Marine Radioactivity Assessment Using Advanced Data Analytics Techniques

Project Report

Group 6 (Quan Gu, Cheuk Hong Ip, Ting Yu, Bo Zhi)

Data Analytics, San Jose State University

Data 240: Data Mining

Dr. Taehee Jeong

October 29, 2023

Abstract

This research is inspired by the concern of the nuclear water discharge to the Pacific Ocean from August 2023 from Fukushima, Japan, which might cause a significant increase in radiation levels in the marine ecosystem. The dataset was collected from the MARIS database, which consists of over 275,000 entries across 54 columns from 1999 to 2021, and aims to uncover hidden trends, patterns, and implications in nuclear waste management for the benefit of stakeholders. The analysis reveals significant temporal trends, depth-related variations in nuclear activity, and distribution patterns of different nuclide types. With the help of this examination, stakeholders, policymakers, and the public will be able to navigate the implications of this monumental decision and gain crucial insights into the potential outcomes of environmental, economic, and health. The patterns observed between 1999 and 2021 indicate that while nuclear energy remains a promising alternative to traditional energy sources, the environmental ramifications are profound. This study emphasizes the importance of effective nuclear waste management, the necessity for strict regulations, and innovative disposal methods. As the nexus between radiation levels and seafood safety becomes increasingly significant, an analysis has been conducted on global data from MARIS to delineate nuclear pollution trends.

Introduction

As a result of the Fukushima Daiichi nuclear power plant (FDNPP) disaster on March 11, 2011, the Japanese government resolved to discharge contaminated water of at least one million metric tons into the Pacific Ocean by August 2023. Both national and international policy discussions are expected to be impacted long-term by the release of radioactive material from Fukushima. The radiation from 137Cs is the most significant concern related to human health from the Fukushima release because it can cause genetic mutations and increase the risk of cancer in humans. This isotope has the ability to travel long distances and form soluble compounds that remain in various forms, such as mineral-free and particulate organic matter. It potentially poses a long-term threat to the environment (Liao et al., 2023). Seafood consumption with accumulated radioactive substances over extended periods can lead to various health complications. Due to the dispersal of radioactive pollutants by oceanic currents, these effects extend beyond Japan to other coastal countries and, eventually, to other water bodies (Guo et al., 2022). It has been shown that nuclear wastewater releases may lead to the emergence of genetically altered marine species in offshore areas, putting marine farming, fishing, and even the broader seafood industry at risk (Guo et al., 2022). The purpose of this study was to examine the trends in radioactive pollution found in the more than 275,000 items of MARIS IAEA and better understand the wider consequences of nuclear waste sampling. Hidden patterns and insights provide valuable information that can empower stakeholders' and policymakers' decision-making processes with the knowledge needed to develop more effective containment and mitigation strategies, safeguarding the environment and public health and raising public awareness.

Related Researches

As we all know, high-dose radiation exposure brings significant health hazards. (“Health Effects of Radiation,” n.d.). Through more than 100 years of study, scientists know quite a bit about how radiation harms living tissue. Radiation can directly break bonds in the DNA. In addition, it can break water molecules surrounding the DNA, which also produces damage to cells and organs. As a long-term effect, many searches mentioned that radiation could lead to cancer. In the actual case study, many groups focus on the Chornobyl accident, which happened in April 1986. Zablotska (2011) group found that ‘10–15 years after the Chornobyl accident, thyroid cancer risk was significantly increased among individuals exposed to fallout as children or adolescents’.

