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Analysis of the application of remotely operated underwater vehicles in nuclear power plants

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1. Introduction

The performance and evolution of nuclear energy as an efficient energy source is one of the studies that have already brought decisive results for the strengthening of this matrix as a viable investment option. Many European countries are still satisfied and tend to invest even more in research and development in various areas of nuclear energy, not only in the technological side of power generation, but also in the social acceptance of this powerful resource. In Brazil, with a water crisis looming, it is of fundamental importance that nuclear energy be highlighted and gain notoriety whenever deciding on an energy resource that can replace the gap arising from hydroelectric plants collapse.

However, the advancement of nuclear energy is not only associated with its energy performance, but also with the ability to develop satisfactory solutions for the negative impacts on life and environmental issues. All processes needed for nuclear power plant operation are based on safety principles and have developed and improved over the years, ideally assuring radiation and waste control management [1].

Technology is an intrinsic issue in human society and its definition, somewhat obvious, is not easily accessible. The consensus found among the references is that technology is a set of knowledge, techniques, skills, and processes that are intended for the production of a material or activity. It is important to emphasize that the impacts of technology are not always positive, however, its development is essential so that society finds new alternatives for obsolete processes. The most didactic example of the use of this definition of technology is the creation of industrial robots [2], [3].

The name robot is of Czech origin "robota", which means "slave work" and its first mention goes back to 1920, when a playwright played a character who imitated a machine that replaced the slave in heavy and dangerous work, but the concept of machines that perform human work is much older, with records of 500 years BC. With the emergence of Computer Numerical Command - CNC, robots started to receive commands via remote control, where a human being could intervene and program movements and, today, with numerous robots and in advanced research, robotic systems are categorized according to their use, such as “drones”, space robots and surgical robots. And in industry, the consolidation of fixed or mobile robotic systems is evident and they replace humans in high-risk and repetitive activities [4].
The best-known types of robots are mobile ones that are divided into: land, air, underwater and nanorobots, which can be teleoperated, semi-autonomous or autonomous [5]. Considering that robots, mainly industrial ones, have as their main function, the search to overcome human limitations, underwater robots play this role even more effectively because they perform tasks in an environment that has several limiting factors, including pressure and temperature.
Remote controlled underwater robots are technically called ROV - Remotely Operated Vehicle - and perform activities in submerged environments by means of a constant manipulation of a pilot or operator who remains on the surface. The operator is responsible for controlling the vehicle's movements and receiving data from sensors and cameras coupled to the ROV in real time. Such operation is possible only through the umbilical cable connecting the vehicle to the operator. This particularity includes ROV in the classification of teleoperated mobile robots [6].
This summary will highlight the application of underwater vehicles in nuclear power plants, advancing a broad view of possibilities and fostering research and development of resources that ensure safety and results for process improvement, such as routine inspections through non-destructive techniques.

2. Methodology

Literature data using ROV and/or other underwater technologies were used as a research tool in situ and ex situ in underwater activities in nuclear power plants.

3. Results and Discussion

The International Atomic Energy Agency (IAEA) strongly recommends and fosters research related to the development of robotic systems for operations in nuclear power plants, given that in 2020, the agency approved the financing of 5 innovative projects in decommissioning and environmental remediation. The agency believes that robotics must be constantly present in the evolution of nuclear energy in the world to ensure that future energy networks are reliable, secure, and sustainable, and calls the projects presented as the evolution of nuclear robotics [7].
Therefore, there are numerous studies and projects designed to meet the needs of non-destructive inspection in nuclear power plants, however, few references are focused on underwater demands, but those that exist are consistent and accurate in meeting the established goals.
Studies related to the improvement of processes in the underwater environments of nuclear power plants are only common nowadays. In 1999, Koji developed an underwater robot called AIRIS-21 – Advanced Inspection System for Reactor Pressure Vessel – which performs non-destructive visual inspections on the reactor pressure vessel, including weld control. Its small size and flat shape allow the vertical thrusters to keep the robot fixed to the wall and carry out thorough inspections in small spaces, in addition to being able to be controlled in several other ways due to the configuration of its thrusters and sensors [8].
The semi-autonomous vehicle KeproVt - Korea Electric Power Robot for Visual Test - was built in 2004 and works with a technology called a vision processor that consists of a camera installed on the surface of the water and when obtaining the image of the robot, it calculates its location and orientation which is controlled in any position and movement within the reactor vessel. Robot positioning and direction errors are within ± 1 cm in three-dimensional space and ± 2◦, respectively. The system was successfully implemented in Unit 1 of the Yonggwang Nuclear Power Plant, in a PWR-type reactor, and brought a significant reduction to the process that was previously carried out by a camera installed on an 18-meter telescopic pole [9].

