2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
***ISBN:* 978-85-99141-03-8**

TEST AND IMPLEMENTATION OF POSITION SENSORS ON LOAD AND UNLOAD [^{18}O]H_2O CONTROL VALVE OF THE TARGET USED IN $^{18}F^-$ PRODUCTION BY PROTON IRRADIATION

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ABSTRACT

The radionuclide ^{18}F used to produce the radiopharmaceutical [^{18}F]FDG has 109.7 min of half-life, becoming your productive chain so peculiar, because since the beginning of [^{18}O]H_2O irradiation until the PET-CT exam there is a period about six hours, and any procedure fail in the productive chain will result in a delay to the PET-CT exam. The absence of the position signs from [^{18}O]H_2O load and unload valve of the target may result in $^{18}F^-$ production loss and even area contamination around the target. In this paper, three types of position sensors, into cyclotron radionuclides production environment in Cyclotron Accelerator Center from IPEN-CNEN/SP were tested. The tests were an indicative to discover the fitter sensor to the [^{18}O]H_2O load and unload valve from target used in [^{18}F]fluoride production. After finding the fitter sensor, it was implemented in $^{18}F^-$ target, supplying the correct position from [^{18}O]H_2O load and unload valve to programmable logic controller, that had the software modified, respecting in this way the valve position. By this way, it was possible to reduce the incidence of fails, increasing the reliability in [^{18}F]FDG productive chain.

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--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. The Fig 1 shows an example of timeline from [^{18}F]FDG productive chain. As the half-life of the product is 109.7 min, the storage is not viable: so the productive 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 as there are few producers centers of this radiopharmaceutical in Brazil, 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 productive 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 1.2 Irradiation Room of the CAC were tested, which is subject 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.

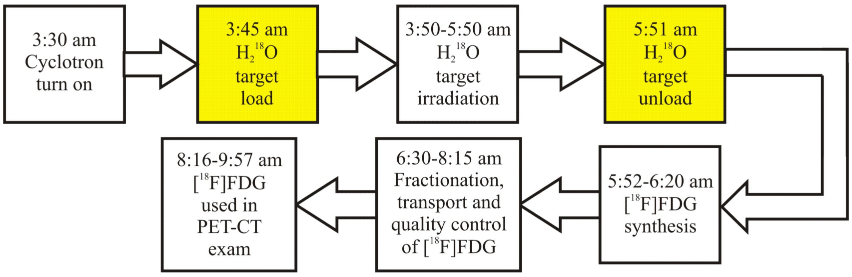

Figure 1. Timeline from [^{18}F]FDG productive chain

2. MATERIALS AND METHODS

To carry out the work we used a cyclotron Cyclone 30 from Ion Beam Applications (IBA) (Conard, 1990, IBA, 1994), two target to $^{18}F^-$ production from IBA (IBA, 2004), with niobium insert of 2.4 and 5 mL and Havar windows cooled by helium (Fig. 2), a target to ^{123}I production manufactured by IPEN with aluminum body, and molybdenum foils cooled by helium (Sumiya, 2006), inductive proximity sensor from Sense model PS2-8GM45-E (Sense, 2006), reedswitch from Reed Switch Development Corp. model 2230-1051-100 (Reed Switch Development Corp., 2008), microswitch from Camden type V4 model CSM3510A (OKW Electronics, 2008), 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 software was used the S5/S7 for Windows IBH Softec software (IBH Softec, 2000).

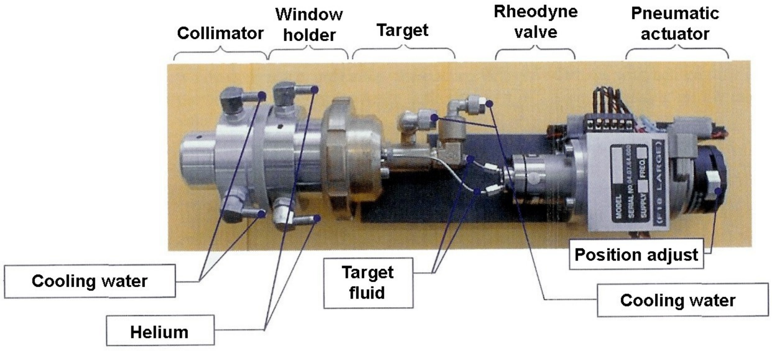

Figure 2. $^{18}F^-$ target from IBA

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. 2. 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 (Fig. 3). 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 are used protons 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 two hours and are made from one to three irradiation by day. In routine irradiation of ^{123}I are used protons of 30 MeV and beam current of 50 μA, for a period about six hours. At the beginning of each week the sensors activation was monitored by Geiger-Muller counter. The three sensors supported 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.

