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Impact of Marine Nuclear Pollution on Coastal Cities

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Abstract:

With the global energy transition, nuclear power has developed rapidly, but has further triggered the issue of marine nuclear pollution. Marine nuclear pollution spreads through ocean currents and the biological chain, affecting the durability of building materials, residents' health, and seafood trade. This paper aims to systematically analyze the sources and diffusion mechanisms of marine nuclear pollution, evaluate the impacts of nuclear pollution on corrosion of coastal city building materials, health risks to residents, and trade effects, further explore the current status and development trends of nuclear wastewater treatment technologies and radiation-resistant materials, and propose a monitoring and policy coordination framework. This paper finds that marine nuclear pollution causes microcracks and aggravated corrosion in building materials, significantly increasing urban infrastructure maintenance costs; radioactive nuclides accumulate through seafood, raising residents' risk of chronic cancer; the trade market has shrunk due to fear of nuclear pollution, affecting the economic development of coastal areas. By introducing efficient purification technologies and copper-based radiation-resistant materials, the spread of pollution and structural deterioration can be effectively reduced, ensuring ecological and urban safety. This study provides a theoretical basis and technical path for interdisciplinary governance of marine nuclear pollution, contributing to the coordinated realization of sustainable development and environmental security in coastal cities.

Keywords: Economic Impact of Nuclear Contamination; Marine Nuclear Pollution; Environmental Governance; Coastal Infrastructure Vulnerability.

1. Introduction

As the global energy structure continues to transform since 2023, nuclear energy is gradually replacing traditional fossil energy sources with its low-carbon and high-efficiency advantages. Currently, there are

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more than 440 nuclear power units in operation globally, with some countries accounting for more than 20 per cent of nuclear energy. However, as nuclear energy is widely developed, its potential environmental risks have gradually attracted attention. In particular, during the utilization process, a large amount of radioactive waste is discharged, including the residues of historical nuclear tests, and the potential leakage of accidents. Once these radioactive substances enter the ocean, they will spread with the ocean currents and enter the food chain through biological enrichment, thus threatening public health and causing social panic. For example, Australian research found that after the United Kingdom conducted nuclear tests in the Montebello Islands in the 1950s, the plutonium content in the bottom sediment is still 4,500 times the level of other coastal areas. In addition, since the discharge of Fukushima nuclear wastewater in Japan into the ocean in 2023, although the tritium concentration is extremely low, it is still necessary to continue to monitor its long-term spread and ecological impact. Marine nuclear pollution is not only related to ecological security, but also poses a direct challenge to coastal cities that rely on marine resources.

At present, scholars have explored the sources, spread, and ecological effects of marine nuclear pollution. For example, Buesseler et al. analyzed the migration paths of major radioactive isotopes (such as tritium and cesium-137) in Fukushima wastewater, pointing out their long-term geographical diffusion and bioaccumulation characteristics, which exert sustained pressure on the marine ecosystems of the Pacific Rim [1]. Zheng et al. simulated the distribution of plutonium-239 in North American lake sediments following nuclear tests, verifying that nuclear pollution can undergo intercontinental migration through the atmosphere and water bodies [2]. According to the WHO, “even low-dose exposure may increase the risk of cancer and other long-term health problems,” which fully confirms that residual radioactive nuclides in the ocean—even at low concentrations—can enter the human body through the food chain, accumulate over time, and increase the risk of chronic cancer [3]. Regarding urban environmental impacts, Zhang et al. pointed out that radioactive nuclides can induce microcracks in concrete, corrode steel reinforcement, and reduce structural lifespan, thereby increasing the maintenance costs of buildings in coastal cities [4]. These studies provide theoretical support for understanding the full-chain effects of marine nuclear pollution and highlight that nuclear pollution extends beyond the ecological field, also affecting urban safety, public health, and economic sustainability. Collectively, these studies reveal that the dangers of marine nuclear pollution are not limited to ecological aspects but also encompass the health, economy, and infrastructure security of coastal cities, necessitating interdisciplinary cooperation to construct an integrated governance pathway.