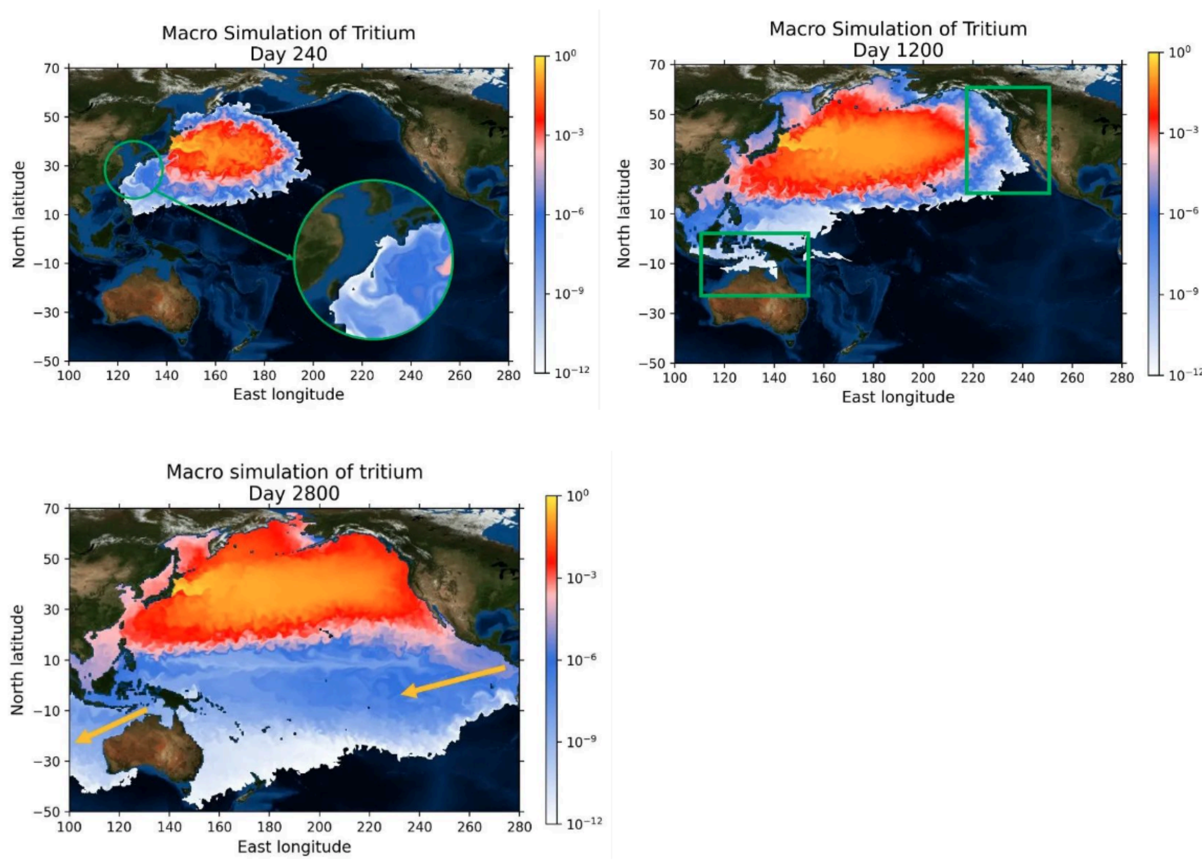
How about we keep a suitable distance from radiation materials? As common people, we do not live near nuclear power plants, nor do we experience any radiation in daily life. Is that safe? The answer is yes and no. Yes, we are safe because we are normally far from radioactive elements. However, the danger is around us. A peaceful ocean is a typical representation.

Nuclear pollutants go to the ocean for different reasons. One of the best-understood ways is the disasters. The most recent and famous one is the Fukushima disaster, which the IAEA classified as a level seven event, the highest in the world (“Fukushima disaster:” 2023). As Iqbal (2021) described, ‘The tsunami disrupted the emergency supply systems necessary to cool the plant’s reactors and caused the melting of numerous fuels, hydrogen explosions, and radioactive releases.’

Another primary reason is nuclear waste disposal. Since 1946, the ocean has been used to dispose of low-level radioactive waste. Although the dumpling was banned internationally in Feb 1994, the effects continue to impact marine and human life. (“Effects of Nuclear Waste on Marine Ecosystems,” n.d.). Even if the radioactive isotopes are very light and no longer detectable in the ocean, they are still a significant threat to human health. (“How Nuclear Pollution Affects The Ocean Waters,” 2020). Because the radioactive isotopes participate in the food chain. They are directly absorbed by kelp, plankton, and invertebrates, and then fish get those radioactive materials through their food. The radioactive matter is concentrated in organisms and goes into the human body by way of the food chain. What’s more, those elements have relatively long lives of nuclides, for example, Calcium-137 has a lifespan of 30 years (“How Nuclear Pollution Affects The Ocean Waters,” 2020). This means they may bring really long-term health impacts, even longer than a human's whole life. And we show the top 10 threatened radioactive elements’ half-life period below.

With the ocean current and migration of fish, radionuclides could travel far away from the incident site. Cs137 radionuclides associated with the Fukushima disaster were found in coastal waters in countries worldwide, such as Canada, Russia, Sweden, and South Korea.(Evangeliou, N., et al., 2017) And a similar situation happens in the Irish Sea. Seals and porpoises also contain radioactive cesium and plutonium. (“Sea Pollution,” n.d.). A research team at Tsinghua University has conducted a simulation to examine the dispersion patterns of nuclear waste released into the ocean by Japan over time, which shows the dispersion of nuclear waste in the ocean by currents and waves clearly:

Figure 1
Marco Simulation of Tritium from Day 240 to Day 2800



Data Analysis 1: General Trend and Pattern

In nuclear waste management, the intricate data patterns necessitate rigorous analysis to discern their broader implications. The data used in this analysis is derived from the MARIS database, which contains over 275,000 entries spanning 54 different columns. The activity measurement of the nuclides above the threshold of Minimum Detectable Activity (MDA) has been selected for the data analysis, which involves 169308 samples in total. The extensive volume and granularity of this data provide an unparalleled opportunity to explore the complex dynamics of nuclear waste sampling and its associated ramifications. Spanning key identifiers such as the MARIS sample ID and laboratory origins to detailed insights on sampling depths, nuclide types, and inherent uncertainties, this dataset harbors a plethora of information. Setting the stage for the subsequent analyses, it is imperative to establish anticipated patterns based on the geolocation of samples, the contributing laboratories, employed methods, and specific nuclides detected. Recognizing these expected trends will shape the analytical methodology and guide the interpretation of outcomes, ensuring that derived insights are meaningful and actionable for stakeholders in nuclear waste management.