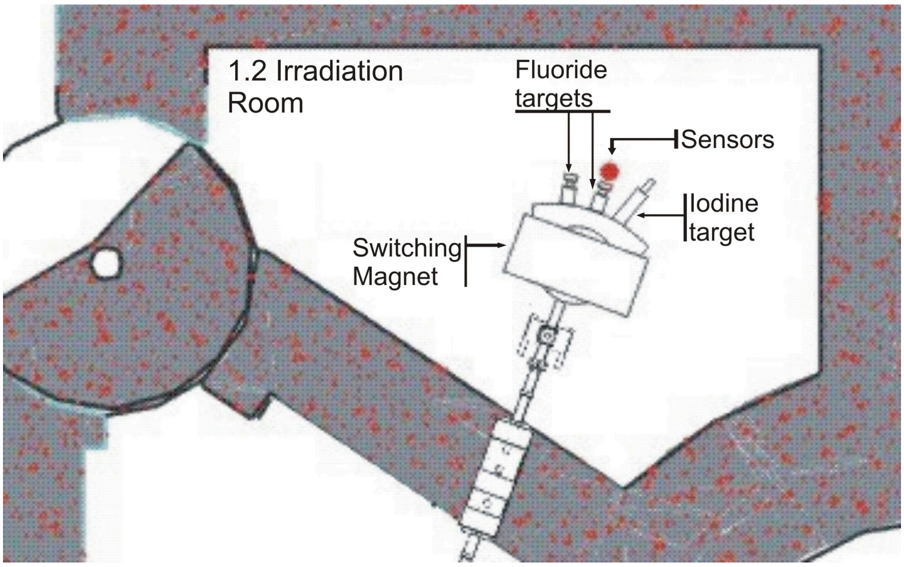

Figure 3. Location of sensors into 1.2 Irradiation Room

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 came 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.4 shows the integrated current as a function of irradiation time.

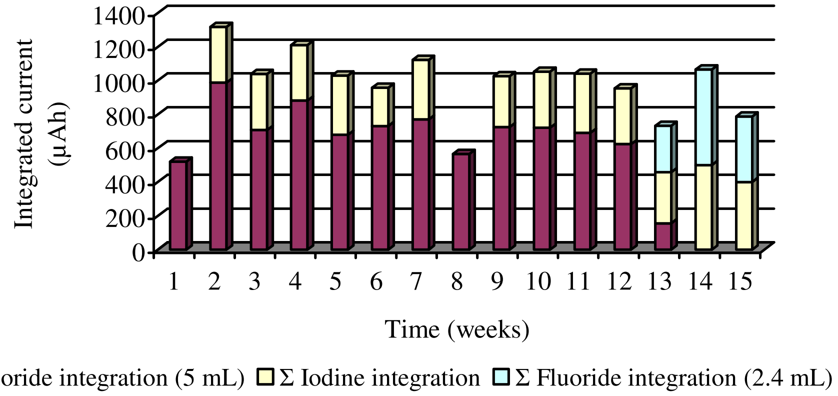

Figure 4. Integrated current from irradiations in 1.2 Irradiation Room

Fig.5 shows the radioactive activation of the three sensors as a function of time that bore the effect of routine irradiation in 1.2 Irradiation Room, the $^{18}F^{-}$ and ^{123}I production. It was found that the inductive sensor showed greater activation than the reedswitch, 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.

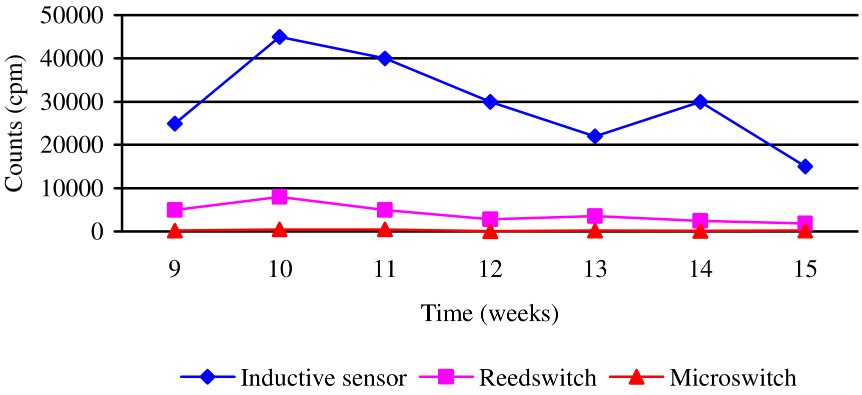

Figure 5. Radioactive activation from three sensors

The three sensors showed no change in its operation until the 11th week. From the 12th week, 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 your work range (between 10 and 30 V). Fig. 6 is shown the inductive sensor control chart (which can be seen the normal functioning of the sensor). In Fig. 7, which represents the behavior of the inductive sensor in 12th week, 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). In Fig. 8, which represents the operation of the inductive sensor in the 15th week, the malfunction had spread throughout the working voltage range of the sensor, with the enlarging of "valley" and "hill" regions.