This study aims to propose a composite governance framework that integrates nuclear wastewater purification with radiation-resistant structural engineering to reduce the ecological, health, and economic impacts of marine nuclear pollution on coastal cities. The paper is structured as follows: the first section reviews the sources and diffusion mechanisms of marine nuclear pollution and its comprehensive effects on coastal construction materials, public health, and seafood trade; the second section provides an in-depth analysis of current nuclear wastewater treatment technologies—including physical, chemical, and biological methods—and their limitations, and evaluates the application prospects of radiation-resistant materials such as Cu-OF and barite concrete in protective structures; the third section proposes a collaborative governance strategy based on international monitoring, institutional design, and financial incentives; finally, through case analysis and simulation modeling, the study explores the feasibility of implementing the proposed framework and its prospects.

2. Sources and Diffusion Mechanisms of Marine Nuclear Pollution

Sources of marine nuclear pollution can be categorized into anthropogenic discharges and natural processes. The former includes nuclear power plant cooling water (containing low-level radioactive nuclides such as tritium and carbon-14), deep-sea dumping of nuclear waste (such as leakage from radioactive waste barrels in the Pacific Ocean), and accidental nuclear leaks. The latter involves the dissolution of submarine uranium deposits and the global migration of atmospheric fallout from nuclear explosions. These pollutants spread through two primary pathways: ocean current transport and bioaccumulation (via adsorption by plankton and ingestion by fish). Ultimately, they form persistent toxicity in coastal sediments and biological chains, posing a dual threat to coastal ecosystems and urban environments. The most representative example is the 67 nuclear tests conducted by the United States in the Marshall Islands from 1946 to 1958, which caused “unprecedented environmental contamination” and led to long-term health damage among island residents.

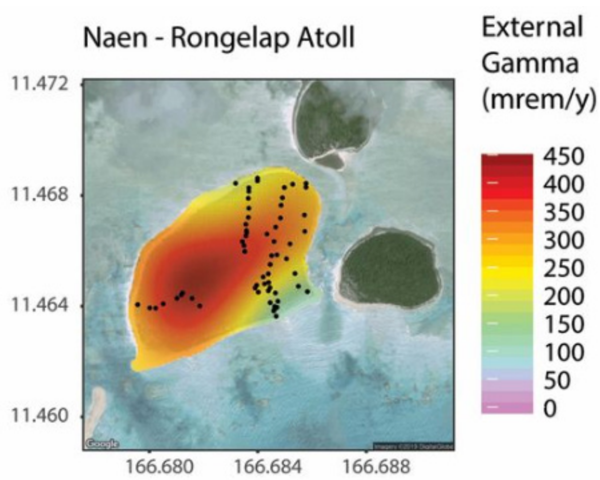

Fig.1 Gamma Radiation Intensity Distribution Outside Rongelap Atoll, Marshall Islands [5]

Fig. 1 illustrates the spatial distribution of surface gamma radiation intensity in Rongelap Atoll (latitude 11.460°–11.472°N, longitude 166.680°–166.688°E), located in the North Pacific nuclear test zone, as recorded in 2019. The black dots indicate field measurement points, and the radiation values were interpolated to generate a continuous distribution model. The right-side color scale indicates radiation intensity (0–450 mrem/year), with red zones (>300 mrem/year) concentrated in the southeastern part of the atoll, peaking at 450 mrem/year (approximately 4.5 mSv/year), nearly double the global average natural background radiation level (2.4 mSv/year). This abnormally high level is directly linked to residual fallout from the 1954 U.S. “Bravo” hydrogen bomb test, demonstrating that significant ecological risk persists even 70 years after the nuclear tests. The distribution of radiation hotspots aligns with the prevailing wind directions during the nuclear detonations, revealing that radioactive nuclides (such as cesium-137 and strontium-90) adsorbed into the soil continue to pollute nearby marine environments[5].

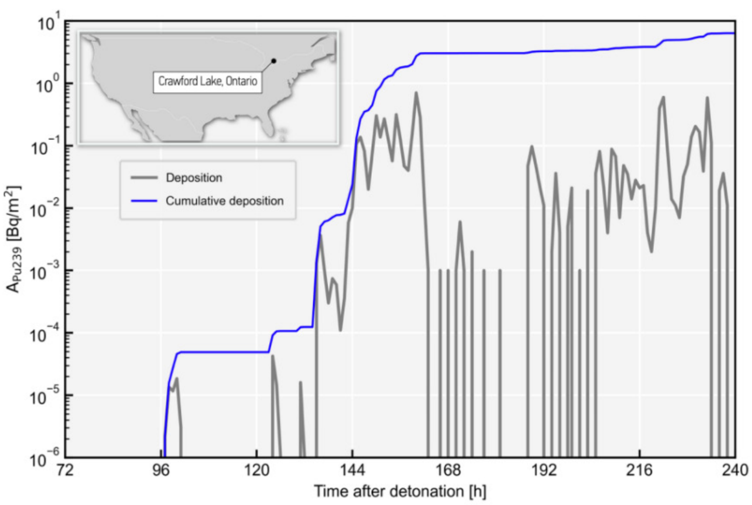

Fig.2. Plutonium-239 Deposition Density Estimates at Crawford Lake (43.468°N, 79.949°W), Ontario, Canada, Following the Trinity Test in New Mexico, United States [6]

