Nuclear Pollution and Its Effects on Marine Ecosystems

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Abstract. Nuclear pollution is a severe environmental problem deriving mainly from industrial activities and can pose extremely negative affect to plants and animal bodies. Nuclear waste also has extreme negative effect on human bodies and can cause various diseases including skin disease, infant deficiency and cancer. There are few studies about the effect of nuclear waste to food webs and how it affects different trophic levels within the ecosystems. This study explains the effect of nuclear pollution on the marine ecosystems and focuses on the transportation of the pollutants through food webs as well as the sufferance of species in different trophic levels. It is concluded that nuclear pollutants can experience biomagnification within food webs and are transported to higher trophic levels by their food consumption. In addition, planktons, fish and seals are representative species of different trophic levels in marine food webs, and these species all suffer from nuclear contamination after nuclear pollutants enter their bodies through biomagnification. Future studies can focus on the process of energy transportation within food webs, such as whether the absorption of energy would be less efficient by higher trophic levels after consuming organisms with nuclear pollutants inside comparing to organisms with no nuclear pollutants. This study propose a explanation of respective effects of different trophic levels in marine ecosystems by nuclear pollutions, which can call on attention to the extreme negative effect of nuclear pollution to marine ecosystems.

Keywords: Nuclear pollution, ecosystem, food webs, biomagnification.

1. Introduction

Nuclear pollution contains radioactive and hazardous waste that poses extremely harm to the ecosystems. Since nuclear energy would not release green house gases when used to produce electricity, it is increasingly applied to produce electricity. In addition, nuclear energy can also be applied in various industries, including nuclear medicine and weapon production. Thus, its high level of exploitation indicates that nuclear waste would not be decreasing in the near future [1]. Nuclear pollution has severe harm to the ecosystem. Nuclear waste contaminates soil and water environment, by which it enters plant and animal bodies and experience biomagnification through food webs. Ultimately, the nuclear waste would accumulate in human bodies, adhere in different organs and tissues, and has severe negative effects to human such as increased potential of having cancer and infant deficiency. Also, since nuclear waste can release radiation, this would lead to skin disease, such as itching, tingling and erythema, if it is exposed to human skin in great amount. Under such circumstances, it is important to research on the situation of nuclear pollution, and evaluate the effect of the nuclear waste in the ecosystem and organisms.

Previously, researchers have conduct studies on the effect of nuclear pollution on certain environment such as the marine ecosystems or the territorial ecosystems. They have also concluded the effect of certain industrial activity that includes the usage of nuclear energy such as nuclear fuel cycles. It is suggested that the nuclear waste from nuclear fuel cycle includes uranium (U)-238, U-235 and U-234, which all enters the ecosystems. Moreover, previous studies also overview on the certain species suffering from the nuclear contamination, such as marine mammals and fish, to identify the harm of radioactive waste on the organisms. However, there lacks studies evaluating the effects on the energy consumption of nuclear contaminated organisms by higher trophic levels, and it is remained unknown whether nuclear waste accumulated in the organs of animals would effect the absorption of nutrients and how nuclear pollutants pose negative effects through food webs and harm organisms on different trophic levels.

In this study, current situation and basic information of nuclear pollution is included, as well as the management of nuclear pollutants. In addition, this study also evaluates the effect of nuclear waste on food webs, including the way radioactive waste enters the bodies of organisms. Lastly, this study explains how nuclear waste poses harm to different trophic levels through food webs in marine ecosystems. This study can improve the understanding of the effect of nuclear pollution within the material and energy transportation through food webs.

2. Nuclear Pollution

"Nuclear waste" and "Radioactive waste" are similar terms, which are both defined by a kind of hazardous waste derives from nuclear reactors, fuel plants or industries. The nuclear waste contains substances that are originally radioactive or are polluted to gain radioactivity [1].

2.1. Sources

The main sources of nuclear waste derive from nuclear fuel cycle, nuclear weapons, industrial wastes, naturally occurring radioactive materials (NORM) and fossil fuel consumption. First of all, in nuclear power plants, partially used nuclear fuel (PUNF) is generated and serves as a nuclear waste to the ecosystems [2]. The front end of the nuclear fuel cycle generates depleted uranium (DU), the uranium (U)-238 isotope and few U-235 content, while the back end of the cycle generates fission products from the nuclear reactors such as U-234. Secondly, nuclear waste from nuclear weapons is mainly alpha emitters such as plutonium (Pu)-239, Pu-238 and polonium (Po). Thirdly, industry produce nuclear waste that contain various emitters, including alpha, beta, or gamma emitters, from activities such as oil well logging. Fourthly, NORM is mainly alpha emitters from elements such as potassium (K)-40. Lastly, fossil fuel consumption results in the exposure of radioactive atoms such as U and barium (Ba) from the crude oil or coal to the air through excavation.

