K130 CYCLOTRON - THE FIRST YEARS OF FULL OPERATION

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During the year 1994 the cyclotron delivered beam for physics experiments and machine development for almost 4000 hours. An operation time of 5000 h/year is expected in the future. A slow pulsing system was installed in the injection line. A phase slit system was designed to increase the extraction efficiency and to reduce activation of the cyclotron, and it was installed in the beginning of 1995. It will be mainly used in isotope production runs with the recently installed multicusp light ion source. A fast spring loaded safety valve was installed in the beamline outside of the cyclotron to protect the cyclotron against vacuum accidents in the beamlines and the experimental area.

1 General

The Jyväskylä K130 cyclotron[1] delivered its first external beam in January 1992. After the completion of the building the installation of the beam lines started in July 1992 and the first physics experiment could be carried out in March 1993. By the end of 1993 three out of eight experimental areas were ready and operational. During that year the cyclotron was operated about 1000 hours. Year 1994 was the first year of full operation. The cyclotron operation time was expected to be 3000 hours. The final count was 3965 hours of beam out of the cyclotron exceeding the goal by 32 %. The biggest users were IGISOL (On Line Isotope Separator) with 37.3 %, RITU (Recoil Mass Separator) with 23.5 % and MAP Medical Technologies (tests for isotope production) with 16.8 % of beam time, respectively. Altogether 20 different ions from protons to $^{84}Kr^{17+}$ were accelerated using all harmonic modes 1, 2 and 3. An operation time of 4500 hours/year is expected in 1995.

In January and February 1994, some ten students were trained to operate the cyclotron. The training consisted of a week of theoretical studies and a week of practical training with the cyclotron. Starting from the end of March 1994 the student operators ran the cyclotron after working hours (evenings and nights) and during the weekends. The staff tuned the cyclotron and the beamlines, however. In the beginning of 1995 another group of operators was trained. Since the students leave the university when they finish their studies we have to train 6 - 8 new operators every year to keep the system running smoothly. We have very good experience with our student operators.

2 Progress on Hardware

2.1 Ion Sources

The ion source group started a light ion source project with LBL in 1994. The new filament driven multicusp source arrived in the beginning of 1995. It will be used mostly for isotope production and light ion induced fission studies at IGISOL. According to specifications the ion source should give a 5 mA proton beam at a normalised emittance of 0.1 π mm mrad [2]. In test runs a total current of 2.5 mA has been reached in a Faraday cup downstream from the source in September 1995. A part of the beam is lost due to problems in the extraction from the source. The source will be taken into use when the extraction has been modified to fulfil the intensity and beam quality requirements.

The main ion source of the K130 cyclotron is an ECR ion source which has been used intensively to inject ion beams into the cyclotron. Both gaseous and solid ion beams have been used. The gaseous ion beams are H, ^{3}He, ^{4}He, ^{14}N, ^{15}N, ^{16}O, ^{18}O, ^{20}Ne, ^{22}Ne, ^{35}Cl, ^{36}Ar, ^{84}Kr and ^{86}Kr. The ^{19}F, ^{28}Si and ^{32}S ion beams have been produced from gaseous compounds. A new method to produce metallic ions from volatile compounds, MIVOC, was developed at JYFL[3]. In this technique vapours of volatile compounds having metal atoms in their molecular structure are used to release metallic elements. The MIVOC technique has resulted in beams of ^{12}C, ^{52}Cr, ^{56}Fe and ^{58}Ni. As an example, 420 enA of $^{56}Fe^{11+}$ has been accelerated to target out of 2.4 eμA of analysed beam from the ECR.

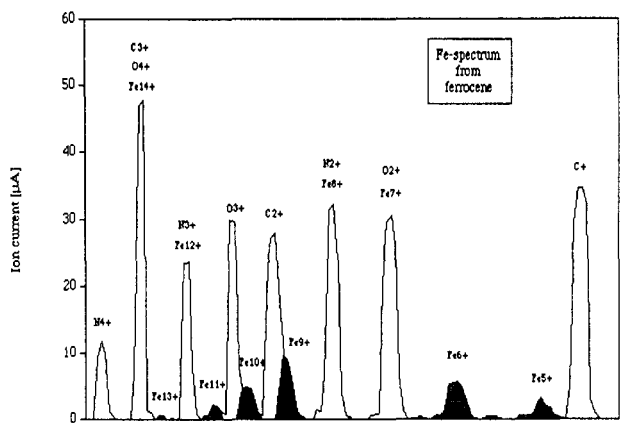

Figure 1: Mass spectrum of iron ions produced with the MIVOC method.