Figure 2

The Trend of the Total Amount of Nuclide in Ocean from 2000 to 2021

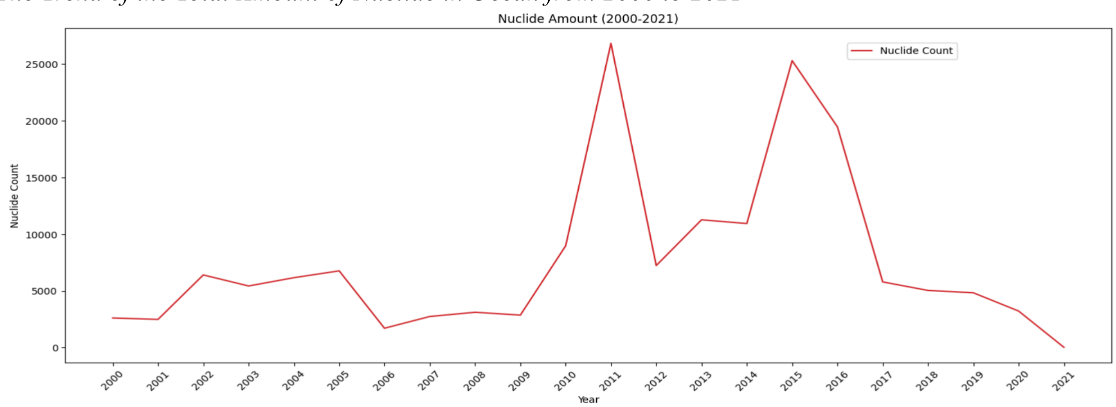


Figure 2 represents the trend of total number of observations for nuclides in the ocean from 2000 to 2021. There are two peaks in the trend, one in 2011, which matches and implies the nuclear disaster in Japan in 2011 as expected, while the other peak in 2015 is abnormally apparent since no media talked about any high amount of nuclear waste 2015 around the world.

Figure 3

Temporal Trends in Nuclear Activity

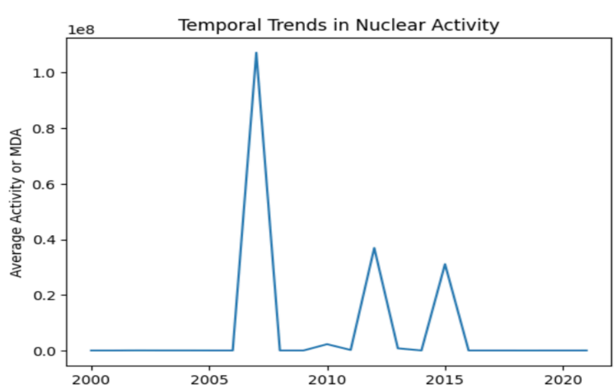


Figure 3 provides a visual representation of the average activity or Minimum Detectable Activity (MDA) of nuclear samples over a two-decade period spanning from 2000 to 2020. Notably, there is a pronounced spike in activity observed around 2005, where the average activity reached its zenith, nearly approaching 1e8. This surge is

distinct and significantly higher in comparison to other years. Post this peak, there's a marked decline, with activity levels stabilizing, albeit with minor fluctuations, between 2010 and 2020. The overall trend, therefore, suggests a period of elevated nuclear activity or detectability in the mid-2000s, followed by a relatively stable phase in the subsequent years. Understanding the factors contributing to this notable rise around 2005 and the ensuing stabilization is crucial for comprehensive insights into nuclear waste management and its broader implications during this timeframe.

Figure 4

Depth vs. Nuclear Activity

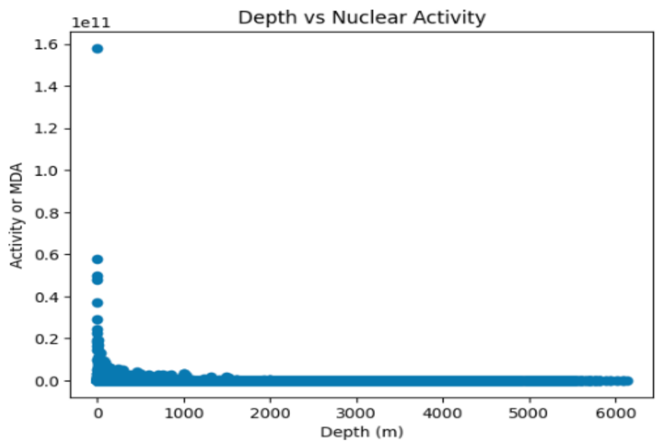


Figure 4 delineates the relationship between the depth (measured in meters) and the corresponding nuclear activity or Minimum Detectable Activity (MDA) of samples. A striking feature of the data representation is the noticeable high activity levels, nearing 1.6e11, at relatively shallow depths, specifically below 1000 meters. As the depth increases, there's a pronounced decline in nuclear activity levels, culminating in a plateau that persists consistently across depths ranging from approximately 2000 to 6000 meters. This trend indicates that higher concentrations of nuclear activity are predominantly present in shallower regions, while deeper areas demonstrate substantially lower and stable levels of nuclear activity. This distribution may have implications for understanding the origins of nuclear residues, their migration patterns, and potential containment strategies, especially in the upper strata of the sampling zones.

