STATUS OF ISL: CONVERTING A MULTI-PURPOSE ACCELERATOR TO A DEDICATED PROTON THERAPY FACILITY

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Abstract

The ion beam laboratory ISL produced fast light and heavy ions for research and applications in solid-state physics, medicine, and industry. In fall 2004 the board of directors decided to close down ISL at the end of 2006. However, in December 2006, a cooperation contract between the Charité (Berlin's Universities Hospital) and the Hahn-Meitner-Institut (HMI) was signed to ensure the continuation of the eye tumour therapy, so far unique in Germany. Accelerator operation will be continued with reduced man-power, requiring modifications of the set-up of the accelerators. A new, dedicated injector for protons will be installed. The key issue will be simpler operations and restriction to the new task to supply protons for the therapy with less man-power but keeping the same high reliability as before.

The last two years of operation of ISL as a full multi-purpose accelerator will be shown and examples of the research work will be demonstrated. The conversion of a multi-ion, variable energy accelerator (see fig. 1) to a dedicated accelerator for eye tumour therapy will be discussed.

OPERATIONS AND DEVELOPMENTS

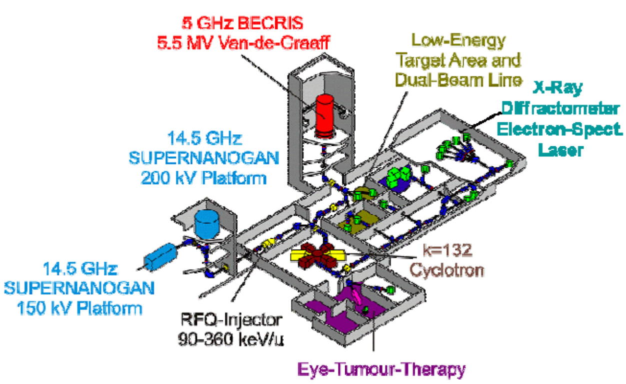

Figure 1: Overview of the ISL facility by the end of 2006. Two injectors feed the cyclotron: A Van-de-Graaff accelerator for light ions, and a frequency variable RFQ equipped with two ECR sources for heavy ions. All high-energy target stations were fully operational.

As a result of the evaluation process in 2004 the referees recommended an increase of man-power "in order to respond to a growing demand in the field of materials modification". However, the board of directors decided to close down ISL by the end of 2006. As a consequence, retired employees were not replaced, technicians were transferred to other departments, and people on temporary contracts left, thus leading to a severe shortage in man-power.

In order to fulfil ISL's commitments to the external users, especially the "Verbundforschung" (research network) of the Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research), restrictions on intended developments and improvements were necessary. Hence, the planned upgrade towards a hybrid ECR source with superconducting coils for the production of extremely high charged ions was cancelled. The development of new "cocktail beams" was reduced. Considering the boundary conditions – due to lack of man-power, about 4500 hours of operation time are scheduled per year – ISL operation went extremely well (see fig. 2). Since 2003, always more than 3200 hours of beam time on target were achieved, reaching an all-time-high of nearly 3500 hours in 2006. Reasons were the complete stop of all R&D activities and the full operation of the new, second ion source for the RFQ, installed in 2005. The latter allowed shorter tuning times, as one source could already be tuned whilst the other one still was delivering beam to the target. Over the past years, beam time losses due to breakdowns amounted to 5%.

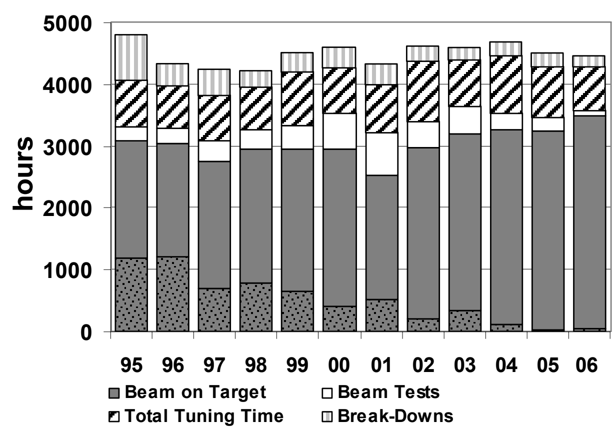

Figure 2: Operations since 1995: The operation is very stable over the past years. In 2006, the maximum beam time on target ever produced was achieved, although the scheduled beam time was less than in previous years. Over the past two years, the request for low-energy beams (dotted area) was below 100 hours.

The lightest ions (protons) and heaviest ions (gold) were the ones most frequently used. For about one quarter of the beam time protons were employed for tumour therapy, materials analysis in archaeometry (high-energy PIXE – Proton Induced X-ray Emission), and radiation hardness testing. Gold ions were utilised for nearly 30% of the beam time for ion beam materials modification and

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materials analysis of thin films (ERDA – Elastic Recoil Detection Analysis).

The facility for extremely slow ions, consisting of a 14.5 GHz ECRIS 4 ion source, a deceleration system, and beam line, was transferred to iThemba. In September 2006, the devices were dismounted together with engineers from iThemba, packed, and shipped to South Africa.

TARGET STATIONS AND ACTIVITIES

The share of the various research fields having received beam time at ISL has stabilised over the past three years.

