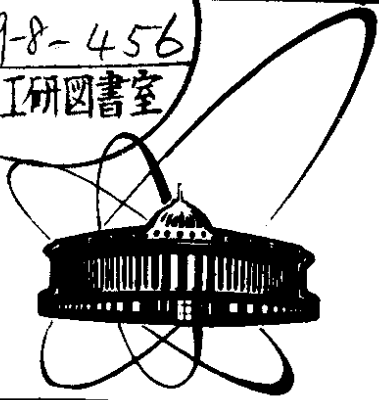


受入  
89-8-456  
高工研図書室



Объединенный  
Институт  
Ядерных  
Исследований  
Дубна

E9-89-324

B. N. Gikal, G. G. Gulbekyan, V. B. Kutner

THE PRESENT STATUS  
OF THE U-400 ISOCHRONOUS CYCLOTRON

Submitted to International Conference  
on Cyclotrons and Their Application, West Berlin,  
May, 1989

1989

## 1. Introduction

The development of heavy ion physics at the Laboratory of Nuclear Reactions is closely related to the construction and development of accelerators providing intense ion beams within a wide range of masses and energies.

There are a cyclic implanter, the U-200, the U-300 and the U-400 cyclotrons.

Presently a cyclotron system consisting of the U-400 and the U-400M cyclotrons is being constructed at the Laboratory. The tandem system is designed for the acceleration of  $^{12}\text{C}$  -  $^{238}\text{U}$  ions to energies of 120-20 MeV/nucleon <sup>/1/</sup>.

In contrast to the majority of the facilities under construction in the world, the U-400 and the U-400M are capable of autonomous operation. In this case the cyclotrons can accelerate ions of elements belonging to the first half of the Periodic Table. To produce still heavier ions it is necessary to use the tandem system.

At the beginning of 1989 the classical cyclotron U-300 was shut down for reconstruction into the U-400M cyclotron <sup>/2/</sup>.

A system for the axial injection of ions has been constructed for the U-200 cyclotron and tested with a  $^4\text{He}^{1+}$  beam. The efficiency of beam transportation from the source to the final acceleration radius was 8-10% for  $I_{inj} < 500 \mu\text{A}$ , 6% for  $I_{inj} = 1 \text{ mA}$ . Presently an external high-current injector is being developed on the basis of a PIG-type ion source.

## 2. The U-400 cyclotron

The first beam was produced at the U-400 cyclotron at the end of 1978. Last year this accelerator was in operation for 5200 hrs, the rest of time was divided between the installation of new equipment and the preventive inspection and maintenance of its units. The operation time of the accelerator was used in the following way:

- 3650 hrs - irradiation of targets;
- 270 hrs - preparation of physical facilities;
- 430 hrs - investigations in the field of the accelerator technique;
- 850 hrs - accelerator preparation and mode optimization.

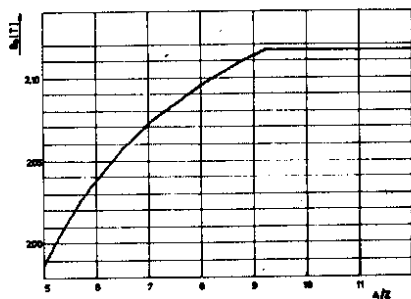


Fig. 1. The dependence of the magnetic field at the centre of the cyclotron on the mass-to-charge ratio of the accelerated ion.

Until presently, the ions of elements from  $^{10}\text{B}$  to  $^{132}\text{Xe}$  with the mass-to-charge ratio of 5-12 have been accelerated at the U-400 cyclotron. The necessary increase in the magnetic field value along the radius for different  $A/Z$  values is provided mostly by a difference in the excitation levels of the main coil (fig. 1). This enables one to have a low-powered correction system consisting of 10 radial and 4 azimuthal coils. Usually, only 2-4 of them are used during experiments.

Basic cyclotron parameters are presented in Table 1.

Table 1

The mass/charge ratio of accelerated ions -	5-12
Magnetic field -	19.87 - 21.17 kG
Frequency of the HF generator -	5.4 - 12.2 MHz
Harmonic mode -	2
Vacuum in the cyclotron chamber -	$1 \cdot 10^{-6}$ - $5 \cdot 10^{-7}$ Torr
Emittance of the external beam:	
horizontal -	$40\pi$ mm mrad
vertical -	$16\pi$ mm mrad

The cyclotron is capable of irradiating physical targets both inside the accelerator chamber and in the 12 channels positioned at 3 levels (fig. 2). Beam extraction in two directions ("A" and "B") is performed via charge exchange.