Figure 5

Activity Across Top Nuclide Types

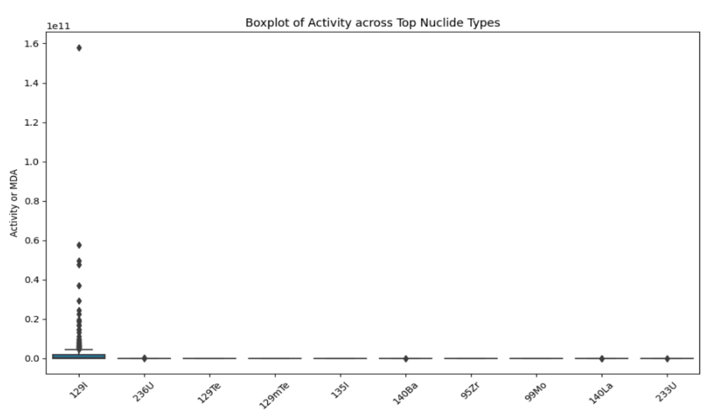


Figure 5 offers an insightful visualization of nuclear activity or Minimum Detectable Activity (MDA) distributions for different nuclides. At a cursory glance, the nuclide "129I" demonstrates significantly higher levels

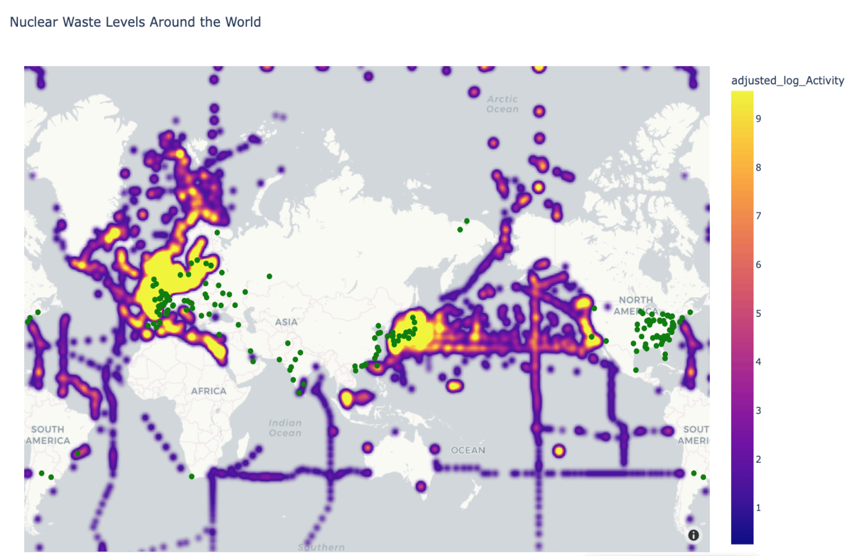
of activity, with a few outlier values reaching upwards of 1.6e11. Notably, the central tendency of this nuclide's activity (as illustrated by the height of the box) remains considerably higher than other nuclides. Most other nuclides, including "236U," "129Re," "239Ne," "135I," "140Ba," "85Zr," "99Mo," "140La," and "233U," exhibit relatively low and closely packed activity levels, signifying a limited spread or variability in their respective activities. The consistently low activity across these nuclides, in contrast to the pronounced activity of "129I," suggests that "129I" might be a nuclide of particular interest or concern in the studied context. The distribution and range of nuclear activity for each nuclide can provide critical insights into potential sources, environmental spread, and containment or mitigation strategies tailored to specific nuclide types.

Data Analysis 2: Hidden Trend

In Data Analysis 2, the focus shifts towards uncovering hidden trends that may take time to discern at a surface-level examination of the dataset. While primary analyses often reveal the overarching patterns in data, there remains a plethora of underlying trends that can provide invaluable insights. These subtle patterns, when decoded, can offer a deeper understanding of the intricacies of nuclear activity, its variances, and potential causal factors. Through sophisticated analytical methods and a meticulous examination of the dataset, this section endeavors to shed light on these concealed trends and their implications in the realm of nuclear research. The two visual representations showcased above delve into the intricate distribution of nuclear waste levels in relation to known nuclear plant sites.

Figure 6

Nuclear Waste Levels Around the World



In **Figure 6**, while preserving the adjusted log activity data, green markers are overlayed, which represent the locations of nuclear plants sourced from an external database. By incorporating these markers, the visualization aims to draw potential correlations between nuclear plant locations and nuclear waste concentrations. Additionally, the deliberate use of a blurred dispersion for each data point was incorporated to counteract any visual misinterpretations that could arise due to proximity to testing spots, ensuring the representation leans more towards indicating nuclear waste density rather than pinpoint accuracy of data points. Together, these graphs provide a multifaceted perspective, potentially revealing the influence of nuclear plants on the distribution of nuclear waste. The map shows that the level of nuclear waste in North America is way less than in Asia and Europe, which implies that Americans use alternative nuclear waste containment and disposal strategies, such as storing the waste on-site in dry casks (Hickman, 2019).

