for radionuclide limits in the United States from FDA (2005), for Japan from Ministry of Health, Labour, and Welfare (2013), for Canada from Health Canada (2008), and for FAO from Codex Alimentarius (2010).

The international standard is based on the Food and Agriculture Organization of the United Nations (FAO) *Codex Alimentarius Commission's CODEX General Standard for Contaminants and Toxins in Food and Feed* where guideline levels and effective dose for human consumption were established for adults and infants.

In Canada, recommended action levels of radionuclides have been established under the *Canadian Guidelines for the Restriction of Radioactively Contaminated Food and Water Following a Nuclear Emergency*. The recommended action levels are divided into three groups: fresh liquid milk, other commercial foods and beverages, and public drinking water.

Additionally, Health Canada also regularly performs a Total Diet Study where over 210 types of food products are sampled and analyzed for radionuclides. Furthermore, Canada also samples milk for the analysis of Sr-90, Cs-137, and other gamma radionuclides (Health Canada, 2011). These efforts demonstrate that the Canadian government is aware of the concerns of radiation, therefore, foods and beverages are monitored to ensure the Canadian population will not experience any ill effects to radiation.

In addition to food, our source of drinking water contains natural radioactive material such as radium, thorium, uranium, and their decay products through contact with rock formations and soil. Radionuclides are most commonly found in groundwater sources and depending on the degree of contact with the natural bearing rocks and soil, the concentration of radionuclides may or may not be a concern if ingested. In Canada, under the *Guidelines for Canadian Drinking Water Quality*, radiological parameters have been established to provide maximum acceptable concentrations (MACs) for natural and artificial radionuclides in drinking water.

Artificial radionuclides

Since the introduction of nuclear technology in the industry, nuclear activities have produced considerable amounts of artificial radionuclides. From nuclear fallout to nuclear plant emission, radioactive residues are introduced and dispersed throughout the atmospheric pathway. These anthropogenic radionuclides can persist in the stratosphere for many months or years before settling and depositing onto plants, and soil, or into ocean and water bodies to contaminate our food chain (Health Canada, 2009). As radioactive contamination enters

our food sources, people can either directly or indirectly ingest the radionuclides. Since radiation is known to accumulate in the tissues of animals and marine biota, the process of bioaccumulation can occur and increase radiation concentration as it is biomagnified in the food chain. Hence, humans are more prone to ingest a greater level of radiation as they are at the top of the food chain. Depending on the biological half-life, type of radiation emission, and level of radiation energy, those factors will determine the amount of time that radiation will persist in our body and the effects that may result.

Nuclear Accidents

Whether the process of nuclear fission is needed to efficiently generate electricity for people or to fuel the nuclear weapon industry, nuclear power has been an ever growing industry for the past 50 years with no end in sight. Unfortunately, due to the obvious risk of the operation, the United Nations (2011) has reported 35 serious accidents to have occurred at nuclear facilities between 1945 and 2007. All of which is assigned a numerical rating using the International Nuclear Events Scale (INES) to assess the severity and safety significance of each event from level 1 as the least severe to level 7 as the most severe (International Atomic Energy Agency, 2009).

One of the most significant accident occurred in Chernobyl on April 26, 1986. Due to the large amount of fission products released from the reactor core, this nuclear accident was the first one ever to receive a level 7 rating on the INES. It was reported that 28 nuclear plant employees were killed and 106 employees were injured and diagnosed with acute radiation syndrome due to the high doses of radiation received (USNRC, 2013). One of the major impacts from the accident was the release of the unconfined radioactive plume, containing mainly Xenon gas, Cesium-137 and Iodine-131 (WNA, 2013). The radioactive cloud expanded to neighbouring countries over Northern Europe resulting in the contamination of drinking water, water bodies, animals, soil, plants, and crops. Today, the major health effect associated with the Chernobyl accident is thyroid cancer, particularly amongst children. In the contaminated areas of Belarus, Ukraine, and the Russian Federation, a dramatic rise (5,000 cases) in thyroid cancer has been diagnosed in individuals who were children at the time of the accident (WHO, 2006). WHO (2006) speculates that the bioaccumulation of radiation in the cow's milk, in combination with their iodine deficiency diet, as well as the children's sensitivity to radiation are the likely causes of the increased incidence rate of radiation-induced thyroid

cancer. The Chernobyl incident is an example of how nuclear accidents can cause detrimental impacts to the surrounding environments by contaminating our food chain and drinking water systems.

