STATUS REPORT ON THE JAERI AVF CYCLOTRON

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The JAERI AVF cyclotron has been used for experiments since January 1992. The total operation time amounted to 20,000 hours in April 1998. We have delivered thirty-three kinds of ion beams and cocktail beams ranging from proton to xenon with energies of 10 - 520 MeV. This paper reports status on performance and operation of the cyclotron and recent development.

1 Introduction

The TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) facilities have been constructed at Takasaki Radiation Chemistry Research Establishment of Japan Atomic Energy Research Institute (JAERI) since 1987 for R&D in materials science and other irradiation purposes. The facilities consist of an AVF cyclotron[1][2] and three different types of electrostatic accelerators: a 3 MV tandem accelerator, a 3 MV single-ended accelerator and a 0.4 MV ion implanter[3].

TIARA is opened for public use : it receives applications of the experimental subjects in wide areas once a year from outside users as well as JAERI staffs. The subjects are approved after the official investigation by TIARA General Program Committee (GPC). To attain an effective outcome of the research program, the utilization time of each accelerator is fairly allotted to the subjects three times per year by the Program Advisory Committee (PAC) under the GPC, which are both publicly organized.

The number of subjects using the cyclotron approved for experiment is shown in Table 1.

Table 1: Number of experimental subjects at various research fields.

Fields of research	*92*	*93*	*94*	*95*	*96*	*97*
Materials for space	10	9	6	6	5	4
Materials for fusion	3	3	3	2	1	2
Biotechnology	9	11	9	10	12	23
Functional material	5	6	9	7	5	4
RI & nuclear chem.	4	7	7	6	6	7
Radiation chem.	4	5	6	6	7	5
Basic technology	5	9	9	10	9	8
Others	3	2	2	2	0	0
Total	43	52	51	50	45	53

The 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 20,000 hours in April 1998.

2 Present Status

2.1 Operation

The yearly operation time is divided into three beam-time periods, each of which consists of 11 weeks. The weekly operation is usually carried out continuously from Monday morning till Friday evening. Regular over-haul is carried

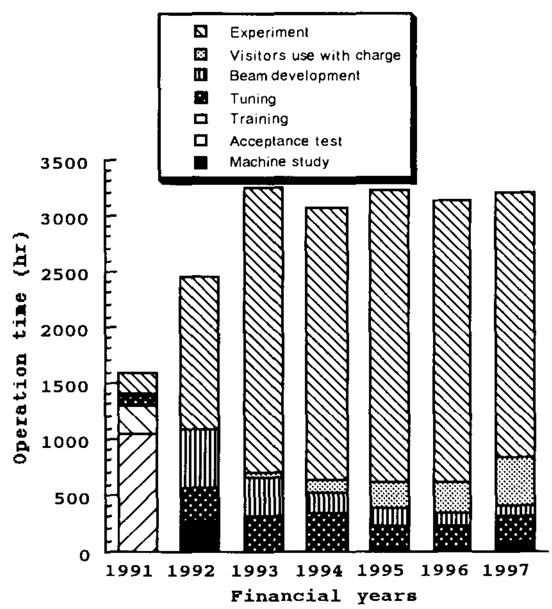

Fig.1: Statistics of the cyclotron operation from 1992 to 1997.

out for 4 weeks in summer. Operation statistics of the cyclotron during past 7 years are shown in Fig.1. The operation time for visitors use with charge, mainly used for irradiation test of semiconductor devices for space, is increasing every year. The accelerated particles and their beam time are also shown 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 Fig. 3.

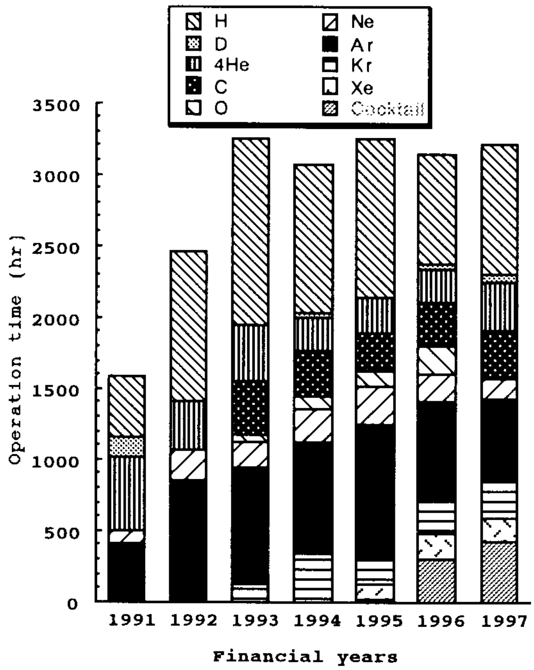

Fig.2: Statistics of the accelerated particles and their beam time from 1992 to 1997.