Figure 7

Nuclear Waste Levels Around the World in 2014

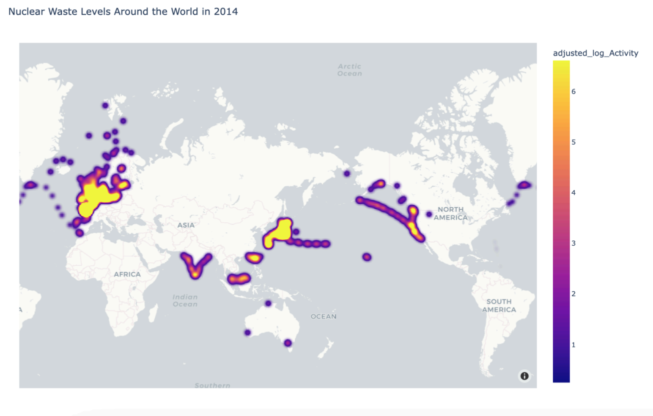


Figure 8

Nuclear Waste Levels Around the World in 2015

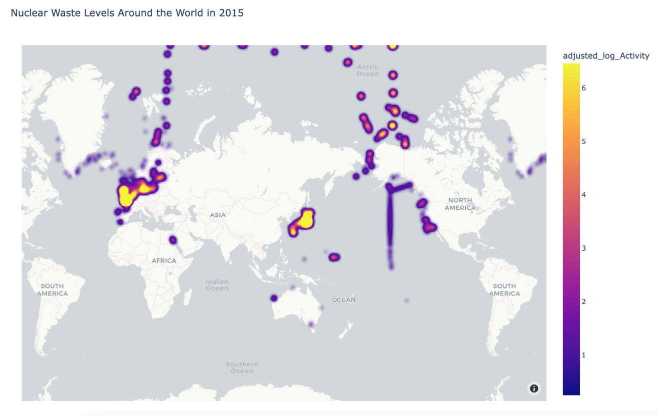


Figure 7 represents the nuclear waste level in 2014, while **Figure 8** represents the nuclear waste level in 2015. The nuclear waste surrounded Western Europe, East Asia, and the West Coast of North America in 2014, and then a year later, in 2015, there were some nuclear waste spotted in the Arctic Ocean. This may be explained by a couple of factors, such as the possibility that waste from these regions has traveled to the Arctic Ocean throughout the year or accidents and nuclear disposal near the Arctic could have caused this.

Figure 9

Nuclear Waste Levels Around the World (1999-2010)

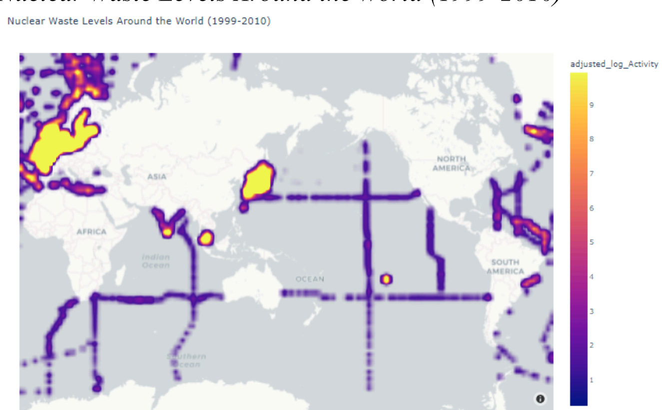


Figure 10

Nuclear Waste Levels Around the World (2011-2021)

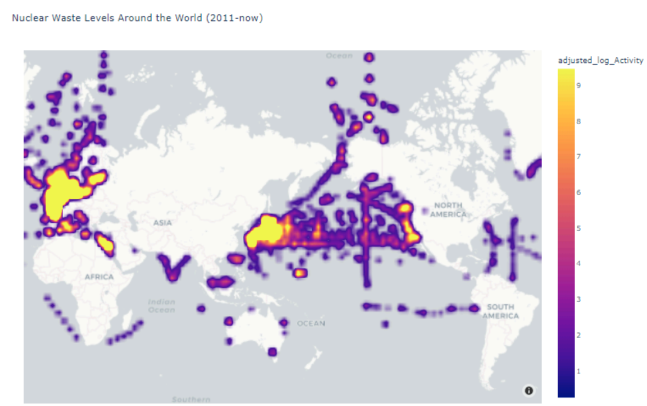


Figure 9 and Figure 10 present the progression of nuclear waste levels around the world over two distinct decades: 1999-2010 and 2011-2021. The evident yellow markings, indicating higher nuclear waste levels, appear to have intensified in specific regions over the years. The first decade, 1999-2010, illustrates pronounced waste concentrations primarily in parts of Western Europe, East Asia, and the West Coast of North America. However, in the second decade, 2011-2021, there was an escalation in nuclear waste concentrations in these areas, with additional prominent regions emerging. Specifically, a noticeable spread is evident across the Eurasian landmass, the northern parts of the Atlantic Ocean, and the Pacific Ocean area between East Asia and the West Coast of North America. Such a trend suggests increased nuclear activities or waste disposal mechanisms in these regions. The proliferation in the latter decade might indicate changes or persisting issues in international policies or practices, leading to the accumulation of nuclear waste in these new areas. Evaluating such trends is vital for understanding the global impact of nuclear waste management and for formulating strategies to address environmental concerns.

