Status Report on the JAERI AVF Cyclotron

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Abstract

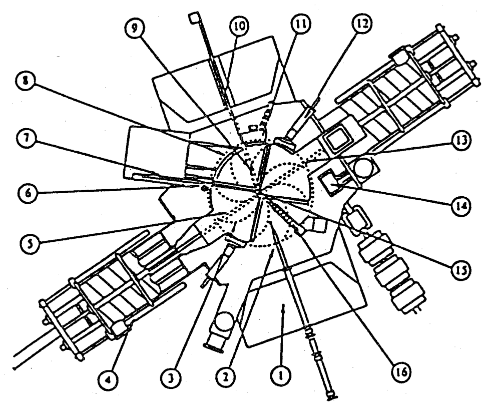
The JAERI AVF cyclotron has been used for experiments since January 1992. The routine operation of the cyclotron began in September 1992. So far, thirteen kinds of ion species ranging from hydrogen through krypton with energies of 10 - 520 MeV were used for experiments of material science and biotechnology. This paper reports status on the performance and operation of the JAERI AVF cyclotron.

I. INTRODUCTION

Japan Atomic Energy Research Institute (JAERI) has constructed new ion beam irradiation facilities, called TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) at the Takasaki Radiation Chemistry Research Establishment under six years program from 1987, to initiate the Advanced Radiation Technology (ART) project. The first phase of the construction for an AVF cyclotron and a 3 MV tandem accelerator was completed in October 1991. In the second phase 3 MV and 0.4 MV electrostatic accelerators were installed in February 1993, and TIARA will be in full operation at beginning of 1994. The ART project is intended to make use of the characteristics of ion beams to various fields and technology: R & D on materials for space and nuclear fusion reactors, new functional materials and biotechnology.

Large AVF cyclotron have been used mostly for fundamental nuclear physics and medical application to radiation therapy and radioisotope production so far. The JAERI cyclotron[1] is the first one dedicated to R & D in materials science and other irradiation purpose. In the ART project, it was considered necessary that many kinds of ions from proton to heavy ions can be accelerated in a wide range of acceleration energies. The wide availability of acceleration energy range from a few MeV to several hundreds MeV was realized by the AVF cyclotron.

The cyclotron has worked for about 4,100 hours from April 1991 to March 1993. Since the last symposium in 1991 (Saitama) the beam acceleration tests has been tried for H^{+} (20 and 70 MeV), $^{40}Ar^{11+}$ (330 MeV), $^{36}Ar^{8+}$ (195 MeV), $^{36}Ar^{10+}$ (195 MeV), $^{20}Ne^{6+}$ (120 MeV), $^{20}Ne^{7+}$ (260 MeV) and $^{12}C^{5+}$ (220 MeV) ions. The accelerator failures happened 341 times from April 1991 to March 1992.



(1) Yoke, (2) Main probe, (3) Dee, (4) Resonator, (5) Puller, (6) Dee voltage pickup, (7) Deflector probe, (8) Deflector, (9) Phase slit(II), (10) Magnetic channel probe, (11) Magnetic channel, (12) Capacitive frequency tuner, (13) Phase slit(I), (14) Gradient corrector, (15) Inflector, (16) Phase probe

Fig.1 Schematics drawing of the AVF cyclotron.

II. BRIEF DESCRIPTION OF THE JAERI AVF CYCLOTRON SYSTEM

A. *Cyclotron*

A schematic drawing of the cyclotron is shown in Fig.1. The cyclotron is a 4-sectored variable energy AVF machine with an extraction radius of 923 mm. The acceleration electrodes consist of a couple of 86-degree dees, each connected with resonant cavity. The beam energy is variable up to magnet rigidity limit of 110 q^2/A for all ions except protons. The maximum energy of protons is limited to 90 MeV by the vertical focusing properties and the RF frequencies. The JAERI AVF cyclotron (K-number=110) is of the model 930 of Sumitomo Heavy Industries, Ltd. The cyclotron is basically the same model as the CYCLONE(Unversite Catholique de Louvain). The original design of a RF cavity, an inflector and the deflector was modified in order to make allowance for accelerating 90 MeV protons. A movable-panel type resonator originally proposed was replaced by a $\lambda/4$ coaxial type resonator with a movable shorting plate for generating a maximum acceleration voltage of 60 kV. A phase probe was additionally

Table 1. Results of extracted intensity and transmission.