The most recent nuclear catastrophe occurred at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant in Japan. On March 11, 2011, an earthquake and tsunami caused extensive damage to the nuclear facility that led to the release of radioactive material to the atmosphere and the Pacific Ocean. As of 2013, the nuclear facility continues to experience radionuclide leakage creating world-wide concerns regarding the potential risk of radiation exposure and seafood safety (TEPCO, 2013a). Through the assessment of this level 7 INES incident, IRSN (2012) estimated that 135 different types of radionuclides and their respective progeny, including isotopes of Tellurium, Neptunium, Radioiodines, and Cesium were released. Between March 2011 and February 2012, the Japanese Ministry of Health analyzed 18,350 food products for the 3 major isotopes released in this incident (iodine 131, cesium 134, and cesium 137) and found 642 of the products to have exceeded the standard radiation limit (IRSN, 2012). The fallout of the accident have contaminated products including leafy vegetables, fruits, tea leaves, mushrooms, cow's milk, and seafood. In contrast to the Chernobyl accident, not only did the radioactive plume released radiated particles into the terrestrial environment, the radionuclides released from the plant have impacted the marine ecosystem due to the plant's close proximity to the ocean body. During the summer of 2011, the Japanese authorities sampled marine organisms around the power plant for levels of Cesium 134 and 137 and found some organisms, such as wakame, sea urchins, and Japanese sand lances, to have levels exceeding the provisional regulation limits (IRSN, 2012). Although certain aquatic life around the Fukushima district has been found to exceed the maximum allowable levels for consumption of Cs-134 and Cs-137, there has been no evidence that seafood caught off the coast of North America has exceeded the national safety food limits. The Canadian Highly Migratory Species Foundation tested Pacific Albacore Tuna (a migratory fish that travels in Japanese waters) for radioactive material and no residues of I-131, Cs-137, and Cs-134 were detected in the samples (CHMSF, 2013). This is a possible indication that radionuclide contamination of seafood is localized in the region of Japan therefore, North American citizens should not be concerned with the possibility of contamination in seafood unless new research states otherwise.

Accumulation and excretion of radioactive material by marine organisms

A concern for seafood radioactive contamination is bioaccumulation. Bioaccumulation of radiation refers to the accumulation of radionuclide in the tissues of living organisms. Fish undergoes bioaccumulation as it uptakes radionuclides when it ingest contaminated phytoplankton, sediments, or water. Although the consumed radioisotopes are deposited into their body, over time, they are excreted through their urine, gills, and feces (Pacchioli, 2013). While Cs-134 and Cs-137 has a relatively long half-life, they are not persistent in fish and phytoplankton. Radiocesium concentrates in the muscle tissues, such as filet of fish, but their excretion rate is relatively efficient, with a daily loss of 2% (Fisher, Madigan, & Baumann, 2012). In addition, radiocesium has a lower uptake in marine phytoplankton as opposed to freshwater phytoplankton due to the higher abundance of potassium and sodium in the sea.

Another concern of radioactive contamination is biomagnification and this refers to the increase of radionuclide concentration as it moves up the food chain. Cesium shows modest biomagnification in the food chain, much lower than methyl-mercury due to its high assimilation efficiencies and excretion rates in fish (Fisher et al., 2012). By relating these facts to the Fukushima contamination, if the marine water is contaminated with Cesium radionuclide, the risk of ingesting high concentrations of radiation would be low to negligible.

Current findings

Since the Fukushima nuclear plant incident, Japan has made continuous efforts in monitoring for radiation in their water bodies, ocean soils, and foods. They performed nuclide analysis of fish and shellfish at different location points, focusing on ocean areas within 20 km radius of Fukushima Daiichi (TEPCO, 2014). To this day, the majority of the fish caught were found to contain Cs-134 and Cs-137 varying in the degree of concentration, a few fish samples have even measured to 100,000 Bq/kg (TEPCO, 2013b). However, from the data collected by Japanese Ministry of Health, Labour, and Welfare (MHLW), the radionuclide testing revealed that high counts of radioactive contamination of food is localized to the prefectures surrounding the Fukushima Daiichi nuclear plant, such as Ibaraki, Tochigi, and Gunma (Kendall, 2012).

