Applications of Artificial Intelligence in Oceanic Nuclear Contamination Management

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***Abstract*—Recently, nuclear pollution in the ocean has become a hot debate. The unprecedented advancement of Artificial Intelligence (AI) has engendered practical applications for addressing environmental issues such as nuclear contamination in oceans. AI algorithms and applications have been widely studied in multiple scientific fields, however, the research on marine science, especially oceanic nuclear contamination is limited. To fill in the gap in the related field, this paper introduces four major categories of AI technologies in oceanic nuclear contamination management, explores their applications in six companies/institutions across three leading countries, and compares the similarity and differences among them. It is found that UK, Japan, and China mainly use robots or drones for nuclear contamination management, and rely heavily on state fundings and the scientific output from research institutions. On the other hand, different countries have various objectives and motivations to drive AI in this area. What is more, we found that although most traditional big IT companies have not clearly stated the usage of AI in marine pollution, the need to diminish the impacts of nuclear pollution in oceans will inevitably urge new applications of AI in oceanic nuclear contamination.**

Keywords—Artificial Intelligence, Oceanic Nuclear Contamination

I. Introduction

Artificial Intelligence (AI) is becoming a fundamental force to transform many industries in the world. It can replicate human intelligence, analyze data patterns, and enhance decision marking of all kinds. AI algorithms have been very successful in many scientific fields, such as autonomous driving [1], medical imaging [2], geophysics [3], and earth science [5]. In the area of earth science, one significant but always overlooked area is marine science. As marine scientific research enters a new era of "marine intelligence", and the quality of data collected is continuously improving, AI can find its place to effectively find patterns in massive set of data and give solutions to government, big companies, or oceanic research institutions. Due to the significance of AI, the related topics are getting more attention from marine researchers in recent years [5].

Most recently, marine habitats have been threatened by pollutions, especially nuclear pollution, which has become an unavoidable trend that affects many human activities and even jeopardize human lives [6]. Such contamination may come from sources such as direct dumping of nuclear waste, sediment runoff from contaminated land, underwater nuclear testing, and accidental leaks from nuclear power plants. Growing concerns on the level and severity of pollution in the oceans and coastal zones have driven advances in the field of new technologies such as AI. And AI is proved to be effective for mapping and monitoring marine nuclear pollutions [6]. Finding a way to protect marine ecosystems has become a priority to ensure a symbiotic and sustainable future. AI has made a prominent contribution in dealing with the problems of marine nuclear pollution [7]. It protects the environment from the threat of nuclear contamination by providing accurate and rapid detection, efficient management, and effective mitigation strategies.

Currently, we are still at the beginning stage of using AI in marine sciences, especially in the area of nuclear contamination management. In this paper, we first introduce the concurrent AI applications used in handling three nuclear contamination issues, we will then illustrate the applications of AI in six companies/institutions across three leading countries. At last, a comparison between the three countries will be discussed, and the implications will be given.

II. AI Technologies in the Area of Oceanic Nuclear Contamination

Artificial Intelligence (AI) technologies have been increasingly applied to various aspects of nuclear contamination management. This includes nuclear detection, monitoring, decontamination, and disaster response [8]. It provides a sophisticated, safe, and effective mechanism to monitor, detect and mitigate nuclear contamination in the marine environment. Several major AI technologies have been frequently studied in the area of oceanic nuclear contamination management. They are: machine learning and analytics, deep learning, computer vision, and robotics [19]. Below is a breakdown of different AI techniques used in the field to deal with nuclear contamination.

A. *Major AI Technologies*

- *Machine Learning and Analytics*

Machine learning is the basis for automation, and machine learning algorithms can make accurate predictions from large amounts of collected data [7]. Research has shown that machine learning provides an effective solution to reduce pollution in the marine environment. After collecting a large amount of data on variables related to the marine environment, many machine learning algorithms can help to process the data accurately, and then analyze and predict the area of influence and dispersion trajectory of the pollution [9]. There are many Data-driven Machine Learning (DDML) algorithms that can help in dealing with nuclear contamination. As an unsupervised learning algorithm, clustering method can

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identify shaped groups in a data set. It provides help in identifying the subject of nuclear waste disposal patents [10]. In addition, logistic regression can model binary response data from mixed experiments, which can identify the main factors affecting nuclear decommissioning strategies [11]. In recent years, research on the role of machine learning in the field of radioactive waste disposal in the nuclear industry has shown an incremental trend and has received great attention from scholars [12].

