Measurement of Scattered Radiation from RDS- 111 Cyclotron

Thesis

Submitted in partial fulfilment of the

requirement for M.Sc.

in Physics

by

Ayman Fathy Eshak Nashed

B.Sc. of Physics

To

Faculty of Science

Cairo University

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Abstract

The radioisotope delivery system cyclotron (RDS 111) was installed at the Nuclear Medicine department of the IMC (International Medical Center) to produce ^{18}F which is a positron emitter isotope used for positron emission tomography (PET) imaging. The ^{18}O water is used as a target material to be bombarded by a proton beam of energy of 11 MeV from the cyclotron to produce ^{18}F. Then ^{18}F is transferred to the chemistry unit to prepare F-18 fluorodeoxyglucose (FDG).

The operational parameters which influence the yield of ^{18}F as: transmission, number of previous bombardments on the target (target status) and time of bombardment were studied at fixed parameters (target current (40 μA), target body 1 or 2, volume of ^{18}O (1.2mL), energy of the beam (11 MeV), with no rinsing of the target after the end of bombardment (EOB) and enrichment of ^{18}O water concentration (minimum 97% atom of ^{18}O))

From the results it was found that: as the time of bombardment increases the yield increases as in Figs. (19, 20), also the target needs a rebuild after about 30 to 33 runs. It was found also that as the transmission increases the yield increases as in Fig. (21).

There are parameters that change during the production of ^{18}F such as: pressure of the target and ion source current. It was found that as the time of production increases during the run the pressure on the target increases and the ion source current decreases, as in Figs. (24, 25).

According to the yield of ^{18}F, the stray radiation around the cyclotron changes, at the fixed parameters of target current (40 μA), target body 1 or 2, volume of ^{18}O (1.2m), energy of the beam (11 MeV), no rinsing of the target after the end of bombardment (EOB) and enrichment of ^{18}O water concentration (minimum 97% atom of ^{18}O), and also at the variable parameters as time of

bombardment (from 10 minutes to 120 minutes), transmission values from 56% up to 64% and number of previous bombardments on the target (target status).

The results of gamma stray radiation around the cyclotron are found in Fig. (26).

The results of measuring neutron doses around the cyclotron are found in Fig. (29).

The measurements of the exposure dose for the occupational worker are also listed in table (9).

The measurements of gamma radiation were done using TLD badges, portable survey meter and pocket dosimeters, and the measurements of neutrons were done by TLD badge (LiF6).

All personal exposures were found to be within the dose limit of the ICRP (60).

The assessments of standard deviation of data for all measuring devices were done.

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Introduction and aim of the work

Positron Emission Tomography (PET) is a minimally invasive method of nuclear medicine imaging that uses short-lived radiopharmaceuticals to detect and assess perfusion and metabolic activity in various organ systems. Computed tomography (CT), magnetic resonance imaging (MRI) and radiology are diagnostic modalities but PET can provide information about function and metabolism that is complementary to the structural information with high-resolution. PET can also provide functional image of regional biochemistry that is more sensitive and accurate for detecting the presence of a tumor.

Using FDG (^{18}F fluorodeoxyglucose) imaging, malignant tumor cells can be detected because of their enhanced glycolytic rate under anaerobic conditions as compared with nonmalignant tissue cells.

The radiopharmaceuticals FDG decay by emitting positrons which further interacts with an electron in the body-organ, resulting in their annihilation. A pair of 511 keV gamma ray photons is emitted and moved in opposite directions. These are detected by various coincidence methods. The FDG short-lived positron emitting radiotracers of biological elements 2-[^{18}F] fluoro-2-deoxy -Dglucose are received from the chemical processing control unit (CPCU) which is responsible for transfer of ^{18}F to FDG by chemical reaction.

The radiopharmaceutical ^{18}F are produced by the RDS-111 cyclotron of 11 Mev energy by the reaction ^{18}O (p-n) ^{18}F and due to this reaction there are stray radiation produced in the cyclotron room.

Other PET radionuclides produced by cyclotron are listed in table (1)

Table 1. PET Radionuclides

Radionuclides	Half-life	Target	Nuclear Reaction	Chemical form	Irradiation time	EOB Yield (mCi)
^{11}C	20 min	N_2 gas + 0.5% O_2 gas	$^{14}N(p,\alpha)^{11}C$	$^{11}CO_2$, ^{11}CO, $H^{11}CN$	30 min	3000
^{15}O	2 min	N_2 gas + 1% O_2 gas	$^{14}N(d,n)^{15}O$ $^{15}N(p,n)^{15}O$	$^{15}O_2$, $C^{15}O$, $C^{15}O_2$, $H2^{15}$	6 min	1200
^{13}N	10 min	$H_2{}^{16}O$	$^{16}O(p,\alpha)^{13}N$	$^{13}NH_3$	30 min	450
^{18}F	110 min	$H_2{}^{18}O$	$^{18}O(p,n)^{18}F$	$^{18}F^-$	60 min	2500
		^{20}Ne gas + 0.3% F_2	$^{20}Ne(d,\alpha)^{18}F$	$^{18}F_2$	60 min	300

In emergency and during cyclotron run one may be obliged to enter the cyclotron room, so this person will be exposed to the stray radiation (photons and neutrons) inside the room. So it is important to know the distribution of such radiation inside the cyclotron room.

