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IMPACT OF NUCLEAR POWER PLANTS ON SEA TURTLES AND ENVIRONMENTAL EDUCATION STRATEGIES TO RAISE AWARENESS

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ABSTRACT
Despite the importance of nuclear energy in the energy matrix and in various sectors, its waste and processes can generate serious risks to the marine environment, such as the bioaccumulation of radionuclides in turtles and mortality caused by water cooling systems. This article analyzes the environmental impacts of nuclear power plants on sea turtles, focusing on radioecology and environmental education strategies as conservation tools. The study combines a literature review with data from technical visits carried out at the Angra dos Reis Nuclear Power Plant, highlighting the challenges faced by these species in Brazil, where five of the seven species of sea turtles occur. The results reinforce the importance of turtles in marine ecosystems, being important bioindicators for the evaluation of environmental contamination. Environmental education strategies are proposed, such as community involvement, awareness in schools and awareness campaigns aimed at tourists and fishermen, demonstrating their effectiveness in mitigating impacts and promoting sustainable practices. It is concluded that environmental education is an indispensable instrument for the awareness of society and the conservation of sea turtles, especially in regions with nuclear activities, reinforcing the need for integrated actions between the community, governments and industries.

Keywords: Marine animals, Bioaccumulation, Radioecology, Contamination, Marine conservation.

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INTRODUCTION

Nuclear energy, widely recognized for its potential in power generation, also plays different roles in various areas, as described by Motter (2018). Applications such as food preservation and production, sterilization of surgical materials, development of new plant cultivars, space exploration with thermonuclear rockets, and nuclear medicine for diagnostics and treatments. In addition, its use encompasses scientific research and global security initiatives, such as peace treaties (Motter, 2018; Carvalho and Oliveira, 2017). These multiple applications highlight the versatility and relevance of nuclear energy in different scenarios of society.

However, despite its advantages, nuclear energy raises significant environmental concerns, particularly with regard to radioactive waste. This waste has a potentially serious impact, especially on marine ecosystems and organisms such as sea turtles. Recent studies, such as that of Conrad et al. (2023), have pointed to the presence of anthropogenic uranium in turtles that inhabit areas close to nuclear test sites. In addition, accidents such as those at "Three Mile Island", "Chernobyl" and "Fukushima" underscore the environmental risk associated with nuclear power, highlighting the profound impact these events can have on marine life, with sea turtles being particularly vulnerable.

In view of this scenario, the main objective of this article is to analyze the impacts of nuclear power plants on sea turtles, considering the effects of radioactivity and the industrial mechanisms involved, such as cooling systems. In addition, the study proposes environmental education strategies that seek to sensitize society to the conservation of these endangered species, reinforcing the importance of sustainable practices for the protection of marine biodiversity.

METHODOLOGY

This article presents the results of a research carried out in 2024, through a survey of bibliographic material, consisting of scientific articles, books and videos, on sea turtles and the main species existing in the Brazilian territory motivated by a technical visit carried out to the company Eletrobras Eletronuclear in 2022.

Then, the main mechanisms by which nuclear power plants affect marine life were analyzed, with emphasis on the analysis of existing control, research and management measures to assist in mitigatingthe impacts of nuclear power plants and promoting the conservation of sea turtles. In addition, a survey of actions with conservation and

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environmental education strategies was carried out to promote the protection of sea turtles in areas under the influence of nuclear power plants, as well as in other areas of the Brazilian territory. At the end of the research and based on the survey of the bibliographic material collected, the challenges, perspectives and strategies of environmental education tohelp in the conservation of sea turtles were presented.

RESULTS

RADIOACTIVITY: THE DISCOVERY OF A NEW SOURCE OF ENERGY

Great discoveries have been made throughout the history of humanity, which have contributed to its existence. The advancement of science has contributed to the discovery of different sources of energy, including nuclear. Its use is present in areas such as medicine and in the production of electricity.