- *Deep Learning*

Deep learning (DL) is a highly accurate tool for categorizing and recognizing image and sound data. The potential for using DL to analyze a variety of data in coastal ecology is outstanding [13]. For example, Radioactivity Monitoring in Ocean Ecosystems (RAMONES) believes cutting-edge AI and DL algorithms can be used to process and model marine radioactivity multimodal data [14]. Specifically, deep convolutional neural network (CNN)-based hotspot detection will be developed to solve detection and recognition tasks [14]. A CNN trained in image classification will find the function that best maps pixel inputs to categories, such as the presence of fish, plankton, or ropes in a photo [13]. The results of [15]'s study confirm that DL algorithms can help to develop the Autonomous Underwater Vehicle (AUV) Robot, handle trash detection and removal by evaluating the collected data.

- *Computer Vision*

Computer vision automatically obtains descriptions or important parameters from images of physical objects, and its image classification technology can be used for real-time marine pollution monitoring tasks while maintaining high accuracy and low training requirements [16]. In addition, [17] pointed out that the combination and development of computer vision technology with sensors and gamma ray imaging instruments can achieve unprecedented detection, location, and mapping capabilities of radioactive and nuclear materials, which is of great significance to future marine nuclear contamination management.

- *Robotics*

Marine robots including autonomous underwater vehicles (AUVs) are key tools in the fight against ocean pollution [15] and are commonly used to understand ocean and environmental issues, protect the ocean from pollution, and conduct deep-water surveys [18]. In terms of nuclear contamination management, AUVs are expected to provide autonomous, adaptive radioactivity monitoring to monitor sea water and provide rapid response capabilities based on event-driven online decision-making processes in various scenarios [14].

To summarize, the above content introduces the application of four major AI technologies in managing nuclear contamination treatment. Machine learning algorithms can predict the spreading path of nuclear contamination, and are mainly responsible for prediction and management. DL and computer vision technologies are more advantageous in the task of nuclear contamination monitoring, which can automatically detect the data and transmit them back to the research center. After helping to monitor marine environmental data, the robots are also expected to take action to explore the dangerous underwater environment and make more contributions for nuclear decontamination.

B. AI APPLICATION AREAS

In terms of specific application areas in oceanic nuclear contamination, AI is helpful in the below functional areas: detecting and monitoring oceanic nuclear contamination, nuclear waste management, and nuclear decontamination.

- *AI in Detecting and Monitoring Oceanic Nuclear Contamination*

AI technologies, especially machine learning and deep learning have been used in detecting and monitoring nuclear contamination levels in the oceans [14]. These systems can rapidly process large volumes of data to detect radionuclide concentration, temperature, salinity, and pH levels within the marine environment [10][11]. Machine learning algorithms can be employed to identify contaminated areas and assess radiation spread. Furthermore, AI models that integrate historical and live data can predict trends in the movement and eventual fate of radioactive substances in the ocean [19].

- *AI in Nuclear Waste Management*

AI has a significant role to ensure a safe handling, transportation, and disposal of nuclear waste, which is a primary source of nuclear contamination in oceans. Machine learning and data analytics can categorize and prioritize nuclear waste based on its severity, type, age, and risk levels [20]. Moreover, robotics are especially effective for radioactive waste management, they will be used for waste generation, collection, characterization, sorting, packaging, conditioning, storage, and disposal. They can further optimize routes for nuclear waste transportation to ensure minimum risk [21].

- *AI in Oceanic Nuclear Decontamination*

Given the immense risks and challenges involved in hands-on human intervention in nuclear contaminated areas, AI-powered robots become a solution. Robotic systems like AUVs can be relied to take on the herculean task of nuclear decontamination in the ocean. It can generally reduce risks to damage human health and marine life [15]. For example, the survey robots and working robots from Hitachi Japan can help in the progress of decommissioning. They can automatically detect harmful radiations, collect contaminated samples, and assist in cleaning procedures [22]. In the future, we believe advanced AI algorisms can optimize decontamination methods by considering various factors, such as the contamination level, type, season of marine life and water temperature.