Additionally, Fig. 2 shows the deposition process of plutonium-239 in Crawford Lake, Canada, following the 1945 “Trinity” nuclear test conducted by the United States. Although the detonation site was over 2,000 kilometers away, initial deposition occurred on the fourth day after the explosion, reaching its peak between the sixth and seventh days. This indicates that radioactive particles can be transported through the atmosphere and enter freshwater systems via precipitation. This case provides clear evidence of nuclear pollution’s capacity for transregional dispersion through air and water [6].

In summary, both the localized radioactive fallout in nuclear test areas like the Marshall Islands and the transboundary atmospheric diffusion mechanism demonstrated by Crawford Lake confirm that nuclear pollution exhibits global mobility and poses long-term ecological risks.

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These findings warrant serious attention from the international community.

3. Impacts of Marine Nuclear Pollution on Coastal Cities

3.1 Impacts on Building Materials

Relevant studies have indicated that nuclear pollution causes harm not only to trade and public health but also to building materials. Specifically, gamma rays and alpha/beta radioactive decay products can induce corrosion and structural degradation through radiation and radiolysis. Research shows that radiation increases porosity, triggers microcracks, and ultimately reduces compressive strength, thereby raising the likelihood of corrosion [7].

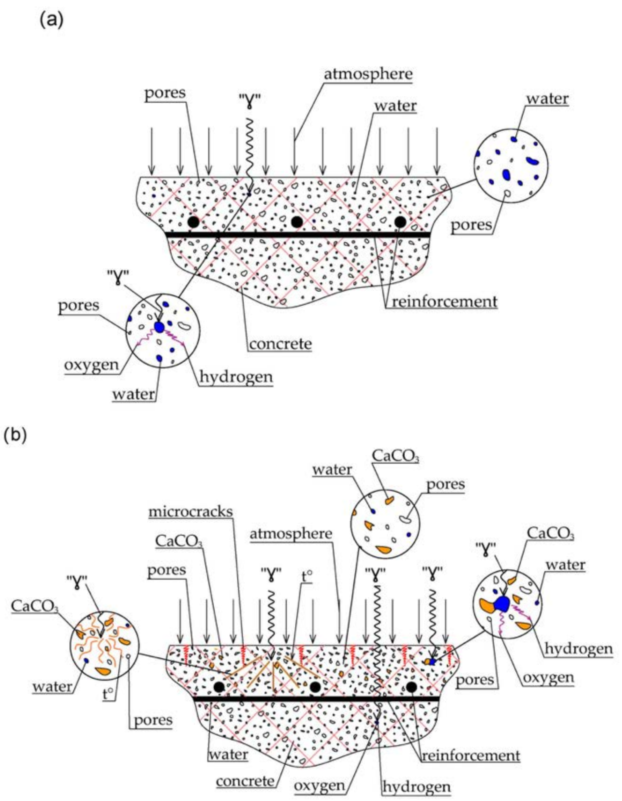

Fig.3 Conceptual diagram of reaction mechanisms in reinforced concrete exposed to gamma radiation [8]

Fig. 3 shows that in the early stage of gamma ray irradiation, the water in the capillary pores of concrete will continue to hydrate and undergo radiolysis to release oxygen. When the concrete's resistance is low, oxygen and CO_2 diffuse to the steel surface, forming a passivation film that temporarily reduces corrosion. However, over time, $Ca(OH)_2$ reacts with CO_2 to produce $CaCO_3$ that fills pores. Although this reduces permeability, it also causes oxygen accumulation, eventually breaking down the passivation film and causing the corrosion current to increase[8].

