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THIRTY YEARS APPLICATION OF CYCLOTRON FOR RADIONUCLIDE PRODUCTION

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On the basis of 30 years experience of radionuclide production on the main problems connected at the application of cyclotrons for radionuclide production are discussed.

1. Introduction

As it is know cyclotrons are used for production of neutron deficiency radionuclides which this difficult or impossible to produced in nuclear reactors. The characteristic feature of cyclotron produce radionuclides is their high specific activity which is one of the most important factors of their successful application.

The published data show that the use of cyclotron produced radionuclides continuously increases especially in medicine. At present it is universally recognized that for the production of all types of radionuclides it is necessary to have three types of cyclotrons:

1) a small cyclotron (proton energy 10-15 MeV) for production of short-lived radionuclides used in positron - emission tomography;

2) a big cyclotron (proton energy 60-70 MeV) for I-123 and Sr-82 production ;

3) middle cyclotron (proton energy 22-30 MeV) for production of the main amounts of radionuclides which are necessary for medicine and the other applied purposes.

The last type of cyclotron is the mostly used cyclotron for radionuclide production . Our cyclotron /1/ put into operation in 1963 is of the third type. This cyclotron in the following period was modernised more than once and the technology of radionuclide production was also being continuously improved. Such activity gave us the possibility to increase regularly the production rate of the cyclotron and satisfy the constantly rising requirements in produced radionuclides.

During the last 30 years these requirements were increased approximately 15 times.

2. Features of cyclotrons used for radionuclide production.

The use of cyclotrons for radionuclide production makes a number of special demands to them which make them differ from the cyclotrons used for research purposes.

The main feature of production cyclotrons is the high intensity of internal beam reaching 500-1000 μA, that is 100 times more than the intensity usually used for research purposes.

The high intensity beams make it necessary to match carefully the beam relative to dees as even the small local loss of the beam on the dees results in their high activation and even to their damage. That is why one of the most important features of production cyclotron is the minimising of beam loss on dees.

The use of high intensity beam for internal target bombardment requires the spreading of the beam on target surface for decreasing specific heat load on the bombarded target surface. Such artificial increase of bombarded surface is reached: 1) by grazing beam incidence at small angle; 2) by using rotating target; 3) by artificial excitation of coherent radial oscillation of the beam; 4) by using the vertical scanning of the beam.

A very necessary condition of successful cyclotron operation in the time of bombardment of internal targets by a maximum intensity beam is the use of continuous remote monitoring of the target surface temperature. For this purpose it is convenient to use devices measuring infrared radiation from the target surface /2/.

The high radioactivity level of cyclotron parts resulted from the irradiation with charged particles and neutrons requires high reliability and durability of cyclotron parts to minimise radiation dangerous repair works.

And at last the most important condition to provide high production rate of cyclotron while producing radionuclides is the development of target assemblies and target technology which allows high heat load without damage of irradiated material.

3. Main characteristics of the cyclotron

Our cyclotron is a classical 1.5 m cyclotron operating at two levels of magnetic field. It allows to accelerate protons and deuterons to energies proper for production of the most of the used radionuclides. The characteristics of internal beams of the cyclotron are shown in the table 1.

Table 1: The characteristics of internal beams of the cyclotron

Accelerated particles	Particle energy, MeV	Beam intensity, μA
Protons	21.0	1000
Deuterons	21.0	1000

From 1990 year we use only internal beam as the use of electrostatic deflector together with high intensity internal

-beam results in difficulties caused by high radioactivity level of dees and deflector.

High intensity of internal beam is provided by careful vertical matching of the beam. To control the vertical distribution of the beam the three lamella probe is used /3/.

The radial distribution of the beam on the final radius is identified by means of a probe having vertical lamella. The position of the beam orbit centre is performed by the method of two probes /4/.

To control the temperature of the surface of the target being irradiated an infrared radiometer is used /5/. By means of this device it is possible not only to measure the temperature, but to determine approximate distribution of temperature on target surface. The application of such device allows us to perform irradiation of targets at maximum permissible temperature and to prevent overheating and damage of the irradiated material in proper time.

The cyclotron is in operation 24 hours without day off. The beam time of cyclotron is about 7000 hours per year which corresponds to about 82 per cent of annual time. The rest 18 per cent of time is spent on repair work, to switch the cyclotron from one mode of operation to another and to replace the irradiated targets.

At present we use only one type of target assembly. This is the target with grazing beam incidence at
8 ° angle.

The position of the target in the cyclotron is shown in fig.1.

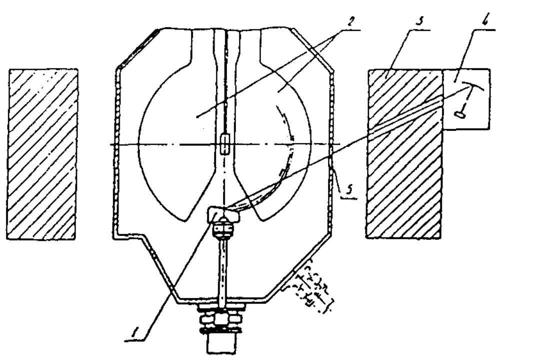

Figure 1 : Plane view of internal target position in IPPE cyclotron : 1 - target, 2 - dees, 3 - magnet yoke, 4 - infrared radiometer, 5 - window passing infrared radiation

The base of the target is a copper plate with bent edges. Metals to be irradiated are plated on the external flat surface of the target. The back surface-face of the target is cooled by flowing water and for the best cooling it has ribs /6/. Such target is show in fig.2.