2.2. Components

Nuclear waste mainly contains radionuclides, which are unstable chemical elements and produce radiation through the process of decaying or breaking down to reach more stable conditions. Nuclear waste is classified to mainly four categories: Very-Low-Level Waste (VLLW), Low-Level Waste (LLW), Intermediate-Level Waste (ILW) and High-Level Waste (HLW), and the volumes of the categories are presented below in Fig. 1. As is presented in Fig. 1, the main kind of waste is Low-Level Waste, containing 74% of the total pollutants; the second most kind of waste is Very-Low-Level Waste and owns a proportion of 15%; Intermediate-Level Waste contains 10% of the total waste; and the least proportion is owned by High-Level Waste, containing 0.2% of the total waste [3].

The half life of radionuclide is a key indicator of classifying nuclear waste, which represents the time radionuclide needs to lose half of its radioactivity. The more radioactivity a radionuclide owns, the faster it decays, resulting in a shorter half life which emit more gamma rays. On the other hand, radionuclides with less radioactivity have longer half life and tend to be alpha and beta emitters. To be specific, VLLW (concrete, bricks, valves, etc.) is mainly resulted from natural radioactivity and has no negative effects on human or the ecosystems. LLW has radioactivity below 4 gigabecquerels per tonne (GBq/t) of alpha activity and 12 Gbq/t beta-gamma activity, and is mainly consistent of paper, clothing, rags from industry or nuclear fuel cycle. Moreover, ILW generates heat for less than two kilowatt/cubic meter (kW/m^3) and forms from contaminated reactor decommission such as chemical sludges and resins. Lastly, HLW emit heat more than 2kW/m^3 and generates from the reactor core of nuclear fission.

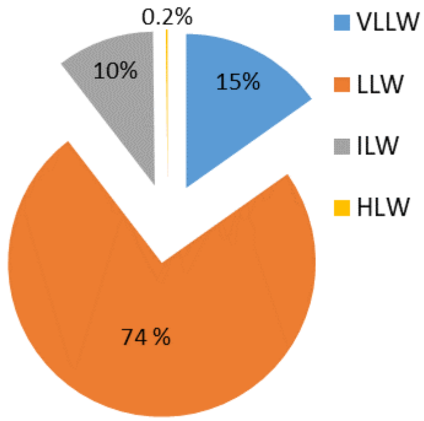

Figure 1. Radioactive Waste Volume. https://www.euronuclear.org/wp-content/uploads/2019/02/Waste-types.png

2.3. Current Situation and Management

As radionuclides in nuclear waste lose their radioactivity, this process can last for tens of thousands of years, making nuclear waste extremely hazardous and present threat for future generations. Information from world nuclear association suggests the aims of nuclear management is to reduce the volume of nuclear waste and transforming it into immobile forms to decrease its hazard. The main treatment methods of nuclear waste are incineration, compaction, cementation, vitrification.

First of all, incineration is mostly suitable for treating LLW, which involves incinerating the radioactive waste in a special kiln to 1000°C to reduce the volume of the waste. During the process, the gases produced must be filtered before entering the atmosphere and the resulting ash from the incineration must experience further treatment such as cementation to be disposed.

Secondly, compaction reduces the volume of nuclear waste by simply compact waste with compactors, which have compaction force up to 1000 tonnes. This method is mostly presented to treat with LLW and ILW.

Thirdly, cementation is used for treating ILW and LLW. Cementation involves using special grouts to immobilize the nuclear waste to forms such as sludges or flocks. During the process of cementation, nuclear waste is firstly placed in containers while grout is added afterwards. Then, the mixture of nuclear waste and grout is transformed to the form of powder. After that, sludges and flocks are prepared and the powder mix of nuclear waste and grouts is added. Later, the produced solids can be stored or disposed.

Last but not least, vitrification is used for treating HLW and also lower level wastes. The process of vitrification is able to immobilize nuclear waste and is widely applied in countries in Europe and Asia. HLW is mainly presented in liquid forms and needs to be transformed to powder by calcination. Following that, the powder is incorporated into borosilicate glass, which can remain stable for thousands of years, and then poured in to canisters to form solid mixture and sealed for ultimate storage or disposal [4].

3. Effects of Nuclear Pollution on Organisms

Nuclear waste travel through various environmental pathways including the atmosphere, water, territory and poses negative effects on the ecosystems via emission of radiation.

3.1. Ways Nuclear Wastes Enter Organisms

3.1.1 Atmosphere

Nuclear waste is released into the atmosphere through nuclear fuel cycle or incineration. Radionuclide particles in the atmosphere may travel via rain or snow and then land on water, soil or surface of plants and animals. Particles that land on plant surfaces may enter the body of herbivores through ingesting the plants; while particles that land on soil and water may be dissolved in waters and enter plant tissue through the uptake of water by roots.