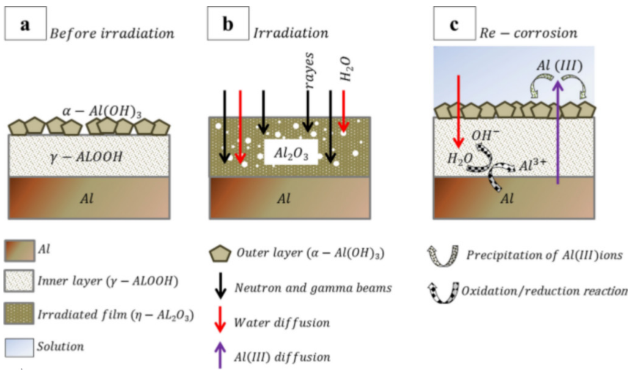

Fig.4 Conceptual diagram of corrosion behavior in aluminum alloy under prolonged radiation exposure [9]

Marine nuclear pollution causes damage not only to concrete but also to other construction materials, such as aluminum alloy. Figure 4 shows the corrosion mechanism of aluminum alloy under long-term irradiation: in image (a), an initial $Al(OH)_3$ film forms; in (b), radiation causes dehydration and reordering of the film, making it brittle; and in (c), a repetitive peel-and-regenerate mechanism accelerates corrosion significantly [9].

Beyond theoretical explanations, experimental studies have demonstrated that even at low gamma dose rates (e.g., 11 Gy/h), anaerobic corrosion rates of carbon steel increase under accelerated conditions[8].