III. AI APPLICATIONS IN LEADING COMPANIES/INSTITUTIONS

To illustrate their current applications, we purposely selected three countries that are facing different challenges of oceanic nuclear contamination. The countries are also chosen as they have capabilities, resources, and technological solutions to handle nuclear contamination. UK is a well-established capitalist country in the traditional sense. It is typical enough to represent how a western country handle nuclear contamination. Japan itself seriously suffered from fukushima disaster ten years ago, and currently the unclear water has polluted the nearby ocean. China represents the big category of countries that largely get involved in monitoring and detecting oceanic nuclear contamination. We believe the selection of these three countries are representative and diverse enough to cover the breadth of innovations and applications of AI in the field.

A. United Kingdom

UK mainly relies on the national center to handle nuclear contamination issues. And this nuclear contamination in UK mainly covers the contamination other than oceanic ones. The National Centre for Nuclear Robotics (NCNR) is a consortium of eight universities, led by the University of Birmingham, whose mission is to remove radioactive material from UK. NCNR is enabling faster, safer, and cheaper solutions to secure radioactive environments and finding ways to dispose nuclear waste by uniting leading experts in robotics, artificial intelligence, sensors, radiation and resilient embedded systems [23].

- *University of Birmingham Extreme Robotics Lab*

Robots developed by NCNR can dispose nuclear waste safely. Robots can be remotely controlled to safely store or properly dispose radioactive materials, and autonomously perform complex tasks including sensing, grasping, cutting and manipulating waste [24]. In this regard, the University of Birmingham Extreme Robotics Lab in the NCNR consortium has developed the most powerful, most versatile and fastest computing autonomous grasping algorithm in the world. Fully autonomous machine capable of grabbing arbitrary objects from randomly self-occluding nuclear waste piles [25].

- *University of Lincoln*

Drone on-site inspections are important for detecting radiation levels during routine monitoring and after emergencies. NCNR's use of drones, or unmanned aerial vehicles (UAV), reduces the need for humans to enter radioactive environments. Yet there are still clear challenges in remotely measuring outdoor sites to reveal radiation sources and autonomously locate them [24]. For this problem, a team from the University of Lincoln in the NCNR consortium aims to improve existing solutions by using wheeled robots that can autonomously traverse challenging terrain to implement radiation mapping capabilities. Probabilistic radiation maps are gradually constructed, and sensing points are automatically selected to drive the robot's autonomous exploration [26].

Besides NCNR, two companies or institutions in UK also provide similar nuclear detection services. For example, Sellafield Ltd. is able to use AI to manage three forms of nuclear waste by recognizing patterns in data and predicting outcomes [27]. Another government owned company – National Nuclear Laboratory is also able to use robotics to make the nuclear waste sorting and navigating processes safer [28].

B. Japan

Tokyo Electric Power Company (TEPCO) has been playing a leading role in the decommissioning process of the Fukushima Daiichi nuclear power plant. It has mainly used remotely-operated AI robotics to navigate high-level radiation areas within the reactor buildings, thereby reducing the ecological impact of nuclear contamination. TEPCO further established International Research Institute for Nuclear Decommissioning (IRID) that brings together a wide range of domestic and international companies and organizations to collaborate on the development of technologies related to solving nuclear contamination problems [29].

- *Hitachi-GE Nuclear Energy Ltd.*

As a member of IRID, Hitachi-GE was established in 2007 by Hitachi Ltd. and General Electric Company of the United States to participate in the nuclear energy business. They developed the submersible crawling and swimming robot for use in fuel removal investigations at the Fukushima Daiichi nuclear power plant. The submersible swimming robot will probe the interior of the water-filled power plant building, and can be used as a device to detect the location of nuclear power plant stagnant water leaks from underwater. The robot, which has the basic shape of a stable mobile device, consists of two small tracks that can change shape to pass through narrow spaces [30].