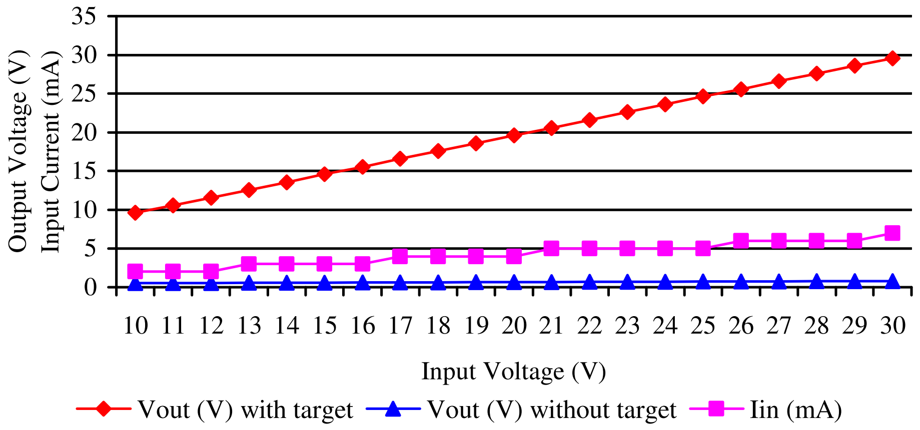

Figure 6. Inductive sensor control chart

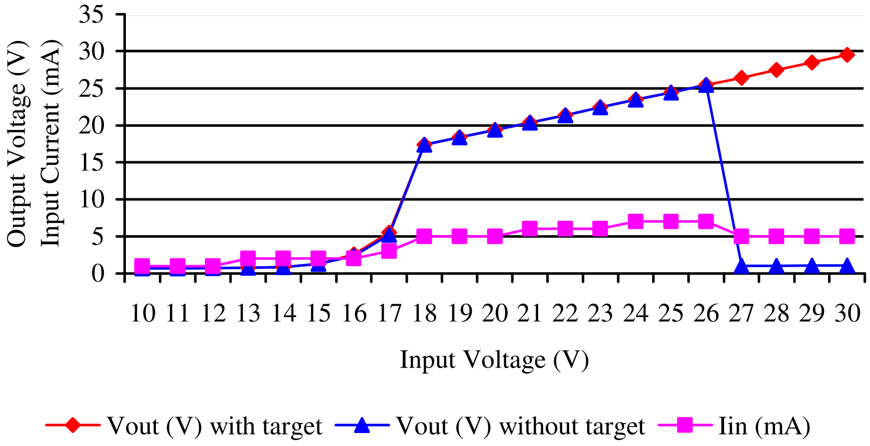

Figure 7. Behaviour of inductive sensor on 12th week

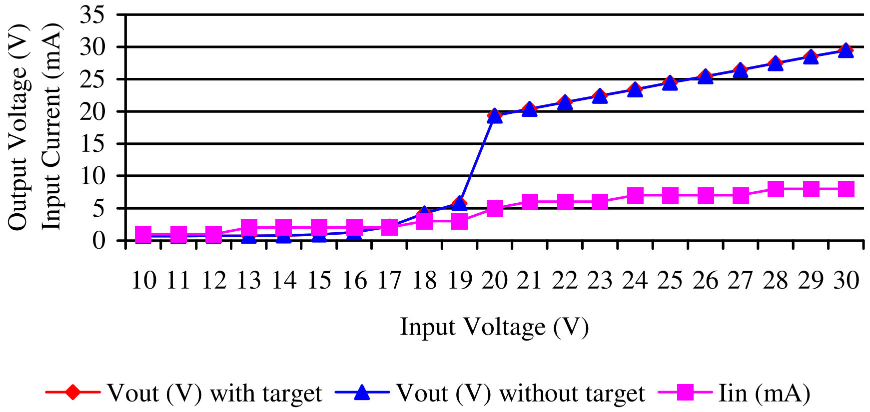

Figure 8. Behaviour of inductive sensor on 15th week

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 (hill region, Fig. 7 and 8), these false drives may result in damage to equipment of the process, production incidents and even more serious accident, in the case that such sensors would be used in safety systems at nuclear and radioactive facilities where there is the occurrence of radiation and neutrons emissions that can damage the sensor.