In Canada, the Canadian Food Inspection Agency (CFIA) has conducted testing for radioactivity in domestic fish. On August 22, 2011 and February 10, 2012, they have caught fish samples from the coast of Vancouver Island, mainland rivers, and coastal waters off of Port Hardy. The tested samples included albacore tuna, salmon, pollock, and hake. The results of all the samples were lower than the minimum detectable concentration, therefore, the products were below Health Canada's safe action levels (CFIA, 2013).

The United States has also implemented rigorous surveillance on seafood imported from Japan and domestic seafood harvested from the US Pacific coastal waters. As of March 2014, the US Food and Drug Administration has found no evidence that the seafood supply harvested from the coastal waters of US are present with Fukushima radionuclides and stands firm on the fact that the public should not be concerned with seafood contamination (U.S. Food and Drug Administration, 2014).

Role of EHOs

This research paper was written from an environmental health officer's perspective whose mandate is to protect the health of the public. The findings of this research will shed some light on the current status of BC's seafood supply in regards to radiation pollution from Fukushima. The role of the environmental health officer is to act as a risk communicator to the public. By providing the public with the risks or potential risks, they will be able to make informative decisions on what they feel is appropriate to maintain their health and safety standards. Thus, this report serves as a risk communication tool to educate and inform the public that there is an absence of radiation pollution in the seafood supply harvested in the Pacific Ocean.

Purpose of Research

Radiation is a growing subject in this world and radiation research has advanced significantly over the past century. Due to the growing exposure of anthropogenic radiation, the public is more aware and concerned for the potential health impacts. It is crucial to gain an understanding of our surrounding to determine the risk in order to exercise protective control over our health.

The purpose of this research was to analyze fish harvested in the Pacific Ocean for the presence or absence of radiation contamination in the BC seafood

supply. In return, the results of this study will answer questions from concerned citizens regarding the risk to consume local seafood.

Theory: Basic Radiation Physics

Radioactivity

When atoms of a given element with excess nuclear energy (i.e. in the nucleus) are unstable, they undergo nuclear transformations and lose their excess energy through a process known as **radioactive decay**. Therefore, they are called radioactive nuclides or **radionuclides**.

The time rate of change (decay) in the number $N(t)$ of nuclei of a radioactive element is proportional to the number of nuclei present:

$$\frac{-dN(t)}{dt} = \lambda N(t)$$

The proportionality constant λ is called the **Decay Constant, in units of 1/second (s^{-1})**.

Therefore: $N(t) = N_0 e^{-\lambda t}$

Where N_0 is the number of nuclei at time = 0 and t the time in seconds.

The quantity of radioactive material, expressed as the number of atoms N undergoing radioactive decay per unit time, is called activity (A).

$$A = \lambda N$$

A is expressed in units of Becquerel (Bq)

Types of Ionizing Radiation Emitted by Radioactive Elements

In general, when atoms undergo nuclear transformations (decay), they may emit one or more of the predominant radiations: gamma rays (γ), Beta (β) particles or Alpha (α) particles. Some heavy elements (e.g. Californium-254) emit also neutrons in addition to γ , β , and α .

Beta decay: It occurs with emission of electrons when a nucleus has either too many neutrons (emission of negative electrons) or too many protons (emission of positive electrons or positrons).

Alpha decay: occurs essentially in heavy elements with ejection of ${}^2_2\text{He}^4$ nuclei (Alpha particles) from decaying nucleus.

Gamma rays: They are emitted after Beta (β)-decay or Alpha (α)-decay when the nucleus is unstable (metastable).

In this project, the focus will be on gamma emitters such as Cesium-134 and Cesium-137.

Half-life T of a Radioactive Material

The half-life T of a radioactive material is the time required for the radioactivity to decrease by 50%. The half-life is related to the decay constant λ by the expression:

$$T = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

- Physical half-life T_p : It is the time required for a radioactive element to lose half of its radioactivity by physical decay.

$$T_p = \frac{0.693}{\lambda_p}$$

λ_p = physical decay constant

- Biological half-life T_b : It is the time taken for the radioactivity of a material in a specified tissue, organ or region of the body (or any other specified biota) to halve as a result of biological processes (excretion).

$$T_b = \frac{0.693}{\lambda_b}$$

λ_b = biological decay constant

- Effective half-life T_e : It is the combination of physical half-life and biological half-life

T_e is expressed as:

$$T_e = \frac{T_p T_b}{T_p + T_b} = \frac{0.693}{\lambda_e}$$

λ_e = effective decay constant = $\lambda_p + \lambda_b$

Radiation Dosimetry: Absorbed Dose, Equivalent Dose, and Effective Dose

- **Absorbed dose D:**

It is the amount of ionizing radiation energy ΔE absorbed per unit mass Δm of biological tissue:

$$D = \frac{\Delta E}{\Delta m}$$

The absorbed dose D is measured in units of Gray (Gy) and 1 Gy = 1 Joule/Kg.