### 3. Beams of the U-400 cyclotron

The spectrum of ions accelerated at the cyclotron has been determined by the demands of physical experiments. A high-current

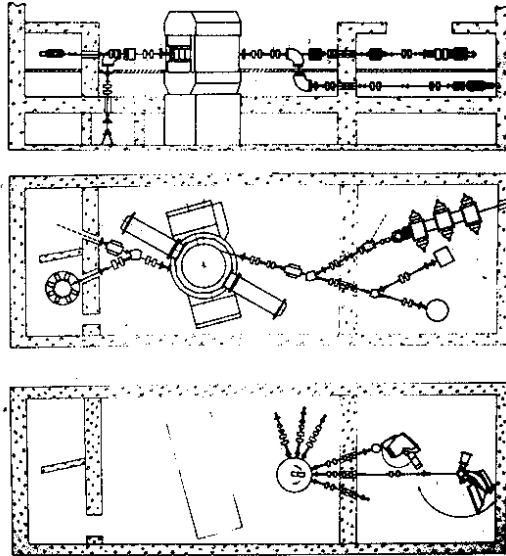


Fig. 2. The lay-out of the U-400 ion guides location.

internal PIG-type source allowed to obtain ion beams of both gaseous and solid materials.

The ions accelerated include ions of rare isotopes such as  $^{18}\text{O}$ ,  $^{58}\text{Fe}$ ,  $^{64}\text{Cu}$ ,  $^{70}\text{Zn}$ , etc. The high degree of sample enrichment has permitted the beam intensity at the level of the basic isotopes.

Ion beam extraction in both directions is performed via charge exchange on thin graphite foils of  $40\text{--}200\ \mu\text{g}\cdot\text{cm}^{-2}$  thickness <sup>/5/</sup>. On passing the extraction foil the charge increases 2.5-4.5 times.

The extraction coefficient is practically determined by the charge distribution and makes 30-100%. The maximum beam intensity is limited by the thermal durability of the extraction foil and is  $7 \cdot 10^{12}$  pps for Ar,  $1\text{--}1.5 \cdot 10^{13}$  pps for light ions of oxygen and neon. Under these conditions the foil lifetime is about 24 hrs <sup>/6/</sup>.

Table 2 presents the parameters of the ions accelerated at the U-400. The energy of ions and the maximum intensity are indicated for the internal beam. The energy of the external beam is determined by the characteristics of the extraction system. The beam intensity depends on one of the factors: the extraction coefficient, the