Discussion

Figure 2 shows two peaks in the levels of total nuclide samples in both 2011 and 2015. During a magnitude 9.0 earthquake off the coast of northeastern Japan in 2011, a tsunami slammed into the Fukushima nuclear plant and knocked out power and cooling systems, triggering meltdowns in three reactors. This explains the peak of the levels of total nuclide samples in 2011. **Figures 7** and **8** are backed up with evidence that the spread of the nuclear wastes also aligns with the peak in total nuclide samples observed in 2015. This hidden pattern suggests a potential dispersal route or a change in waste management during this period. With the support from **Figure 9 and Figure 10**, the progression of the worldwide nuclear waste level between 1999-2010 and 2011- 2021 is enormous. It appears to have intensified in the Pacific Ocean area between East Asia and the West Coast of North America over the years. **Appendix A Figure A1** provides an insight into the top 10 radiation types and half live of Nuclide from 2000 to 2021. 137Cs is one of the isotopes that was released from the Fukushima nuclear accident and can last 30 years in the ocean. **Appendix A Figure A2** shows the spread of the 137Cs from the nuclear waste till 2021. Western Europe and East Asia have the most 137Cs amount. Raising public awareness and providing education on nuclear energy to inform public about the benefits and risks of nuclear energy. Further research in nuclear waste management can promote the development of new, safer nuclear technolgoies.

The investigation into the distribution and intensity of nuclear waste levels juxtaposed with the locations of nuclear plants provides essential insights into the global landscape of nuclear activity from 1999 to 2021. Initial observations from the temporal trends highlight a significant peak in nuclear activity around 2010, shown in **Figure 3**. This surge may be attributed to various factors, such as an increased reliance on nuclear energy or specific geopolitical events, which warrant further exploration. When examining the depth versus nuclear activity shown in **Figure 4**, a clear trend emerges: nuclear activity showcases a sharp decline as depth increases. This pattern suggests that deeper regions, perhaps oceanic trenches or deep terrestrial layers, experience reduced nuclear contamination. The decrease could be attributed to the dilution effect in vast water bodies or the natural burying and sedimentation processes on land. A comprehensive view of activity across different nuclide types shown in **Figure 5**, as represented in the box plot, offers a nuanced understanding of nuclear waste distribution. Some nuclides display a concentrated range of activity, indicating consistent usage or disposal patterns, while others reveal a broader spread, hinting at varying decay rates or disposal methods.

The spatial comparison of nuclear waste levels with known nuclear plant sites is particularly revealing, as shown in **Figure 6**. Clear correlations emerge in certain areas where nuclear waste concentrations seem to resonate with the presence of nuclear plants. Although the visualization incorporates a blurred dispersion to counter potential misinterpretations, the data suggests potential spill-over effects of nuclear plants or impacts of nuclear waste transportation. As shown in **Figure 6**, North American nuclear waste levels are significantly lower than those in Asian and European countries, suggesting that alternative nuclear waste containment and disposal strategies are working. To determine whether nuclear waste management practices in North America are sustainable and safe over the long term, further research is necessary into the specific factors contributing to them.

Conclusions

The implications of this study underscore the significance of robust nuclear waste management practices. The patterns observed between 1999 and 2021 indicate that while nuclear energy remains a promising alternative to conventional energy sources, the environmental ramifications are profound. These findings emphasize the need for stringent regulations, vigilant monitoring, and innovative waste disposal methods. Alternatively, governments should develop more sustainable energy besides relying on nuclear energy.

Given that the dataset only covers until 2021, it is crucial for future research endeavors to incorporate the latest data, ensuring a comprehensive understanding of global nuclear activity. This proactive approach will not only shed light on emerging trends but also pave the way for sustainable and safe nuclear practices in the future.

Reference

Liao, H., Sun, D., Yang, Z., Huang, W., & Di, Q. (2023). Health impact of nuclear waste water discharge from the Fukushima Daiichi nuclear plant. *medRxiv*, 2023-04.

Guo, J., Liu, Y., Wu, X., & Chen, J. (2022). Assessment of the impact of Fukushima nuclear wastewater discharge on the global economy based on GTAP. Ocean & Coastal Management, 228, 106296.

Murakami, S., & Bateman, T. (2023). Japan to release Fukushima water into Ocean from Aug. 24.Reuters.https://www.reuters.com/world/asia-pacific/japan-release-fukushima-water-into-ocean-starting-aug-24-2023-08-22/

Hickman, Hannah. (2019, November 9) What Happen to Neclear Waste in the U.S. https://www.nei.org/news/2019/what-happens-nuclear-waste-us#:~:text=Where%20Does%20Nuclear%20Waste%20End,on%2Dsite%20in%20dry%20casks.

