SET-UP FOR RADIOACTIVE BEAMS ON STANDARD TRANSPORTATION LINE UNITS OF THE CYCLOTRON U-240.

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The existing on the U-240 cyclotron equipment are considered as set-up of on-line separator of the radioactive secondary nuclei from nuclear reactions induced by heavy ion beams of this accelerator with internal and external (ECR) ion sources. The possibilities of the effective secondary beam facility are evaluated: physical opportunities to produce residual nuclei at the U-240 acceleration conditions, their kinetic energies, charge distribution of the produced secondary ions after target, mainly CN system evaporation residues. The data are used for optical calculations of the magnetic units layout and main characteristic of the separator are determined. Comparison with features of the medium energy on-line mass separator is represented.

On medium energy accelerators recently were developed and commissioned the mass separators of secondary particles. Despite of complexity of such set-ups consisting of large number of magnetic-optical elements, capable to deflect and to focus particles with large magnetic rigidity (energy of tens and hundred MeV/u) such installations are designed due to large number of problems, which can be solved with their help. The basic advantages of fast nuclei separators in comparison with usual ones, working in line with the accelerator are reduction of time and increasing of efficiency of desirable nuclei delivery to a place of their study or uses and absence of many technological processes.

We already discussed possible modes of operations of the equipment created on U-240 for realization of polarization experiments [1] at the other problems solution of experimental nuclear physics at medium energies. Opportunities of use of this equipment to separate the secondary products of reactions here will be discussed in more details, particularly about creation of the set-up for the solution of the scientific and applied problems, basic of which are:

- Study of decay ways of compound nuclei on evaporation residues.
- Spectroscopy of radioactive nuclei with short time of life (> 1 μs).
- Production of radioactive nuclei beams for researches in the field of nuclear physics.
- Implantation of a wide class of radioactive atoms in various samples of materials for researches in various areas of a science and engineering.
- Realization of the marked atoms method on biological objects with use of short lived isotopes (times of life about some days).

In the following calculations the characteristics of the U - 240 [2] are used taking into account an installation of the ECR heavy ions source with external injection system in the future. The ions acceleration to the maximum achievable energy E_1 at the accelerator and energy per unit of weight E_1/A_1 if the ions have a charge q with $A_1 > 2$) may be evaluated by the expressions:

$$E_1 = 120\, q^2/A_1\,, \quad E_1/A_1 = 120 q^2/A_1^2 \qquad (1)$$

At interaction with a nucleus A_2, resulting in fusion $A = A_1 + A_2$ kinetic energy can be estimated with

$$E = E_1A_1/(A_1+A_2), \quad E/A = E_1A_1/(A_1+A_2)^2 \qquad (2)$$

and energy of compound nucleus excitation with ratios

$$E^* = E_1A_2/(A_1+A_2)+Q, \quad E^*/A = (E_1A_2/A+Q)/A \quad (3)$$

For not too heavy ions with $q = Z = A/2$ the limiting kinetic energies of compound nuclei are close to 30 MeV/u at $A_1 >> A_2$ and $30\,(A_1/A_2)^2$ at $A_1 << A_2$.

Dependence E/A as a function of atomic weight of a target nucleus is shown in the Fig.1 for a number of ions with A<40. It is visible, that with a set of ions given on the Fig.1 it is possible to produce the compound nuclei with energy more than 1MeV/u up to A= 100.

Despite lacking of theoretical expressions for definition of an average charge of ions, after passing through substance depending on their energy there is well checked up empirical ratio [3], on the basis of which the calculations are made. The Fig.2 is the results of such calculations for rather wide energy range of ions with enough nuclear weights set. Taking into account, that half-width of charge distribution is roughly determined by a ratio $d=Z^{0.45}$ for Z=4-50 it makes values for d 2 - 7.

From Fig.2 follows that in energy conditions which there are at the U-240 recoil nuclei may be completely without an electronic environment (q/Z = 1) only for light systems with A < 20, for more heavy recoil ions the Gaussian distribution are realized. Thus, there is essential difference of conditions of mass separator work of the recoil compound