The absorbed dose alone does not determine the biological effects.

- **Equivalent dose H:**

The equivalent dose H applies only to single irradiated organs or tissues, not the whole body. It is equal to the product of the absorbed dose D by a dimensionless radiation weighting factor W_R specific to each type of radiation:

$$H = W_R D$$

The equivalent dose is measured in units of Sievert (Sv) and 1 Sv = 1 Joule/Kg

For X-rays and gamma rays, $W_R = 1$

- **Effective Dose E:**

The effective dose E takes into account both the type of radiation involved and the organ exposed to radiation.

E applies to the whole body. It is the combination of all organ equivalent doses H_T to convey a whole body dose' i.e. the weighted sum of all organ equivalent doses $W_T H_T$:

$$E = \sum_T (W_T H_T) = W_1 H_1 + W_2 H_2 + W_3 H_3 + \dots$$

Where:

- W_T is the tissue weighting factor for tissue T; it is a dimensionless quantity. Table 2 gives the value of for different organs and tissues.

- H_T is the equivalent dose of tissue T

Like the equivalent dose H, the effective dose E is measured in units of Sievert (Sv).

Important to note: The effective dose is the dosimetric quantity that determines the biological effects of ionizing radiation.

Table 2: Tissue Weighting factor, WT

Organ or tissue	WT
Lung, stomach, colon, bone marrow, breast	0.12
Gonads	0.08
Thyroid, esophagus, bladder, liver	0.04
Bone surface, skin, brain, salivary glands	0.01

Methodology

Based on their availability and popularity in BC, fifty-two samples were chosen from ten species of fish and three species of shellfish (refer to table 3). All the samples were purchased at local seafood markets in the Greater Vancouver Regional District. For each type of fish, two samples were taken from different seafood markets for a total of twenty fish samples. And for each shellfish type, three to four samples were taken from different markets for a total of thirty-two shellfish samples.

Results

The radionuclide analysis of fish and shellfish samples bought from various local seafood vendors in Greater Vancouver Regional District (GVRD) in 2014 of January and February are shown in appendix 1 and 2. A summarized version is shown below in table 5. Cesium-134, Cesium-137, and other radioisotopes were not detected in all 52 fish and shellfish samples collected in January and February 2014. For all of the analyzed samples, the GR-135 Plus digital screen displayed “background” indicating that

Table 3: Selected fish and shellfish species

Fish and Shellfish Species	Harvest Location	No. of Sample
Ahi Tuna	Pacific Ocean	2
Albacore Tuna	Pacific Ocean	2
Rockfish/Snapper	Pacific Ocean	2
Sole	Pacific Ocean	2
Halibut	Pacific Ocean	2
Black Cod	Pacific Ocean	2
Ling Cod	Pacific Ocean	2
Pacific Cod	Pacific Ocean	2
Sockeye Salmon	Pacific Ocean	2
Coho Salmon	Pacific Ocean	2
Mussel	Pacific Ocean	12
Clam	Pacific Ocean	10
Oyster	Pacific Ocean	10

The samples were analyzed with the gamma-ray spectrometer called *EXPLORANIUM*® GR-135 Plus “Identifier” Radioactive Isotope Identification Device (RIID) to identify the presence or absence of gamma radioactive isotopes. This machine is up to date with its calibration frequency. The detection limit of the instrument is given in terms of dose rate in the user’s manual: 0.01 µSv/hr. This is acceptable as the object of testing is to detect the presence of S-137 and Cs-134 in fish, not to measure the radioactivity concentration in the samples.

Although the GR-135 Plus detects a variety of radionuclides, this research study was monitoring closely for Cesium-137 and 134, as the presence of these two radionuclides will highly indicate an association with radiation contamination from the Fukushima fallout.

there were no unusual radionuclide(s) detected other than the background nuclide that is naturally existing in the environment during the 1 minute sample period. Thus, all samples were tested negative for the presence of radioactivity.

Discussion

The absence of radiation from the fish and shellfish samples is a positive finding for seafood consumers as well as the fishing industry. This suggests the marine organisms harvested from the Pacific coastal waters of North America that are sold at the seafood markets in GVRD are likely not contaminated with radiation from Fukushima. To extrapolate the results further, there should be no health implication from radiation exposure when consuming seafood harvested from the west coast.