These exposures depend on the operating parameters of the cyclotron.

The aim of this study is the measurements of stray radiation at different sites at a certain operating condition.

2.1 Theoretical background

2.1.1 Proton accelerators

In recent years, proton accelerators for producing radioactive isotopes were developed rapidly. The first, in 1994, was a 30 MeV intense current proton cyclotron (CYCIAE 30) constructed by CIAE (Chinese Institute of Atomic Energy), whose beam energy could be adjusted from 15 MeV

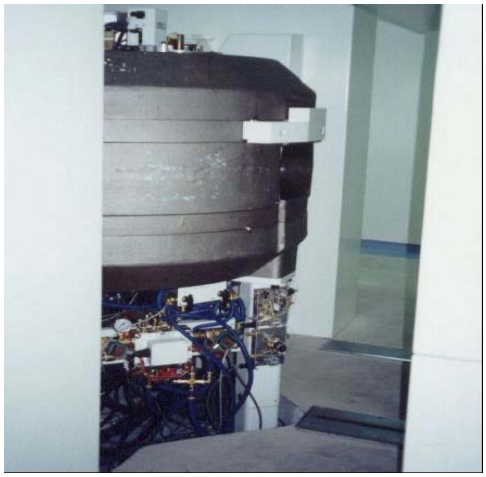

Figure (1) Proton accelerator

to 30 MeV, with the maximum target current of 370 μA . The machine has been specially designed to produce medium and short-lived radioisotopes for medical use. The radioisotopes include ^{18}F, ^{201}Tl, ^{57}Co, ^{67}Ga, ^{123}I, and ^{103}Pd. In Sichuang University, a domestically produced 13.5 MeV cyclotron has also been used to produce radioisotopes, such as ^{57}Co, ^{109}Cd, ^{211}At, and ^{199}Tl. In the Shanghai Institute of Nuclear Research Academia Sinica during 1997, a 30 MeV proton cyclotron was imported from IBA Company in Belgium to produce ^{18}F, ^{67}Ga, ^{89}Sr, ^{123}I, ^{188}W, ^{188}Re, and ^{201}Tl as diagnostic medicines. During 1998~2000, seven sets of 11 MeV compact negative hydrogen-ion cyclotrons (RDS-111) were imported from the CTI company (Computer Technology Imaging) in the U.S.A. to produce short-lived positron-emitting isotopes for use in PET and as

radio labeled compounds. The short-lived positron–emitting isotopes produced by the machines include ^{11}C, ^{13}N, ^{15}O, and ^{18}F. In this case the RDS-111 targets are gas targets and liquid targets. The beam current on the target is about 40 μA. The accelerated negative ion beam is extracted at the extraction radius by passing through a thin carbon stripper foil to remove the electrons to produce a proton beam. The extraction efficiency from the foils is approximately 99%. Figure (1) shows the RDS-111 cyclotron for PET uses (**F. Alves et al., 2007).**

2.1.2 Cyclotron production of fluorine-18

Medical imaging techniques are designed to provide high quality, in vivo pictures of internal human structure, biochemical and/or physiological events. Many of these techniques capture geometrical information, while others record functional information. Positron Emission Tomography (PET) is an imaging technique that can capture metabolic activity within the body. This technique is particularly useful in the detection and staging of, different cancers and Alzheimer's disease.

PET imaging utilizes radiopharmaceuticals labeled with positron emitting radioisotopes. The most widely used compound is 2-deoxy-2-[^{18}F] fluoro-D-glucose (18FDG), which is a sugar labeled with fluorine-18 isotope. After the patient is injected with this compound, the sugar travels throughout the body. Areas with high metabolic rates will, in turn, have elevated concentrations of fluorine-18 from the metabolically trapped radiopharmaceutical **(Phelps M. E., 2004).**

Fluorine-18 decays by positron emission with a half-life of 109.7 minutes. The positron has a range of only a few millimeters in tissue before it slows sufficiently to combine with an electron. The annihilation reaction results in a pair of 511 keV photons separated by 180°. Because of this behavior, the photons can be recorded using detectors in coincidence, and a 3-dimensional functional image can be computed **(Matthew H. Stokely, 2007).**