Due to heavy use of the ECR source the MIVOC technique has mainly been studied with a residual gas analyser where useful quantities of ^{48}Ti and isotopes of ^{54}Fe and ^{60}Ni have been measured. The compounds containing the pure isotopes were synthesised at the Department of Chemistry, University of Jyväskylä.

2.2 Beam Pulsing

A slow pulsing system (rise time 1.5 μs) was installed in 1994 in the injection line. It consists of 500 mm long electrodes 60 mm apart with the maximum deflection voltage of 1 kV. Normally a voltage of 400 V is enough to stop the whole beam (measured suppression factor is $>10^5$). The pulsing system has been used at IGISOL and RITU with good results.

2.3 Buncher

Since the last Cyclotron Conference a buncher in the injection line has been tested and taken into use[4]. Both first and second harmonic frequencies are used. Typically the buncher increases the extracted beam current by a factor of 5. The best achieved value has been 7. In that case the buncher has worked also as an active phase selector, i.e. it has increased the extraction efficiency by moving ions into a suitable RF-phase window (phase slits remove ions from the phase from which ions cannot be extracted).

2.4 Phase Slits

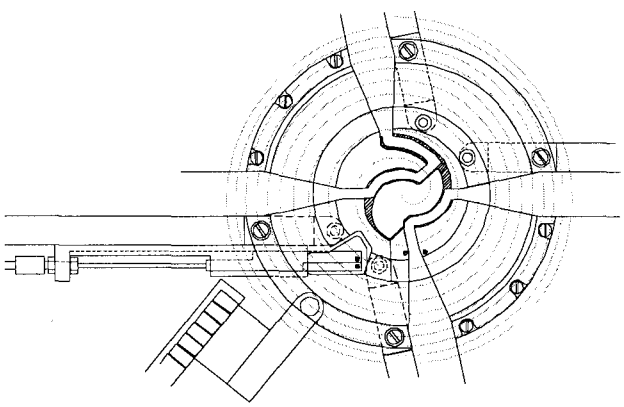

Figure 2: New central region with phase slits

A phase slit system was designed and installed in the central region of the cyclotron in early 1995 to increase the extraction efficiency and to reduce activation of the cyclotron. It consists of two remotely controlled vertical pins which can be moved linearly and independently of each other. Preliminary tests have shown desired increase of extraction efficiency. Naturally the total extracted current with the slits is smaller. The phase slits will be studied in more detail when the multicusp ion source is taken into use. Up to now they have not been used in production runs.

2.5 New Extraction Unit

A project to build a new extraction unit was initiated already in 1994. The coil for the electromagnetic channel was ordered from Scanditronix Magnet AB and it arrived in summer 1994. The rest of the parts will be manufactured in-house as a non-high priority work except for the servo units. The extraction unit is expected to be ready in 1996. The new unit will be identical to the old one, except for the deflector material. The entry part of the septum will be manufactured from graphite instead of copper in order to minimise activation.

2.6 Beam Energy Measurement

To measure the beam energy a time-of-flight system was designed and installed. It consists of two scintillator detectors to measure gamma rays from a target (normally a collimator) which are 13.61 m apart (ca. 2.3, 4.6 or 6.9 RF periods depending on the harmonic mode). The detectors use common NIM electronics so that the time difference between the detectors is determined only by the cable lengths being constant (about 0.5 ns). The active detector is chosen with a switch.

The preliminary results show an accuracy of about 0.5 % in the beam energy which roughly corresponds to the energy difference between the two last turns at the second harmonic mode (260 turns). The system has so far been used only with the second harmonic mode.

The latter detector (longer distance form the cyclotron) can be used to study the time structure of the cyclotron beam in order to optimise the extraction towards single turn extraction since at that position successive turns have enough time separation due to different velocities (typically v=*0.1-0.2 c*).

A parallel TOF system consisting of two cylindrical capasitive pick-ups with a distance of an integer number of the bunch distance is under construction. The electronics (amplifiers) will be modified from that of our phase probe system[5]. One pick-up is fixed and the other is movable so that the distance can be adjusted to match with an integer number of bunch distances. The bunch distance (measured) and the known RF frequency together with the harmonic number determine the velocity of the ions, and hence the energy can be calculated[6].