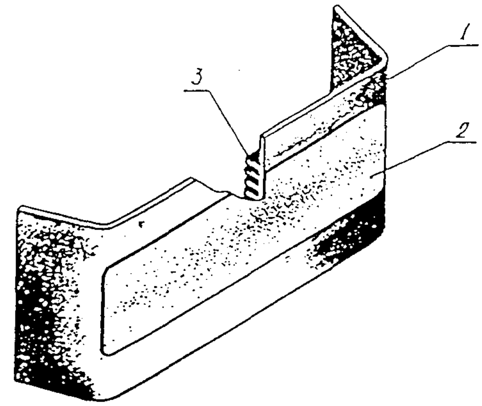

Figure 2: Isometrical view of internal target : 1 - cooper base of target, 2 - irradiated material, 3 - cooling ribs.

The moving away of irradiated target is performed by remote control. The metals which are to be irradiated are plated on the target surface by different methods: 1) by means of electro-plating, 2) by means of diffusion welding in vacuum, 3) by means of vacuum covering. The size of the coverings is 30x100 mm. The thickness of the coverings is from 0.1 mm to 0.2 mm.

4. *The characteristics of radionuclide production methods*

At present on the cyclotron about 20 radionuclides are produced. However, about 90 per cent of the cyclotron operation time is spent for production of the most used 5 radionuclides. The main characteristics of production methods of these 5 radionuclides are given in table 2.

Cobalt-57 is produced by bombardment of enriched nickel-58 (≈ 99 %) with 21.0 MeV protons. Nickel is plated on copper base of the target by galvanoplating. The thickness of coating is 0.2 mm. At beam intensity of 670 μA (≈ 14 kW) the temperature of the target surface being irradiated is about 310°C .

Gallium-67 is produced by two methods: 1) by bombardment of enriched zinc-68 (≈ 98 %) with 21.0 MeV protons; 2) by bombardment of enriched zinc-67 (≈ 92 %) with 21.0 MeV deuterons.

Zinc is plated by means of galvanoplating on the copper base of target which was previously covered with nickel 0.01 mm thick. The thickness of zinc coating is 0.15 mm. At beam intensity of 240 μA (≈5 kW) the temperature of the target surface being irradiated is about 150°C.

Germanium-68 is produced by bombardment of the alloy (65% gallium and 35% nickel) with 21,0 MeV protons. Alloy is plated on copper base of the target by means of hot pressure of the powder. The thickness of coating is 0,35 mm. At beam intensity of 290 μA (≈ 6 kW) the temperature of the target surface is about 250°C.

Table 2 : The main characteristics of production methods the mostly used 5 radionuclides

Produced radionuclide	Irradiated material	Particles	Beam curent, μA	Yield, mCi/μAh
Cobalt-57	Ni-58 - 99.0 %	21.0 MeV protons	670	0.038
Gallium-67	Zn-68 - 98.0 % Zn-67 - 92.0 %	21.0 MeV protons 21.0 MeV deuterons	240 240	2.56 2.10
Germanium-68	allow: Ga - 65 % Ni - 35 %	21.0 MeV protons	290	0.010
Cadmium-109	Ag-109 - 96 %	21.0 MeV deuterons	620	0.012
Indium-111	Cd-112 - 98 % Cd-111 - 96 %	21.0 MeV protons 21.0 MeV deuterons	100 100	2.83 2.10

Cadmium-109 is produced by bombardment of enriched silver-109 (≈ 96%) with 21.0 MeV deuterons. The silver-109 plate 0.18 mm thick is welded on the copper base by means of diffusion welding in vacuum.

At beam intensity of 620 μA (≈ 13 kW) the temperature of the target surface being irradiated is about 250 °C.

Indium-111 is produced by two methods: 1) by bombardment of enriched cadmium-111 (≈ 96 %) with 21.0 MeV deuterons; 2) by bombardment of enriched cadmium-112 (≈ 98 %) with 21.0 MeV protons. Cadmium is plated on copper base of the target by galvanoplating. The thickness of coating is 0.12 mm. At beam intensity of 100 μA (≈ 2 kW) the temperature of the target surface being irradiated is about 80°C.

5. Conclusion

At present it is universally recognized that for the radionuclide production H^- cyclotrons /7/ are preferable. Undoubtedly these cyclotrons are very convenient for bombardment of gas and other complex targets.

However, in our opinion for bombardment of metallic targets the use of internal beam of common cyclotrons is more preferable if these cyclotrons are provided with systems for vertical and horizontal beam scanning on the target surface. The advantage of such cyclotrons in comparison with H^- cyclotrons is the possibility to use an internal beam of higher intensity, simple and modest maintenance and accordingly high reliability and stability in operation.

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