Uranium (U) is used as fuel in nuclear reactors, for the production of electricity. Its use requires care, taking into account the accidents that have already occurred around planet Earth. Marie and Pierre Curie were responsible for the discovery of radium and polonium, elements that emit millions of times more radiation than uranium. Marie Curie was the first woman to receive the Nobel Prize, in view of the discovery of the phenomenon called radioactivity. Wilhelm Roentgen accidentally discovered in 1895 a mysterious type of lightning, which could pass through almost all substances, except bones and other solid objects. These solids were projected onto a film used in the experiment and defined the phenomenon as x-rays (Martins, 2002).

Henri Becquerel discovered in 1896 that uranium produced a type of spontaneous radiation, which resembled x-rays, and was unable to explain the nature of this radiation. His discovery revolutionized medicine in the identification of inflammatory and neurological diseases and cancer. Marie Curie died in 1934 of leukemia, a rare disease that affects the bone marrow, as a result of exposure to radiation, due to the lack of protection techniques, which exist today. The remains of Marie and Pierre Curie were transferred to lead coffins in France and to this day their notebooks can only be used with protection (BBC NEWS BRASIL, 2023).

Within this context, the main challenge with regard to radioactivity is how to use it safely and responsibly. Nuclear energy is one of the alternatives to fossil fuels, being one of the most controversial, because of the management of radioactive waste produced in the process. The leftovers of uranium fission, which generates heat to produce water vapor,

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generating energy, are highly radioactive and need to be stored properly, since there is still no way to return them to nature without causing damage to the environment and living beings or at least dispose of them (Souza and Ferreira, 2017).

Nuclear plants are not risk-free either. Accidents such as those that occurred in Chernobyl (1986), Fukushima (2011), the accident with Cesium 137 in the city of Goiânia (1987) and the dropping of the bombs on Hiroshima and Nagasaki (1945) were the most evil legacy of the scientific advance caused by the discovery of radioactivity. Despite being discovered for peaceful use, the story showed its destructive potential when used without proper care (BBC NEWS BRASIL, 2023).

NUCLEAR ENERGY AND ITS IMPORTANCE IN THE BRAZILIAN ENERGY MATRIX

One of the important aspects when talking about energy matrices is Brazil's energy policy, with a view to reducing CO2 emissions through the exploration of various forms of energy. It is a great challenge in the energy transition and energy demand, and good management of these resources is necessary.

Nuclear energy is one of the possible energy sources to meet this demand, and Brazilian energy policy is a fundamental element in the social, economic and environmental development aspects, taking into account technological innovations, climate change, sustainable development, efficient use of energy resources, low-carbon sources and electrification, digitalization of processes, controls and services (Brasil, 2018).

In 2018, nuclear energy corresponded to 1990 MW and 1.2% of the Brazilian energy matrix. Brazil, with a continental territory, has many natural riches, abundance of energy resources, climatic conditions to supply the total energy demand for the next thirty years many times over. Most of the electricity consumed in Brazil comes from hydroelectric plants, occupying large areas, and depends on hydrometeorological conditions that, as a result of climate change, suffer from the scarcity of rain, with the need to adopt new sources for generating electricity.

Among them, solar, wind, tidal, thermal, biomass, and nuclear, with uranium being used as a fuel material to drive turbines, through water heated by the heat generated in the fission process (Carvalho and Gracher, 2021). Thus, it is evident the need to adopt strategies for energy supply, in view of present and future demands.

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SEA TURTLES IN BRAZIL

Sea turtles are animals that play an important role in Brazil's marine ecosystems. In the country, there are five of the seven species of sea turtles on the planet: the giant or leatherback turtle (Dermochelys coriacea), the hawksbill turtle (Eretmochelys imbricata), the olive ridley turtle (Lepidochelys olivacea), the loggerhead turtle (Caretta caretta), and the arowana or green turtle (Chelonia mydas) (Pizetta, 2023, p. 9). These species face several challenges. A combination of factors such as overfishing, habitat destruction, and sea contamination has determined the biological and behavioral conditions of turtles (Carvalho et al., 2020, p. 26).