2.7 Vacuum

A fast valve was installed in the main beam line just behind the cyclotron. The closing time of this safety valve is about 20 ms which should be fast enough to protect the cyclotron cryo pumps and liner surfaces. The vacuum gauge that triggers the valve is 7.4 meters downstream from the valve. The valve has been triggered a couple of times after some smaller vacuum accidents (e.g. a target chamber has been vented without closing a gate valve in the beam line), and it has worked satisfactorily. The pressure in the cyclotron main tank has in those cases increased to about 10^{-5} mbar from the normal pressure of 10^{-7} mbar which is far below the critical value. The cyclotron vacuum is divided into two volumes: the liners separate the iron pole and the trim and harmonic coils from the main vacuum. In addition to four gravitation based safety valves there are four foils which will be punctured by needles if the pressure difference between the two volumes exceeds 35 mbar. After a puncture the cyclotron must be opened and the foils changed which takes several days. This can be avoided by the use of the fast safety valve.

A pressure regulated dry nitrogen supply was provided for the venting of vacuum equipment. It includes an 80 litre tank (pressure 5 mbar over normal air pressure) and the distribution tubing along the beam lines.

2.8 Beam lines

Several new beam lines to experimental caves at the target hall were installed during the past year. The current status of the floor-level beam lines is presented in figure 3. The beam line to cave 7 is used for in-beam gamma ray spectroscopy. We are installing new beamlines for a 1.5 m scattering chamber and an irradiation station inside cave 6. The work will be completed by the end of 1995. The lines to caves 8 and 9 serve for in-beam electron- and neutron spectroscopy respectively.

Collimators and beam dumps, especially in the beam lines where high energy light ions are intensively used, were redesigned and made from graphite in order to decrease the build-up of long-lived residual radioactivity. Some of the graphite collimators were insulated from the beam tube and were connected to the current measurement system, especially in the isotope production beam line where high intensities of light ions are used.

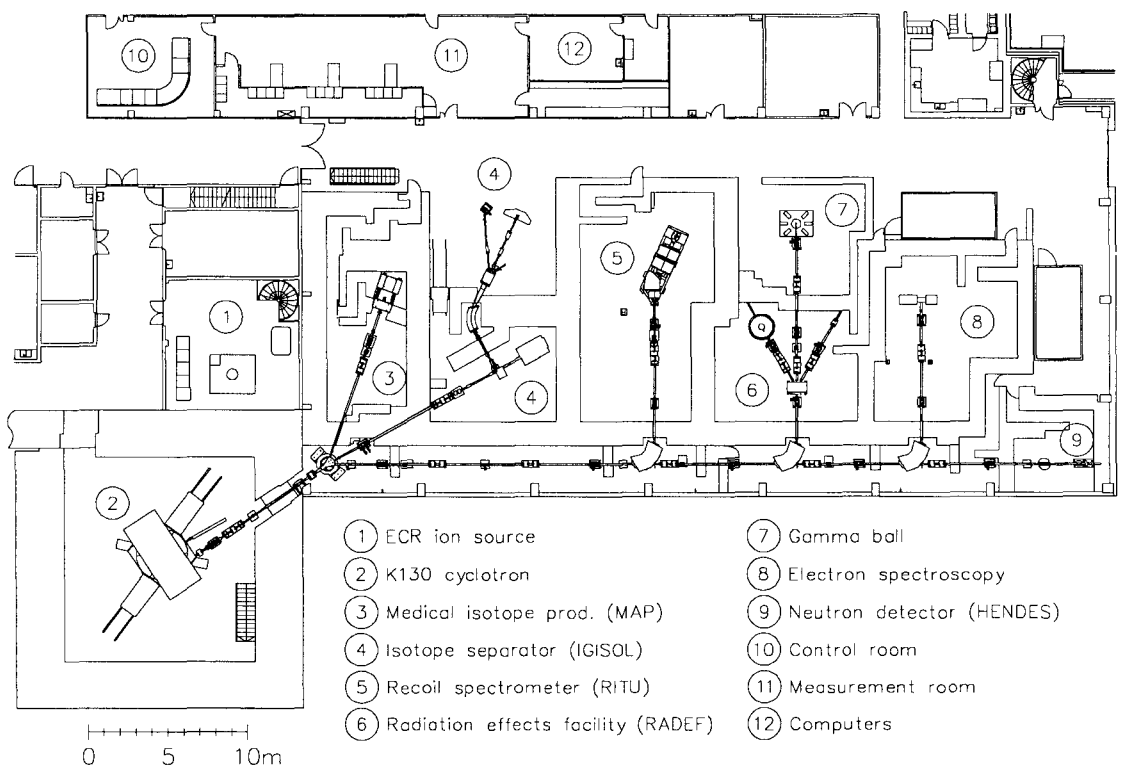

Figure 3: The lay out of the K130 cyclotron laboratory.

