Abstract

A large number of materials tests in the scope of the European Fusion Technology Programme are presently under way, including:

- irradiation of stainless steel samples for post-irradiation measurements of mechanical properties,
- in-beam creep and in-beam fatigue crack growth experiments,
- fundamental radiation studies on ceramics, steel, vanadium alloys, and other materials,
- helium implantation into steel and vanadium alloy samples for subsequent neutron irradiation in a fission reactor,
- cross section determination using high energy neutrons produced through the (p,n) reaction in 7-Li.

Medical research by proton irradiation of selected organs in laboratory animals, and production of radioisotopes have been taken up recently.

1. Facility description

1.1 Accelerator

MC-40 is a variable energy light ion cyclotron.

The accelerator system consists of two separate identical RF cavities with RF power amplifiers placed on each side of the cyclotron magnet.

The cavities are of A/4 type with 90° dees. The stems pass through the vacuum chamber via a flange with pipe supporting insulators (Al₂O₃) and are bent vertically in order to reduce the horizontal extension of the accelerating system.

The coarse tuning of the cavity is performed by a moving short sliding up and down on the vertical part of the stem outside the vacuum chamber.

Fine tuning of the cavity is performed by a movable capacitive plate (flap) at ground potential, facing the edge of the dee. The flap is used in the automated fine tuning (feedback loop) system.

The whole acceleration structure inside the vacuum chamber can easily be reached when the upper yoke of the magnet is risen (hydraulic lifting system).

The RF power amplifiers are directly attached to the cavities and can be easily removed from the cavity.

1.2 Experimental facilities

The extraction of the beam is obtained through an electrostatic deflector.

### Table I: Characteristics of the ISPRAC MC-40 Cyclotron

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pole diameter</td>
<td>115 cm</td>
</tr>
<tr>
<td>Magnet weight</td>
<td>60 tons</td>
</tr>
<tr>
<td>Main coils max curr.</td>
<td>850 A</td>
</tr>
<tr>
<td>Sectors</td>
<td>3</td>
</tr>
<tr>
<td>Hill gap</td>
<td>100 mm</td>
</tr>
<tr>
<td>Valley gap</td>
<td>180 mm</td>
</tr>
<tr>
<td>Max. magnetic field</td>
<td>2.1 Tesla</td>
</tr>
<tr>
<td>Extraction radius</td>
<td>50 cm</td>
</tr>
<tr>
<td>Trim coils</td>
<td>8</td>
</tr>
<tr>
<td>Harmonic coils</td>
<td>6 sets</td>
</tr>
<tr>
<td>RF cavities</td>
<td>2, A/4</td>
</tr>
<tr>
<td>Dees</td>
<td>2, 90°</td>
</tr>
<tr>
<td>Beam aperture</td>
<td>20 mm</td>
</tr>
<tr>
<td>Tuning</td>
<td>Moving shorts</td>
</tr>
<tr>
<td></td>
<td>and trim</td>
</tr>
<tr>
<td>RF range</td>
<td>12.5 - 27 MHz</td>
</tr>
<tr>
<td>Frequency stability</td>
<td>1 x 10⁻⁴</td>
</tr>
<tr>
<td>Amplitude stability</td>
<td>1 x 10⁻³</td>
</tr>
<tr>
<td>max. dee peak volt.</td>
<td>44 KV</td>
</tr>
<tr>
<td>Ion source</td>
<td>P.I.G. type</td>
</tr>
<tr>
<td>Chimneys</td>
<td>2</td>
</tr>
<tr>
<td>Cathode lifetime</td>
<td>2 weeks (p;dl 50 hours (00)</td>
</tr>
<tr>
<td>Current stability</td>
<td>±1.5% (short time)</td>
</tr>
</tbody>
</table>

### Table II: Particle beam intensities

<table>
<thead>
<tr>
<th>Particles</th>
<th>E-range (MeV)</th>
<th>Max. extr. beam curr. (µA)</th>
<th>Energy spread ΔE/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>10 - 38</td>
<td>65</td>
<td>0.005</td>
</tr>
<tr>
<td>Deuterons</td>
<td>5 - 19</td>
<td>65</td>
<td>0.01</td>
</tr>
<tr>
<td>Helium-4</td>
<td>10 - 38</td>
<td>30 at max energy</td>
<td>0.01</td>
</tr>
</tbody>
</table>
A steering magnet adjusts the horizontal position of the extracted beam at the center of the exit port. Extraction efficiencies measured at the target typically range from 50% to 80% and depend on the type of ions and on their energy. Other typical elements in the exit beam line are a quadrupole triplet (for focusing), an adjustable collimator, a 0 to 400 Hz wobbling system, a viewer, a fast valve, a beam profile monitor and a movable Faraday cup.