Sea turtles have a complex life cycle and make use of different environments throughout their lives, which implies changes in habits. Although they are marine, they use the terrestrial environment (beach) for spawning, ensuring the appropriate place for the incubation of eggs and the birth of the chicks. At birth, the chicks immediately head for the high seas (Eckert et al., 1999).

They carry out long migrations between feeding and breeding areas, with females returning to beaches to spawn. The hatchlings, at birth, face a challenging journey to the sea, where they begin their marine life (Farah, 2017). They play an important role in maintaining the health of marine ecosystems, contributing to the balance of food chains and the health of coral reefs. Therefore, the protection of these species is essential for their survival and for the health of the oceans as a whole (Pizetta et al., 2023).

DISCUSSION

IMPACTS OF RADIOACTIVITY AND COOLING SYSTEMS ON SEA TURTLES

Sea turtles are of great ecological importance, and are vulnerable to the effects of nuclear power plants. Thermal pollution directly and indirectly impacts sea turtles, generally juveniles, which shelter and feed in these regions (Marcodalvi et al., 2011).

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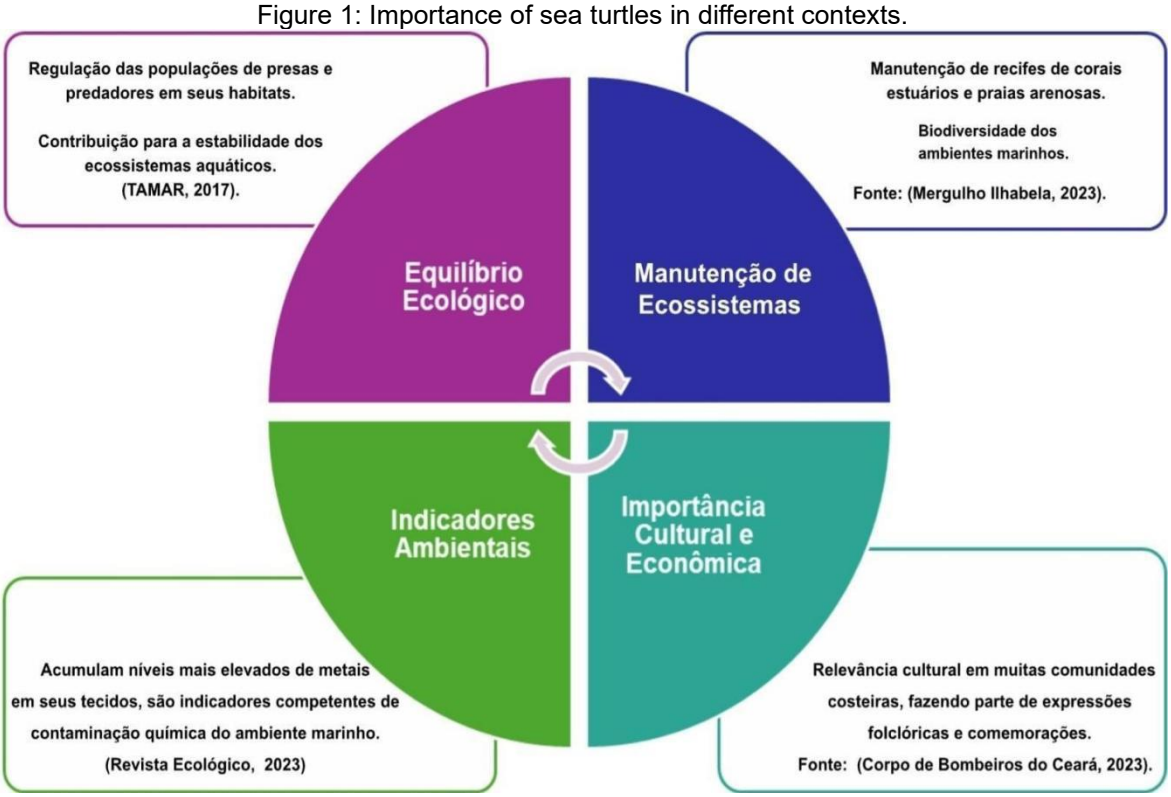
Figure 1: Importance of sea turtles in different contexts.



