CYCLOTRON RIC-30: 10 YEARS OF THE OPERATION

Eliseev I.A., Kaplun V.G., Rogozev B.I., Stepanov A.V., Suzikov A.G., Jagol'nikov S.V.

MD RF Second Central Scientific Research Institute, SPA "V.G. Khlopin Radium Institute ", SPA " D.V.Efremov Scientific Research Institute of Electrophysical Equipment"

Abstract

An operating experience of cyclotron RIC-30 is represented. Its sufficient reliability and possibility of operation in the regime of radionuclides production is confirmed. The basic unresolved question is obtaining the current of external and internal beams, close to the certified values.

CYCLOTRON DESCRIPTION

Cyclotron RIC-30 (development of SPA" D.V.Efremov Scientific Research Institute of Electrophysical Equipment" is in operation from 1993. Accelerator it is placed in the specially designed building, in rooms of which are established basic, general technical and accessory equipment (Fig. 2), including: cyclotron RIC-30 (Fig. 1); control system of accelerator; the extraction system and transport of beam to the remote targets with the beam extraction into the atmosphere and vacuum chamber; the set of internal target devices and system for the installation of external targets; means and devices for providing the radiation safety, monitoring-measuring equipment, the means of storage and information processing, other technical equipment. Accelerator RIC-30 - the isochronous sector-focusing one-dee cyclotron with pot electromagnet is intended [1] for the production of radionuclides on the internal and external beams with the aid of the appropriate target devices. The proposed and achieved characteristics of the cyclotron are given in Table 1.

Table 1:

<table>
<thead>
<tr>
<th></th>
<th>Proposed</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External (mA)</td>
<td>200</td>
<td>60 (5-10)</td>
</tr>
<tr>
<td>Internal (mA)</td>
<td>1000-500</td>
<td>500(250)</td>
</tr>
<tr>
<td>Proton energy (MeV)</td>
<td>28</td>
<td>28 (28.5)</td>
</tr>
<tr>
<td>RF frequency (MHz)</td>
<td>17.6</td>
<td>17.5(17.4)</td>
</tr>
<tr>
<td>Dee voltage (kV)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Magnetic field (T)</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Current of main coil (A)</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>Extraction radius (mm)</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Deflector angular width (°)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Deflector voltage (kV)</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>Pressure in vacuum chamber (torr)</td>
<td>$2 \times 10^{-5}$</td>
<td>$2 \times 10^{-5}$</td>
</tr>
<tr>
<td>Power consumption (kW)</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

Figure 1: Cyclotron RIC-30

Figure 2: Plan view of the RIC-30 arrangement

Structure of the magnetic field of cyclotron - four-sector with the weak spirally. Four concentric coils with the independent supply are used for the precise fine
adjustment of field. Azimuthal magnetic bumps are corrected by two groups of the harmonic coils.

The ion source of slit type with the hot cathode is introduced into the accelerating chamber vertically through the hole in pole.

The diagnostic equipment of cyclotron includes 3 probes (basic, in dee and in deflector), the collimators and sensors of the beam profile, and also Faraday's cylinders, which provide control of the parameters of internal and external beams. Channel of beam extraction - electrostatic.

To fulfill the program of applied-scientific studies, mainly, on the study of the yields of radionuclides in different nuclear reactions and the operating time of the isotopes of scientific and technical and medical purpose, first of all with Co-57, Ga-67, Cd-109, TI-201, the work on equipping of cyclotron additionally by the internal target, made on the base of main probe, was carried out. The calculated approach angle of beam to the fixed water-cooled target is -5°. In this case the length of beam trace is 40 mm, the width of track ~ 6... 8 mm is determined by the vertical size of the beam (see Fig. 3). Target is located in the valley of magnetic system, i.e., in the region of the maximum value of a radius of the orbit of protons. Target equipment ensures the automated (input-output) and extraction of the target. In the initial stages of operation the current of internal beam did not exceed 50 mA, which proved to be insufficient for the implementation of the program of the radionuclides production. In the course of studies it was revealed, that the limitations of current were caused by the design features of dee, which give to it insufficient high quality factor, i.e. to the complexity of obtaining high accelerating voltages and to the significant losses of beam on initial radii. In connection with this the solution about the replacement of dee was accepted. The project of new dee with the aperture 50 mm with the increased quality factor and by the improved water cooling was made with the help of the colleagues from Dzelepov Laboratory of JINR. As a result the current of internal beam was increased to 250 mA with duty factor 2.5. In this case the task of reduction in the power density on the target, up to the tolerance levels, arose. For its solution on the cyclotron RIC -30 for the first time was realized vertical scanning of the beam [3] due to the variable radial component of magnetic field, obtained by supplying the harmonic current to the concentric winding, located in the region of target alignment. An increase in the uniformity of the power density of beam on the target in the vertical plane is achieved by the selection of phase of scanning voltages relative to the phase of accelerating voltage. Radiography of standard beam trace on internal target during the switched on regime of scanning is given in fig. 4. The dependence of a relative increase in the dimensions of beam trace on the value of current of scanning is represented in fig. 5. The operating range of the currents of scanning lies within the limits 6.0 – 9.5 A.

As a result of the introduction of these/conditions of the scanning beam regime the dissipated power on the internal target was increased to ~5.5 kW.