3.1.2 Water

Water ecosystems contain nuclear waste from deposition of atmospheric pollutants, release of radioactive water, and industrial activities such as mining and seepage. The radioactive particles move with the water and may deposit on rocks or the surface of marine plants. Later on, radioactive particles may initially enter the plant tissue through the uptake of water and then be transferred to animals through consumption of the contaminated plants, or simply enter marine animals through uptake of water with radioactive substances or plants with the pollutants on their surface [5]. Plankton may contain radioactive pollutants after the uptake of contaminated water, while fish in marine ecosystems may be contaminated with radioactive pollutants after ingesting polluted plants such as kelp.

3.2. Negative Impacts of Nuclear Wastes in Organisms

Radioactive pollutants in nuclear waste have negative effects on the DNA of organisms. As demonstrated by previous study, a carbon metabolism pathway can be altered by radiation and affects the DNA methylation [6]. In the Fig. 2, (A) represents the normal carbon pathway while (B) represents the altered pathway by radiation. In the normal carbon pathway in Fig. 2.A, methionine (MET) is transformed to S-adenosylmethionine (SAM) with the help of methionine adenosyl transferase 2A (MAT2A). After that, the methyl group (CH_3) of SAM contributes to the maintenance of DNA methylation after replication with DNA methyltransferase DNMT-1. On the other hand, when exposed to radiation, the transformation from MET to SAM is disrupted and will cause nonsufficient level of CH_3 for DNA methylation replication. As a result, hemi-methylated DNA is formed after replication instead of normal form of methylated DNA.

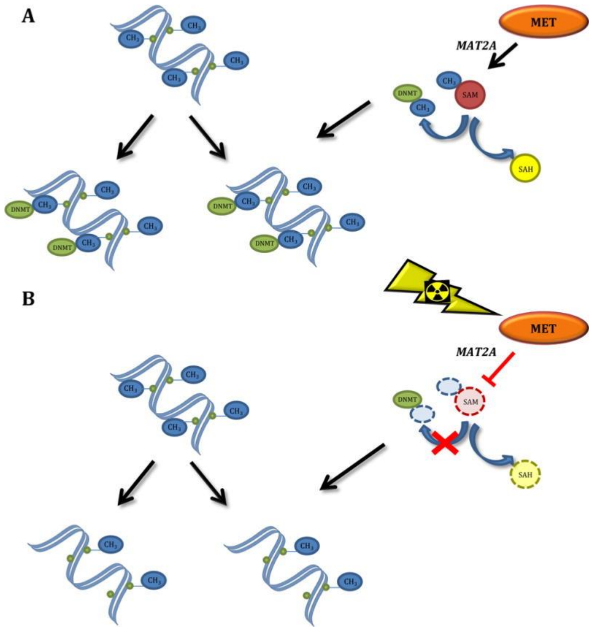

Figure 2. Alterations in the methionine cycle as a mechanism of ionizing radiation-induced DNA hypomethylation. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5411327/bin/nihms854737f2.jpg

4. Impacts of Nuclear Pollution to Food Webs

4.1. Biomagnification of Nuclear Waste

Biomagnification represent the process of uptake of a chemical, such as heavy metal, pesticide or microplastic, is transported via food chains to higher trophic levels so that the concentration of the chemical in the apex level of the food chain exceed that of the equilibrium level in the ecosystem [7].

Chemicals that can experience biomagnification need to perform high persistence from degrading in the environment. Consistently, radioactive pollutants mostly have half lives that last for tens of thousands of years, as is shown in Table 1. From the information in the table, Uranium-238 has half life of 4.468 billion years; Uranium-235 has half life of 703.8 million years; Plutonium-239 has half life of 24.11 thousand years; Cesium-137 has half life of 30.05 years; and Polonium-210 has half life of 138.38 days. These pieces of information shown that while half life of radionuclides varies extremely between different elements, most of the half lives last over years. Since the energy transportation and biomagnification via food webs is a dynamic process and happens continually within days through the process of foraging and the consumption of lower trophic levels, the persistence of radioactive pollutants is sufficient to perform biomagnification through the food web. As a evidence in previous study, the existence of Cesium-137 is testified in the arctic food chain, consisting lichen-reindeer/caribou-man, and also performs biomagnification in the same food chain [8].