Table 2

Ion	Internal beam		External beam			
	E (MeV/nuc1)	I (c <sup>-1</sup> )	E (MeV/nuc1)			I (c <sup>-1</sup> )
			II	II	I	
11 <sub>Ar</sub> <sup>2+</sup>	18.0	2 10 <sup>12</sup>	9.0	12.0	18.0	2 10 <sup>12</sup>
14 <sub>N</sub> <sup>2+</sup>	12.4	2 10 <sup>14</sup>	7.0	9.5	--	1.5 10 <sup>13</sup>
15 <sub>N</sub> <sup>2+</sup>	8.4	2 10 <sup>14</sup>				
16 <sub>O</sub> <sup>2+</sup>	7.9	3 10 <sup>14</sup>	4.0	8.8	--	1.5 10 <sup>13</sup>
18 <sub>O</sub> <sup>3+</sup>	17.5	4 10 <sup>13</sup>	7.0	10.0	16.2	1.5 10 <sup>13</sup>
20 <sub>Ne</sub> <sup>2+</sup>	5.3	2 10 <sup>14</sup>	4.2	5.4	--	1 10 <sup>13</sup>
20 <sub>Ne</sub> <sup>3+</sup>	13.4	2 10 <sup>14</sup>	7.5	10.0	14.5	1 10 <sup>13</sup>
20 <sub>Ne</sub> <sup>4+</sup>	20.0	2 10 <sup>12</sup>	10.	14.3	21.4	2 10 <sup>12</sup>
22 <sub>Ne</sub> <sup>3+</sup>	13.0	2 10 <sup>14</sup>	4.2	8.4	12.1	1 10 <sup>13</sup>
27 <sub>Al</sub> <sup>3+</sup>	6.1	5 10 <sup>13</sup>				
31 <sub>Ar</sub> <sup>4+</sup>	7.4	1 10 <sup>13</sup>				
40 <sub>Ar</sub> <sup>4+</sup>	5.3	1.5 10 <sup>14</sup>	3.8	5.3	--	7 10 <sup>12</sup>
40 <sub>Ar</sub> <sup>5+</sup>	7.9	9 10 <sup>13</sup>	5.0	7.0	--	7 10 <sup>12</sup>
40 <sub>Ar</sub> <sup>6+</sup>	13.4	3 10 <sup>12</sup>	6.5	9.3	14.0	1 10 <sup>12</sup>
48 <sub>Ti</sub> <sup>3+</sup>	5.6	4 10 <sup>13</sup>	4.1	5.5	--	7 10 <sup>12</sup>
49 <sub>Ti</sub> <sup>5+</sup>	5.4	2 10 <sup>13</sup>				
50 <sub>Ti</sub> <sup>5+</sup>	5.0	1 10 <sup>13</sup>				
51 <sub>V</sub> <sup>5+</sup>	5.5	5 10 <sup>13</sup>				
52 <sub>Cr</sub> <sup>6+</sup>	6.8	5 10 <sup>12</sup>	4.4	6.4	--	2 10 <sup>12</sup>
53 <sub>Cr</sub> <sup>5+</sup>	5.3	1 10 <sup>13</sup>				
54 <sub>Cr</sub> <sup>5+</sup>	5.3	1 10 <sup>13</sup>				
55 <sub>Mn</sub> <sup>6+</sup>	5.5	6 10 <sup>13</sup>	4.2	6.0	--	6 10 <sup>12</sup>
56 <sub>Fe</sub> <sup>6+</sup>	5.3	3 10 <sup>13</sup>	4.2	5.7	--	6 10 <sup>12</sup>
58 <sub>Fe</sub> <sup>6+</sup>	5.3	2 10 <sup>13</sup>	3.8	5.3	--	3 10 <sup>12</sup>
58 <sub>Ni</sub> <sup>6+</sup>	5.2	1 10 <sup>13</sup>	4.0	5.4	--	3 10 <sup>12</sup>
64 <sub>Ni</sub> <sup>6+</sup>	5.3	1 10 <sup>13</sup>				
64 <sub>Zn</sub> <sup>7+</sup>	4.2	1 10 <sup>12</sup>				
70 <sub>Zn</sub> <sup>8+</sup>	5.2	4 10 <sup>11</sup>				
76 <sub>Ge</sub> <sup>8+</sup>	5.3	2 10 <sup>12</sup>				
84 <sub>Kr</sub> <sup>9+</sup>	6.0	5 10 <sup>11</sup>				
90 <sub>Zr</sub> <sup>11+</sup>	9.0	1 10 <sup>11</sup>				
129 <sub>Xe</sub> <sup>12+</sup>	4.6	5 10 <sup>9</sup>				
129 <sub>Xe</sub> <sup>11+</sup>	3.8	5 10 <sup>9</sup>	2.3	3.3	--	1.5 10 <sup>9</sup>

I - one-turn extraction  
 II - two-turn extraction  
 III - three-turn extraction

durability of the extraction foil, limitations due to biological shielding. It should be noted that for some ions (<sup>40</sup>Ar<sup>4+</sup>, <sup>48</sup>Ti<sup>5+</sup>, <sup>55</sup>Mn<sup>6+</sup>, <sup>56</sup>Fe<sup>6+</sup>, <sup>51</sup>V<sup>5+</sup>) the intensities of internal beams listed in the table have been obtained only after long irradiation. At the beginning of the irradiation cycle intensity is several times smaller (fig. 3). The gradual increase in intensity is associated with the step-by-step optimization of the ion source which is necessary for obtaining a concrete ion charge state and for the better adjustment of the accelerator itself.

The energy of the external beam depends on the dynamics of the beam after passage through the stripping foil. This dynamics depends mainly on the ratio of charges before ( $Z_1$ ) and after ( $Z_2$ ) charge

exchange. For each charge exchange coefficient ( $Z_2/Z_1$ ) there is a definite range of foil positions along the radius at which the

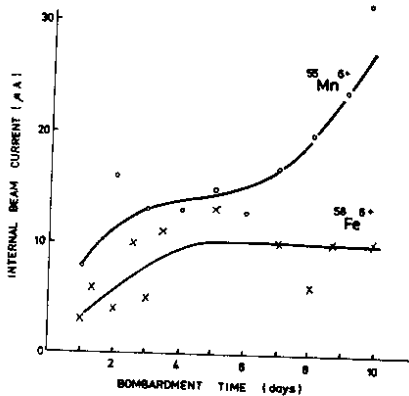


Fig. 3. The time dependence of the intensity of  $^{55}\text{Mn}^{6+}$  and  $^{58}\text{Fe}^{6+}$  beams during the irradiation cycle.

maximum extraction efficiency is provided. One-, two- and three-turn extractions from the U-400 cyclotron have been performed. The extraction mode depends on the number of beam turns on the sector-valley boundary after passing through the extraction foil and before entering the ion guide.