For expanding the test possibilities of cyclotron, first of all, with an increase in the beam current in more than 250 mA was designed and prepared the second target, installed on the place of deflector probe. A basic difference in the second target – increasing to ~ 7 kW dissipated power, which makes it possible to carry the radionuclides production with the current up to 300 mA.

At present the losses of beam on initial radii of acceleration (to 170 mm), lead to the significant warming-up of the central region. In connection with this the attempts to increase the current of internal beam to the proposed value of about 500 mA lead to the development of breakdown phenomena.

For the purpose of the optimization of the electric field structure in the central region and to decrease of losses SPA" D.V.Efremov Scientific Research Institute of Electrophysical Equipment" was carried out the calculation of the dynamics of particle motion in the central region and formulated recommendations regarding the correction of field due to the special electrodes in the form of cover plates to the dee lips. However, preliminary tests did not yield positive results.

While performing of setup work by developer the current of external beam up to 10 µA was obtained. In this case the coefficient of extraction composed less than ~10%, which led, if to increase internal current, to the significant warming-up of deflector and to the development of breakdowns. Tuning of the extraction regime by the correction of deflector position and change of the currents in harmonic coils did not lead to the desired result.

Figure 3: Radiography of beam on the target without the vertical scanning

Figure 4: Radiography of beam on the target with the vertical scanning

In the course of conducting the tests on cyclotron RIC-30 the number of the deficiencies, which hamper its operation was revealed.

1. Power of the cooling system of cyclotron is insufficient for the maintenance in the summer time of the operating temperature of the heat-transfer agent of internal outline within the permissible limits, which significantly limits the operational capabilities of cyclotron.
to the disturbance of heat withdrawal because of the RF devices to the external cooling circuit of cyclotron, led free water was required.

2. Possibility of an increase in the internal current due to the decrease of duty factor was limited due to the development of breakdown phenomena as a result of the excessive heating of the walls of resonator from RF losses and forming the local region insufficient high vacuum. Vacuum pumps, installed at the maximum distance from the position of resonator, do not ensure effective evacuation from this region. The installation of additional pump in immediate proximity of the resonator made it possible to solve this problem.

3. Realized regime of the work of the oscillator tubes (tetrode GU-92A - penultimate cascade and triode GU-66'A - the final stage) of power-supply RF system leads to the high currents of rest and as consequence to the excessive energy consumption (according to our estimation - 30 kW). In connection with this question the modernization of high-frequency generator is examined.

4. Elements of the tanks for cooling the lamps of the terminal and penultimate cascades of RF supply, which are located under the potential 10 kV and 6 kV, in view of the special features of their design concept are subjected to intensive electrochemical destruction, which contributes to the appearance of sudden flows of water and to the failure of lamps.

Radiological Situation.

In the course of operating the cyclotron the system of providing radiation safety, developed at the stage of design, provides for the following basic forms of radiation monitoring:

- the operational monitoring of the rate of the neutrons dose and gamma-radiation, surface pollution by in β-active radionuclides, the volumetric aerosol activity of air and volumetric activity of water of the internal cooling circuit of cyclotron;
- the stationary monitoring of the rate of the dose of gamma-radiation and rate of the dose of neutrons in the technological rooms (hall of cyclotron, halls of peripheral target devices);
- individual personnel monitoring.

The results of radiation monitoring, obtained in the course cyclotron running, for the parameters of beam given above, give the following fundamental characteristics of radiological situation and dose loads of operational personnel during the operation RIC-30:

1. Dose characteristics of the fields of neutron and gamma-radiation outside the biological protection do not exceed background values.

2. During the work RIC-30 on internal beam (standard regime) in the hall the rate of the dose of neutrons is from 50 to 150 mZv/h, and the rate of the dose of gamma-radiation - from 30 to 60 mZv/h.

3. In 0.5 hours after the disconnection of cyclotron the rate of the dose of gamma-radiation in the hall is from 10 to 50 mkZv/h in the places of performing work on the prompt service of the systems of cyclotron (target devices, RF system, the source of ions). The values of the rate of the dose of gamma-radiation from the induced activity in vacuum chamber of cyclotron after prolonged (> month) stoppage RIC-30 lie in the range from 0,5 to 10 mZv/h.

4. Average value of the annual individual dose of personnel in the last 5 years composes ~3 mZv, which indicates a sufficient level of providing radiation safety during the operation of cyclotron.

Operational Indices.

cyclotron RIC-30 is characterized by a comparatively small energy consumption. In the operating mode on internal beam the energy consumption does not exceed 250 kW·h. The indices of average annual operating time in the last 5 years are represented in Table 2.

Table 2:

<table>
<thead>
<tr>
<th>Years</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working time (h)</td>
<td>1520</td>
<td>1850</td>
<td>1710</td>
<td>1930</td>
<td>2150</td>
</tr>
</tbody>
</table>

As a whole, work experience on the cyclotron RIC-30 showed its sufficient reliability and possibility of operation in the regime of radionuclides production. Work on an increase in the internal beam current to 500 mA with a simultaneous increase in the power of target is planned. Obtaining the external beam current, close to the proposed value, remains the basic unresolved question.

REFERENCES