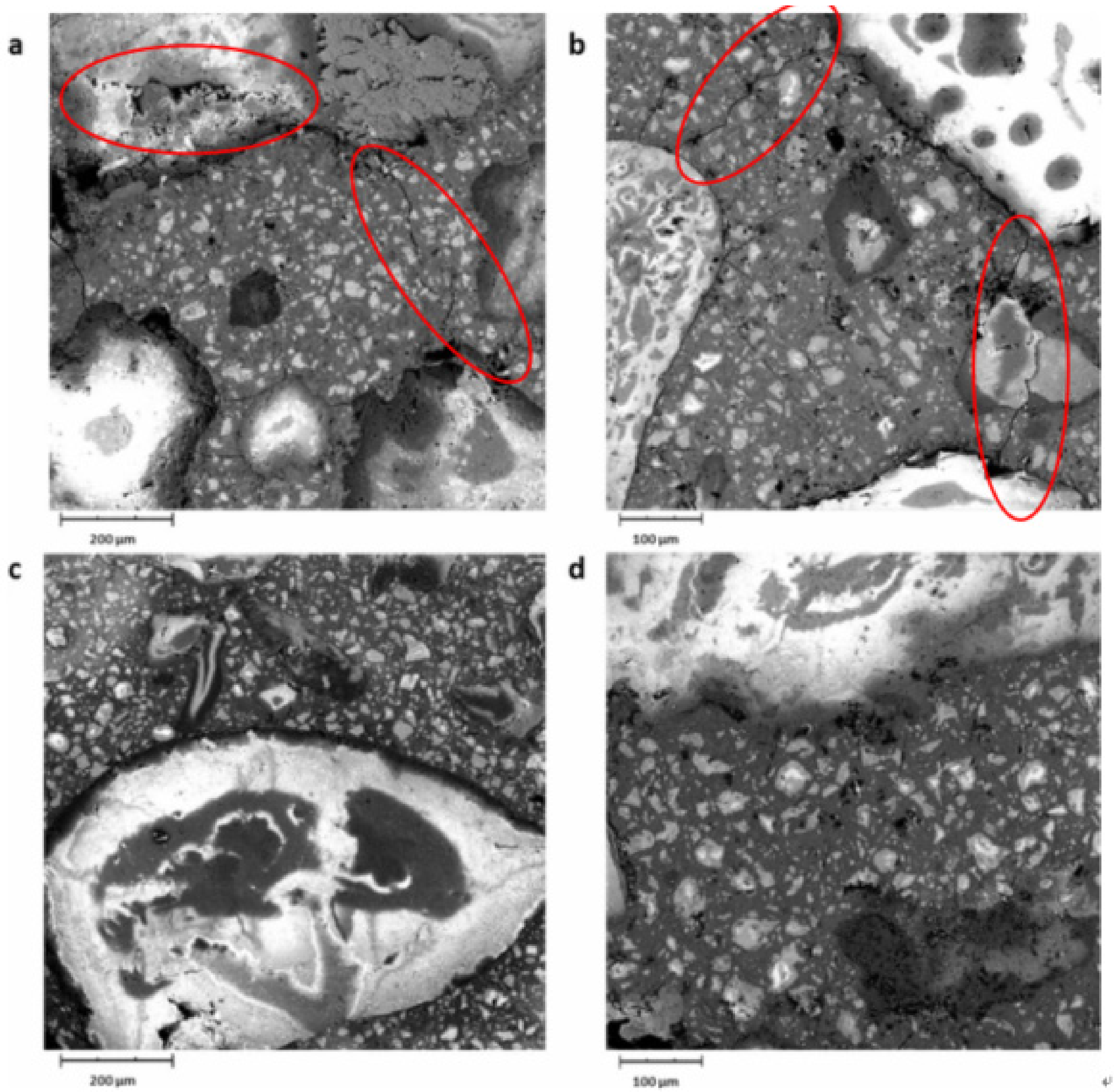

Fig.5 Effects of radiation on concrete performance [10]

Fig. 5 presents SEM images of cement mortar samples: images (a) and (b) show stimulated samples with significant cracking, while control samples exhibit no visible cracks. This demonstrates the damaging effects of gamma radiation on building materials [10]. Additional data confirm that under a gamma dose of 1000 kGy (e.g., from Cs-137), porosity increases from 12.5% to 19.1%, accelerating the propagation of microcracks [8]. In a real case, groundwater near the Fukushima nuclear plant in 2014 showed Sr-90 concentrations as high as 5,000,000 Bq/L, with the concrete in accumulation areas exhibiting 2.3 times faster crack propagation. These results confirm the structural damage caused by nuclear pollution [10].

From this, it can be inferred that nuclear pollution causes building degradation in coastal cities, leading to increased repair costs and labor demand. For example, damage to undersea cables has been shown to incur average repair costs of £500,000–£1,000,000 for communication cables and up to £10 million for power cables [11]. Since nuclear pollution accelerates material aging and wear, infrastructure maintenance costs in affected coastal cities are expected to rise, potentially reducing expenditures in other development sectors.

3.2 Impacts on Public Health

According to an empirical study in the Liguria region of Italy, coastal residents rely heavily on locally caught seafood: 92% of respondents regularly consumed fish and

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seafood, 55% consumed fresh seafood 1 to 3 times per week, and 68% obtained their catch-of-the-day from local markets and small retailers. Traditional fish like sardines and mackerel are consumed frequently due to availability and cultural preference. This consumption pattern demonstrates that geographical proximity directly influences seafood intake, confirming high seafood consumption rates in coastal cities [12].

As marine nuclear pollution increases and spreads, residents with high seafood intake in these coastal cities face growing risks. According to a science communication interview by Sun Yat-sen University, radioactive nuclides exhibit bioaccumulation through marine food chains. Higher trophic-level organisms accumulate more radionuclides by feeding on lower-level species. For instance, Sr-90 accumulates in fish and shellfish, and once consumed by humans, it can substitute for calcium ions in bones, continuously releasing radiation and significantly increasing the risk of bone cancer and leukemia. Historical events like the Minamata disease incident in 1956 demonstrated the devastating health effects of such pollutants. Caused by mercury accumulation in the food chain, it resulted in severe neurological damage, birth defects, and death. The Cs-137 present in current nuclear wastewater exhibits similar bioaccumulative behavior. With a half-life of 30 years, it reaches the highest concentrations in apex marine organisms. Once it enters the human body via seafood, it releases radiation over a prolonged period, inducing cellular mutations and posing threats even more severe than conventional chemical pollutants [13,14].

3.3 Impacts on Trade

Marine nuclear pollution not only increases the cost of maintaining coastal infrastructure (e.g., corrosion of port facilities due to radionuclides) but also triggers public health concerns that directly impact seafood consumption and provoke trade bans from other countries, causing systemic declines in city trade chains. For example, in August 2023, China imposed a full ban on Japanese seafood imports. As a result, Japan's seafood exports to China plummeted by 92.3% in fiscal year 2024 (down to just ¥3.5 billion). Scallop exports to China dropped to zero. Although Japan shifted focus to the Vietnamese market, where scallop exports increased 7.9-fold, it could not offset the loss of the Chinese market. Consequently, Japan's total seafood exports for the year fell by 17%. Simultaneously, Russia imposed its ban on Japanese seafood in October 2023, further shrinking trade opportunities. Even in Hong Kong, which did not fully ban Japanese seafood but restricted imports from 10 prefectures, local consumption declined—e.g., a sushi restaurant in Quarry Bay saw reservations drop by half [15]. This chain reaction highlights how nuclear contamination creates a triple threat for coastal cities: structural damage, public panic, and trade decline. Addressing this crisis requires international monitoring and transparent data to restore trust in trade systems.