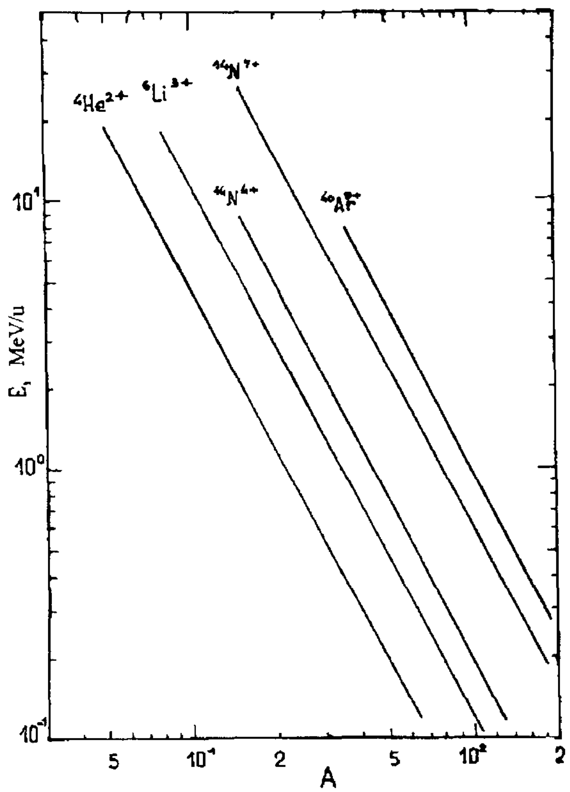

Fig.1 Kinetic energy of compound nuclei $A=A_1+A_2$ after interaction A_1 ions of accelerator maximum energy with A_2 targets

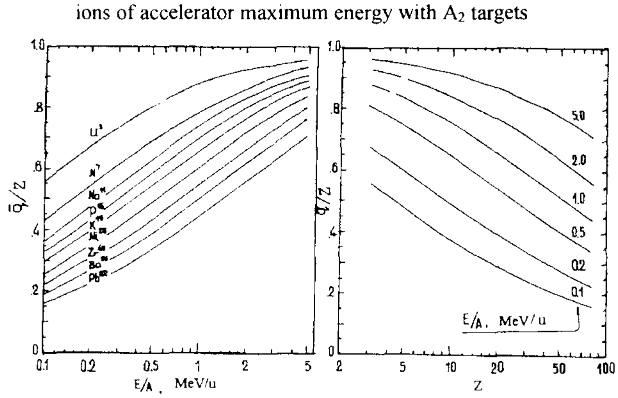

Fig.2. Ratio of mean ion charge q to Z as a function of energy (left) and nucleus charge (right).

nuclei at the mentioned circumstances from work of the same set-up in an energy range some tens MeV/u where an electronic environment of residue nuclei are skinned completely. The situation will be better for direct reactions products owing to their speed practically is equal to speed of ions incident on a target and the high energy per unit causes q = Z. The distribution on a charge of analyzed ions will result in losses of determined nuclei type at selection unique q/A.

The escaping products from target (rests of compound nuclei after their deexcitation) can be estimated by calculations of total reactions cross sections and compound nucleus formation cross section on available nowadays parametrizations of these values found on the basis of experimental data of the heavy ion - nucleus interaction. The examples of calculation σ_R and σ_{CN} for ^{14}N ions of 150 Mev incident on targets with Z = 2-82 (He - Pb) are shown in Fig.3 (circles and light rectangulars are the various authors parametrization of σ_R, dark rectangulars are σ_{CN}). One can see, that for target nuclei more heavy than Be the differences of σ_R predicted by various parametrizations are <20 % and values σ_R are within range of 1-3 bn. Approximately a half of processes of reactions total cross section proceeds through a compound nucleus formation. The total reactions cross sections of Ar ions with energy 192 MeV have the same order (triangles in Fig.3).

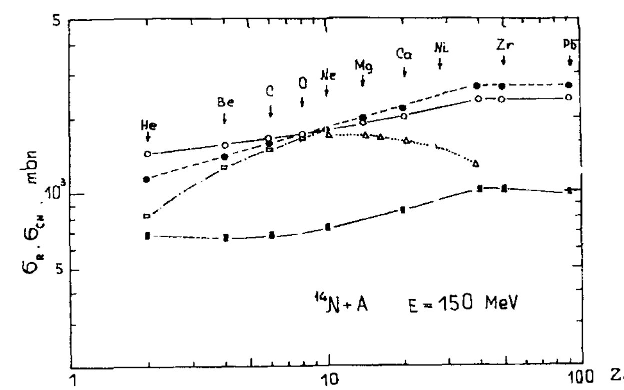

Fig.3. Total reaction and formations of compound nucleus cross section for $^{14}N^{+4}$ (150 MeV) and $^{40}Ar^{+8}$ (192 MeV) ions as a function of target nucleus charge Z_2.

With energy increasing at use of ECR - source of heavy ions up to 25-30 MeV/u σ_{CN} decreases and the direct mechanism of reactions begins to prevail, projectilelike products will fly forward with speed of an incident ions. As at a compound nucleus formation so in the second case the yield of products is sharp directed forward, and the differential cros sections are tens - hundred bn/sr. With thickness of a target $\sim 10^{19}$ cm^{-2} and solid angle of mass separator acceptans $\sim 10^{-3}$ sr. the intensity of products under angle almost equal 0° will be 10^{-5} - 10^{-6} from intensity of an initial beam, i.e. $(10^7 - 10^6)$ s^{-1} at a current on target ~ 1 pμA.