In 2011, Entergy and Areva inspected 253 welds and submerged components while a camera rod method simultaneously inspected 213 welds and components out of the water. This method guaranteed a highly safe inspection work, with quality results and reduction of up to 3 people exposed to radiation. Areva is currently the company responsible for the underwater inspections that take place at the Brazilian Nuclear Center [10].
A limiting characteristic of underwater vehicles in operations in confined and dangerous environments is the presence of the umbilical cord. An ideal underwater robot for nuclear power plants is desired without a communication cable with the surface, with powerful lights to increase more quality in the capture of images, high resolution cameras with resistance to constant radiation and thrusters inserted in positions that allow high maneuverability and stability. However, the absence of the umbilical can interfere with the other functions of the ideal vehicle and for this, studies such as the one by Mazumdar et al (2012) that invest in a system without umbilical, with waterjet propulsion and highly compact for inspections not only in the reactor pressure vessel as well as in pipelines. The toughest difficulty to deal with is in the system's communication and navigation since the submerged environment imposes communication difficulties via electromagnetic waves [11].
Among the articles researched for the preparation of the current work, two stood out for presenting unpublished studies aiming to solve technological limitations present in inspections by remotely operated vehicles in nuclear power plants. In China, researchers have developed a 3D underwater vehicle model for welding inspections and repairs to fuel and refueling pool structures. Until then, many projects foresee the use of underwater robots for visual inspections, but few include operational tools that perform repair and measurement tasks [12]. And, in 2018, in Argentina, Robador et al. developed an autonomous underwater vehicle, technically called AUV - Autonomous Underwater Vehicle - which can carry out inspections and is able to collect various data for it is composed of sensors and its control is autonomous and pre-programmed, that is, there is no need for an operator to be close to the inspection site and the vehicle does not have an umbilical cable for navigation. The project still faces several obstacles and difficulties, but it brings a great stimulus to the scientific community demanding solutions for inspections and monitoring in these environments [13].
In Brazil, IPEN - Institute for Energy and Nuclear Research - has researchers and active research with the objective of producing remotely operated underwater vehicles that can only efficiently carry out non-destructive visual inspections and routine monitoring in research reactors as well as collect data and parameters that are relevant to maintain the ideal functioning of the reactors and extend the useful life of the equipment and tools involved in the entire process.
It is common ground that robotic underwater vehicles developed for operations in nuclear power plants aim to obtain satisfactory and reliable results so that components integrity can be assessed in advance and that accidents are avoided. Within the various application possibilities, the main concern and need is that the developed system contributes to reducing the exposure and time of exposure to radiation of the operating and inspection personnel and thus increasing the generation period without harm and risks, maintaining the reliability and sustainability of nuclear power plants [8] [9] [10] [11] [12] [13].
Besides being a challenging job, in addition to all the complexity of a nuclear environment, underwater vehicles need to deal with the submerged environment inside the plants, the presence of these robots tends to bring only benefits and technological limitations are being overcome by solutions each more accurate and reliable.
It is important to emphasize that there is a gap of information available for the definitive conclusion of the work, since the use of ROVs is strictly linked to inspection operations and technical reports that are rarely published or made available to third parties. The authors will continue to search for technical information, whether to expose positive or negative results of the use of this technology in the nuclear industrial environment.

4. Conclusions

One of the most outstanding challenges in nuclear robotics is ensuring that systems are reliable, accurate and that they perform tasks and operations with repetition without losing the quality of the results obtained. All technological advances, which are increasingly appearing quickly and effectively, can and should be studied aiming the processes improving and the methodologies ripening that already exist within the inspections of

nuclear power plants. Given that, with the advancement of integrated circuits in the 1990s, mobile robots equipped with tools began to replace stationary robots, and this is the trend setting for more promising and dedicated technologies to emerge.
The encouragement of the research and development of technologies designed exclusively for nuclear power plants is of fundamental importance, even considering that technological projects generally demand high costs and lofty and detailed budgets. The knowledge applied to the incentive may greatly benefit operations helping the growth of nuclear energy in Brazil.

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