Table 1. Partial description on half-life of radionuclides

Radionuclides	Half life
Uranium-235	$7.038*10^8$ years
Uranium-238	$4.468*10^9$ years
Plutonium-239	$2.411*10^4$ years
Carbon-14	5730 years
Radium-226	1600 years
Cobalt-60	5.270 years
Cesium-137	30.05 years
Polonium-210	138.38 days

4.2. Impacts on Organisms of Different Trophic Levels in Marine Ecosystems

In previous study, plankton, which is the primary producer in marine food chains, is negatively affected by nuclear waste, demonstrated with the example in lake Karachay, which is contaminated by radioactive waste since 1951 [9]. As a result, the biodiversity of the planktons in the lake Karachay is extremely low, with only four species available in the reservoir of 0.16 million cubic meters. As radioactive pollutants enter higher trophic levels, fish is negatively affected by the pollutants as well [10]. The reproductive function is negatively affected in fish, as well as the fertility rate and the development of offspring. Abnormalities and deficiency rate is largely increased in the fish living in the radioactive contaminated water. Marine mammals such as Harbour seals (*Phoca vitulina*) are in the apex level of marine ecosystems, and they are also affected by biomagnification of radioactive pollutants, namely Carbon-14 [11]. The biomagnification of Carbon-14 in the seals increase the risk of radioactive dose in the organism.

4.3. Impacts on Human

Human is in the apex level in the trophic level in ecosystems. Thus, nuclear waste can enter human body through the transportation via food webs as well as other pathways. The existence of nuclear waste in human can cause negative health effects and sickness to human.

4.3.1 Ways nuclear waste enters human bodies

Nuclear waste enters human body through four types of contamination: internal contamination, radioactive contamination, external contamination and radiation exposure. Internal contamination regards the process by which human ingest or inhale radioactive pollutions when eating, drinking and breathing. It also represent the process radioactive pollutants enter the human body through wounds in the skin. After the pollutants enter human body, they might exit the body through sweat, urine or exhalation while some of the pollutants might deposit in different organs inside. Radioactive contamination occurs when radioactive pollutants deposit on the surface of objects or human bodies through the atmosphere, water, territory or other organisms. This process is similar to external contamination, by which radioactive pollutants interact with the surface of human body and can even cause internal contamination when the pollutants transfer into the human body. Radiation exposure is presented when humans are exposed to the emission of radiation by radioactive pollutants. During radiation exposure, the radiation passes through human body in the forms of waves or particles. This mostly commonly happens occasions such as x-rays.

4.3.2 Health effects of nuclear waste to human bodies

The exposure and contamination of nuclear waste can cause both short-term health effects and long-term health effects on human.

Short-term health effects of radioactive pollutants includes Acute Radiation Syndrome (ARS) and Cutaneous Radiation Injury (CRI). ARS occurs when human receive high rose of radiation in a short period and the radiation penetrates at least most of the human body. Initial symptoms of ARS includes nausea, headache, vomiting and diarrhea, starting minutes to days after the intense exposure of radiation and might last for a short period of minutes to days. These symptoms might be followed by another sickness including tiredness, fever, coma and skin damages such as inching or appearance of redness. ARS is often cured by reducing infections, maintaining hydration and recovering bone marrow. CRI is a symptom of ASR that specifically happens when radiation cause skin damages to people. Symptoms of CRI are mainly itching, tingling, erythema (skin redness) and edema (swelling).

Long-term health effects of radioactive pollutant on human mainly includes cancer and prenatal radiation exposure. The greater the exposure of radioactive to human, the greater the risk of developing cancer. Radiations such as x-rays and gamma rays are called ionizing radiations, which are capable of damaging DNA in human bodies and cause cancer consequently. Prenatal radiation exposure occurs when fetus is exposed to radiation from the mother's body or penetrated radiation. This effect is most severe before the 18^{th} week of pregnancy. A developing fetus experience high rate of cell division and is thus highly sensible of radiation, which may cause stunted growth, abnormal brain functions or cancers to the fetus [12].

5. Conclusion

Nuclear pollution is a severe environmental problem that can pose extremely negative affect to plants and animal bodies and accumulates through food webs that lead to human body as a ultimation. This study focuses on the transportation of nuclear waste through the food web and how it affects organisms in different trophic levels. Having the atmosphere, water environment and territorial environment as medium, nuclear waste enters the body of organisms by directly being consumed with basic live activities, such as organisms breathing in the particles in the atmosphere, or by being transported to organisms after they eat other species that have nuclear waste inside their body. In addition, nuclear waste can experience biomagnification through food webs in marine ecosystems and harm different trophic levels such as planktons, fish, seals and, ultimately, human bodies. In the future, researches can be conducted to study the effect of nuclear waste to the energy absorption in organisms and thus explain the specific effect of nuclear waste to the process of energy transportation through food webs in marine ecosystems as well as other environment conditions. This study serves as a explanation of pathways of nuclear waste entering food webs and how different species in the food webs is affected by nuclear pollution respectively, which help call on attention to the current situation of nuclear pollution and its harm to the ecosystems.

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