4. Methods to Reduce Nuclear Pollution

4.1 Reducing the Damages Caused by Nuclear Pollution

Currently, nuclear pollution treatment mainly relies on three categories of technologies: physical, chemical, and biological methods. Physical methods such as membrane separation technologies (including nanofiltration and reverse osmosis) utilize semi-permeable membranes that allow water molecules to pass under applied pressure while blocking dissolved radioactive ions. These methods offer high separation efficiency and automation, and are widely used in both the pretreatment and final purification of high-level radioactive wastewater. However, they suffer from serious membrane fouling, high replacement costs, and limited selectivity for multivalent ions in complex wastewaters [16].

Chemical methods include precipitation treatment, which involves adding alkalis, iron salts, or sulfides to convert radioactive ions into insoluble compounds that are then removed through solid-liquid separation. Ion exchange methods use functional resins to exchange ions with radionuclides in the pollutants. However, their exchange capacity is limited, their treatment efficiency is constrained by the frequency of resin regeneration, and the spent resin itself becomes a new source of radioactive solid waste [17].

Biological methods rely on radioresistant microorganisms or algae to adsorb or biotransform radionuclides. Although these are environmentally friendly and suitable for large-scale, low-concentration contamination, their efficiency is low, cycles are long, and they are sensitive to environmental conditions; thus currently not viable for areas with high levels of radioactive pollution [18].

To overcome the limitations of existing methods, researchers are exploring breakthroughs in material development, process optimization, and bioengineering. In materials science, new adsorbents such as Prussian Blue nanoparticles, graphene oxide, and MOFs (metal-organic frameworks) demonstrate higher selectivity and adsorption capacity due to their large surface area and multifunctional groups, especially effective for removing long-lived isotopes like cesium-137 and strontium-90 [19]. In membrane separation, researchers are embedding photocatalytic nanomaterials into membrane matrices to develop composite membranes with anti-fouling and radionuclide degradation capabilities, thereby extending membrane life and improving purification efficiency [20].

Furthermore, interdisciplinary efforts in synthetic biology and environmental engineering are enabling the application of engineered microorganisms in nuclear pollution remediation. For example, genetic modification of metal ion response pathways enhances microbial adsorption and metabolism even in radioactive environments. These advances are gradually shifting nuclear pollution treatment from traditional "isolation" strategies to more "efficient transformation" approaches.

In addition to optimizing the treatment process of nuclear wastewater itself, enhancing the radiation resistance of construction and equipment materials in contaminated environments is also a critical strategy for mitigating ecological and human harm. Many radioactive pollutants persist for long periods and have high penetration capabilities, especially gamma rays, which can penetrate water, concrete, and even metal equipment, posing long-term threats to maintenance personnel and surrounding ecosystems.

Therefore, improving the "shielding capacity" of materials has become a research focus. According to a study on arXiv, high-purity copper (Cu-OF) and lead, due to their excellent shielding properties against gamma rays, are recommended for use in key components such as subsea nuclear pollution protection devices, nuclear wastewater pipelines, and reactor containment structures. The key metric for evaluating shielding performance is the Half-Value Layer (HVL)—the thickness of material required to reduce radiation intensity by half. Copper's HVL is approximately 50% lower than aluminum's, meaning that at the same thickness, copper reduces gamma radiation penetration twice as effectively. This implies that copper has superior radiation attenuation per unit volume, making it more effective at isolating radioactive sources from personnel or sensitive equipment [21].

Enhancing material resistance not only reduces the cumulative radiation dose to workers during decommissioning or maintenance but also extends the safe service life of facilities. Therefore, incorporating radiation-resistant materials into nuclear pollution defense systems is a key structural strategy for preventing contamination spread and personnel exposure, and a major trend in nuclear environmental engineering design.

4.2 Policy Recommendations for Reducing Nuclear Pollution

To resolve the dual dilemma of "responsibility shifting" and "technical-financial burden" in marine nuclear pollution governance, this paper proposes a "monitoring-finance-tax coordination framework" that integrates international agreements with domestic policies to internalize pollution costs.