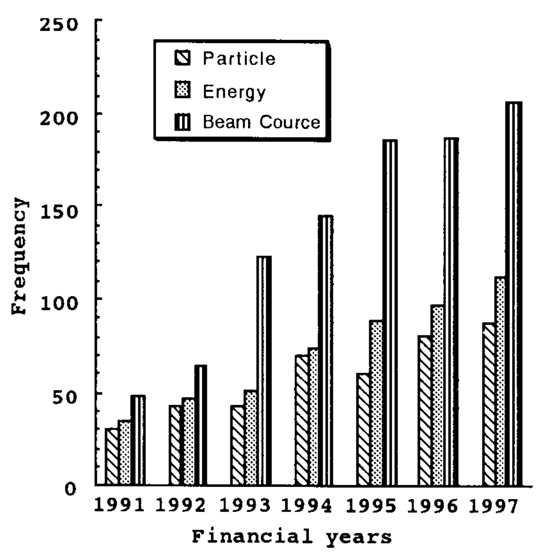

Fig.3: Frequency of particle, energy and beam course change from 1992 to 1997.

2.2 Maintenance and Status

It is clear that the power supplies for the magnets, constructed nearly 10 years ago, cannot keep the regulation stability. Stability of the current outputted from the power supply is preserved by monitoring the voltage of the shunt resister. We have replaced the shunt resisters of the power supplies for the main magnet and the analyzing magnets. After replacement of the shunt resisters, the stability of the power supplies for the main magnet and the analyzing magnets is less than $\pm 1\text{x}10^{-5}$ for 8 hours and 4 hours, respectively. It is better than the stability before the replacement.

In a few years, we have had the following machine troubles:

(1) A high voltage of an ECR ion source broke down by increasing a humidity in the room.

(2) An inflector stem (about 150 kg weight) crashed on a cyclotron upper yoke from a stem carrier.

(3) A leakage from bellows, which are used for pressing the contact fingers of the movable shorting plate against the wall of the coaxial type resonator with high pressure air, caused a vacuum in the acceleration chamber worse.

(4) A cooling water leakage (about 50 l) from the baffle slit of the magnetic channel in the acceleration chamber of the cyclotron.

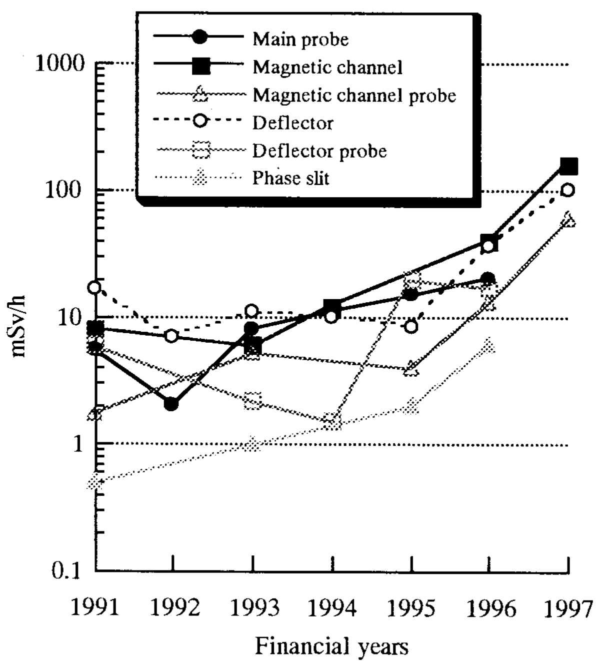

Fig. 4: Accumulation of induced radioactivity in the acceleration chamber of the cyclotron.

The accumulation of induced radioactivity in the acceleration chamber is making it more difficult to conduct maintenance work inside the cyclotron. The strong sources of radiation are the electrostatic deflector (100 mSv/h) and the magnetic channel (160 mSv/h) as shown in Fig. 4. For the protection against radiation hazards, it replaced some of the strongly activated parts, such as the electrode of the electrostatic deflector, main probe, magnetic channel and magnetic channel probe in January 1998.

