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Development of a Submersible Robot (ROV) to Support Visual Inspection in Triga Type Research Nuclear Reactors

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1. Introduction

A remotely controlled submersible robot (ROV) was developed for visual inspection of submerged equipment and pipelines, including submerged nuclear reactors and depleted fuel element storage pools. ROVs are unmanned vehicles operated remotely by a person that allow the operator to remain in a comfortable environment while the ROV works in unhealthy environments [1].

The equipment was manufactured with components of reduced monetary value and additive manufacturing. The ROVs will feature AISI 403 stainless steel shielding to protect against gamma radiation, allowing access to places with ionizing radiation. However, the focus is only on radiological protection against gamma radiation, despite the presence of neutrons from fission. In submerged nuclear reactors. All reactors have control rods that capture neutrons, slowing the reaction and minimizing neutron emission [1].

The IPR-R1 Triga reactor, which first became critical 60 years ago, requires regular visual inspections due to the natural aging of its fuel elements. These inspections are necessary to detect signs of wear, such as stains and corrosion spots, which can be mitigated through an aging management plan. The aging plan was developed such a plan based on recommendations from the International Atomic Energy Agency (IAEA), which includes visual inspections every two years [2]. It is therefore justified to use visual inspection devices to promote the detection of possible corrosion points.

The Gamma Irradiation Laboratory – LIG, located on the CDTN premises is classified as a Category II Multipurpose Panoramic Irradiator, manufactured by MDS Nordion in Canada, Model/serial number IR-214 and type GB-127, equipped with a Cobalt-60 source dry storage with maximum activity of 2,200 TBq or 60,000 Ci [3].

ROV tests were carried out under gamma ionizing radiation, on the LIG premises, at different dose rates in order to measure the resistance of the ROV circuit to radiation.

2. Methodology

The ROV design was created in a CAD environment using a horizontal approach to stabilize it. Stainless steel tubes were used to protect the propellers and motors, which were fixed by 3D printed PLA supports. Stainless-steel tubes were cut and machined on a lathe. The parts were left with a wall measurement of 3 mm, and subsequently assembled and welded using the coated electrode welding process. A 3 mm thick stainless-steel plate was also welded to the rear of the ROV. The parts designed in PLA plastic were printed using the stereolithography technique on a 3D printer.
Calculations related to shielding were carried out with parameters obtained on the Phy-X platform, which is an online platform for calculating parameters relevant to shielding and dosimetry [4]. The parameters for sizing the shield are the parameters provided by the tests carried out at LIG. A source of cobalt-60 with 60,000 Ci is considered.
The ROV's movements and commands were then defined, the circuit was designed and the ROV and the control unit were assembled.

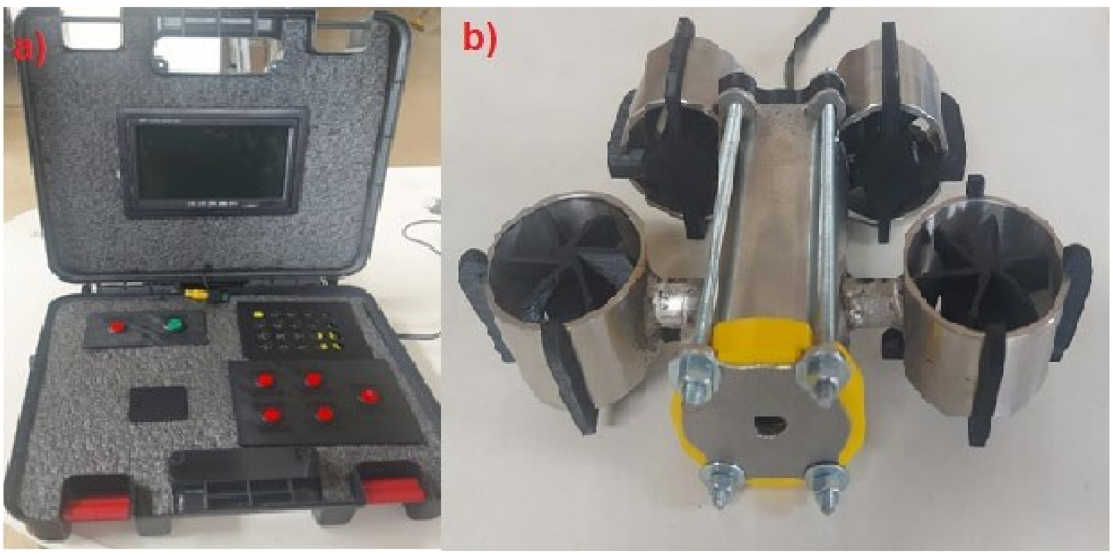

Figure 1: a) Front view of the control unit. b) Assembled ROV

In order to carry out the radiation exposure tests at LIG, a program was made in order to make one of the engines run intermittently to investigate the operation of the ROV between the tests. The main components to be evaluated during the tests are an Arduino Nano® board equipped with an ATMEGA162® processing chip and a generic CMOS camera, commonly used in surveillance devices or automobile maneuvering assistance systems.
Table I presents and lists each test performed. It is worth highlighting here the possible variation of 10% more or less of the recorded dose, as well as the activity of the source on the day of the tests, which was 54.696,47 Ci.

Table I: Parameters of the irradiation test done in the LIG.

