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Technical note

Testing which is the fitter position sensor for a cyclotron liquid target

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HIGHLIGHTS

- We tested position sensors into cyclotron irradiation room.
- The position sensors were subjected to gamma radiation and neutrons.
- The inductive proximity sensors did not pass in test.

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ABSTRACT

The [^{18}F]FDG has 109.7 min half-life, there is a period about 6 h between the beginning of [^{18}O]H_2O irradiation until the PET–CT exam. Any fail in production chain will result in delay to the PET–CT exam. The absence of the position signs from [^{18}O]H_2O target valve may result in ^{18}F production loss. Three types of position sensors were tested. After finding the fitter sensor it was possible to reduce the incidence of fails, increasing the reliability in [^{18}F]FDG production chain.

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1. Introduction

The Cyclotron Accelerators Center (CAC) of the Energy and Nuclear Research Institute (IPEN) is the largest Brazilian producer of radionuclide ^{18}F (up to 407 GBq, 11 Ci per day), used in the radiopharmaceutical [^{18}F]FDG, 2-[^{18}F]fluoro-2-deoxy-D-glucose (up to 203.5 GBq, 5.5 Ci per day). This radiopharmaceutical is used in devices called PET–CT scanner (Positron Emission Tomography–Computed Tomography) in diagnostic imaging for detection of tumors and to monitor therapies in nuclear medicine. As the half-life of the product is 109.7 min, the storage is not viable so the production chain follows the Just in Time model where the quantity produced is determined by the daily demand. A failure in any procedure during [^{18}F]FDG production may delay or prevent the supply of product to the customer, and its short half-life prevents economically the transport over long distances, there are very few options for immediate replacement supplier. Therefore, the reliability of the production chain has vital importance to all involved in PET–CT exams using the radiopharmaceutical [^{18}F]FDG. During some ^{18}F productions on CAC, failures occurred in [^{18}O]H_2O load and unload system, due to incorrect positioning from [^{18}O]H_2O in and out control valve of the target resulted in loss of production and even contamination by ^{18}F near the target. To overcome this problem three different types of sensors (microswitch, reedswitch and inductive sensor) in the environment of irradiation room of the CAC were tested, which is subjected to high doses of gamma radiation and neutrons due to the routine production of ^{18}F and ^{123}I, then the most appropriate sensor was mounted in pneumatic actuator that controls the position of the valve, and changes were made in the programmable logic controller that makes the control of the entire ^{18}F irradiation system.

2. Materials and methods

To carry out the work we used a cyclotron Cyclone 30 from Ion Beam Applications (IBA) (Conard et al., 1990, IBA, 1994), two target to ^{18}F production from IBA (IBA, 2004), with niobium insert of 2.4 and 5 mL, Havar windows cooled by helium and a double 3-way Rheodyne valve (Fig. 1), a target to ^{123}I production manufactured by IPEN with aluminum body, and molybdenum foils cooled by helium (Sumiya and Sciani, 2008), inductive proximity sensor from Sense model PS2-8GM45-E (Sense, 2013), reedswitch from Reed Switch Development Corp. model 2230-1051-100

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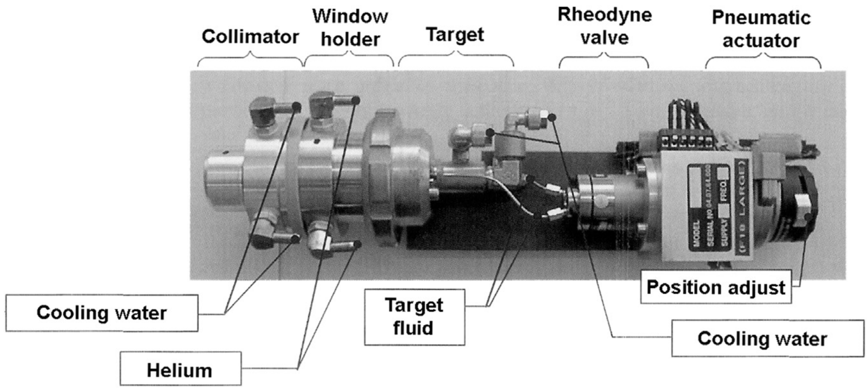

Fig. 1. ^{18}F target from IBA.

(Reed Switch Development Corp., 2013), microswitch from Camden type V4 model CSM40510A (Camden Electronics, 2013), Hewlett-Packard power supply model E3612A, Fluke multimeter model 87 III and Geiger–Muller counter from Eberline model RM25, with Eberline probe model HP360. To rewrite the programmable logic controller the Step 7-Micro/WIN for Windows (Siemens, 2008) software was used.

