ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP025

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

FEASIBILITY STUDY FOR CONVERTING THE CS-30 INTO A VARIABLE ENERGY CYCLOTRON FOR ISOTOPE PRODUCTION USING THE INTERNAL TARGET SYSTEM*

H. A. Kassim, King Saud University, Riyadh, Saudi Arabia
F. M. Alrumayan†, A. M. Hendy
King Faisal Specialist Hospital & Research Center, Riyadh, Saudi Arabia
F. Akhdar, Imam University, Riyadh, Saudi Arabia

Abstract

This paper reports a method to reduce the beam energy of the CS-30 cyclotron from 26.5 down to 10 MeV using the internal target system in CS-30 cyclotrons for isotopes production. Irradiations of solid targets, in this type of cyclotrons, take place when the target is positioned horizontally inside the cyclotron tank. In its final position, the target plate interrupts the beam from completing its orbit and nuclear reactions take place. Calculations are made to determine the beam energy as a function of radius. Verification of the new method was achieved by producing pure Ga-68 at an energy level of 11.5 MeV.

INTRODUCTION

Production of radioisotopes by CS-30 cyclotron at KFSHRC started in 1982 with seven targets, each positioned at the end of a beamline. In addition to these seven beamlines, it is also possible in this type of cyclotron to irradiate a solid target internally. A special ISO-RABBIT mechanical system connects the cyclotron with one of the hot cells to receive the target before irradiation and deliver it after irradiation. The internal target is located inside the cyclotron tank at the edge of the pole where the proton has gained full energy of 26.5 MeV [1]. Table 1 illustrates the specification of the CS-30 cyclotron [2].

Cyclotrons have an extraction system, comprising the equipment that extracts the beam from the accelerated region to the main beamline of the cyclotron. In negative ion cyclotrons (whose accelerated particles are negative ions), this is done by stripping electrons from the negative ions using carbon foils. In positive ion machines, the mechanism is more complicated, consisting of an electrostatic deflector (which has two parts: a septum. Septum made of tungsten, held at zero potential, and a high voltage electrode) and a magnetic channel to eliminate the magnetic field effect of the extracted beam. On the last rotation, particles experience a strong electric field capable of modifying slightly the trajectory of their orbit [3-6].

Figure 1 illustrates the internal target mechanism of a CS-30 cyclotron, which holds the target plate (to be irradiated) in final position at the edge of the pole where the proton energy is 26.5 MeV.

*Work supported by NSTIP strategic technologies program in the kingdom. Award No. (14-MAT-1233-20).
†rumayan@kfshrc.edu.sa

Table 1: Main Specification of CS30

Parameter	Value
Proton Energy	26.5 MeV
Deuteron Energy	15.0 MeV
He-3 Energy	38.0 MeV
He-4 Energy	30.0 MeV
External Beam Power	2000 W
Pole Diameter	38 inch
Weight	22 t
Number of Dees	2
Acceleration mode	fundamental
Voltage Gain Per Turn	100 kV

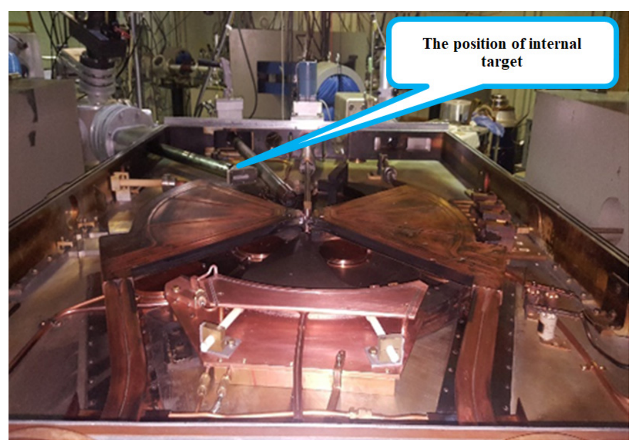

Figure 1: The normal position of the internal target during irradiation at 26.5 MeV.

This paper reports the possibility of reducing the cyclotron energy from 26.5 down to 10 MeV by moving the internal target mechanical system toward the central region of the cyclotron. The low energy beam, then, can be used to produce low energy-produced isotopes such as Ga-68 (produced at 11.5 MeV).

ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP025

CALCULATIONS OF BEAM ENERGY AND TARGET MODIFICATIONS

Calibration Curve of the CS30 Cyclotron

In order to, precisely, specify the energy level as a function of radius, the calibration curve was calculated as following [3]:

Consider the isochronous field of a cyclotron, i.e.:

$$\langle B\rangle = \gamma B_0 \,, \tag{1}$$

where B_0 is the cyclotron average magnetic field and γ equals to:

$$\gamma = \frac{1}{\sqrt{\left(1-\frac{r^2}{\alpha^2}\right)}}, \tag{2}$$

where;

$$\alpha = \frac{E_0}{ecB_0}\,, \tag{3}$$

$$E_0 = m_0c^2 = 938.2\ MeV\,, \tag{4}$$

$$T = (\gamma - 1)E_0\,, \tag{5}$$

where T is the energy level at different radii. Figure 2 shows the calibration curve of the CS30 Cyclotron.