Source: The authors, adapted from Carvalho et al. (2022).

Relating the impacts of nuclear power plants to turtles. We highlight Pereira (2023), describes that turtle shells can store traces of radiation. In the United States alone, some nuclear activities in the past have contaminated more than 80 million cubic meters of soil and 4.7 billion cubic meters of water, and turtles are inserted in this context, being an important biological indicator for the identification of sources of nuclear contamination, in the context of radioecology (Pereira, 2023).

Radioecology is the branch of ecology that studies the behavior of radionuclides in the environment and their interactions with living organisms, investigating how radionuclides disperse in different environmental compartments (such as soil, water, and air) and how they affect biota, including the biological effects of ionizing radiation on living beings (Mazzili, 2016). Radioecology is fundamental for the assessment of radiological risks and for the implementation of environmental protection measures (Pereira, Kelecom and Py Júnior, 2011).

Another important impact observed during the research, in addition to the radioactivity present in the turtles' shells, is the process of capturing seawater for use in the cooling system of industrial processes in the nuclear area. Pizetta et al. (2023) address the environmental impacts of seawater abstraction for cooling systems in industries, mainly

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highlighting the risk to sea turtles. The use of "Once-through Cooling" (OTC) cooling technology has been identified as a significant threat, leading to the incidental capture and death of turtles.

Studies show that in some plants mortality can be high due to injuries caused by catchment structures and cooling systems. Specifically, the Santa Lucie Nuclear Power Plant in Florida has documented the capture and death of many turtles. Between 1976 and 1988, 1,631 loggerhead turtles (*Caretta caretta*) and 269 green turtles *(Chelonia mydas*) were captured with a mortality rate of 7.5% for loggerhead turtles and 6.7% for green turtles. In Brazil, the Angra 2 Plant also presented similar problems: between August 2010 and September 2013, 175 turtles of the species *Chelonia mydas* and *Eretmochelys imbricata were captured*. Of these, 73 were found dead and 102 were released after rehabilitation. The deaths were attributed to drowning and trauma caused by the cleaning structures of the solid waste retention grids.

To reduce these impacts, Pizzeta et al. (2023) suggested several mitigation measures, such as the installation of protection mechanisms in catchment structures, the use of closed cooling systems that would reduce the need for seawater, and the constant monitoring of incidental catches. The recommendations point out in the study, the rescue and rehabilitation of captured turtles, the performance of necropsies on deaths, and the awareness of workers about the importance of protecting turtles and the adoption of mitigation measures (Pizetta et al., 2023).

The results of the research highlight the widespread use of nuclear energy, which goes beyond electricity generation, including applications in nuclear medicine, food preservation, and even space exploration (Motter, 2018). However, according to Menezes et al. (2014), in the environmental context, particularly in areas close to nuclear power plants such as Angra dos Reis – RJ, the impacts on sea turtles are worrying. It is necessary to assess the environmental impacts of these plants, especially on marine organisms.

Other risk factors include vehicle traffic on beaches, which can compact turtle nests, run over hatchlings, and cause stress to females during spawning. Water pollution, by organic and inorganic elements, also harms the diet and life cycle of sea turtles. Vessel traffic poses a threat of collision for these species (Santos, Silva, and Souza, 2023).

According to news published on the "Portal Bem Paraná", a survey by UFPR (Federal University of Paraná) highlighted that interaction with vessels is a serious threat to

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sea turtles in Paraná, with 76 of the 153 cases of injuries recorded between 2015 and 2022 attributed to collisions (Bem Paraná, 2024).

Sea turtles are species considered to be in danger of extinction or in critical danger of extinction, and the main causes of decline in these populations are of anthropic origin, such as pollution of the seas, in addition to other unsustainable practices. Regarding the biology and reproduction of sea turtles in Brazilian waters, 5 species occur in Brazil (*Caretta caretta, Chelonia mydas, Eretmochlys imbricata, Lepidochelys olivacea*, and *Dermochelys coriácea*).