The microswitch, the inductive sensor and reedswitch were separately packed in plastic bags (to avoid possible contamination), and positioned as close as possible to the work region, behind the pneumatic actuator shown in Fig. 1. At this position, the components would suffer the action of radiation produced during the ^{18}F and ^{123}I irradiation which occurred in this irradiation room similar that would receive at working position. The ^{123}I irradiation is routinely performed once a week, while the ^{18}F routine irradiations are done five days a week. In ^{18}F irradiation, protons are used with energy of 19 MeV and beam current of 50 μA (5 mL target) or 30 μA (2.4 mL target), the irradiation lasts around 2 h and are made from one to three irradiations by day. In routine irradiation of ^{123}I, protons of 30 MeV are used with a beam current of 50 μA, for a period about 6 h. At the beginning of each week the sensors activation was monitored by Geiger–Muller counter. The three sensors sustained the action of gamma radiation and neutrons that are byproducts of ^{18}F [$^{18}O(p, n)^{18}F$] and ^{123}I [$^{124}Xe(p, 2n)^{123}Cs \rightarrow ^{123}Xe \rightarrow ^{123}I$, $^{124}Xe(p, pn)^{123}Xe \rightarrow ^{123}I$] routine irradiation.

The sensors were tested as follows: the microswitch was connected to multimeter through their common and normally open contacts and its lever pushed to drive the contacts, the conductivity is tracked by the multimeter. The reedswitch was connected to multimeter through its two wires, the driver magnet was come near and the closing of the contacts was monitored by multimeter through the conductivity. The inductive sensor was fed by a 24 VDC power supply (voltage used by programmable logic controllers of the cyclotron) and voltage output was monitored by multimeter, the trigger was caused approximating a metallic material (target).

3. Results and discussion

Variations of the produced quantities occurred as function the demand by radionuclides and the service intervals on accelerator and irradiation systems. Fig. 2 shows the integrated current as a function of irradiation time.

Fig. 3 shows the radioactive activation of the three sensors as a function of time that bore the effect of routine irradiation in irradiation room, the ^{18}F and ^{123}I production. It was found that the inductive sensor showed greater activation than the reedswitch,

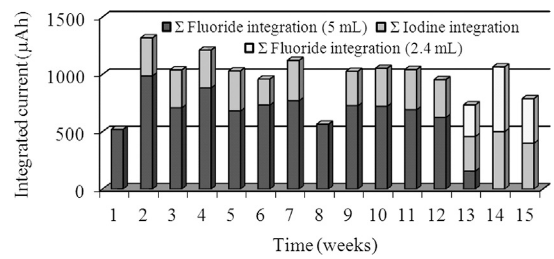

Fig. 2. Integrated current from irradiations.

and it showed greater activation than the microswitch. The inductive sensor, besides nickel-plated brass jacket, has a coil with ferrite core and electronic circuits, while reedswitch and microswitch are made of plastic with internal metal contacts and therefore have less activation.

The three sensors showed no change in its operation until the current integrator reached 11833 μAh, when the inductive sensor showed changes in behavior: provided 24 VDC output, even without the target metal in a position to drive. Despite this defect in PLC working voltage, the inductive sensor remained working well between 27 and 30 VDC. To track operation changes in inductive sensor, it started to have its behavior monitored across the full work range (between 10 and 30 V). In Fig. 4, which represents the behavior of the inductive sensor, it was found a malfunctioning between 10 and 26 V with two distinct regions: between 10 and 17 V formed by a “valley” region, with no signal drive, and between 18 and 26 V formed by a “hill” with unconditional drive (without being necessary to approximate the metallic target). When the current integrator reached 14418 μAh, the malfunction had spread throughout the working voltage range of the sensor, with the enlarging of “valley” and “hill” regions.

Inductive sensors had their widespread use in industry worldwide, its technical characteristics and reliability become crucial in the various types of processes. However, these factors were not sufficient for its appropriateness in the workplace as the irradiation room of a cyclotron accelerator, where the components of the devices installed must bear high doses of gamma radiation and neutrons, which are byproducts of routine irradiation for radionuclides manufacturing. The malfunction of the sensor must be likely to damage from radiation in their electronic circuits; however, a major problem observed was the indication of false triggering in the output (Fig. 4), these false drives may result in serious accident, for example, in the case that such sensors would be used in safety systems at nuclear and radioactive facilities where a false indication may begins an accident scenario.

The reedswitch and microswitch showed less activation than the inductive sensor, and displayed no failures over time they have

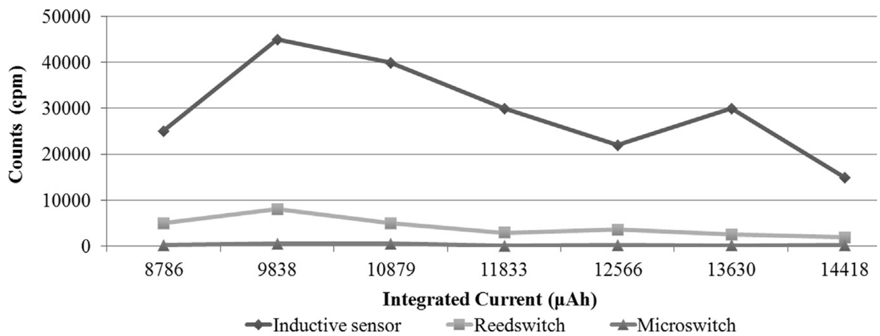

Fig. 3. Radioactive activation from three sensors.