The main requirements of the discussed set-up are connected with good resolution and acceptans. These requirements can be satisfied by systems having residual dispersion and achromasity, which are designed with large number (> 10) magnets of various multipolarity . In conditions U-240 such a kind system can be created on the basis of the equipment incorporated in the project of transport lines of the accelerator beam in connection with prospects of the polarization phenomena research [1]. It contains (see Fig. 4) four dipole magnets and seven quadrupole lenses.

The heavy ions beam of the accelerator is focused by a doublet Q4 on the target M. Products of fusion or other nuclei which are taking off under 0° or in its vicinities (the last allow to carry out dipole magnets KM 7 and KM8) are focused on a plane between magnets of achromatic deflection system on a basis BM3, Q22, BM4. The second wing of achromatic deflection system with lenses Q17 allows to focus a beam in a place B located practically symmetrically to targets M concerning the system of deflection.

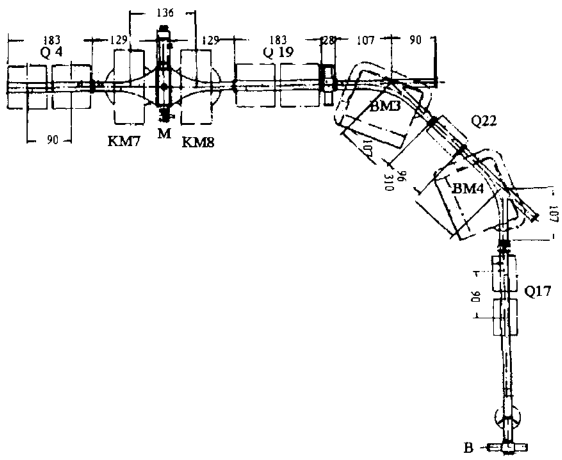

Fig. 4. Layout of the set-up.

The ions optics calculations for section MB carried out in the first order approximation under the program TRANSPORT (see Fig.5) show that from a target M to a place B can be delivered ions with $\Delta p/p$= 0,05 with small increase of a source. In the focal plane situated between BM3 and BM4 particles with different magnetic rigidity are separated on axis x, i.e. in this place it is possible to carry out selection of particles on their magnetic rigidity (selection of mass and charges of nuclei). Large time of flight on the base (MB=13m) allows to identify nuclei also on time of flight, i.e. at development of system it is possible identification of nuclei in the point B on E,M,t.

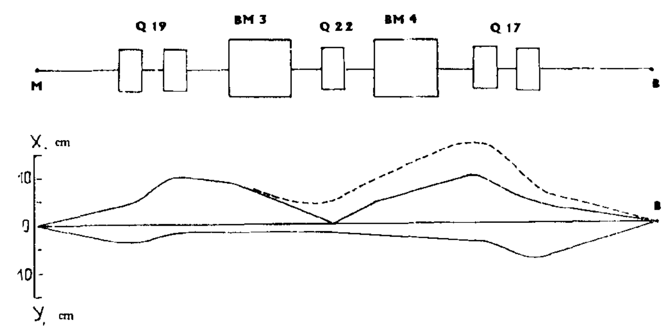

Fig. 5. Results of optic calculations on the distance MB.

The main characteristics of installation together with those of specially developed for GANIL in France [4] and ring cyclotron of RCNP in Japan [5] are shown in the Table.

Table: Main characteristics of the set-up

N	Characteristics	This work	[4]	[5]
1.	Ion energy from accelerator (MeV/u.)	30	80	100
2.	Solid angle, sr	2 10^{-3}	10^{-3}	10^{-3}
3.	Maximum rigidity, Tl m	1.8	3.2	3.2
4.	Deflection angle	2x45°	2x45°	2x30°
5.	Central trajectory radius, m	1.5	2.0	2.2
6.	Dispersion in focal plane	9.8	18	8.4
7.	Maximum slit aperture, mm	±60	±50	±35
8.	Maximum Bρ acceptans	±4.3	±2.71	
9.	Total distance, m	12.8	18	15.7
10.	Dispersion of trajectories length	0.0005	0.001	
11.	Mass resolution, Δ M/ M		0.0045	0.003
12.	Products yields	10^{-5}-10^{-7}	10^{-4}-10^{-6}	

Written off above results of calculation and given in the Table characteristics testify, that on the basis of the available equipment for polarization investigation at U-240 can be created the secondary nuclei separator with rather good characteristics.

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