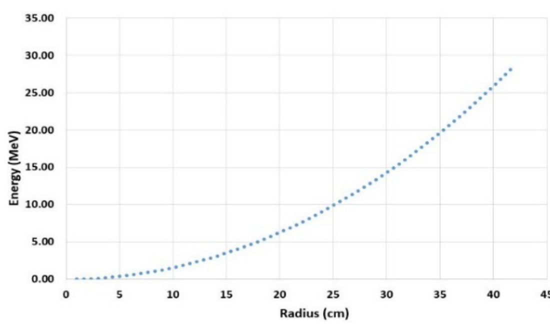

Figure 2: Energy-radius relationship of the CS30.

Beam Position at 11.5 MeV

In order to produce Ga-68 at 11.5 MeV [7], the internal target system was moved inward into a distance of 27 cm from the central region. This value is with respect to an energy level of 11.5 MeV. Beam position on target was examined in two energy levels: at 26.5 MeV Fig. 3 (A) and at 11.5 MeV Fig. 3 (B). At 11.5 MeV, the beam is off-centre and hit the top part of the target plate. Therefore, it is clearly indicated that the radius of curvature is not aligned with the new position of the target as it is in the outer radius case at 26.5 MeV. Therefore, target holder needs to be modified.

Modification of Target Geometry

The target mechanical shaft is off-centre, as shown in Fig. 4. The perpendicular distance between the canter and the shaft centreline d is 10.67 cm. The target surface should be tangential to the beam orbit. From geometry, the angle of the target to be tangential will be:

$$\theta = sin^{-1}\frac{d}{r}, \tag{6}$$

where d = 10.67 cm is the distance between canter and shaft centreline, and r is the orbit radius.

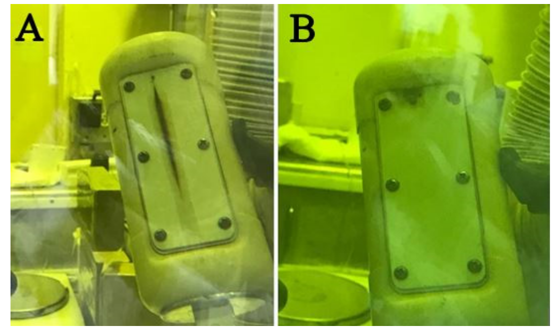

Figure 3: The beam position on the ISO-RABBIT target at (A) 26.5 and (B) 11.5 MeV.

For beam energy of 26.5 MeV, r is 41 cm and θ is 15.04° and for beam energy of 11.5 MeV, r is 27.6 cm, and θ is 22.74°. Target holder should be modified to fit the target carrier. From this perspective, the new dimensions of the target for an energy level of 11.5 MeV (as shown on upper right of Fig. 4) are: a = 7.1 cm, b = 3.6 cm, c = 8.0 cm and d = 0.5 cm.

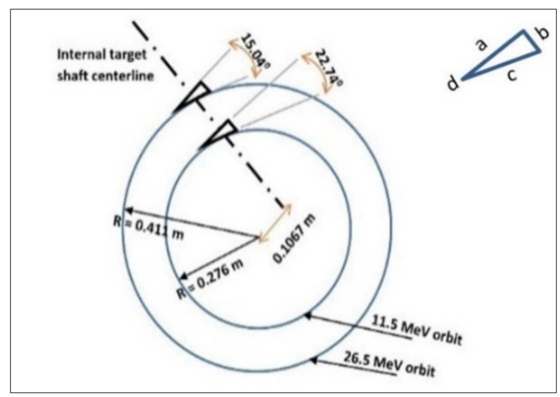

Figure 4: The target surface should be tangential to the beam orbit.

It should be noted that the production of Ga-68 was produced before modifying the target geometry, in order to verify the energy of the cyclotron with respect to the radius.

Ga-68 Production

The enriched Zn-68 was electrodeposited onto a copper disc as target support using a solution comprised of $^{68}ZnCl_2$ and 0.05 N HCl (concentration of Zn-68: 25–30 mg/mL) and a current density of 350 mA (43.75 mA/cm^2). The electroplating process was performed for 20 minutes. The weight of deposited Zn-68 on the copper disc was around 166.0 milligrams. The target was then transferred and mounted in the cyclotron. Figure 5 illustrates the shape of the target before and after being coated with the Zn-68.