Switching from one extraction mode to another changes the ion energy substantially (by 30-40%). In each extraction mode it is possible to change the energy smoothly within a narrow range ( $\pm 5\%$ ) by means of radial and azimuthal foil movement. In

some cases one can expand the regulated range by means of a transfer from one extracted ion charge to another one.

Examples of ion charge spectra after passing through a  $^{59}\text{Co}^{5+}$  extraction foil and the possible regulation of the extraction beam energy are presented in figs. 4 and 5. Similar dependences have been established for several dozens of ions. Possible variants of beam extraction from the U-400 cyclotron are given in fig. 6. The presented experimental data correspond to the mechanism of extraction in the "A" direction.

The scale of foil movement is presented in fig. 7. Beam extraction in the "B" direction is analogous to that in the "A" direction. It is possible to change the extraction foil without breaking the vacuum in the cyclotron chamber for both mechanisms.

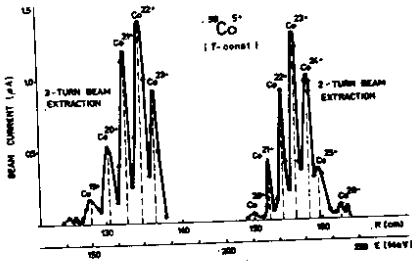


Fig. 4. Typical dependence of the external beam intensity on the radial position of the extraction foil at a fixed azimuth.

Fig. 5. Foil position over the radius and azimuth during the extraction of a Co beam.

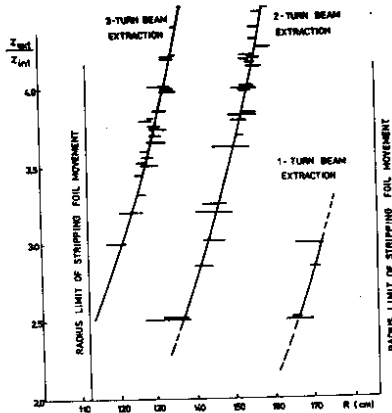
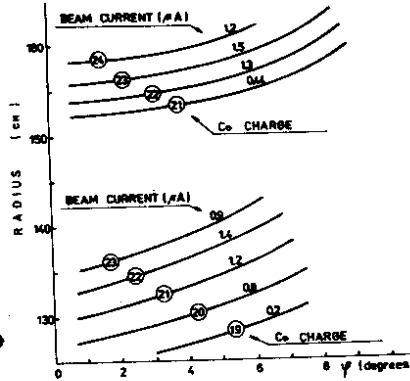


Fig. 6. Experimental dependence of the extraction radius on the charge exchange factor.

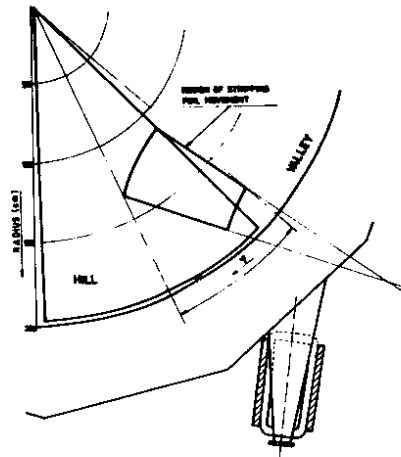


Fig. 7. The region of foil movement.

#### References

1. Yu.Ts.Oganessian et al. Proc. of 10th Int. Conf. on Cyclotrons and Their Application. East Lansing, Michigan, USA, 1984, p.317-321.
2. G.N.Flerov et al. JINR 9-84-555, Dubna, 1984.
3. S.L.Bogomolov et al. JINR P9-88-641, Dubna, 1988.
4. Buj Bing Thuan et al. Proceedings of the 10th All-Union Conference on Charged Particle Accelerators. Dubna, 1986, JINR, 1987, v.I, p.131-155.
5. R.Ts.Oganessian. Proc. of 11th Int. Conf. on Cyclotrons and Their Application. Tokyo, Japan, 1986, p 566-570.
6. B.N.Gikal, G.G.Gulbekyan, V.B.Kutner, R.Ts.Oganessian. Proceedings of the International School for Young Scientists on the Problems of Charged Particle Accelerators. Dubna, JINR, 1984, p.24-42.

Received by Publishing Department  
on May 6, 1989.



WILL YOU FILL BLANK SPACES IN YOUR LIBRARY?