According to Carvalho (2022), sea turtles are considered key organisms in aquatic ecosystems, playing a fundamental role in maintaining the balance of the marine ecosystem and maintaining biodiversity. Studies show that turtles bioaccumulate contaminants, reflecting environmental contamination resulting from human activities. The research also highlights the importance of turtles as bioindicators in environmental monitoring and suggests that the findings may influence future investigations into radionuclide contamination in marine and terrestrial ecosystems (Conrad et al., 2023).

Pereira (2023) highlights the study of four species of turtles (Biological classification: class Reptilia, order Chelonia), where radiation sources were detected from sites that were the scene of nuclear tests: the Marshall Islands and the Mojave Desert, in Nevada, USA, while the other two came from sites contaminated by nuclear waste leaks. The research concludes that, to ensure the protection of sea turtles, a joint effort involving the community, companies and government agencies is necessary.

These species, such as *Chelonia mydas* and *Caretta caretta,* play an essential role in the balance of marine ecosystems (Carvalho, 2022). Studies by Barros et al. (2020) show that the construction of sea barriers at the Angra I Plant is a mitigation measure to protect the local fauna, but there are still considerable challenges due to thermal pollution and vessel traffic, which cause injuries and stress to turtles.

EXPERIENCE REPORT - TARTARUGA VIVA PROJECT

A technical visit experience carried out in July 2022 at the Almirante Álvaro Nuclear Power Plant - CNAAA was essential for understanding the protection and conservation practices of sea turtles. The technical visit carried out at the Nuclear Power Plant in Angra dos Reis had as its main objective to learn about its operating process. It was an awakening in obtaining new knowledge and in an unprogrammed way. The presentation of

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the Live Turtle Project was an additional knowledge that motivated the research and writing of this article. The visit provided a differentiated learning to understand the operation of the plant and the potential impacts on marine life, especially sea turtles.

The "Tartaruga Viva" project, carried out in partnership with the State University of Rio de Janeiro and Eletronuclear, aims to monitor these populations, providing important data on their behavior and health conditions (Eletronuclear, 2024). Sea turtles also bioaccumulate contaminants, being efficient bioindicators for environmental monitoring, especially in relation to radionuclide contamination (Conrad et al., 2023). The results obtained highlight the urgency of conservation actions and the importance of projects such as "Tartaruga Viva", which not only protect sea turtles, but also promote Environmental Education and awareness about the preservation of marine ecosystems.

ENVIRONMENTAL EDUCATION

With regard to Environmental Education, the "Manual of Marine and Coastal Ecosystems for Educators" highlights the importance of environmental education in the conservation of marine and coastal ecosystems in Brazil, addressing the need for sustainable development and the protection of biodiversity. Within this context, sea turtles are highlighted as vulnerable species that face several challenges.

The manual mentions that tall buildings and plantations on the coast increase the shade of turtle spawning beaches, generating an imbalance in the populations of males and females, since the sex of the hatchlings is determined by the temperature of the sand where the eggs are incubated. In addition, the incidence of artificial light on the beaches disorients the females during spawning and the chicks at birth, making it difficult for them to move towards the sea.

In addition, the manual provides information on sea turtle conservation and seeks to train educators to promote awareness of the challenges these species face and the importance of their protection. The National Action Plan for the Conservation of Sea Turtles is a strategy to protect sea turtles in Brazil, prepared by institutions such as ICMBio and the Pró-TAMAR Foundation. The plan proposes specific actions, such as reducing incidental catch, population surveys, and awareness-raising programs in fishing communities. It emphasizes collaboration in international forums. It is a commitment to integrate conservation, research and environmental education in favor of the protection of these endangered species (Marcodalvi et al., 2011).

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To sensitize society about the importance of sea turtle conservation, environmental education strategies are essential. Through this study, some strategies are presented in Chart 1 below.