3 Use of the Cyclotron

3.1 Isotope Production

Isotope production at the laboratory takes place in collaboration with a commercial company, MAP Medical Technologies Oy. During the year 1994 we concentrated on producing ^{82}Sr with a 75 MeV proton beam. A typical beam intensity was 5 μA which is one tenth of the desired current. The beam intensity will increase when the new light ion multicusp ion source is taken into use. Short irradiation tests confirmed the yield of 0.35 mCi/μAh of ^{82}Sr.

MAP has several different ^{123}I radiopharmaceutical products which are currently used for imaging and functional studies of the thyroid, kidneys, brain, myocardium and for tumour detection. Therefore test runs for the ^{123}I production were started in October 1994. Currently we are using the reaction $^{127}I(p,5n)^{123}Xe(T_{1/2}$ = 2.08 h) $\mapsto ^{123}I(T_{1/2}$ = 13.2 h) with a thick NaI target and 75 MeV proton beam. In the future we plan to use the reaction $^{124}Xe(p,2n)^{123}Cs \mapsto {}^{123}Xe \mapsto {}^{123}I$ and $^{124}Xe(p,pn)^{123}Xe \mapsto {}^{123}I$ with a gas target and a 30 MeV proton beam.

3.2 Nuclear Physics

Nuclear physics at JYFL concentrates on the structure of nuclei in extreme states for their spin, temperature and isospin. This program is carried out in close collaboration with several foreign research groups. In 1994, 80 % of the beam time was dedicated to nuclear physics. The on-line isotope separator IGISOL has been mainly used to study neutron-rich exotic isotopes via light ion induced fission[7]. Relatively high production rates have made possible detailed spectroscopic studies of many very neutron-rich nuclei. Also several test experiments on light-ion induced fusion have been performed. As an example proton-rich titanium isotopes (secondary beam from IGISOL) have been used for collinear laser-spectroscopic studies.

The gas filled recoil separator RITU is used to study neutron-deficient isotopes of heavy elements[8]. During 1994 nine new isotopes, $^{210,211}Th$, $^{203,204}Ra$, ^{200}Fr, ^{197}Rn and $^{193,194,195}At$, were synthesised. The slow pulsing of the cyclotron beam has made it possible to search for relatively long-lived activities produced with small cross section.

In-beam gamma spectroscopy has been carried out with TARDIS and TESSA arrays, transported from the Daresbury and Liverpool laboratories.

One of the beam lines is dedicated to electron spectroscopy. The main tool is the superconducting solenoid from Liverpool with a 25 pixel Si detector array designed and successfully used in prompt electron-electron coincidence measurements.

Nuclear fission dynamics in heavy ion reactions is studied with a neutron spectrometer HENDES[9]. At the moment, six out of 48 position sensitive neutron detectors are installed. This project is a collaboration between JYFL, V.G. Khloplin Radium Institute of St. Petersburg, Dubna and Kurchatov Institute.

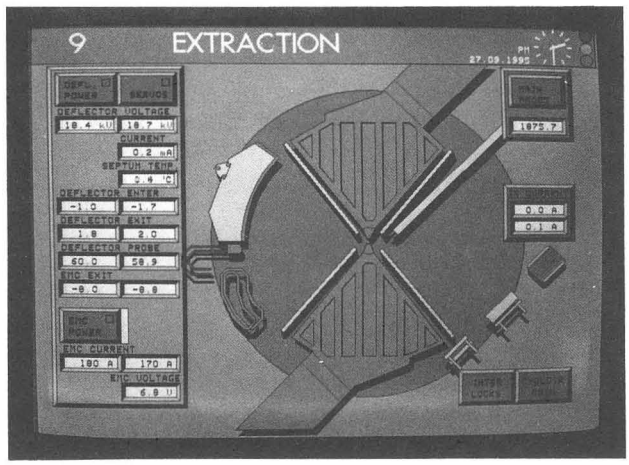

Figure 4: A typical screen of the cyclotron control system.

4 References

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