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 a ratio of the beam current measured with the main probe at r = 900 mm to that with the Faraday cup (FC) just after the cyclotron.

Table 2: Results of extracted intensity and overall transmission.

Ion	Energy (MeV)	Extracted Intensity (eμA)	Extraction Efficiency (%)	Overall Transmission (%)
H^+	10	12	80	27
	20	5	77	21
	30	5	67	22
	45	30	79	14
	50	5	44	14
	55	5	63	14
	60	5	57	22
	65	3	-	12
	70	5	42	12
	80	3	47	13
	90	10	48	7.7
D^+	10	11	29	3.7
	35	40	59	4.6
	50	20	49	7.2
$^4He^{2+}$	20	5.5	69	11
	30	1.4	42	10
	50	20	62	17
	100	10	32	10
$^{12}C^{5+}$	220	0.25	77	22
$^{16}O^{5+}$	100	1.7	34	8.1
$^{16}O^{6+}$	160	1.9	58	21
$^{16}O^{7+}$	225	0.2	54	10
$^{16}O^{7+}$	335	0.05	29	4.2
$^{20}Ne^{6+}$	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	0.1	43	1.2
$^{40}Ar^{8+}$	175	3	73	15
$^{40}Ar^{11+}$	330	0.6	86	20
$^{40}Ar^{13+}$	460	0.03	63	24
$^{84}Kr^{20+}$	520	0.05	72	20
$^{129}Xe^{23+}$	450	0.2	72	11

The average extraction efficiencies for harmonic 1, 2 and 3 are 56%, 63% and 56%, respectively.

The overall transmission efficiency is defined by a ratio of the beam current with the FC just after the analyzing magnet at the injection line to that with the FC just after the cyclotron. The average transmission efficiencies for harmonic 1, 2 and 3 are 13%, 16% and 11%, respectively.

3.2 Cocktail beam acceleration

Cocktail beam acceleration is one of the most time-saving methods for changing the ion species and/or the energy. Ion "cocktail" which is composed of ions with the same or very close mass to charge ratio (M/Q), is produced in a ECR ion source, injected into the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency.

For research in materials science and biotechnology, linear energy transfer (LET) is one of essential parameters that determines radiation effects in a material. Different LET can be brought about in a target material by changing ion species and/or energy of an incident particle. In order to meet a request of users to use different ion beams in the same beam time, cocktail beams of M/Q=4 and 5 have been developed.

The results of the cocktail beam acceleration test are summarized in Table 3. The ion species were identified by a pulse height obtained with an SSD, where the energy of the cocktail ions is approximately proportional to a mass number.

Table 3: Results of a cocktail beam acceleration tests.

Ion	M/Q	Frequency (MHz)	Energy (MeV)
$^{15}N^{3+}$	4.9995	13.868	56
$^{20}Ne^{4+}$	4.9976	13.873	75
$^{40}Ar^{8+}$	4.9948	13.881	150
$^{84}Kr^{17+}$	4.9354	14.047	323
$^4He^+$	4.0021	11.908	25
$^{12}C^{3+}$	3.9995	11.916	75
$^{16}O^{4+}$	3.9982	11.919	100
$^{20}Ne^{5+}$	3.9979	11.920	125
$^{40}Ar^{10+}$	3.9957	11.927	250
$^{84}Kr^{21+}$	3.9952	11.928	525

The cocktail of $^{15}N^{3+}$, $^{20}Ne^{4+}$, $^{40}Ar^{8+}$ and $^{84}Kr^{17+}$ were injected into the cyclotron simultaneously. By changing the RF frequency to the optimum value for each ion species, one of the cocktail was fully accelerated and extracted from the cyclotron. The beam phase of the other ions gradually drift toward the deceleration phase region according to the difference of the M/Q values. Dependence of beam intensity on the RF frequency is shown in Fig.5. The extracted beam current for 56 MeV $^{15}N^{3+}$, 75 MeV

$^{20}Ne^{4+}$, 150 MeV $^{40}Ar^{8+}$ and 322 MeV $^{84}Kr^{17+}$ ions are 0.7, 1.0, 2.0μA and 0.08μA (electrical ampere), respectively. Pulse height spectra of the M/Q=4 cocktail ions obtained at three different RF frequencies are shown in Fig. 6.