- *Toshiba*

With the support of a government program, Toshiba as another member of IRID helps reduce the risk of radiation in contaminated water by using the Advanced Liquid Processing System (ALPS) to divert a large portion of the radionuclides [31]. Starting in 2016, Toshiba developed dry ice blast decontamination equipment that could do an effective job of removing contaminants. The robot can decontaminate contaminated areas without generating secondary waste by spraying and directly inhaling dry ice in the contaminated area during the evolutionary treatment phase before nuclear contamination is discharged [32]. It investigates the location of melted fuels, greatly aiding in the decontamination and decommissioning processes.

C. China

China already has internationally advanced marine radiation environment monitoring technology—a series of sea, land, and air intelligent nuclear emergency radiation rapid monitoring equipment. They were specifically designed for nuclear accident emergency needs. Due to the use of proprietary hardware system design, and advanced AI algorithms, the equipment has the advantages of intelligence, speed, and accuracy. In addition, these technologies have been applied in many units such as nuclear power plants and scientific research institutes in China, and has achieved good economic and social benefits.

Regarding to the nuclear power plant, as the largest nuclear power operator in China, China General Nuclear Power Group (CGN) believes that AI will provide more help for nuclear power. The use of AI technology can significantly improve the safety and availability of all nuclear power plants by detecting faulty conditions in complex environments, forecasting faults in advance, diagnosing the causes of faults in a timely manner, while providing precise suggestions for countermeasures. Robotics and intelligent equipment are also an important direction of nuclear industry intelligence. Nuclear power robots can replace people sneaking into the nuclear power plant to shoot and deliver images, so that people can truly understand the real situation inside the nuclear power plant. [31]

Similarly, China National Nuclear Corporation (CNNC) launched a project on the application of AI in the nuclear technology industry in 2019. The goal of the project is to apply AI to the entire nuclear technology industry chain, including uranium mining, fuel assembly production, nuclear equipment manufacturing, nuclear power plant design, construction, and operation, as well as nuclear environmental protection and nuclear power generation [33].

Currently, the research on nuclear energy by these two State-Owned-Enterprises focuses mainly on nuclear energy development and waste treatment within the plants, with less research on measures to deal with the marine nuclear pollution component. However, in some Chinese research institutes and universities, researchers have made some progress in the development of AI technologies for marine nuclear wastewater. These technologies have also been successively supported by CNNC and CGN [33].

- *Southeast University and North China Electric Power University*

Southeast University and North China Electric Power University developed an equipment that includes a marine radiation and nuclide diffusion monitoring system based on drones and unmanned ships. The system uses AI to obtain real-time detected radionuclide dispersion data, process and transmit it to a remote terminal. Therefore, it can be used to monitor the nearby sea environment during normal operation. When an accident occurs at a nuclear power plant, core data can be quickly obtained to take faster response measures [34].

- *Nanjing University of Aeronautics and Astronautics*

Unmanned online monitoring equipment for marine radioactivity around nuclear power plants is of great significance in the event of a radioactive material leakage accident [35]. The Nuclear Technology and Multidisciplinary Innovation Research Center of Nanjing University of Aeronautics and Astronautics designed the intelligent marine radioactive in-situ monitoring mooring buoy to respond to nuclear accident emergencies. Compared with traditional methods, its sampling-free online monitoring method based on gamma spectrometers improves real-time nuclear autonomy, and can feed back sufficient radioactivity data more quickly and continuously [36].

IV. SUMMARY OF SIMILARTIES AND DIFFERENCE

A. Similarities

Overall, the main technologies applying AI to nuclear contamination management in UK, Japan and China focus on robots or drones. Using robots or drones, remote control can be used to replace manual labor and perform nuclear decontamination tasks in contaminated areas or monitor the radiation environment in real time.