Chart 1: Proposals for Environmental Education actions for the preservation of sea turtles.

Proposal	Environmental Education Strategy
Community Involvement	Encourage active participation of the local community, especially in areas to rescue stranded turtles and report sightings, as already done in the "Live Turtle" project
Raising awareness in schools in the region	Insert content about the ecological importance of sea turtles and the impacts of human activities on the school curriculum, with emphasis on practical activities.
Awareness and sensitization campaigns	Carry out awareness campaigns aimed at tourists and fishermen about the importance of preserving beaches and reducing the use of plastics that directly affect turtles

Source: Prepared by the authors, 2024

Figure 2: Environmental Education Strategies for the preservation of sea turtles.

Source: Prepared by the authors, 2024.

The conservation of sea turtles requires integrated actions and educational strategies that engage different social actors, with a focus on sustainable practices and conscious behaviors. The table presents three proposals for Environmental Education that are aligned with ecological and educational principles described in the literature.

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The involvement of the local community is a potentiating point for the success of conservation initiatives. Active participation in projects such as "Tartaruga Viva" increases the efficiency of monitoring actions and fosters a sense of belonging and environmental responsibility in residents of coastal areas. According to Dias and Castro (2020), community environmental education strengthens people's relationship with the territory and promotes a culture of conservation based on practical and direct actions. In addition, Oliveira et al. (2021) highlight that marine fauna rescue actions generate positive impacts by reducing the time of exposure of animals to adverse conditions, increasing their chances of survival.

The inclusion of content related to the preservation of sea turtles in the school curriculum contributes to the formation of a generation that is more aware of environmental challenges. Hands-on activities, such as guided visits to beaches or animal rehabilitation centers, make learning more meaningful and engaging. As Freire (1996) points out, education must be a liberating process, connecting theory and practice to transform reality. Moura and Santos (2019) reinforce that educational actions in schools have a lasting impact, especially when children act as multipliers of knowledge in their families and communities.

Awareness campaigns aimed at tourists and fishermen are essential to reduce the negative impacts of these human activities on beaches and oceans. Raising awareness of reducing the use of plastics, for example, is aligned with combating marine pollution, which is one of the main threats to turtles (UNEP, 2022). Educational campaigns with participatory approaches, such as workshops and lectures, have been shown to be effective in increasing environmental perception and promoting behavior changes (Silva et al., 2020).

The strategies presented in the table stand out for their integrated approach and relevance to the conservation of sea turtles. Community involvement, formal education and targeted campaigns are pillars of a transformative Environmental Education. To amplify the impacts, it is necessary that these actions are continuous, monitored and adapted to local realities. The literature reinforces that successful conservation projects combine awareness, mobilization, and empowerment of the populations involved (MMA, 2020).

CONCLUSION

Environmental Education encompasses the potential to sensitize society about the conservation of sea turtles, especially in areas of influence of nuclear power plants. These

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regions present complex challenges, including direct impacts, such as incidental capture in cooling systems, and indirect impacts, such as radionuclide bioaccumulation in turtles.

The strategies discussed in this article, such as community engagement, sensitization in schools, and awareness campaigns, demonstrate the potential of environmental education to transform attitudes and practices, promoting the conservation of sea turtles and, by extension, the protection of marine ecosystems. Projects such as "Tartaruga Viva" highlight the effectiveness of partnerships between the community, academia and the industrial sector in mitigating impacts and strengthening preservation practices.

In addition, the integration of educational actions with technological and regulatory measures, such as the improvement of cooling systems and continuous environmental monitoring, is essential to reduce the impacts on turtle populations. This approach reinforces the need to join efforts between different social actors, including governments, companies, and non-governmental organizations, to ensure the sustainability of actions.

Finally, this article contributes to the reflection on the role of environmental education as a transformative element in the relationship between technological development and environmental conservation. Raising awareness among local populations and implementing long-term educational strategies are crucial for the balance between energy advancement and the preservation of marine biodiversity, especially in times of climate change and increased pressure on natural resources

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