The switching magnet has seven ports and six beam lines, and six beam lines are now equipped and routinely used. In Fig. 2, the Cyclotron building is shown divided into the laboratory wing, which is a controlled area in terms of radiation protection, and an office part.

The specific irradiation equipment presently in use comprises:

- Irradiation chambers for proton damage or helium implantation in material specimens, some with connected in-beam creep or fatigue crack growth apparatus.
- Radioisotope production stations, with automatic extraction of the targets.
- Biomedical irradiation station.
- High energy neutron source, producing a neutron spectrum similar to the fusion spectrum.

Specimens can be cooled directly by jets of purified helium from a closed loop system, or indirectly by water-cooled support plates. Temperature control is normally obtained by pyrometers.

2. Utilization

The Ispra Cyclotron was acquired specifically as a facility for studies of radiation damage in fusion reactor materials, both as displacement damage and gas (hydrogen and helium) production damage. This secures Ispra a rather unique position among the numerous comparable cyclotron facilities in the European countries (about 25) which are all largely devoted to solid state or nuclear physics, biomedical applications and radioisotope production.

In fact a large number of materials tests in the scope of the European Fusion Technology Programme are presently underway. They include:

- Basic studies on the kinetics of displacement damage.
- Irradiation of AISI 316 and AMCR samples for post-irradiation measurements of mechanical properties.
- In-beam creep experiments on AISI 316 samples.
- Fundamental radiation studies on SAP, vanadium and vanadium alloys, silicon monocrystals, iron (pure) gold, copper, nickel DENSIMET, ELERODUR (Cu, Cr, Zr, alloy), crystalline and amorphous SiO2, boron carbide, ceramics and numerous others materials.
- Simultaneous light ion irradiation and fatigue crack propagation on AISI 316 and AMCR steel samples.
- Irradiation of copper and tungsten samples for post-irradiation examination of induced damage.
- In-beam fatigue crack propagation experiments on AMCR steel samples.
- Helium implantation into vanadium and vanadium alloy samples for subsequent neutron irradiation in a fission reactor.
- Cross section determination using high energy neutrons produced through the (p, n) reaction in 7-14.

Fig. 1 MC 40 Accelerator

Fig. 2 Cyclotron Laboratory
Another field of cyclotron activities concerns the production of isotopes, mainly used as tracers in medical research, by the Ispra Environment Program and for other scientific/technical applications.

In particular, a number of radioisotopes are mostly produced via $(p,xn)$ reactions using solid or liquid targets. Among these reactions, the principal ones are $^{201}$Tl, $^{202}$Tl, $^{46}$V, $^{206}$Bi.

A last activity is beginning in the laboratory in the field of radioisotopes used in nuclear medicine. As a first step, we have successfully tried a production station for $^{67}$Ga, produced from a natural zinc target.

In this case, a maximum current of $54\mu$A was used. In the future, production of other radioisotopes of medical interest is foreseen. In particular, we think that $^{11}$In, $^{201}$Tl, $^{67}$Ga, $^{81}$Rb, and $^{18}$F are of principal interest for the European Community countries.

Medical research by proton irradiation of selected organs in laboratory animals has been taken up recently. In an experiment made in collaboration with M. Negri Institute, male rats were irradiated on the cortex with $60\,\text{Cy}$ Bragg peak protons in order to open the blood-brain-barrier permitting the study of pathogen factors which can be responsible for epilepsy in men.

3. Future Development

3.1 Equipment

New equipment presently under consideration includes:
- a second He-loop for the cooling of irradiation targets,
- a new long-life ion source for the existing MC-40,
- a new high power (2.5 kW) target for radioisotope production for medical use.

3.2 Utilisation

The main development for the coming three to four years will be an increase of radioisotope production for medical, industrial, and scientific purposes.

Simultaneously, new applications in the fields of proton nuclear activation (PNA) in medicine and industry will be developed.

Surface structure analysis of ion implanted materials will be new tasks for the Ispra Cyclotron in the scope of advanced material studies.

4. Bibliography

- M. Scholz, "Light Ion irradiation creep in tensile", EUR 31/5, in press.