There are several possibilities to explain why the fish and shellfish samples tested negative for Cs-134 and Cs-137. Firstly, the absence of radiation could suggest that the Pacific Ocean was not impacted by the large release of radionuclide waste from the damaged nuclear plant in Fukushima. As the largest ocean on earth, it is likely that the vast volume of Pacific Ocean has rapidly and effectively diluted and dispersed radioactive waste through the mixing of currents. It is possible that dilution would successfully reduce the level of radionuclide concentration resulting in negligible impact to marine life. Secondly, suggested by the data released by the Japanese MHLW (Kendall, 2012), radioactive contamination is only localized

as radioisotope concentration appears to be prevalent only in prefectures near Fukushima. Since contamination is not widespread throughout Japan, this indicates that radioactive waste does not travel far distances and will not travel at a global scale, thus, the further one is away from the contamination site, the less likelihood a contamination can occur. For that reason, countries surrounding Japan, let alone Canada and United States, would not be affected by the nuclear contamination. Lastly, if marine organisms, especially migratory fish such as albacore tuna and sockeye salmon, uptakes radionuclides after exposure to contaminated sites around Japan, the extensive transoceanic distance

Table 4: Summary of radioactivity results from Pacific Ocean fish and shellfish samples collected in January and February of 2014.

	Species	Sample Code	Radioactivity (Absence or Presence)
Fish	Alhi Tuna	1A01, 1A02	Absence
Fish	Alhi Tuna	1B01, 1B02	Absence
Fish	Albacore Tuna	9A01, 9A02	Absence
Fish	Albacore Tuna	9B01, 9B02	Absence
Fish	Sole	3A01, 3A02	Absence
Fish	Sole	3B01, 3B02	Absence
Fish	Halibut	4A01, 4A02	Absence
Fish	Halibut	4B01, 4B02	Absence
Fish	Black Cod	5A01, 5A02	Absence
Fish	Black Cod	5B01, 5B02	Absence
Fish	Ling Cod	6A01, 6A02	Absence
Fish	Ling Cod	6B01, 6B02	Absence
Fish	Pacific Cod	10A01, 10A02	Absence
Fish	Pacific Cod	10B01, 10B02	Absence
Fish	Sockeye Salmon	7A01, 7A02	Absence
Fish	Sockeye Salmon	7B01, 7B02	Absence
Fish	Coho Salmon	8A01, 8A02	Absence
Fish	Coho Salmon	8B01, 8B02	Absence
Fish	Rockfish/Snapper	2A01, 2A02	Absence
Fish	Rockfish/Snapper	2B01, 2B02	Absence
Shellfish	Oyster	18A01, 18A02	Absence
Shellfish	Oyster	18B01, 18B02	Absence
Shellfish	Oyster	18C01, 18C02	Absence
Shellfish	Oyster	18D01, 18D02	Absence
Shellfish	Oyster	19A01, 19A02	Absence

Shellfish	Oyster	19B01, 19B02	Absence
Shellfish	Oyster	19C01, 19C02	Absence
Shellfish	Oyster	10A01, 10A02	Absence
Shellfish	Oyster	10B01, 10B02	Absence
Shellfish	Oyster	10C01, 10C02	Absence
Shellfish	Clam	11A01, 11A02	Absence
Shellfish	Clam	11B01, 11B02	Absence
Shellfish	Clam	11C01, 11C02	Absence
Shellfish	Clam	12A01, 12A02	Absence
Shellfish	Clam	12B01, 12B02	Absence
Shellfish	Clam	12C01, 12C02	Absence
Shellfish	Clam	12D01, 12D02	Absence
Shellfish	Clam	13A01, 13A02	Absence
Shellfish	Clam	13B01, 13B02	Absence
Shellfish	Clam	13C01, 13C02	Absence
Shellfish	Mussel	14A01, 14A02	Absence
Shellfish	Mussel	14B01, 14B02	Absence
Shellfish	Mussel	14C01, 14C02	Absence
Shellfish	Mussel	15A01, 15A02	Absence
Shellfish	Mussel	15B01, 15B02	Absence
Shellfish	Mussel	15C01, 15C02	Absence
Shellfish	Mussel	16A01, 16A02	Absence
Shellfish	Mussel	16B01, 16B02	Absence
Shellfish	Mussel	16C01, 16C02	Absence
Shellfish	Mussel	17A01, 17A02	Absence
Shellfish	Mussel	17B01, 17B02	Absence
Shellfish	Mussel	17C01, 17C02	Absence