At the international level, a transnational nuclear pollution monitoring network is proposed. Participating countries would collectively subscribe to radioactive liability bonds. If a country exceeds discharge limits (e.g., cesium-137 concentration >10 Bq/m^3), it would be required to compensate affected nations proportionally based on the level of impact, such as if a country's discharge reduces seafood trade in a neighboring coastal city. The compensation would be drawn from the country's bond funds. If violations occur frequently within a year, additional penalties and bans on exporting nuclear power equipment could be imposed to limit pollution emissions.

At the domestic level, a "pollution tax with technological reinvestment" mechanism should be implemented. Enterprises would be taxed based on the toxicity and quantity of discharged radioactive substances. These tax revenues would then be reinvested in waste resource recovery projects—such as reusing nuclear waste (e.g., Finland's Onkalo repository converts decay heat into electricity)—and in funding nuclear waste treatment technologies. This closed-loop taxation system would promote technological upgrades in pollution control, turning the "polluter pays" principle into a "benefit for innovators" paradigm of sustainable development.

5. Conclusion

This study systematically examined the multidimensional impacts of marine nuclear pollution on coastal cities, including damage to building materials, health risks to residents, and disruptions to seafood trade. It further explored the current status and future direction of pollution mitigation technologies and radiation-resistant materials. By analyzing domestic and international cases of nuclear pollution—such as the Marshall Islands and Fukushima wastewater discharge—alongside experimental images and data, the study revealed the multi-pathway transmission mechanisms of marine nuclear pollutants, highlighting their long-term persistence and covert nature. It emphasizes that marine nuclear pollution poses a compound risk to coastal cities across structural, ecological, and economic dimensions.

The findings indicate that radionuclides in marine pollution significantly accelerate the corrosion of concrete and

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metal materials, increasing infrastructure maintenance costs. These pollutants also demonstrate evident bioaccumulation in seafood—especially isotopes such as strontium-90 and cesium-137—which can enter the human body via the food chain and cause chronic health hazards. Furthermore, nuclear contamination leads to declines in consumer confidence and triggers trade embargoes, thereby disrupting the industrial chain and fiscal spending structures of coastal cities.

In terms of response strategies, this paper proposes an integrated governance framework combining advanced nuclear wastewater purification technologies (e.g., membrane separation, MOF adsorption), high-shielding materials (e.g., Cu-OF), and policy instruments (e.g., international nuclear pollution bonds, domestic pollution tax mechanisms). Together, these approaches can effectively mitigate pollution damage and support sustainable development.

Looking ahead, research on marine nuclear pollution must further strengthen data monitoring systems and risk quantification models, particularly for simulating the dynamic relationships among pollution sources, transmission pathways, and ecological-health impacts across multiple scales. Continued interdisciplinary collaboration is also essential, spanning materials science, environmental engineering, and policy design, to achieve a coupled technical-institutional response to nuclear pollution. The composite governance approach proposed in this study offers a reference for resilience building and policy formulation in coastal cities facing long-term nuclear risks, while also laying a foundation for globally coordinated nuclear energy safety and environmental governance.

References

[1] Buesseler, K.O., et al. (2020). Fukushima-derived radionuclides in the ocean: Transport, fate, and impacts. Annual Review of Marine Science, 12, 389–412.
https://www.annualreviews.org/content/journals/10.1146/annurev-marine-010816-060733

[2] Zheng, J., et al. (2021). Distribution and deposition of Pu-239 in sediments following atmospheric nuclear weapons tests. Science of The Total Environment, 769, 144752.
https://www.sciencedirect.com/science/article/abs/pii/S0265931X22002016

[3] World Health Organization (WHO). (2023). Ionizing radiation and health effects. Retrieved from https://www.who.int/news-room/fact-sheets/detail/ionizing-radiation-and-health-effects

[4] Zhang, X., et al. (2019). Radiation-induced degradation of reinforced concrete in nuclear power plants. Construction and Building Materials, 221, 230–240.
https://www.mdpi.com/2076-3417/14/24/11856

[5] M.K.I.L. Abella, M.R. Molina, I. Nikolić-Hughes, E.W. Hughes, & M.A. Ruderman, Background gamma radiation and soil activity measurements in the northern Marshall Islands, Proc. Natl. Acad. Sci. U.S.A. 116 (31) 15425-15434, https://doi.org/10.1073/pnas.1903421116 (2019).