Copplestone, D., Toal, M. E., Johnson, M. S., Jackson, D., & Jones, S. R. (2000). Environmental effects of radionuclides-observations on natural ecosystems. *Journal of Radiological Protection*, *20*(1), 29. https://iopscience.iop.org/article/10.1088/0952-4746/20/1/304/meta

Dolchinkov, N. T., & Karaivanova-Dolchinkova, B. E. (2016). RADIATION EFFECT ON HUMAN AND LIVING NATURE. *Science. Business. Society.*, *1*(5), 59-61. https://stumejournals.com/journals/sbs/2016/5/59.full.pdf

Fesenko, S. V., Alexakhin, R. M., Geras' kin, S. A., Sanzharova, N. I., Spirin, Y. V., Spiridonov, S. I., ... & Strand, P. (2005). Comparative radiation impact on biota and man in the area affected by the accident at the Chernobyl nuclear power plant. *Journal of environmental radioactivity*, *80*(1), 1-25. https://www.sciencedirect.com/science/article/abs/pii/B9780857091321500134

Fowler, S. W. (2011). 210Po in the marine environment with emphasis on its behaviour within the biosphere. *Journal of environmental radioactivity*, *102*(5), 448-461. https://www.sciencedirect.com/science/article/abs/pii/S0265931X10002407

Aoyama, M., & Hirose, K. (2008). Radiometric determination of anthropogenic radionuclides in seawater. *Radioactivity in the Environment*, 11, 137-162. https://www.sciencedirect.com/science/article/abs/pii/S1569486007110044

Raabe, O. G. (2010). Concerning the health effects of internally deposited radionuclides. *Health physics*, 98(3), 515-536. https://journals.lww.com/health-physics/abstract/2010/03000/concerning_the_health_effects_of_internally.6.aspx

Iryna, P. (2017). Toxicity of radionuclides in determining harmful effects on humans and environment. *J Environ Sci*, *1*(2), 115-119. https://fortunepublish.com/articles/10.26502.jesph.96120011.pdf

Geras' kin, S., Evseeva, T., & Oudalova, A. (2013). Effects of long-term chronic exposure to radionuclides in plant populations. *Journal of Environmental Radioactivity*, *121*, 22-32. https://www.sciencedirect.com/science/article/abs/pii/S0265931X12000720

Gagnaire, B., Adam-Guillermin, C., Bouron, A., & Lestaevel, P. (2011). The effects of radionuclides on animal behavior. *Reviews of Environmental Contamination and Toxicology Volume 210*, 35-58. https://link.springer.com/chapter/10.1007/978-1-4419-7615-4_2

Povinec, P. P., Gera, M., Holý, K., Hirose, K., Lujaniené, G., Nakano, M., ... & Gažák, M. (2013). Dispersion of Fukushima radionuclides in the global atmosphere and the ocean. *Applied Radiation and Isotopes*, *81*, 383-392. https://www.sciencedirect.com/science/article/abs/pii/S0969804313001486

Yu, W., He, J., Lin, W., Li, Y., Men, W., Wang, F., & Huang, J. (2015). Distribution and risk assessment of radionuclides released by Fukushima nuclear accident at the northwest Pacific. *Journal of Environmental Radioactivity*, *142*, 54-61. https://www.sciencedirect.com/science/article/pii/S0265931X15000077

Wu, X., Zhang, Y., & Feng, X. (2023). The impact of Japanese nuclear wastewater discharge into the sea on the global economy: Input-output model approach. *Marine pollution bulletin*, *192*, 115067. https://www.sciencedirect.com/science/article/abs/pii/S0025326X2300499X

Guo, J., Liu, Y., Wu, X., & Chen, J. (2022). Assessment of the impact of Fukushima nuclear wastewater discharge on the global economy based on GTAP. *Ocean & Coastal Management*, *228*, 106296.

https://www.sciencedirect.com/science/article/abs/pii/S0964569122002721

Xu, M., Zhang, Y., Cao, S., Li, Y., Wang, J., Dong, H., & Wang, Y. (2023). A simulated toxic assessment of cesium on the blue mussel Mytilus edulis provides evidence for the potential impacts of nuclear wastewater discharge on marine ecosystems. *Environmental Pollution*, *316*, 120458. https://www.sciencedirect.com/science/article/abs/pii/S0269749122016724

Wang, Q., Zhang, H., & Huang, J. (2022). Japan's nuclear wastewater discharge: Marine pollution, transboundary relief and potential implications from a risk management perspective. *Ocean & Coastal Management*, *228*, 106322. https://www.sciencedirect.com/science/article/abs/pii/S0964569122002988

Liu, Z. (2023). How Does Nuclear Wastewater Discharge Affect Fishery and Marine Environment: A Case Study of Japan. In *E3S Web of Conferences* (Vol. 424, p. 04012). EDP Sciences. https://www.e3s-conferences.org/articles/e3sconf/abs/2023/61/e3sconf_icree2023_04012/e3sconf_icree2023_04012.html

Health Effects of Radiation. (n.d.). Centers for Disease Control and Prevention. https://www.cdc.gov/nceh/radiation/health.html#:~:text=How%20Radiation%20Affects%20Your%20Body,to%20cancer%20later%20in%20life

Zablotska, L.b., Ron, E., Rozhko, A.V., Hatch, M.,..., Masyakin, V.B. (2011, Jan). Thyroid cancer risk in Belarus among children and adolescents exposed to radioiodine after the Chornobyl accident. *British Journal of Cancer.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3039791/

Fukushima disaster: What happened at the nuclear plant? (2023, August). https://www.bbc.com/news/world-asia-56252695

