A PRODUCTIVE CYCLOTRON AND ITS APPLICATIONS

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The demand for cyclotron-produced radioisotopes has been rapidly increasing for recent years in China. For this purpose, a cyclotron named as CYCIAE-30 was built by the end of 1994 and put into operation in February 1995. Since then, many kinds of products have been providing to hospitals and medical centers, such as ^{201}Tl, ^{111}In, ^{67}Ga, ^{68}Ge, ^{57}Co, ^{18}F etc. The production of ^{186}Re is being researched. Development of ^{123}I is envisaged.

1 Introduction

In China there are more than 186 sets of SPECTs (including dual and triple head SPECT), 110 gamma cameras, and 1 PET had been installed[1]. Another three PET centers will be established. They usually consume large amount of ^{99m}Tc radiopharmaceuticals, some kinds of cyclotron-produced isotopes are also needed. CIAE has developed the technology of ^{99}Mo extraction from irradiated highly enriched ^{235}U target, established ^{99m}Tc generator production line. But there is no any accelerator which could be specially used to produce isotopes in quantity at CIAE as well in China. Only a few of institutes or universities could experimentally produce isotopes by cyclotron. Radioisotopes are mainly produced by reactors in our country before 1995. Most of cyclotron-produced isotopes were imported, however very short-life radioisotopes, especially positron emitters, can not be imported. In order to promote the applications and research of cyclotron-produced radioisotopes, CYCIAE-30 designed to dedicate to the isotope production was built at CIAE and come into operation at the beginning of 1995. This is the first productive cyclotron in China. Its mission was fixed on the medical used radioisotope production.

2 CYCIAE-30

2.1 Design

CYCIAE-30 has the unique negative ion design that makes dual simultaneous target bombardment and very high extraction efficiency possible, thereby minimizing internal activation of the machine. Two of the ten extraction ports are connected with irradiation stations, one is for bombardments of solid targets, the other one only for a liquid target used to produce ^{18}F with $H_2{}^{18}O$ target material through nuclear reaction of ^{18}O(p,n)^{18}F. Operation of CYCIAE-30 is fully automated. All functions of every system are controlled by means of a personnel computer. Negative hydrogen ion is stripped by a carbon foil, and transformed into proton when it is accelerated up to expected energy. Proton energy can be adjusted from 15Mev to 30Mev by control of the stripping target unit. Maximum beam current is 350μA.

2.2 Construction

The construction of CYCIAE-30 was in cooperation with Ion Beam Application (IBA) of Belgium according to contract.

The parts provided by IBA are

(1) Center region including the dee tips of the R.F. accelerating system with the electrostatic inflector

(2) External multicusp H-minus ion source. axial injection system

(3) Stripper probe system for extraction and stripper probe system electronics

(4) Computer control system

(5) High power beam stopper for the beam transport system

(6) Solid target system with pneumatic transport system

The parts manufactured by CIAE as follows

(1) Magnetic system

(2) RF accelerating system

(3) Cyclotron vacuum system

(4) Cyclotron cooling system

(5) Extraction switching system

(6) Beam transport system

(7) Power supplies

The cyclotron vault, hot cell, aseptic rooms and all radiochemical laboratories were constructed by local firms. With these facilities, commissioning of the machine was done at the end of 1994 and proven to be successful.

2.3 Main specifications and Operation

The maximum beam current designed was 350μA. During commissioning , the top beam current reached on solid target was 372μA. Routine operation beam current is from 20 to 250μA, incident proton energy from 18 to 30Mev, power consumption from 60 to 90kW with different beam power.

3 Isotope Production

3.1 Targetry

Six kinds of radioisotopes have been produced by use of the solid target system. In this equipment, an aluminum carrier transports the target plates from the target station to the unloading hot cell and back. The carrier moves pneumatically in a rectangular aluminum tubing. At the receiving station in the hot cell, a pneumatic tool, installed in a drill press, allows an easy dismantling of the target from the carrier. The active target can then be transferred to another cell for processing, while a new unirradiated target is mounted on the carrier.

