OPERATION AND MAINTENANCE FOR JAERI AVF CYCLOTRON SYSTEM

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Abstract

The AVF cyclotron system[1]-[3] in TIARA facility has been smoothly operated since the first beam extraction in March 1991. The operation time for a year is about 3200 hours on an average through recent nine years.

Especially, the cyclotron system is needed the frequent alteration of operation condition according to many kinds of ion species required from the experimenters.

In order to improve the beam quality and quantity, we have carried out continuously so far many reconstruction and development. Furthermore, now we are advancing various countermeasure to form the micro beam of 1µm size by means of several issues, such as the installation of a flat-top acceleration system, reconstruction of the cyclotron centre region, and so on.

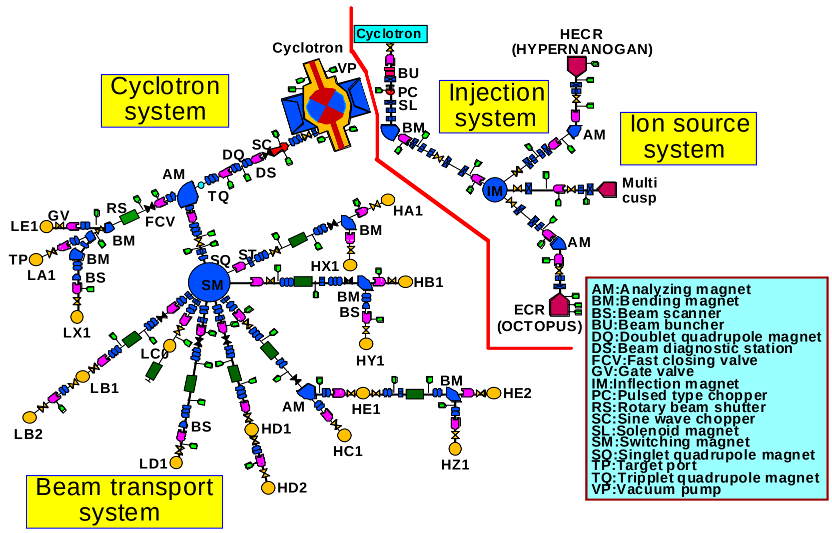

Figure 1 : The outline of whole cyclotron system.

1 INTRODUCTION

The TIARA (Takasaki Ion Accelerators for Advanced Radiation Application), which has another meaning of the papal triple crown in Roman Catholic, has been introduced to promote mainly for materials science and biotechnology at Takasaki branch office in JAERI (Japan Atomic Energy Research Institute). The building of the TIARA facility was completed on Dec, 1990.

The TIARA facility is equipped with four ion accelerators. The largest one is 930S AVF cyclotron which was fabricated by SHI (Sumitomo Heavy Industries, Co. Ltd). One of three electrostatic accelerators is a tandem accelerator with terminal voltage of 3 MV, the others are a 3 MV single-ended accelerator and a 400 kV ion implanter for low and medium energy within our facility. We can deliver various ion species to the users with a wide range of energy from 20 keV to about 1 GeV.

2 CYCLOTRON SYSTEM

Figure 1 shows the outline of the cyclotron system. We have three ion sources, both of “Hypernanogan” and “Octopus” are ECR types, usually generate heavy ions heavier than helium. A multi cusp has a hot filament, is small one, also only makes proton and deuteron. Ion beam goes into the horizontal injection line and is deflected to upward direction. The ion beam is injected into the cyclotron from the bottom, then is extracted after acceleration. The most intense beam can be got at LA1 port (among 17 ports) in the light ion room 1. After the analyzing magnet, the ion beam is distributed up to seven beam courses by the round switching magnet (SM).

For the convenience to the users, we can form single pulse beam by the combination of sinusoidal and pulsed type chopper. Three beam scanners can provide uniform irradiation area about 5-10 cm square within 10 % by means of X-Y double scanning by triangular wave. Furthermore, the beam attenuators, which have the reduction rate of 10^{-10}, are installed in the injection line.

Figure 2 is a photograph of 930S cyclotron just after the installation. This has the K-value of 110, harmonic numbers of 1, 2 and 3 are available. The range of RF frequency is covered 10.6 to 22.0 MHz. The maximum magnetic field is 1.67 T at extraction radius when the main coil current is flowed at 900 A.

3 OPERATION AND MAINTENANCE

First beam of helium 2+, 50 MeV was successfully extracted on late Mar in 1991. After the acceptance test, training and tuning were continued for about 9 months, actual operation for research experiment was begun on the trial base on Jan, 1992.

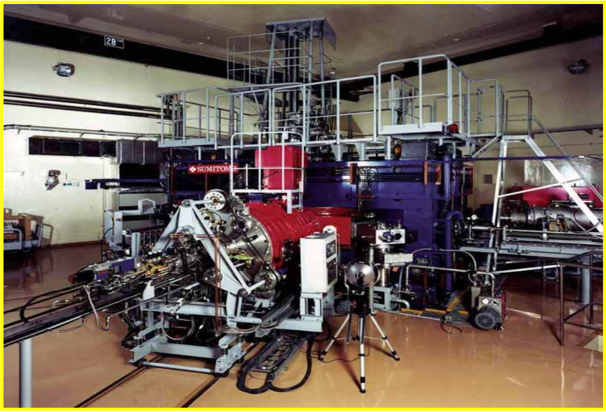

Figure 2 : General view of 930S cyclotron just after installation

3.1 Serious troubles

So far, we experienced a lot of various troubles for 12 years. A few of typical serious troubles are shown below. On Jun in 94, the rotating vanes in the TMP, as shown in Fig. 3, were broken to thousand pieces surrounding the beam line. This 600 L/s TMP was put at the beam transport line upstream the HD1 port. We could not know the cause of this breakdown although the inspection of residual vane pieces was carefully investigated by the special metal company. The removal of broken pieces around the SM and along the trunk line was need. Luckily, in the cyclotron, we could not discover any pieces from this TMP.

On Sep in 96, an inflector stem was fallen during the working for harmonic change, because of insufficient interlock sequence and careless operation. The weight of this stem was about 350 kg, and height of the dropping was about 1.7 m. Several covers and dumping rubber were wound by the falling impact, however fortunately anyone suffered damage at all. After trouble, of course, we exchanged broken and damaged parts, improved an interlock sequence for the inflector change, also added on the balancing weight behind the tower frame.

Next, on Nov in 01, the vacuum leak suddenly happened when several μA intense beams of proton 70 MeV had been tuned. We confirmed that this vacuum leak came from the meltdown of magnetic channel case by beam bombardment, as illustrated in Fig. 4. The cause of this trouble was the reason why the position of baffle slit "IN" was not correct only about 3 mm.

Furthermore, water leakage in the vacuum chamber occurred several times so far. The most serious leakage was generated at the entrance of magnetic channel. The amount of leakage water was estimated at about 50 litters. And, the contact fingers for shorting plate in the resonator were melted once because of poor vacuum of the cyclotron.

Figure 3 : Broken TMP.

3.2 Operation and Utilization

Some statistical data related to the operation and experimental utilization for past years is explained followings. The number of experimental subjects is almost around 50 for past 11 years. However, subjects for biotechnology greatly increase up to 35 from 9.

Operation time and accelerated particles are shown in Fig. 5. Operation time has been kept more than 3000 hours certainly although we had a lot of various troubles as mentioned just before. The numeric value of 3192 hours on the average for recent nine years is completely the same as the sea level of second highest mountain in Japan, its name is "Kita-dake" located in Southern Alps. By the way, the quantity of proton is roughly same over 10 years, and the cocktail beam appears slightly in 95, then gradually increases. Furthermore, a metallic ferric ion was also delivered first in 99.

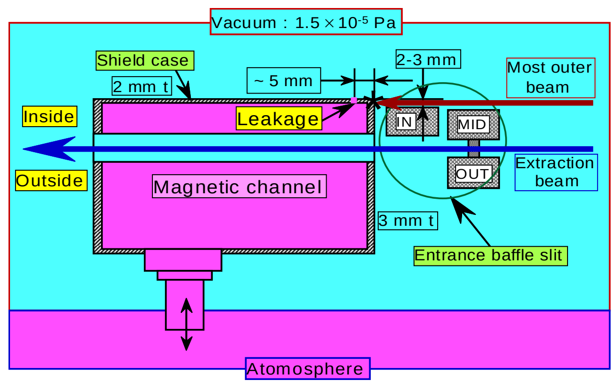

Figure 4 : Vacuum leakage at magnetic channel.

For recent 7 years, an allotted beam time almost does not change, while the time for beam tuning rather increases. The time for beam tuning occupied by the field of biotechnology becomes to be large rapidly. The ratio of its occupation already reached 54 % of the whole time at the end of last fiscal year.

Figure 6 shows the frequency of the change of harmonic number, particle, energy and beam course. These frequencies increase year by year, especially the change of beam course attains to about 300 times. We

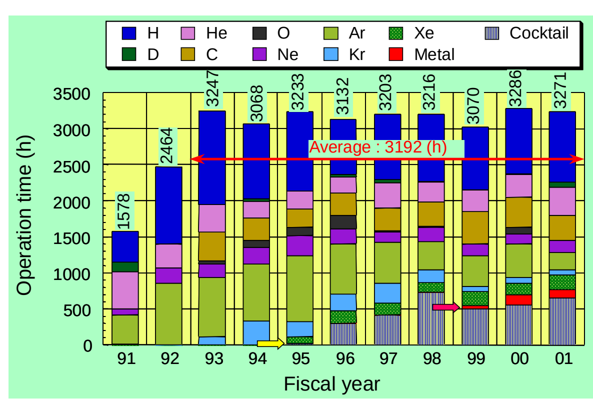

Figure 5 : Statistics of the accelerated particles and their beam time for past 11 years.

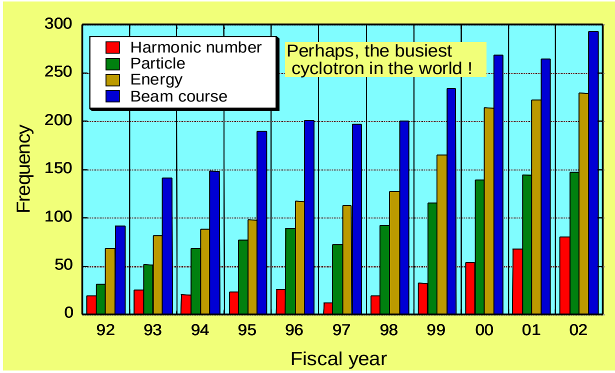

Figure 6 : Frequency of the change of harmonic number, particle, energy and beam course for past 11 years.

think without consulting anyone that our cyclotron is the busiest cyclotron in the world. This is our catchphrase.

Furthermore, actual operation chart is very complicated by the cascades of short-time utilization. We usually start the beam delivery at 14 or 15 o'clock on Monday. Generally, Start-up time including the harmonic change is taken four hours, and standard changing time for ion species is three hours. The change of the beam course or user is required one hour under same species. The minimum allotted time is 30 min for individual user.

The operation chart is usually made so as to satisfy as enough as possible various requests from the users. In an example of last Feb, eleven hours are divided into nine bio-users commonly. And the other user hopes to utilize every Monday morning, another user requests to get twice only one hour interval from 15 to 16 o'clock in 2 Wednesdays for one month.

As these circumferences, the efficiency of machine time slowly lowers with the reduction of about 2 % for a year. The efficiency is defined the ratio of time for beam tuning to allotted beam time. This condition is a little serious problem for our experimental utilization.

3.3 Duty Condition and Schedule

The cyclotron system is operated continuously during one week from Monday morning to Friday evening. Therefore, duty condition for operators is determined based on this situation. Unit operation crew of two persons changes their shifts every 12 hours at 9:00 in the morning and 21:00 at night through five weekdays. And, the other two persons or four persons work for day duty during 9:00 to 17:30.

Basically, the number of operators is required eight at least. In actual, nine operators work for our cyclotron system, one of them functions as a reserve in case of the occurrence of private business or sudden illness.

The cyclotron facility has been also utilized through a year with the exception of periodical maintenance and some inspection. The utilization schedule for experiment consists of three periods. First period is Apr to Aug, second Sep to Dec and third Jan to Mar, respectively. According to the utilization schedule through Japanese fiscal year (JFY) 2003, usable machine time for each period is 1302, 1290 and 874 hours in turn, total time through a year is summed up 3466 hours. Because the efficiency of the machine time has been predicted at 0.75 based on the present condition, the allotted beam time for users will be estimated at just 2600 hours. As the reference data, usable machine time was 3324 hours for JFY 2002.

3.4 Maintenance

We will stop the cyclotron system for four weeks for overhaul and extra two weeks for beam tuning in summer season during JFY 2003. And for two weeks in next spring, the system will be stopped again for some reconstruction and maintenance.

Table 1 shows a periodical maintenance list every year, two years or more for the devices and parts. We used to do many kinds of maintenance and inspection for different intervals according to the recommendatory period and actual condition. Especially, we have paid special attention for those devices which are classified into the periodical interval more than three years. Of course, we take care of the cyclotron every year.

4 DEVELOPMENT AND IMPROVEMENT

A few examples of our activities connected with development and improvement are described below. One of them is the development of cocktail beam[4]-[5]. An example of cocktail beam M/Q=4 is illustrated in Fig. 7. Single ion species can be extracted easily by the only slight change of RF frequency after several cocktail ions with M/Q=4 are injected into the cyclotron simultaneously. As the users can get quickly desired ion species every a few minutes, the efficiencies for their experiments were improved drastically.

Actually, a series of cocktail beam M/Q=5 is used

Table 1 : Periodical maintenance list for devices and parts.

ITVL	Contents	Mk	Remark
1	Cyclotron (Position, Insulation, Mechanical operation, RF system)	#	930S
	Power supplies (~30)	#	
	Lubrication oil for rotary pumps (~50)	%	
	Inflector electrodes (14)	#	H=1,2,3
	Power distributers for Insulating inspection (7)	#	Regulat.
	Radiation monitors (~40 ch)	#	n, γ
	Interlock sequence and indication (1 set)	#	Regulat.
	Number of operations for principal equipments (5)	#	
	Insulation and voltage check for ion pumps (32)	#	
	Leak detectors for harmful gas (1 set)	#	
	Radiation dose at various positions (40)	#	n, γ
	Safety (light weight) doors (5)	#	
2	Cryogenic pumps (9)	#	Overhaul
	Sinusoidal chopper (1)	#	40 kV
	Beam scanners (3)	#	X-Y
	Shielding (heavy weight) doors (7)	#	
	Batteries for TMP (10)	%	Recomm

ITVL	Contents	Mk	Remark
3			
4	Cooling fans (~320)	%	34000 h
	Batteries for sequencer (~20)	%	RAM
5	Battery set for uninterrupted power supplies (5)	%	Recomm.
Once	Synflex (Nylon) tube⇒Rubber tube (Only principal part)	&	Reliabi.
	Synflex tube (Whole system)	%	Reliabi.
	Control (push button) switches (~4000)	&	Poor
	O-rings for flow meter in cooling system	%	Poor
	Bellows for contact finger in RFresonator (~50)	&	Leakage

Notation, &:Renewal or Replacement, %:Exchange, #:Inspection, (n) : The number of instruments.

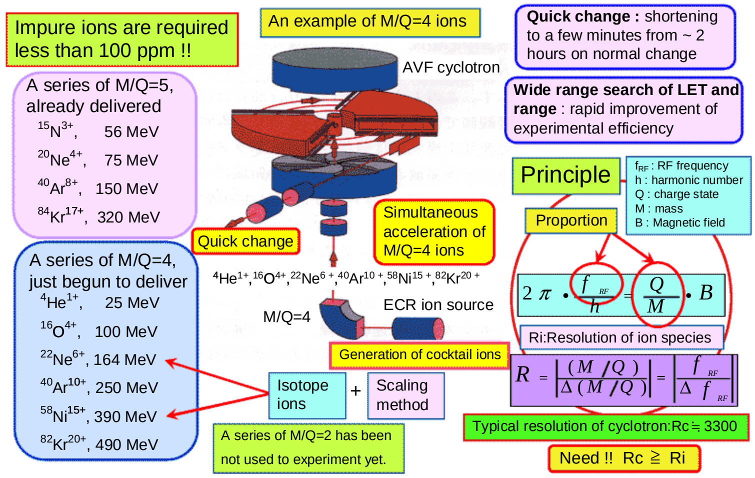

Figure 7 : An example of “Cocktail beam” with M/Q=4.

frequently. On the other hand, in case of M/Q=4, we add isotope ions on the original series because of the reduction of impurity ions which are required less than 100 ppm.

We had worried about serious beam decrease, especially early operational condition and high magnetic field. Therefore, operators had to adjust sometimes using the most outer trimming coil. In order to investigate this phenomenon, we measured various physical quantities such as temperature, magnetic field by carefully designed NMR, displacement using a precise laser hologauge, accelerated beam phase and transmission. And, thermal analysis dealt with three-dimensional model was also carried out by SHI. Based on the comprehensive consideration and measurement result[6], we concluded that the cause of beam decrease originated into “magnetizing factor effect”.

This effect is explained followings. If the median plane space changes the shape or distance, it will affect magnetic field where revolving ions pass through. Actually, it is confirmed that the whole body of the cyclotron expands slightly because of the temperature rise by heat transfer.

We performed the measures for stabilization of the cyclotron beam[7]. Principal heat sources in the cyclotron are main coil and trimming coils as shown in Fig. 8. We inserted the water jacket panel between main coil stack and lower yoke, and we reconstructed a new exclusive cooling system, which is separated from common cooling loop for twelve pairs of trimming coils. After reconstruction, the beam condition became to be stable for very long time more than 50 hours without any tunings.

On last March, the flat-top system[8] was added on the original cyclotron system because the energy spread is needed to restrict less than 200 ppm for the micro beam formation. Prior to the designing, we measured several important characteristics for flat-top system by the cooperation of Riken and Tohoku University. In our flat-top system, fifth-harmonic RF wave with the frequency range of 55 to 110 MHz is superimposed on the fundamental RF. After the preliminary test and tuning, now we are sometimes operating the flat-top system to improve the beam quality of 20Ne7+, 260 MeV ion, which is one of the candidates of micro beam species.

In addition, we have also developed an operator assistance system for visual beam adjustment[9]. It is made sure that the simulation of beam trajectory using this system faithfully reproduces the actual beam condition. The simulation result of the beam envelope along the longest beam transport line to the HZ1 port was obviously in accordance with the amount of the floor sinkage at trunk beam line just behind the cyclotron.

5 PRESENT STATUS

The list of ion species accelerated by our cyclotron so far is summarized in table 2. We have already developed 63 ion species. Ion species with harmonic number 2 are occupied up to 50 % of all. The highest energy of 36Ar18+ is 970 MeV which is close to 1 GeV. The best T_{all}, we usually call it “transmission”, is 31 % for D+, 25 MeV.

Finally, we would like to show only two examples of research activities. The research for the movement of molecules and ions in a plant has been carried out[10]. The principle of positron annihilation is applied to this research. Sample plant is put at the centre between a pair of BGO-scintillator arrays. The movement of

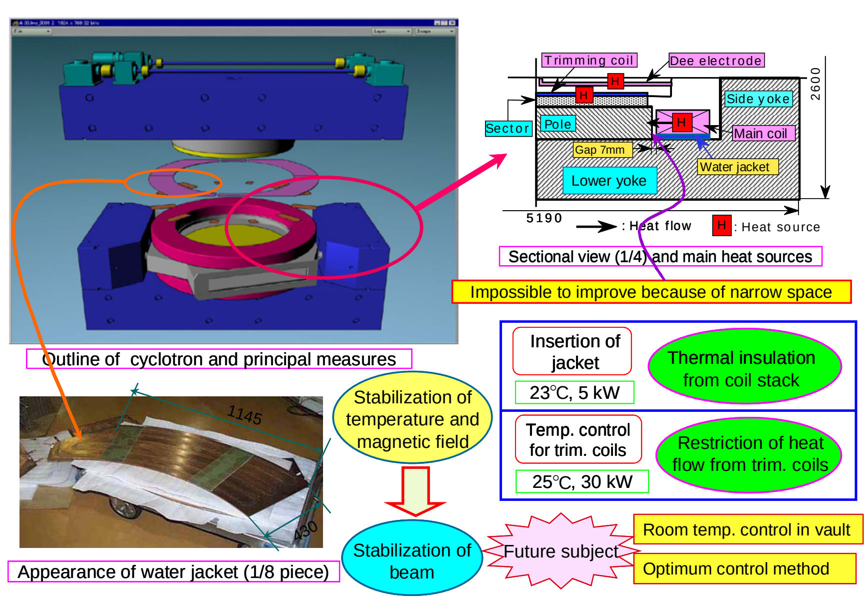

Figure 8 : Measures for stabilization of cyclotron beam.

radioisotope-labelled material in the barley and soybean is investigated visually.

Another one is the research for ion-beam breeding of plant. Especially, heavy ion beams have superior possibility for mutation induction in comparison with low LET radiation such as gamma rays and electrons. Recently, carnation flowers with new colour and shape have been developed by ion beam irradiation in cooperation with Kirin Brewery Co., Ltd. Those have been already commercialized as “Vital Ion Series”[11]. And, chrysanthemum flowers have been also studied by same manner, we hear that they will be sold in the market in near future.

6 SUMMARY

As mentioned before, we have realized the reliable operation and maintenance for 12 years since 1991. Simple our summary for these is shown in Fig. 9. The operation and maintenance are always required the reliability and durability. And, the repair has to be done as quickly as possible. On the other hand, development, improvement and reconstruction should be continued to further progress the research activities in the future. These issues including two groups function as the both wheels of motive vehicle for the cyclotron system. Of course, it is the precondition for success that the members of our cyclotron group keep to have their zeal, aspirations, responsibility and so on.

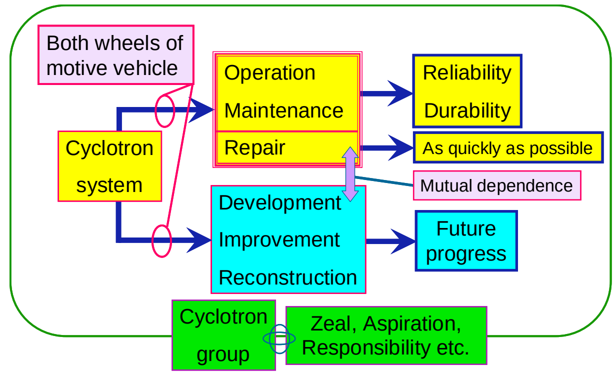

Figure 9 : Simple summary for operation and maintenance.

ACKNOWLEDGEMENT

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We also wish to express our thanks to Dr. M. Saidoh and Dr. Y. Ohara in our technology center for the continuous support and assistance.

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Table 2 The List of ion species accelerated by JAERI AVF cyclotron so far.

Ion species	Energy (MeV)	Beam (emA)	Text (%)	Tall (%)	Ion species	Energy (MeV)	Beam (emA)	Text (%)	Tall (%)	Ion species	Energy (MeV)	Beam (emA)	Text (%)	Tall (%)
H^+	10	12	80	27	$^{4}He^{2+}$	108	1.6	M/Q=2		$^{36}Ar^{10+}$	195	0.1	43	1.2
	20	7	77	23	$^{12}C^{3+}$	75	2.0	M/Q=4		$^{36}Ar^{18+}$	970	10^5 cps	M/Q=2	
H^+	30	5	67	22	$^{12}C^{5+}$	220	1.0	77	22	$^{40}Ar^{8+}$	150	2.4	M/Q=5	6.2
	45	30	79	14	$^{12}C^{6+}$	320	0	M/Q=2			175	3.0	73	15
	50	5	44	14	$^{14}N^{3+}$	67	4.0	43	10	$^{40}Ar^{10+}$	250	0.2	M/Q=4	
	55	5	63	14	$^{15}N^{3+}$	56	0.70	M/Q=5	5.0	$^{40}Ar^{11+}$	330	0.7	86	22
	60	5	57	22	$^{16}O^{4+}$	100	5.0	M/Q=4	22	$^{40}Ar^{13+}$	460	0.03	63	24
	65	7	62	12	$^{16}O^{5+}$	100	4.0	34	21	$^{40}Ca^{9+}$	200	2.0	61	11
	70	5	42	12	$^{16}O^{6+}$	160	1.9	58	21	$^{56}Fe^{11+}$	210	1.4	M/Q=5	16
	80	3	47	13	$^{16}O^{7+}$	225	1.0	82	13	$^{56}Fe^{15+}$	400	0.59	66	28
	90	10	48	7.7	$^{16}O^{7+}$	335	0.1	41	6	$^{58}Ni^{15+}$	390	0.01	M/Q=4	
D^+	10	11	29	3.7	$^{16}O^{8+}$	430	0	M/Q=2		$^{82}Kr^{20+}$	490	10^6 cps	M/Q=4	
	20	5.6	80	16	$^{20}Ne^{4+}$	75	1.5	M/Q=5	6.6	$^{84}Kr^{17+}$	320	0.08	M/Q=5	5.0
	25	15	88	31	$^{20}Ne^{5+}$	125	0.01	M/Q=4		$^{84}Kr^{18+}$	400	0.04	60	2
	35	40	59	13	$^{20}Ne^{6+}$	120	1.6	53	18	$^{84}Kr^{20+}$	520	0.06	72	22
D^+	50	20	49	7.2	$^{20}Ne^{6+}$	200	0.80	Scaling	10	$^{84}Kr^{21+}$	525	0	M/Q=4	
$^{3}He^{2+}$	60	8.2	68	18	$^{20}Ne^{7+}$	260	3.0	70	19	$^{102}Ru^{18+}$	320	0.02	54	3
$^{4}He^{+}$	25	3.6	M/Q=4	13	$^{20}Ne^{7+}$	270	0.28	Scaling	14	$^{129}Xe^{23+}$	450	0.2	72	11
$^{4}He^{2+}$	20	5.5	69	12	$^{20}Ne^{8+}$	350	1.5	63	23	$^{197}Au^{31+}$	500	0.02	49	3
	30	10	42	10	$^{20}Ne^{10+}$	540	10^5 cps	M/Q=2		M/Q = 2, 4 and 5 : Cocktail beams				
	50	20	62	22	$^{22}Ne^{6+}$	165	0.007	M/Q=4		Color notation		H=1	H=2	H=3
$^{4}He^{2+}$	100	10	32	10	$^{36}Ar^{8+}$	195	2.5	73	13	Total : 63 species				

Text : ratio of the beam current at the Faraday cup just behind the cyclotron to that at 900 mm of the cyclotron radius.

Tall : ratio of the beam current extracted from the cyclotron to that injected into.

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