Ion	Energy (MeV)	Harmonic No.	Frequency (MHz)	Injection Voltage (kV)	Extracted Intensity (eμA)	Extraction efficiency (%)	Overall Transmission (%)
H^+	10	2	14.97	3.10	10	68.1	12
	20	2	21.03	6.28	4.6	77.3	11
	45	1	15.46	8.64	30	78.6	14
	70	1	18.92	12.47	5.0	41.7	12
	90	1	21.14	15.11	10	39.0	2.0
D^+	10	2	10.63	3.10	11	29.0	3.7
	35	2	19.70	11.00	41	59.0	4.6
	50	1	11.76	9.53	21	48.8	7.2
$^4He^{2+}$	20	2	10.67	3.40	5.5	37.9	11
	50	2	16.77	8.53	20	54.0	15
	100	1	11.81	10.15	10	31.5	6.4
$^{12}C^{5+}$	220	2	20.42	14.32	0.17	77.3	15
$^{20}Ne^{6+}$	120	3	17.70	9.10	0.30	30.8	2.0
$^{20}Ne^{7+}$	260	2	17.48	11.70	0.33	40.0	19
$^{36}Ar^{8+}$	195	3	16.82	10.24	2.4	28.9	8.8
$^{36}Ar^{10+}$	195	3	16.83	8.19	0.10	43.0	1.2
$^{40}Ar^{8+}$	175	3	15.14	10.06	3.0	73.3	9.8
$^{40}Ar^{11+}$	330	2	13.68	9.39	0.21	30.0	5.0
$^{40}Ar^{13+}$	460	2	16.24	11.71	0.03	54.0	9.0
$^{84}Kr^{20+}$	520	2	11.98	8.81	0.004	17.0	1.7

installed for measuring relative beam phases.

B. *Ion source and injection line*

Two types of ion sources, a multi-cusp ion source for light ions and an ECR ion source for heavy ions, were installed. Both sources are located on the underground floor outside the cyclotron vault. The transmission of the ion sources beams are less dependent on ion species and beam current and its typically 95%. The beam buncher is placed at 1581.6 mm below the medium plane of the cyclotron. The buncher is of two-gap klystron type with $2/\lambda$ mode. The bunching efficiency of 2.5 to 3 has been obtained for all ions. The beam is axially injected into the cyclotron through several focusing lenses. Then, the beam is inflected by 90° at the center of the cyclotron by spiral inflector. The details of the ECR ion source is reported in a separate paper at this symposium[2].

C. *Beam chopper system*

The chopping system was made to reduce repetition of naturally bunched beam from the cyclotron (11 MHz - 22 MHz) down to 1 kHz - 1MHz. A pulse voltage chopper (P-chopper) was installed in the injection line to chop DC beams from the ion sources into pulse beams with intervals of 1 μs - 1 ms and with duration several times as long as the RF period of the cyclotron. A sinusoidale voltage chopper (S-chopper) was installed after the exit of the cyclotron to extract a single beam pulse from train of plural beam pulses. The single pulse extraction was made for 50 MeV $^4He^{2+}$ using a couple of choppers, with the P-chopper voltage interval of $60\tau c$ (3.5μs),τc is RF period of the cyclotron, and 1/6 reduction rate of the S-chopper[3].

III. ACCELERATOR PERFORMANCE AND OPERATION

A. *Extraction current and transmission*

Particles accelerated and extracted so far are listed in Table 1. Protons and deuterons are generated by the multicusp ion source, and other ions by the ECR ion source. The extraction efficiency is the beam intensity ratio of the main probe at r=900 mm to the Faraday cup just after cyclotron. The beam transmission efficiency between before injection and after extraction is averagely 8.7%. Recently it amounts up to 10 - 15%. The best extraction and transmission efficiency was 79% (H^+ 45MeV) and 19% ($^{20}Ne^{7+}$ 260 MeV), respectively.

B. *Schedule of operation and beam statics*

The JAERI AVF cyclotron is usually operated weekly. One year is divided into 3 beam-time periods, each consisting of 11 - 13 weeks of beam times for allocation by research program committee,intervened by 2 -4 weeks of maintenance and additional beam times and approximately 2 - 3 weeks of no cyclotron operation. The proposed research subjects are examined and beam times allotted once for every period. During a week of acceleration the cyclotron is run from Monday evening till Friday evening except holidays. Regular long term overhauls were caried out for 3 weeks in the summer.