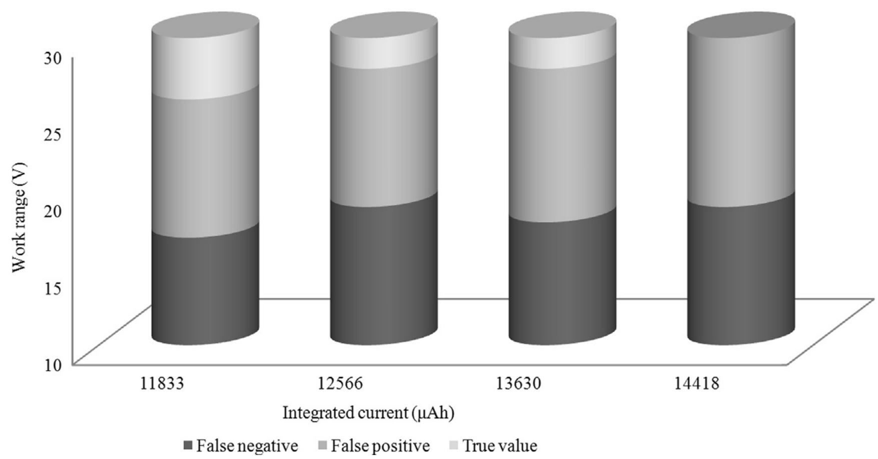

Fig. 4. Behavior of inductive sensor during irradiations.

undergone the experiment, denoting more appropriate to work in an environment such as irradiation room of a cyclotron than the inductive proximity sensor. The microswitch becomes more appropriate than the reedswitch as a valve position indicator because has the installation more simple, because the reedswitch requires the establishment of a magnet for your drive, in addition, the ^{18}F target generally are mounted next to the devices that generate intense magnetic fields, such as cyclotrons main coil or switching magnets, that may interfere with proper operation.

To fix the microswitches on pneumatic actuator it was manufactured one aluminum piece, allowing the positioning of the three microswitches in actuator. Thus, the positions loading, unloading and closed can be monitored. The actuator end of travel cams are used to indicate $+/-30^{\circ}$, but there is no one cam to indicate 0° in actuator. Therefore, it was used a screw in position 0° in actuator that would trigger the closed position marker microswitch.

To control the ^{18}F production target a programmable logic controller (PLC) is used, the PLC's software was modified to receive position signals from the 3-way Rheodyne valve and to run procedures for loading and unloading only when the signs show that the valve is in the proper position for the procedure. With the implementation of position sensors and the change in PLC software it was possible to increase the reliability of the $[^{18}O]H_2O$ load and unload system in ^{18}F production and thus increase the reliability in $[^{18}F]$FDG production chain.

4. Conclusions

The study showed that the inductive proximity sensors, which are widely used in industry for its reliability and robustness, should only be used in nuclear and related area after careful analysis of the environment that will remain. Should be avoided environments subjected to gamma radiation and neutrons, and safety systems of these facilities due to damage that neutron and gamma radiation can cause to the electronics embedded in this type of sensor over time. The International Atomic Energy Agency – IAEA has issued some publications about safety in radioactive facilities, like accelerators and gamma irradiator, however, the recommendations are general as: "… the use of high integrity protective devices in addition to the inherent safety features" (IAEA, 1992), and "… all the equipment inside the radiation room of a irradiation facility, including wiring, electrical equipment, notices and lighting, should be selected so as to minimize failure due to prolonged exposure to radiation" (IAEA, 2010). It is important to highlight that there are no IAEA safety publications about cyclotron accelerators, the IAEA safety reports treat only about electron accelerators and gamma irradiator which produce particles lesser energetic than cyclotrons. There are no recommendations about which test to use to approve or disapprove a component, however, we know, by experience, that most likely the radiosensitivity from a electronic device, integrated circuit based, is proportional your degree of integration. The position sensors type microswitch and reedswitch proved their effectiveness in environments subjected to high rates of gamma radiation and neutrons. The simplicity of construction of these components provides them life span similar to that outside the environment of gamma radiation and neutrons, which make them more suitable for work in this type of facility. The installation of position indicator on loading and unloading valve from ^{18}F target, and the change in PLC software questioning that valve position, made the procedure to be more reliable, resulting in higher reliability in the $[^{18}F]$FDG production chain.

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