Target Irradiation

Ga-68 can be produced by the cyclotron via the ^{68}Zn(p,n)^{68}Ga reaction in a solid target. The copper disc target was transferred into the internal target holder via an automated target transfer system. After that, the target was irradiated by proton-beam energy of 11.5 MeV with beam currents of 40–50 μA for 120 minutes. After irradiation, the

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP025

target was transported from the target holder in the cyclotron vault to the processing hot cell within the radiochemistry laboratory. In the hot cell, the solid target was dissolved. The chemical separation of Ga-68 was per-formed.

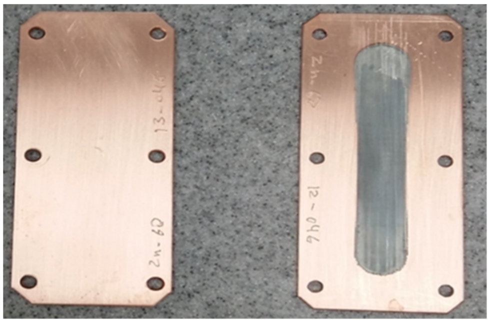

Figure 5: The copper target before and after being coated with the Zn-68.

RESULTS AND DISCUSSION

The radionuclide purity was assessed using gamma-ray spectroscopy equipped with a high purity germanium detector (CANBERRA, model: GC1518) and GENEI 2000 software was utilized. Figure 6 shows the main gamma lines of the Ga-68. To assess the presence of radio isotopic contaminants such as Ga-66 or Ga-67. Such Ga-67 impurities cannot be chemically separated, and the labelled compounds will have the same bio-distribution and kinetics as Ga-68. Measurements of Ga-67 and Ga-66 were made after 12 hours' decay of Ga-68. The Sample was counted for 5 minutes immediately after the end of separation.

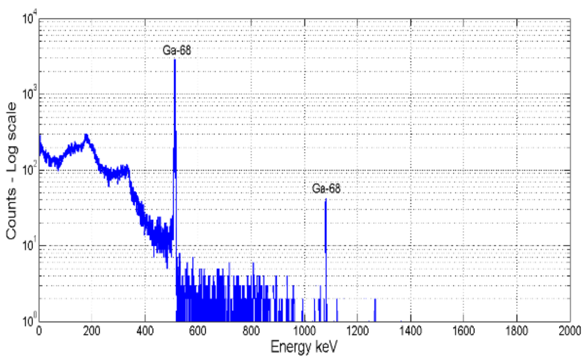

Figure 6: Characterization of Ga-68 by high purity germanium detector after production.

CONCLUSION

The possibility for reducing the cyclotron energy from 26.5 to 10 MeV was achieved in the CS30 cyclotron at KFSHRC. Calculations are made to determine the beam energy as a function of radius. Verification of the new method was achieved by producing pure Ga-68 at an energy level of 11.5 MeV.

ACKNOWLEDGMENTS

We would like to thank Mr. Ahmed Alghaith (Cyclotron engineer), Mr. Hussain Aldossery and Abdulrahman Alomar (Radiochemists) for excellent technical support. This project was supported by the NSTIP strategic technologies program in the kingdom. Award No. (14-MAT-1233-20).

REFERENCES

[1] F. M. Alrumayan, M. S. Shawoo, and M. Vora, "Status report of the cyclotrons C-30, CS-30 and RDS-111 at KFSHRC, Saudi Arabia", in *Proc. Cyclotrons'13*, Vancouver, Canada, Sep. 2013, paper MOPPT001, pp. 28-30.

[2] F. M. Alrumayan *et al.*, "Magnetic field measurement system of CS-30 cyclotron", in *Proc. Cyclotrons'16*, Zurich, Switzerland, Sep. 2016, pp. 196-198. doi:10.18429/JACoW-Cyclotrons2016-TUP13

[3] J. Livingood, "*Principles of Cyclic Particle Accelerators*", D. Van Nostrand Company Inc., 1962.

[4] H. L. Hagedoorn and P. Kramer, "Extraction studies in an AVF cyclotron", *IEEE Trans. Nucl. Sci*. vol. 13, no. 4, p. 64, Aug. 1966. doi:10.1109/TNS.1966.4324177

[5] W. Joho, "Extraction from medium and high energy cyclotrons", in *Proc. Cyclotrons'69*, Oxford, UK, Sep. 1969, paper CYC69C01, pp. 159-179.

[6] W. Kleeven *et al.*, "The IBA self-extracting cyclotron project", in Proc. *XXXIII European Cyclotron Progress Meeting*, Nukleonika 48 supplement 2, pp. 59-67, 2003.

[7] M. Pandey *et al.*, "Cyclotron production of ^{68}Ga via the ^{68}Zn(p, n)^{68}Ga reaction in aqueous solution", *American J Nucl. Med. Mol. Imaging,* vol. 4, pp. 303-310, June 2014.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI