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STATUS REPORT ON JAERI-AVF CYCLOTRON

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Abstract

The JAERI AVF cyclotron has been used for experiments since January 1992. The routine operation of the cyclotron began in September 1992. The total operation times amounted to 10,000 hours in February 1995. So far, twenty-five ion species for ranging from hydrogen through xenon with energies of 10 - 520 MeV were used for experiments. This paper report status on the performance and operation of the JAERI AVF cyclotron.

1. Introduction

The TIARA (Takasaki Ion accelerators for Advanced Radiation Application) facilities have been constructed at the Takasaki Radiation Chemistry Research Establishment of Japan Atomic Energy Research Institute (JAERI) since 1987 for a materials science project using various ion beams in a wide range of acceleration energy. The facilities consist of an AVF cyclotron and three different types of electrostatic accelerators: a 3MV tandem accelerator, a 3 MV single-ended accelerator and 0.4 MV ion implanter.

Large AVF cyclotron , so far, have been used mostly for fundamental nuclear physics and medical application to radiation therapy and radioisotope production. Our cyclotron[1,2] is mainly used for R&D in materials science and other irradiation purposes. These applications of the cyclotron require that many kinds of light and heavy ions can be accelerated in a wide range of energies. To meet the requirement, continuing efforts have been made on new beam development, improvement of beam extraction and transmission, etc.

The operation of the AVF cyclotron for experiment was started from 1992 in daily operation mode on a trial base. The weekly continuous operation was started from September 1992. The total operation times amounted to 10,000 hours in February 1995.

2. Present Status

2.1 Operation

The JAERI AVF cyclotron is usually operated weekly. The yearly operation time is divided into three beam-time periods, each of which consists of 11 weeks of beam-times and allocated to experiments by Program Advisory Committee. Three weeks for maintenance and additional beam-times and about two weeks of operation intervene between the programmed beam-times. The experiment plan and beam-times are allotted for each period. The weekly operation is usually carried out continuously from Monday morning till Friday evening. Regular over-haul was carried out for 4 weeks in the summer.

Operation statistics of the cyclotron during past 4 years are shown in Fig. 1. The percentage of time in last two years used for experiments, beam developments and tuning were about 82%, 8% and 10%, respectively. The accelerated particles and their beam time are also shown in Fig. 2. The beam time for light ions exceed 50% of all as seen in Fig. 2. In order to meet the requests from many groups of researchers, the accelerated particles, their energies and the beam courses were changed as shown in Table 1.

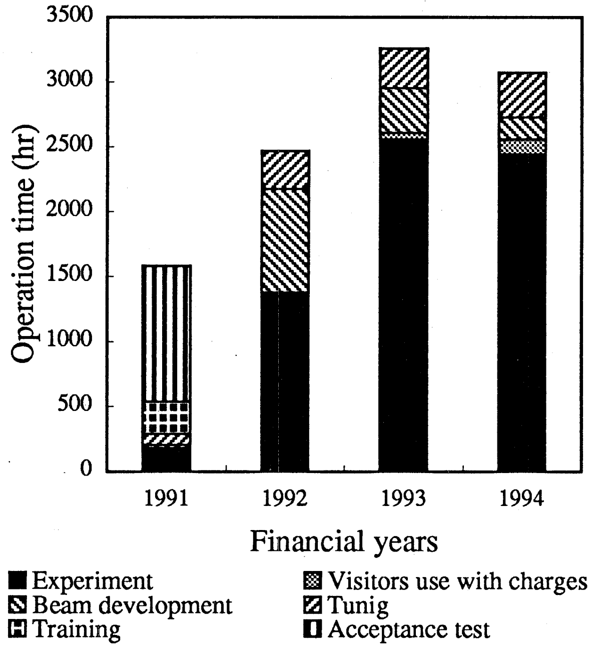

Fig. 1 Statistics of the cyclotron operation from 1991 to 1994.

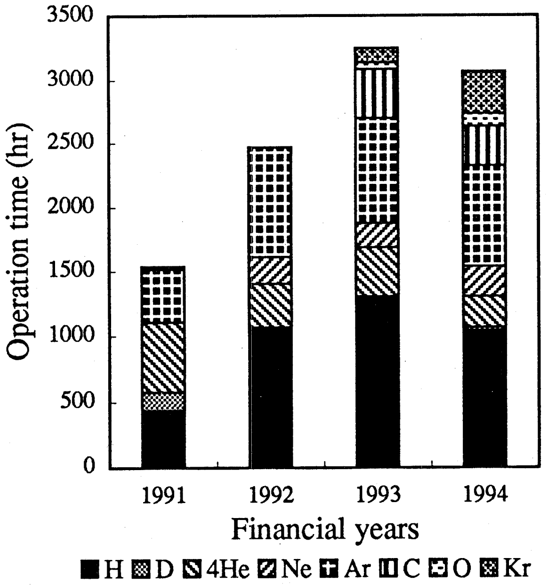

Fig. 2 Statistics of the beam time from 1991 to 1994.

2.2 Maintenance and Status

The beam extraction system consists of an electrostatic deflector and a magnetic channel and also of a gradient corrector to focus the beam horizontally. The positions of the deflector and the magnetic channel can be controlled remotely. However, the position of the gradient corrector of a passive type could not be moved remotely. Recently, the gradient corrector was replaced by remote driving type one for easily optimizing a focus the beam horizontally from cyclotron. A RF amplifiers (EIMAC 4CW800B and 4CW50000E) were also replaced by new ones in the yearly overhaul.

Table 1
Frequency of particle, energy and beam course change in FY.

FY	Particle	Energy	Beam Course
1992	42	47	64
1993	43	51	123
1994	70	74	145

A baffle slit system at the extraction hole of the acceleration chamber in the cyclotron was replaced by remote driving one for easily control the slit width. And we added the plate to this system in order to measure the total beam currents. To measure the beam profile from the cyclotron, the single-wire profile monitor was installed to just after the gradient corrector.

The accumulation of induced radioactivity in the acceleration chamber is making it more difficult to conduct maintenance work inside the cyclotron (maximum dose rate is 25 mSv/h). The strongest source of radiation is the electrostatic deflector. The septum electrodes of the deflector were replaced by new ones. Furthermore, we prepared a set of new deflector for rapid replacement in case of trouble. For the protection against radiation hazards, however, it will be necessary to replace some of the strongly activated parts, such as probe-head, magnetic channel, and magnetic channel probe-head.

3. Beam Development

3.1 Extraction Current and Transmission

Particles accelerated and extracted so far are listed in Table 2. The extraction efficiency is defined by the ratio of the beam current measured with the main probe at r=900 mm to that with the Faraday cup (FC) just after cyclotron. The average extraction efficiencies for harmonic 1, 2 and 3 are 56.0%, 65.5% and 56.3%, respectively.

The overall transmission efficiency is defined by the ratio of the beam current with the FC just after analyzing magnet at the injection line to that with FC just after cyclotron. The average transmission efficiencies for harmonic 1, 2 and 3 are 13.6%, 17% and 12.7%, respectively. Recently it increased up to 15-20%. The best extraction and overall transmission efficiency was 86% for 330 MeV $^{40}Ar^{11+}$ and 26% for 20 MeV H^+, respectively. The maximum beam currents of heavy ions such as Ne, Ar and Kr mainly depend on the ability of the ion source.

3.2 Single pulse Extraction

The beam chopping system consists of a pulse voltage chopper (P-chopper) and a sinusoidal voltage chopper (S-chopper)[3]. The P-chopper was made to chop DC beams from the ion sources into pulse beam in the injection line. The S-chopper was made to extract a single beam pulse after the exit of the cyclotron. The single pulses were successfully extracted for 70 MeV H^+ and 175 MeV $^{40}Ar^{8+}$ ions using a chopping system as shown in Table 3.

Table 2
Results of extracted intensity and overall transmission.

Ion	Energy (MeV)	Extracted Intensity (eμA)	Extraction Efficiency (%)	Overall Transmission (%)
H^+	10	12	68	13
	20	5.0	77	26
	30	2.2	67	22
	45	30	79	14
	50	5	44	14
	60	5	57	22
	70	5	42	12
	90	10	48	7.7
D^+	10	11	39	7.4
	35	41	59	4.6
	50	21	49	7.2
$^4He^{2+}$	20	5.5	69	11
	50	20	62	17
	100	10	62	10
$^{12}C^{5+}$	220	0.25	77	22
$^{16}O^{5+}$	100	1.7	34	8.1
$^{16}C^{6+}$	160	1.9	58	21
$^{16}O^{7+}$	225	0.2	54	10
$^{20}Ne^{6+}$	120	1.6	53	18
$^{20}Ne^{7+}$	260	0.33	70	19
$^{20}Ne^{8+}$	350	1.5	63	23
$^{36}Ar^{8+}$	195	2.5	63	13
$^{36}Ar^{10+}$	195	0.30	43	11
$^{40}Ar^{8+}$	175	3.0	73	15
$^{40}Ar^{11+}$	330	0.6	86	20
$^{40}Ar^{13+}$	460	0.1	63	24
$^{84}Kr^{20+}$	520	0.045	72	20
$^{129}Xe^{23+}$	450	0.20	72	11

3.3 Measurements of Absolute Beam energy

The energy of the ion particle has been measured absolutely by using the crossover technique[4]. This technique is based on scattering kinematics, in particular the variation with the angle of the energy of the particles scattered by elastic and inelastic processes from deferent target nuclei. It requires a target consisting of a homogeneous mixture of reference nuclei having well-known excited states and projectile nuclei. The absolute energy of the incident particle is obtained from an angle, "crossover angle", at which the recoil projectile particles from light nuclei and the inelastically scattered particles from reference nuclei having well-known excited states have the same energy.

A 10 MeV proton was chosen since the crossover angle is relatively large and it is easy to detect the particles at backward angles. A 2.78mg/cm^2 polyethylene film was used as the target including hydrogen and carbon nuclei to use the 4.439 MeV excited state in carbon. To detect the scattered particles at around the crossover angle, a semiconductor detector was mounted on a movable arm.

Figure 3 shows a typical pulse height spectrum obtained at an scattering angle of 40° with a nominal 10 MeV proton in the scattering chamber. The left peak is inelastic scattering on carbon nuclei and the right one is elastic scattering on hydrogen nuclei.

The relationship between the scattered angles and the pulse heights in the both interactions is shown in Fig. 4. The crossover angle was evaluated from the crossing point of the interpolating lines for the energies of the elastic and the inelastic scattering. To compensate an asymmetric factor of the scattering geometry, left and right angle measurements were carried out.

The average value of the crossover angle obtained from both angles was 44.3° . The absolute beam energy was evaluated at 9.9 MeV in this case. The uncertainty of the measurement is now under estimation.

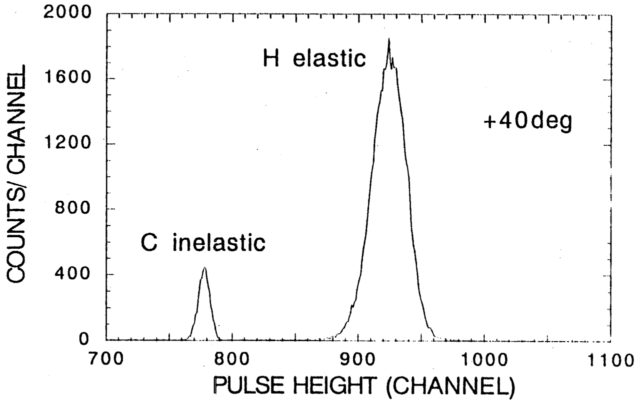

Fig. 3 Pulse height spectrum at an scattering angle of 40 deg. for a nominal 10 MeV proton.

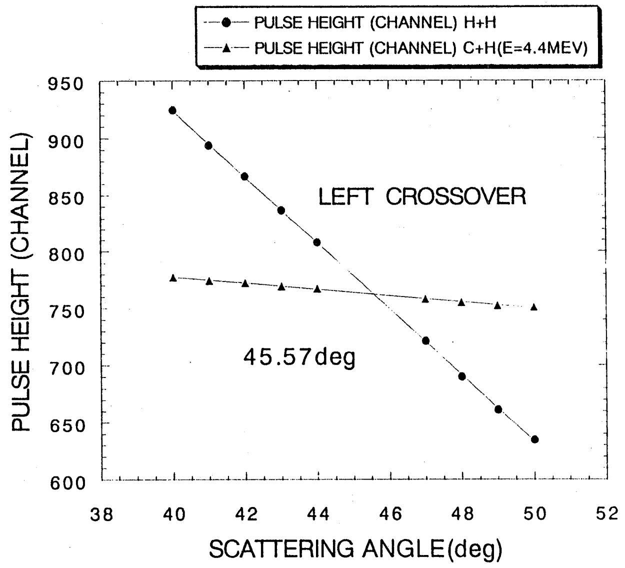

Fig. 4 Relationship between the scattering angle and the pulse height for the elastic scattering and the inelastic scattering.

3.4 Test of Metallic Ion Generation

The ECR ion beams are presently used for two purposes; (1) injection of highly charged ion beam into the AVF cyclotron, (2) study and development of ECR for high charged ion beams of gaseous and solid elements. A new gas feed was added for isotope gases which are usually very expensive. Tubes from gas cylinders are connected to the common line will be less than 3 cm^3. Now it is used for ^{36}Ar and ^{129}Xe. Test generation of metallic ions are carried out by using insertion of ceramic rods into ECR plasma. Ions of Ni are generated from NiO and Cr are $CrSi_2$ and Cr_2O_3. Though the insertion depth was not optimized, maximum charge states are 17 for Ni and 15 for Cr, and ion beam currents are enough for acceleration by the cyclotron as shown in Table 4 5). These materials were chosen according to the result obtained previously by generation of Al, Mo, B and La ions, and beam stability were good.

Table 3
Results of single pulse extraction.

particle	$^{40}Ar^{8+}$	H^+
energy	175 MeV	70 MeV
pulse interval	3.3 µs	2.11 µs
	4.75 µs	1.27 µs
pulse width	-	1.95 ns
charge	7*10^{-14} C/pulse	2*10^{-15} C/pulse
detector	SSD	Sintilator

Table 4
Extracted beam current for ceramic roads.

Material		NiO	$CrSi_2$	Cr_2O_3
Beam		^{58}Ni	^{52}Cr	^{52}Cr
currents	17+	0.5		
(eµA)	16+	1.0		
	15+	1.8	0.5	0.5
	14+	2.8	1.8	1.2
	13+	3.8	-	-
	12+	4.0	4.0	1.9
	11+	-	5.8	2.7
	10+	4.4	-	-
	9+	2.1	5.2	1.5
	8+	1.2	4.5	0.9

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