In addition, in the process of developing technologies, the three countries all rely on state fundings and joint research institutions or universities to achieve the goals. For example, the UK NCNR cooperation project involves international experts from 8 universities in UK, and more than 30 nuclear industry partners [23]. It also has received an investment of 42 million pounds from UK government [23]. The UK government, through agencies such as Environment agent, Innovate UK, the Natural Environment Research Council (NERC), and other bodies, provides funding for innovation in environmental science and technology. Especially pilot tests were conducted in the unclear area by using AI [37]. However, the effectiveness of the investment is yet to known. For Japan, in 2012, TEPCO received US$12 billion funding from the Japanese government for the decommissioning of the Fukushima Daiichi nuclear power plant [39]. At the same time, IRID took the decommissioning of the Fukushima Daiichi Nuclear Power Plant as an urgent issue and carried out relevant research and development work. This would not work out without bringing together domestic and foreign wisdoms [29]. The Japanese government's investment in AI and robotics, particularly in response to the Fukushima Daiichi nuclear disaster, has led to significant technological advancements. For instance, AI-driven robots and autonomous vehicles have been developed and deployed for inspection, monitoring, and remediation tasks in environments that are hazardous to humans [38]. These technologies not only improve safety but also enhance the public information and trust toward nuclear contamination. Finally, China invests heavily in R&D across various technology sectors, including AI. Government funding, often channeled through universities, research institutes, and partnerships with private companies, supports the development of innovative technologies. For instance, advanced AI technologies from China are developed by national research institutes such as the CGN, CNNC, National Ocean Technology Center and other local universities [36][34]. Similar with other countries, the effectiveness of supporting AI development and usage in China still need time to prove. At last, we also noticed that the R&D support of the three countries focuses on different areas of artificial intelligence in marine nuclear pollution management. This means that there is a possibility that the investment of national funds could limit the diversity of research areas.

B. Differences

Although UK, Japan, and China are all pioneers in the development of AI in the field of nuclear contamination, their key research areas and motivations are different. For example, UK is focusing on nuclear waste disposal to achieve the goal of eliminating radioactive material from UK [23]. Japan, on the other hand, is committed to the Fukushima recovery mission, and therefore focuses on developing robot-based nuclear decommissioning projects. To meet the emergency needs of nuclear accidents, China is committed to developing on-site monitoring based on UAVs.

From the benefits perspective, UK is in a leading position with the help of advanced technologies and sufficient talent reserves. These enable it to have faster, safer, and cheaper solutions to the nuclear waste problems [23]. Japan is gradually mitigating nuclear disasters by pooling domestic and foreign wisdoms. China has developed internationally advanced technologies, and achieved a high degree of agility to nuclear risks [35]. Further comparison results were summarized in table 1.

TABLE I. DIFFERENCES BETWEEN THREE COUNTRIES

	UK	Japan	China
History	Long history of unclear energy protection	Fukushima Daiichi nuclear disaster	New in the area, and part of its nuclear energy program
Technological capabilities	R&D in nuclear waste handling	Robot based nuclear decommissioning	UAV based site monitoring, nuclear safety technologies.
Motivation	Clear radioactive material [23]	Revitalization of Fukushima [30]	Prevent contamination incidents. Handle nuclear accident emergency [35]
Benefits	Achieve best nuclear solutions	Mitigate nuclear disasters	High agility to nuclear risks

V. CONCLUSTION

The growing importance of AI and the sense of environmental protection imply an urgent need and development of AI technologies in the area of oceanic nuclear contamination. As a result, many countries, research institutions, and big enterprises all over the world are aggressively exploring ways to implement AI and big data-based solutions to tackle ocean pollution issues. For examples, big IT companies can play a significant role in leveraging AI technologies to address marine pollutions via various means. They can contribute in creating more advanced AI algorithms and machine learning models, can partner with governments and NGOs to deploy AI technologies, and can provide innovative technological solutions and data platforms. In this article, we first introduced four major AI technologies that are commonly used in oceanic nuclear contamination management, and then thoroughly studied three leading countries, and their corresponding measures to handle nuclear contamination or oceanic nuclear contamination. We believe the selection and categorization of these AI technologies and countries are diverse, comprehensive, and representative enough to cover the current state of the field, and to demonstrate the breadth of innovations and applications in oceanic nuclear contamination area. A comparison between three countries with their major institutions was conducted at the end. Our conclusion also conveys that though the traditional nuclear and marine organizations may not explicitly state their use of AI to address marine nuclear contamination, and currently, direct AI-based technologies related to marine nuclear contamination are limited, the trend and investment of using AI in the area of marine nuclear pollution management is non-stoppable. We look forward to more research in the oceanic nuclear contamination area, which can benefit not only research and development in individual countries, but also beneficial for humans in the globe. Future research should investigate and compare the differences across more countries to address the applicability and scalability of the current AI solutions in similar marine science areas in the near future.

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