The reedswitch and microswitch showed less activation than the inductive sensor, and display no failures over time they have 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 as in 1.2 Irradiation Room.

To fix the microswitches on pneumatic actuator it was manufactured one aluminum piece, allowing the positioning of the three microswitch in actuator. Thus, the positions loading, unloading and closed can be monitored. The actuator end of travel cams are used to indicate +/-30º, but there is no one cam to indicate 0º in actuator. Therefore, it was used a screw in position 0º in actuator that would trigger the closed position marker microswitch (Fig. 9).

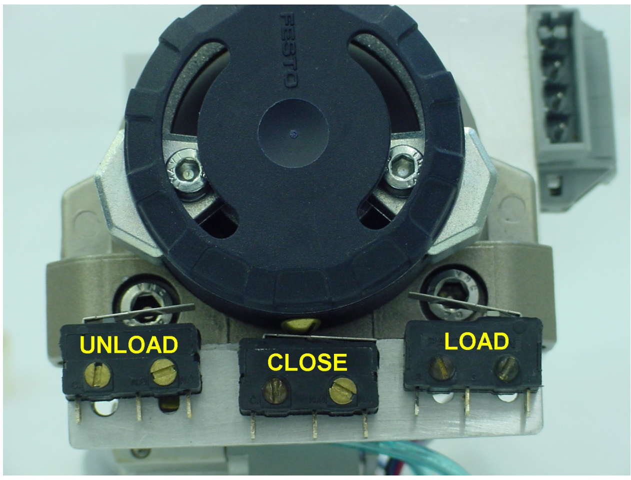

Figure 9. Pneumatic actuator with 3 microswitches

In Fig. 10 is represented the operation diagram of loading and unloading $^{18}F^-$ target. For the process of loading the target the syringe is filled with $[^{18}O]H_2O$, which will then be injected into the cavity of the target through the openings 1 and 2 of the Rheodyne valve, the liquid or gas excess will pass through openings 5 and 4 and will be directed for a vial, after the load of the target the Rheodyne valve is closed, the target is cooled with water and helium and irradiation begins. After irradiation, helium is injected by the openings 6 and 5, which drains the water and $^{18}F^-$ through the openings 2 and 3 to the synthesis module and the valve comeback to the closed position.

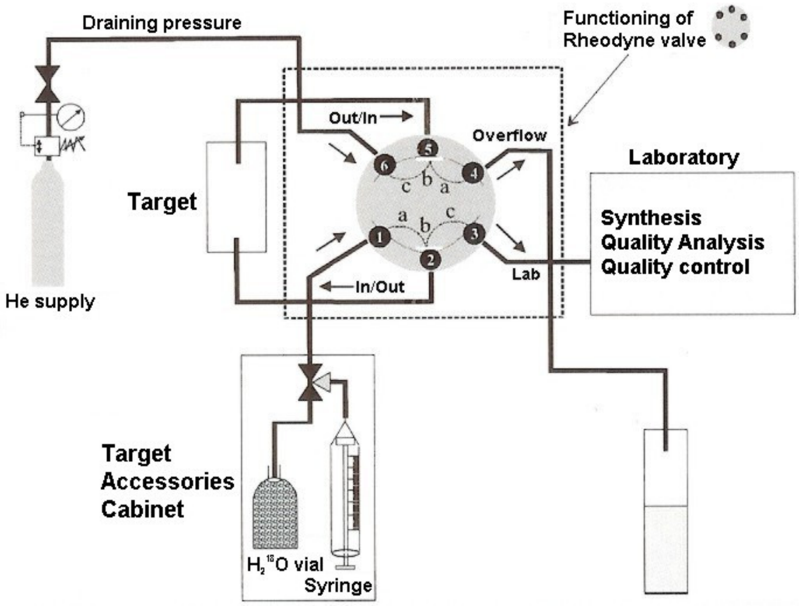

Figure 10. Operation process of load and unload $^{18}F^-$ target from IBA

To control the $^{18}F^-$ production target is used a programmable logic controller (PLC), the PLC's software was modified to receive position signals from the 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 $[^{18}F]FDG$ productive 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 position sensors type microswitch and reedswitch proved their effectiveness in environments subjects to high rates of gamma radiation and neutrons. The simplicity of construction of these components provide them life 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, became the procedure more reliable, resulting in higher reliability in the $[^{18}F]FDG$ productive chain.

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