The cyclotron has been used for experiments since January 1992. The routine operation of cyclotron began in September 1992. The total operation time for the fiscal year 1991 and 1992 were 1578 and 2464 hours, respectively. Monthly operation hours throughout the fiscal year are shown in Fig. 2. We classify the research fields into; 1)Ma-

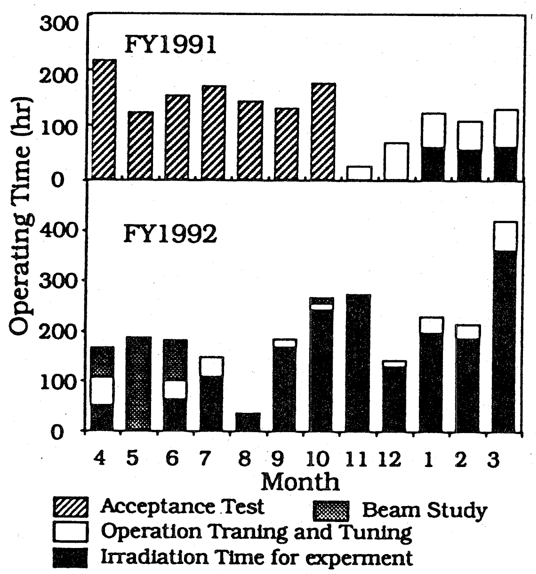


Fig.2 Monthly Operation Hours in Fiscal Year.

Table 2. Distribution of beam time among research fields (%) in 1992 fiscal year.

Research Fields	Number of Subject	%
Mater. for Space Enviroment	10	37.2
Mater. for Nucl. Fusion Reactor	3	0.8
Biotechnology	11	15.7
New functional Materials	4	6.6
Radioisotope, Nucl. Chemistry	3	7.4
Radiation Chemistry	5	7.4
Ion Beam Technology	7	24.8

terials for space environment, 2)Materials for nuclear fusion reactor, 3)Biotechnology, 4)New functional materials, 5)Radioisotope production and nuclear chemistry, 6)Radiation chemistry, and 7)Ion beam technology. The statistics of beam time distributions among these items are shown in Table 2. Figure 3 shows the beam time distribution among accelerated ions.

IV. RECENT IMPROVEMENT

A beam attenuators were installed in the injection line to control the injected ion intensities into the cyclotron. The beam attenuators are made of 0.076mm thick stainless steel of a mesh plate. The beam intensities on the targets can be easily controlled to a rate of 1/2 to $1/10^9$ by the beam attenuators. The deflector probe consists of the differential and integral heads to measured the turn pattern of the beam near the extraction region in the cyclotron. A computer-based operator assistance system is installed at the cyclotron. This system provides CRT display of cyclotron beam trajectories, feasible setting regions, and search traces designed to enhance beam parameter adjustments. The details of this system is reported in a separate paper at this symposium[4].

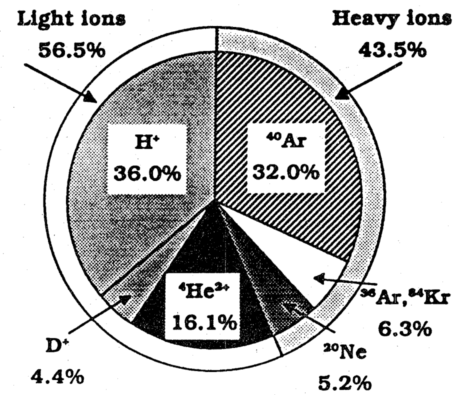


Fig.3 Distribution of beam time among ions(%) from 1991 to 1992.

V. FUTURE DEVELOPMENTS

A 18 GHz ECR ion source for multiply charged ions is now under construction. The ion source will complete in February 1994 and first beam generation will be carried out in next spring. The details of the 18 GHz ECR ion source is reported in a separate paper at this symposium[5].

A high-energy heavy-ion microbeam line for the cyclotron with energies up to several hundreds MeV is also planned for study on cell surgery technology and microdosimetry. AVF cyclotrons have inherent disadvantages in beam focusing ability because of the limited brightness and the large energy spread and divergence. In most microbeam applications under planning, however, a simpler beam collimation method can be used to reduce the beam size by use of a pinhole aperture at the end of microbeam line, because extremely low beam current density is needed at the target.

The high-energy neutron source will be generated by bombarding beryllium targets with deuteron beams. This source is intended to provide relatively intense and uniform neutron beam irradiation over an area within a 20 mm square.

VI. REFERENCES

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