During irradiation, beam current bombards on target surface at the incident angle of 6 degrees. with this way, beam power is decreased by a factor of 1/sin6. Target area is 10mm wide and 96mm long. Targets of Ni, Zn, Cd, Tl, Ag were prepared by electroplating, while Ga target by casting alloy.

^{18}F was produced by a liquid target system for special use. This system was linked with a set of synthesis facilities for ^{18}FDG.

3.2 Isotope Production

With the purpose of isotope production, effective chemical processes for isotope extraction from active targets and advanced technologies for target preparation have been developed. Ga_2O_3 powdered target was initially prepared for producing ^{68}Ge[2]. Now, the GaCu alloy target was bombarded with about 90μA proton beam current. Ga_4Ni target was used by C.Loc'H et al..[3] A very complex solution system was originally employed for preparing ^{58}Ni target[2]. At present, ^{58}Ni is plated with a extremely simple solution that makes it possible to recover enriched ^{58}Ni at the rate of near 100%. In a word, the processes and technologies developed have been improving and work well. Isotopes produced by CYCIAE-30 on large scale are summarized in table 1. Occassionally, ^{109}Cd was produced. The separation process of ^{109}Cd was ever researched at CIAE[4].

4 Development in current and in the near future

^{186}Re is an attractive radioisotope for therapeutic applications, including bone pain palliation, radionuclide synovectomy and radioimmunotherapy due to its nuclear properties which include emission of high energy β rays ($E_{\beta,max}$=1.07Mev), an appropriate half-life ($T_{1/2}$=3.8d).

^{185}Re was used as target to produce ^{186}Re with a neutron capture reaction by reactor, and ^{185}Re was contained in product as carrier. When ^{186}Re is produced by cyclotron with $^{186}W(p,n)^{186}Re$ reaction, enriched ^{186}W will be employed as target. It seems that $^{186}WO_3$ powdered target can not be avoided. N.Shigeta et al. had done some significant fundamental research for the purpose.[6] The key problem to be solved is the design and manufacture of a powdered target system which could withstand higher proton beam current. A research group is devoting attention to it at CIAE.

$^{123}I(t_{1/2}=13h)$ radiopharmaceuticals have the advantages of less absorbed dose and better imaging effects compared with ^{131}I. ^{123}I could be produced through $^{124}Te(p,2n)^{123}I$ reaction with enriched ^{124}Te target without any change of our facilities. But the radionuclidic purity of ^{123}I is not ideal for SPECT imaging owing to containing ^{124}I when the enrichment of ^{124}Te is not high enough.

Through $^{124}Xe(p,2n)^{123}Cs\rightarrow^{123}Xe\rightarrow^{123}I$, $^{124}(p,pn)^{123}Xe\rightarrow^{123}I$ reactions with enriched ^{124}Xe gas target, higher radionuclidic purity ^{123}I can be obtained. This scheme may be adopted for development of ^{123}I.

With regard to nuclear physics, more than 60 kinds of radioisotopes could be produced by CYCIAE-30. But our focus is on the production of medical used radioisotopes.

Table 1: Isotopes produced and their final products

Isotopes	Half-life[5]	Target material	Reaction	Final products
^{201}Tl	3.05d	enriched ^{203}Tl	$^{203}Tl(p,3n)^{201}Pb\rightarrow^{201}Tl$	$^{201}TlCl$ injection
^{111}In	2.81d	enriched ^{112}Cd	$^{112}Cd(p,2n)^{111}In$	$^{111}InCl_3$ solution Labeled compounds
^{67}Ga	3.26d	natural Zn	$^{67}Zn(p,n)^{67}Ga$	^{67}Ga-citrate injection
^{68}Ge	270.8d	natural Ga	$^{69}Ga(p,2n)^{68}Ge$	^{68}Ga generator ^{68}Ge sources
^{57}Co	271.7d	enriched ^{58}Ni	$^{58}Ni(p,2p)^{57}Co$ $^{58}Ni(p,pn)^{57}Ni\rightarrow^{57}Co$	$^{57}CoCl_2$ solution ^{57}Co sources
^{18}F	109.7min	enriched $H_2{}^{18}O$	$^{18}O(p,n)^{18}F$	^{18}FDG

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