Test number	Total dose (Gy)	Dose rate (Gy/h)	Time (min:s)
1	50	352.72	08:17
2	100	352.72	16:47
3	150	352.72	25:17
4	50	697.50	04:07
5	50	1402.76	01:53
6	100	3074.76	01:43
7	1000	6177.3	09:53

3. Results and Discussion

During testing, the camera exhibited artifacts due to electron transit during irradiation, with minor permanent damage observed after the second test. A critical failure occurred at 25 minutes during the third test, indicating permanent damage to the camera's semiconductor. This critical failure was repeated in all subsequent tests a few seconds after the irradiation began, the image returning to a normal state when the irradiation stopped. Subsequent testing was done to cause the Arduino Nano® board to fail.

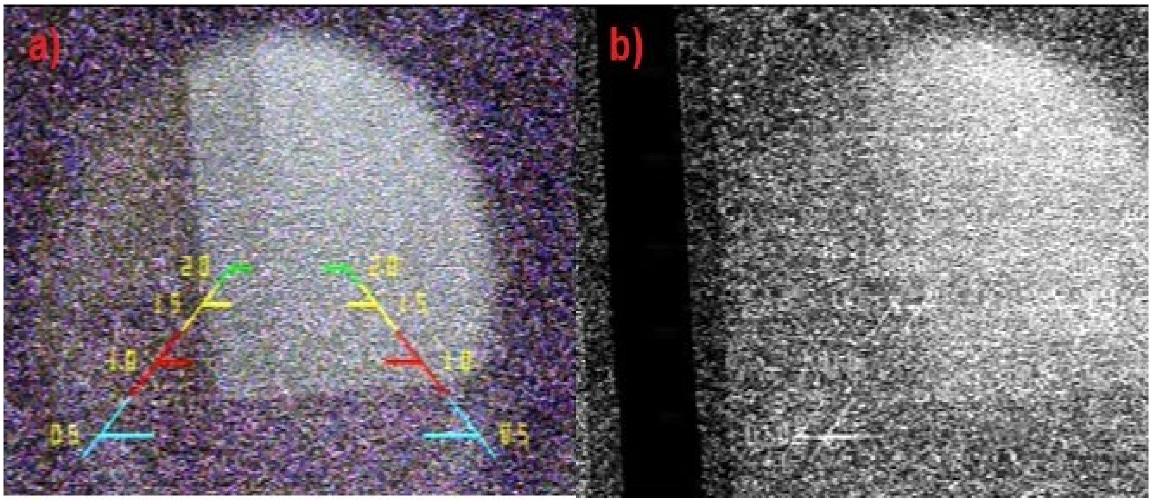

Figure 3: a) Artifacts created due to electron transit during irradiation. b) Critical failure at the camera in the 25 minutes mark in the third test.

The darkening of the glass lens on the front of the camera made it difficult to see the image during the final tests. However, there was no visible failure in the Arduino circuit or the motor. Components made of PLA, a material commonly used in 3D printing, showed no signs of degradation. The camera did not suffer any physical damage other than the darkening of the lens. The Arduino® system still runs the program that was inserted before the test, but it is no longer recognized by any computer, making it impossible to communicate with other devices or insert new programs. The contact adhesive used to bond the inner shell suffered degradation, resulting in the internal parts instantly detaching once the inner shell was removed. It is possible to make a brief comparison between the data collected by the tests and the data previously provided. Tests carried out on a similar camera showed damage in relation to its SNR at different exposure rates, but even at 100 Gy/h for one hour the damage was still slight [5].

This is somewhat confirmed by the tests, since even at dose rates of approximately 300 Gy/h the camera still withstood approximately 45 minutes of exposure, until eventually showing serious damage. Other data that the Arduino® system can work perfectly with a total dose of 54 krad, equivalent to 540 Gy [6].

The Arduino® system used in the test received a total dose of 1500 Gy. The programming that was already stored in the system continued to function perfectly, however its ability to communicate with other computers was affected.

4. Conclusions

The ROV was built using robust materials and techniques such as 3D printing, welding, and machining. Irradiation tests were performed and the camera withstood a total dose of approximately 250 Gy at a dose rate of approximately 350 Gy/h, showing critical failure after 45 minutes. Future prototypes should use better cameras, considering the darkening of the lenses and possible failures caused by gamma radiation. Total mitigation of radiation damage is not a realistic prospect, so factors such as low monetary cost and ease of component replacement must be considered. The Arduino® installed in the ROV was tested for its ability to operate after exposure to a total dose of 1500 Gy. Although it continued to operate, it was not possible to establish communication with any other device after the test, and only the programming that had already been entered into the Arduino® before the test continued to work. This contrasts with previous tests that showed perfect functioning at a dose of 540 Gy. It is worth mentioning that the Arduino® models used are different models, which may contribute to disparities between the tests.

It should also be noted that the article cited considers perfect operation, which did not happen after the tests carried out in this work. The prototype will need to be reformulated by resizing certain components and improving its shielding. Specific shielding for neutrons must also be carried out for tests to be carried out in a nuclear reactor. The Remotely Operated Vehicle (ROV) prototype for visual inspections has been developed, but requires reformulation to resize certain components and improve its shielding. Specific neutron shieldingmust be carried out for tests in a nuclear reactor, considering the materials used to prevent the activation andcreation of radioactive materials. The control unit was designed to receive different types of devices, with interchangeable boards for controlling other devices. In theory, the shielding generated by using the externalhull made of stainless steel is approximately 17%. It should be noted that more tests are still needed to carry out an adequate measurement of the radiation attenuation by the shielding.

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