[6] Philippe, S., Alzner, S., Compo, G. P., Grimshaw, M., & Smith, M. (2023). Fallout from U.S. atmospheric nuclear tests in New Mexico and Nevada (1945–1962) [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2307.11040

[7] Dąbrowski, M.; Kuziak, J.; Dziedzic, K.; Glinicki, M.A. Influence of Environmental Conditions on Steel Corrosion in Concrete Exposed to Gamma Radiation. Mater. Proc. 2023, 13, 44. https://doi.org/10.3390/materproc2023013044

[8] Omarov, R.; Belov, V.; Morozenko, A. Studying Radiation-Induced Degradation of Reinforced Concrete Structures: Review and Numerical Analysis of Reinforcement Corrosion Processes in Concrete. Appl. Sci. 2024, 14, 11856. https://doi.org/10.3390/app142411856

[9] Bagherzadeh, M., Karimi, M., Choopan Dastjerdi, M.H. et al. Long-term irradiation effect on corrosion behavior of aluminum alloy in pool water of low-power research reactor. Sci Rep 13, 17007 (2023). https://doi.org/10.1038/s41598-023-44287-0

[10] Khmurovska, Y., Štemberk, P., Sikorin, S. et al. Effects of Gamma-Ray Irradiation on Hardened Cement Mortar. Int J Concr Struct Mater 15, 17 (2021). https://doi.org/10.1186/s40069-020-00452-7

[11] International Cable Protection Committee (ICPC). (2025, February 24). Damage to submarine cables from dragged anchors. ICPC Viewpoints. Retrieved from https://www.iscpc.org/publications/icpc-viewpoints/damage-to-submarine-cables-from-dragged-anchors/

[12] Spagnolo, A.M.; Maurella, C.; Sartini, M.; Bozzetta, E. Evaluation of Fish and Seafood Consumption in the Adult Population of an Italian Coastal Region and Health Risk Perception from Exposure to Methylmercury. Environments 202 5, 12, 66. https://doi.org/10.3390/environments12020066

[13] Sun Yat-sen University. (2023, August 26). Dialogue with oceanographers and nuclear medicine experts: What is the impact of Japan's nuclear contaminated water? Nanfang Daily via Sun Yat-sen University News Network. Retrieved from https://www.sysu.edu.cn/news/info/2171/1056971.htm

[14] Huxiu.com. (June 27, 2024). Fukushima nuclear contaminated water discharged into the sea for 10 months: seafood exports to China dropped by nearly 60%. Time Weekly. https://m.huxiu.com/article/3181583.htm

[15] New York Times Chinese website. (August 28, 2023). Fukushima nuclear wastewater discharge triggers China's total ban, Japan's seafood exports sufferhttps://cn.nytimes.com/asia-pacific/20230828/fukushima-water-seafood-japan-china/

[16] Kim, S., et al. (2018). Advanced membrane processes for

nuclear wastewater treatment: A review. Desalination, 426, 20–30. https://doi.org/10.1016/j.desal.2017.09.018
[17] International Atomic Energy Agency (IAEA). (2013). Treatment of radioactive wastewater. IAEA Technical Reports Series No. 389. https://www-pub.iaea.org/MTCD/Publications/PDF/TRS389_scr.pdf
[18] Lloyd, J.R., & Renshaw, J.C. (2005). Bioremediation of radioactive waste: Radionuclide-microbe interactions. Current Opinion in Biotechnology, 16(3), 254–260. https://doi.org/10.1016/j.copbio.2005.04.012
[19] Zhang, L., et al. (2021). Highly selective removal of radioactive cesium using Prussian blue-functionalized nanomaterials. Chemical Engineering Journal, 405, 126980. https://doi.org/10.1016/j.cej.2020.126980
[20] Ali, I., et al. (2020). Smart hybrid membranes for the removal of radionuclides from water: A new approach in nuclear waste management. Journal of Environmental Chemical Engineering, 8(5), 104243. https://doi.org/10.1016/j.jece.2020.104243
[21] Bentley, P. M., Hall-Wilton, R., Cooper-Jensen, C. P., Cherkashyna, N., Kanaki, K., Schanzer, C., Schneider, M., & Böni, P. (2021). Self-shielding copper substrate neutron supermirror guides. arXiv. https://doi.org/10.48550/arXiv.2104.02453