Iqbal, J., Howari, F.M., Mohamed, A.O., Paleologos, E.K., (2021). Chapter 20 - Assessment of radiation pollution from nuclear power plants. *Pollution Assessment for Sustainable Practices in Applied Sciences and Engineering*, Page 1027-1053, https://www.sciencedirect.com/science/article/pii/B9780128095829000207

Course:EOSC270/2021/Unregulated and Unknown: Effects of Nuclear Waste on Marine Ecosystems. (n.d.). UBC Wiki https://wiki.ubc.ca/Course:EOSC270/2021/Unregulated_and_Unknown:_Effects_of_Nuclear_Waste_on_Marine_Ecosystems

How Nuclear Pollution Affects The Ocean Waters, The Environment, And Humans. (2020, March 1). Cleaner Seas https://www.cleanerseas.com/how-nuclear-pollution-affects-the-ocean-waters-the-environment-and-humans

Evangeliou, N., Stohl, A., Balkanski, Y., (2017, April). Global transport of Fukushima-derived radionuclides from Japan to Asia, North America and Europe. Estimated doses and expected health effects. Evangeliou. *EGU General Assembly Conference Proceedings.* https://ui.adsabs.harvard.edu/abs/2017EGUGA..19.6605E/abstract

Sea Pollution. (n.d.). https://ypte.org.uk/factsheets/sea-pollution/radioactive-waste

Appendix A
Nuclide Amount Chart and Map

This Appendix contains illustrations of the nuclide in the ocean in terms of type concentration and global geo-distribution.

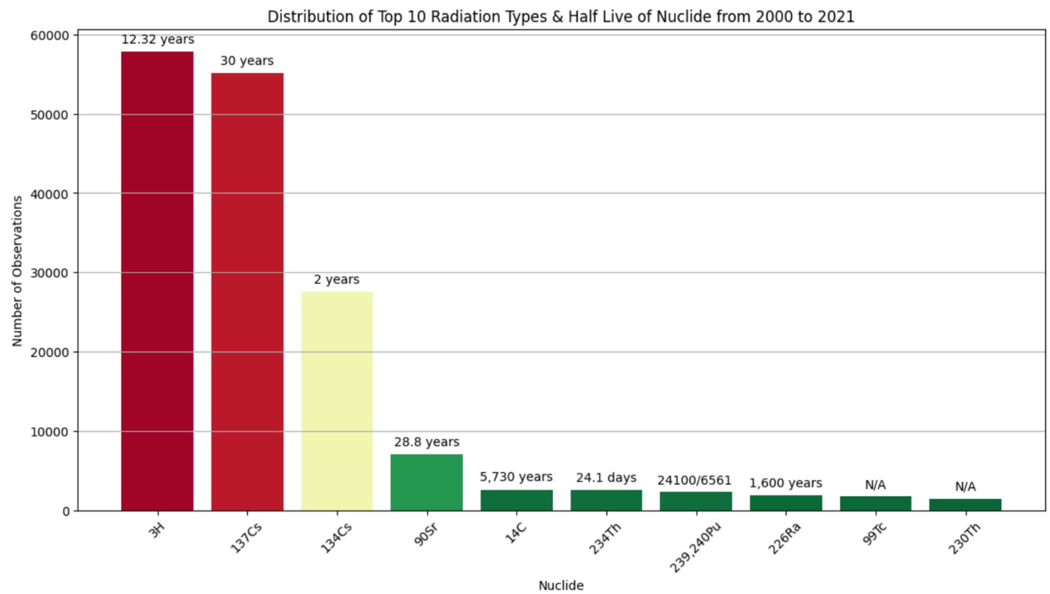


Figure A1. An insight into the top 10 radiation types and the half-life of Nuclide from 2000 to 2021. Among the top 10 radiation matters in the ocean, 4 of them have a known half-life of more than 25 years. Especially for 137Cs, which is one of the isotopes that was released from the Fukushima nuclear accident, and it can take as long as 30 years to reduce to 50%.

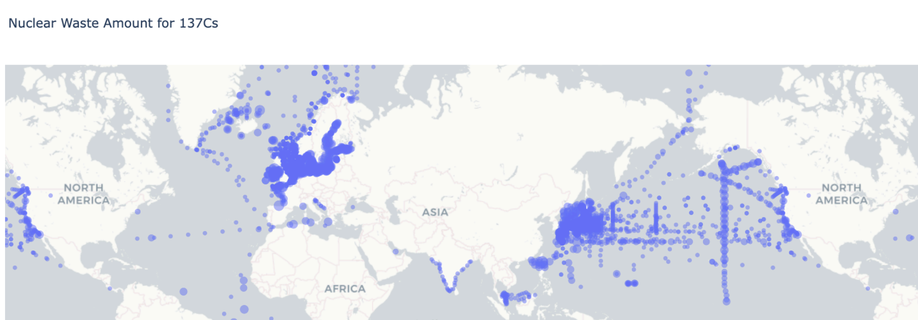


Figure A2. The spread of the 137Cs from the nuclear waste till 2021. The distribution of nuclear waste complies with the international shipping routes. Western Europe and East Asia have the most 137Cs.