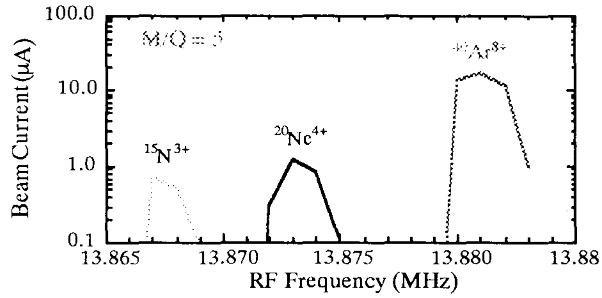

Fig. 5 :Dependence of the beam intensity on the RF frequency for the M/Q=5 cocktail beam. The absolute values of the beam current depend on the tune of the ECR ion source.

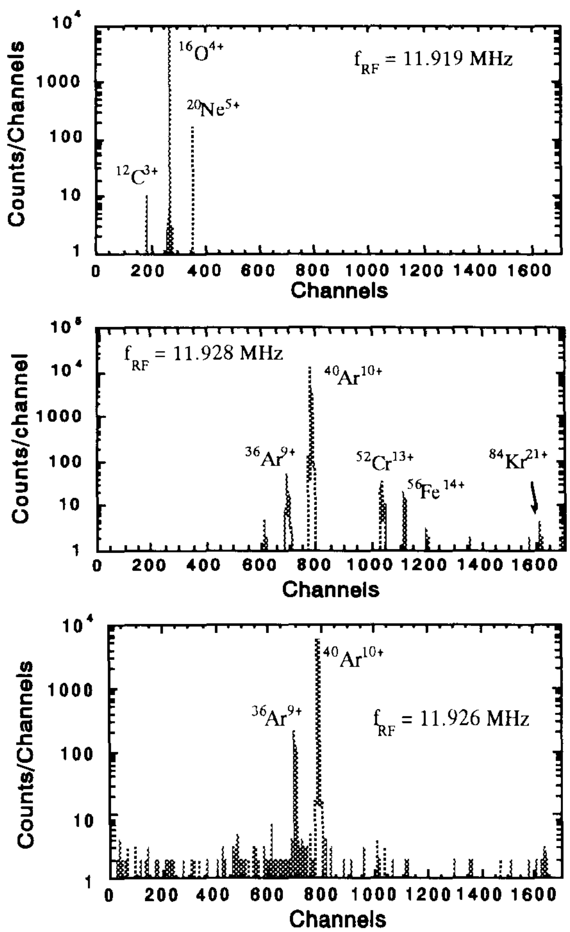

Fig. 6 : Pulse height spectra of the M/Q=4 cocktail ions measured with a SSD.The spectra were obtained at three RF frequencies.

Parameters except for the RF frequency were the same as the 100 MeV $^{16}O^{4+}$.

Multiple ion species were observed in the pulse height spectra, science undesirable cocktail ions were extracted from the cyclotron before entering the deceleration phase region. The insufficient separation of the cocktail ions was due to large phase acceptance of the JAERI AVF cyclotron. In order to eliminated the undesirable cocktail ions, an acceleration voltage was lowered by 28% so that a revolution number could be increased to further the phase drift. A mixture rate of the $^{12}C^{3+}$ and $^{20}Ne^{5+}$ in the 100 MeV $^{16}O^{4+}$ beam was reduced to less than $1x10^{-3}$. The metallic ions such as $^{52}Cr^{13+}$ and $^{56}Fe^{14+}$ were observed as impurity beams. The metals probably come from the walls of the chamber in the ECR source. The time required for changing the ion species and/or energy is only one minute for the cocktail beam acceleration.

3.3 Measurements of Beam Phase

Time resolutions of a beam phase monitor were evaluated by a time-of-flight (TOF) measurement. The beam phase monitor[4] is a fast timing detector with a micro-channel plate (MCP). Secondary electrons emitted from a thin target, a 3 mm thick aluminum-strip, are collected into the MCP by an electrostatic field when ions pass through it. A flight time of an ion is determined using the scintillation counter as a stop counter. TOF measurements have been carried out for 225 MeV $^{16}O^{7+}$ and 220 MeV $^{12}C^{5+}$ beams. The best overall time resolutions are 190 ps FWHM for 225 MeV $^{16}O^{7+}$ and 230 ps FWHM for 220 MeV $^{12}C^{5+}$.

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