You can receive by post the books listed below. Prices -- in US \$, including the packing and registered postage.

D2-84-366	Proceedings of the VII International Conference on the Problems of Quantum Field Theory. Alushta, 1984.	11.00
D1,2-84-599	Proceedings of the VII International Seminar on High Energy Physics Problems. Dubna, 1984.	12.00
D17-84-850	Proceedings of the III International Symposium on Selected Topics in Statistical Mechanics. Dubna, 1984 (2 volumes).	22.00
	Proceedings of the IX All-Union Conference on Charged Particle Accelerators. Dubna, 1984. (2 volumes)	25.00
D11-85-791	Proceedings of the International Conference on Computer Algebra and Its Applications in Theoretical Physics. Dubna, 1985.	12.00
D13-85-793	Proceedings of the XII International Symposium on Nuclear Electronics, Dubna, 1985.	14.00
D4-85-851	Proceedings of the International School on Nuclear Structure Alushta, 1985.	11.00
D1,2-86-668	Proceedings of the VIII International Seminar on High Energy Physics Problems, Dubna, 1986 (2 volumes)	23.00
D3,4,17-86-747	Proceedings of the V International School on Neutron Physics. Alushta, 1986.	25.00
D9-87-105	Proceedings of the X All-Union Conference on Charged Particle Accelerators. Dubna, 1986 (2 volumes)	25.00
D7-87-68	Proceedings of the International School-Seminar on Heavy Ion Physics. Dubna, 1986.	25.00
D2-87-123	Proceedings of the Conference "Renormalization Group-86". Dubna, 1986.	12.00
D4-87-692	Proceedings of the International Conference on the Theory of Few Body and Quark-Hadronic Systems. Dubna, 1987.	12.00
D2-87-798	Proceedings of the VIII International Conference on the Problems of Quantum Field Theory. Alushta, 1987.	10.00
D14-87-799	Proceedings of the International Symposium on Muon and Pion Interactions with Matter. Dubna, 1987.	13.00
D17-88-95	Proceedings of the IV International Symposium on Selected Topics in Statistical Mechanics. Dubna, 1987.	14.00
E1,2-88-426	Proceedings of the 1987 JINR-CERN School of Physics. Varna, Bulgaria, 1987.	14.00

Orders for the above-mentioned books can be sent at the address:  
 Publishing Department, JINR  
 Head Post Office, P.O.Box 79 101000 Moscow, USSR

Гикал Б.Н., Гульбемян Г.Г., Кутнер В.Б.  
Современное состояние изохронного циклотрона  
У-400

E9-89-324

Первый пучок на изохронном циклотроне У-400 был получен 10 лет назад. В 1988 году ускоритель работал 5200 часов из них 3650 часов велось облучение физических мишеней. К настоящему времени на циклотроне были ускорены ионы от  $^{10}\text{B}$  до  $^{132}\text{Xe}$  с отношением массы к заряду 5-12. В циклотроне предусмотрена возможность вести облучение физических мишеней как внутри камеры циклотрона, так и на 12 внешних каналах, расположенных на трех уровнях. Вывод пучков осуществляется методом перезарядки. Энергия и интенсивность пучков ионов зависят от типа частицы и находятся в пределах  $E = 3-20$  МэВ/нуклон,  $I = 1,5 \cdot 10^9 - 1,5 \cdot 10^{13}$ .

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1989

Gikal B.N., Gulbekyan G.G., Kutner V.B.  
The Present Status of the U-400 Isochronous  
Cyclotron

E9-89-324

The first beam was obtained at the isochronous cyclotron U-400 10 years ago. In 1988 the accelerator was in operation for 5200 hrs, 3650 hrs of them was used for irradiation of targets. Until presently, the ions of elements from  $^{10}\text{B}$  to  $^{132}\text{Xe}$  with the mass-to-charge ratio of 5-12 have been accelerated at the cyclotron. The cyclotron is capable of irradiating physical targets both inside the accelerator chamber and in 12 external channels positioned at 3 levels. Ion beam extraction is performed via charge exchange on stripping foils. Energy of the ions and intensity of the external beam depend on the ions type, they are in the range:  $E=3-20$  MeV/nucl,  $I=1.5 \cdot 10^9 - 1.5 \cdot 10^{13}$ .

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1989

13 коп.

Редактор Э.В.Ивашкевич. Макет Р.Д.Фоминой.

Подписано в печать 06.06.89.  
Формат 60x90/16. Офсетная печать. Уч.-изд.листов 0,83.  
Тираж 305. Заказ 42129.

Издательский отдел Объединенного института ядерных исследований.  
Дубна Московской области.