would have provided enough time for the fish to excrete the radionuclides out of their bodies as fish can excrete 2% of the absorbed radiocesium per day. Furthermore, as previously mentioned, marine phytoplankton uptakes radiocesium at a lower amount due to the high potassium and sodium chemistry in the ocean water, therefore, if the fish ingest the marine phytoplankton, it would be ingesting lower concentrations of Cs-137 and Cs-134. As a result, the small volume of radiocesium will have been excreted upon the arrival at the North American coast.

Although 3 years has passed since the Fukushima disaster, the effect of radiation released from the incident continues to be a topical news item for people around the world. Due to the public's well versed knowledge on the long term effects of radiation exposure, concerns for health risk associated in consuming seafood products from the Pacific Ocean is much expected and well within reason. Although research scientists and government organizations have conducted scientific studies and found no reasons to believe pacific seafood products to pose a health hazard to the human body, mistrust and speculation continue to persist in the public for many reasons. For example, the lack of continuous monitoring by government agencies and little research conducted towards marine biota contamination after the incident is not sufficient for the public to completely dismiss the risks involved. More research such as this one is necessary to increase reliability and assurance factors to safely consume seafood. Also, some media outlets continue to fuel panic through publishing misleading news articles and conspiracy rumors to falsely sway the public from factual information. In addition, the lack of confidence in government officials and the suspicion of government's intention pose a challenge for government bodies to communicate the facts and relay messages to the public. With all the contradicting information given by different groups and organizations, it is important for the public to look at the facts within the messages. And through further investigation, one would determine if the facts are supported by evidence that is considered reliable and sound. With the absence of radiation found in all the fish and shellfish samples in this research, it coincides with the other scientific evidence regarding radioactive contamination in seafood harvested post-Fukushima. Although there was one prominent finding of Cs-134 and Cs-137 in Bluefin Tuna (Madigan, Baumann, & Fisher, 2012), the concentrations detected were at negligible amounts to pose a risk to the population. At this moment, the lack of evidence in radioactive contamination

suggests that seafood supply harvested from the West Coast of North American is safe to consume. Research has shown that it is either free from radioactivity or radionuclides are at concentrations far below the safety standard to result in any significant health effect if consumed.

Limitation

Due to the lack of time and resources, only a small proportion of samples could be obtained for testing, therefore, increasing the number of samples and increase the fish and shellfish species would better represent the seafood variety consumed by Canadians.

Conclusion

The findings of this research correlate with the public health messages communicated by government agencies such as CFIA in Canada and FDA in the United States. To this day, there is no evidence leading to believe seafood consumed in BC is contaminated with radionuclides released from the Fukushima nuclear plant. Although research has found radiation in some fish species, the level of radioactivity is well below the risk level where it can induce harm to human health.

Radiation exposure is a concerning hazard to public health as it can result in adverse health effects such as acute radiation syndrome and cancer, therefore, it is extremely important to make well informed choices to reduce the risk of radiation exposure. Although one cannot guarantee that the Canadian food supply will be forever free of radioactive contamination, at this moment, with the findings of this research study and others, there is no evidence to believe that seafood harvested off of the Pacific Coast and sold in BC is contaminated with radiation.

Further, while radiation in fish has not been found at levels that would be harmful to human health, it is important to continue radiation testing on domestic and imported fish in order to monitor for any changes in radiation levels. The devastating incident at the Fukushima Daiichi Nuclear Power Plant will serve as a reminder to us all that radiation exposure will continue to be a risk to public health and our ecological system as long as nuclear technology, weaponry, and activity persist. As a result, the ongoing monitoring of our surrounding environment is crucial to alert us of any potential risk to harm.

Recommendations for future studies

Further research can be conducted on the following:

- Widening the fish and shellfish selections by increasing sample frequency and species type
- Use other radiation devices to test for the presence or absence of alpha and beta radiation
- Conduct further research on whether there is an environmental impact on British Columbia after the Fukushima incident through collecting rain samples, Pacific Ocean water samples, soil samples, etc.
- Sample imported fish, shellfish, crustaceans, and/or aquatic plants that are harvested from Japan or areas in the Southeastern or Eastern Asia region to determine if imported products contain any presence of radiation.

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