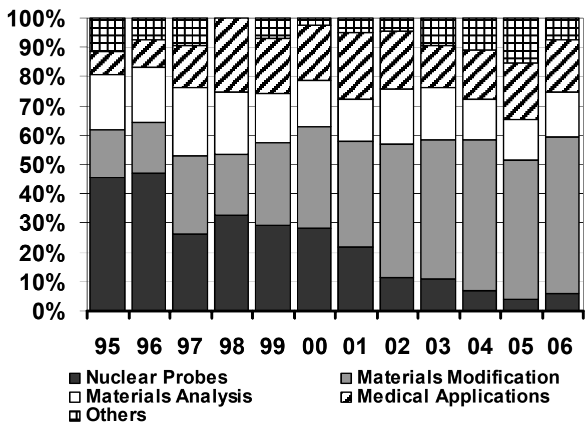

Figure 3: Use of ISL ion beams: Materials modifications became the largest part of research and development at ISL. Most of the corresponding user groups came from universities. Over the past 5 years, the beam time share of the external users was 70%.

Materials Modifications

About 50% of the beam time was used for materials modifications and for ion-solid interactions (see fig. 3), for basic research as well as for industrial applications.

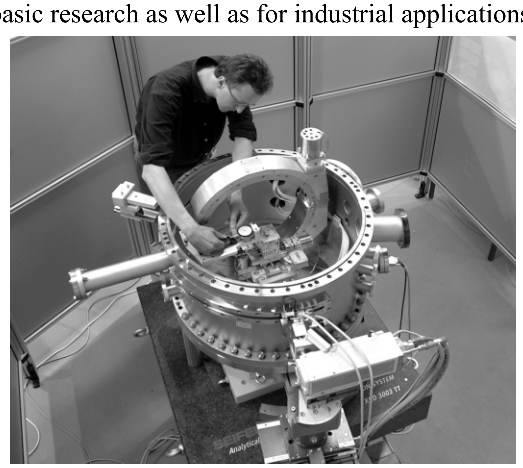

Figure 4: View on the on-line 4-circle X-ray diffractometer, commissioned at the end of 2005.

An example of the various experiments of outside users in the field of materials modifications is the study of nanoscale self-assembly of thin oxide films under swift heavy ion bombardment [1].

NiO shows the ion hammering effect, however, the question whether NiO amorphizes under heavy ion bombardment was not yet answered. First experiments with the new in-situ 4-circle X-ray diffractometer (fig. 4) showed that the borderline of ion hammering lies not between amorphous and crystalline materials but that it is located in the nano-crystalline range [2].

Materials Analysis

Materials analysis obtained 15% of the beam time (fig. 3). Both ERDA and PIXE were operated as a pure user service. With ERDA, about 400 samples each year were analysed, mainly for semiconductor device developments and the solar energy departments of HMI. The properties of the ISL beams – energy range, ion species, beam emittance, pulse structure, and stability – allowed the depth dependent concentration analysis from hydrogen to heavy elements up to a depth of about 3 µm. Thus, the heavy ion ERDA set-up at ISL provided a flexible tool for the investigation of a broad variety of analytical questions, which was unique in Germany.

High-energy PIXE was applied to objects d'art and archaeological items. Overall, more than 2000 samples have been analysed for museums, mainly from the Berlin/Brandenburg region, but also from all over Europe. The advantage of high-energy PIXE – the possibility to measure heavy elements behind thick layers of material non-destructively – is illustrated with the analysis of the dark powder in an old Egyptian glass flacon from the Staatliches Museum Ägyptischer Kunst München. The flacon is still closed by its original wax seal, therefore, the Egyptologists were reluctant to remove the seal in order to analyse the content. The differences in the intensities of the various Pb X-ray lines show that the dark powder contains Pb. Such powders were used as eye make-up.

Others

Radiation hardness testing is part of the research topic "others". Over the last two years, an increasing demand for those tests has been observed. Either high-energy protons or cocktail beams were asked for. The large irradiation chamber BIBER, designed for this purpose, proved to be a flexible and user-friendly installation. Tested devices ranged from boards for satellite on-orbit servicing to solar cells for space applications with nano-carbon tubes embedded in polymer as a back contact.

Medical Activities

In cooperation with the Universitätsklinikum Benjamin Franklin of the Freie Universität Berlin (now: Charité, Universitätsmedizin Berlin, Campus Benjamin Franklin), patients with eye tumours are being treated since June 1998. The proton irradiation facility at the HMI is Germany´s first and, up to now, the only proton therapy centre. In December 2002 as a second medical cooperation partner, the Universitätsklinikum Essen (UKE), joined. In December 2006, a total of 829 patients had been treated at ISL (see fig. 5).

Accumulated experience and additional research by ophthalmologists, radiation therapists and medical physicists lead to an improvement of the projected three years tumour control rate: it could be raised from 94.6% to 99.4% whereas the three years eye retention rate improved from 91.9% to 96.2%.

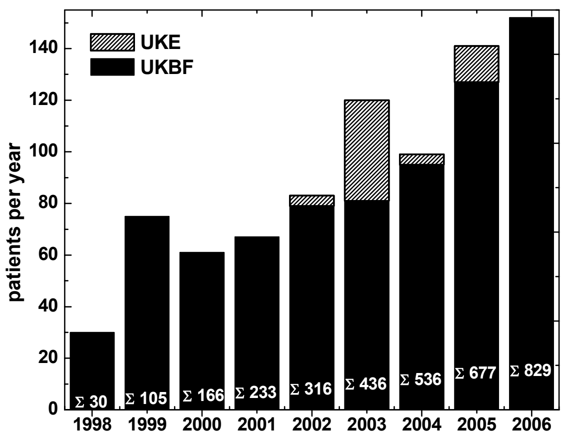

Figure 5: Number of eye tumour therapy patients treated at ISL per year (bars) and in total (white numbers).

In the midterm evaluation report the review committee stated: "The review committee considers the quality of research and development performed during the reporting period as excellent. In terms of the dosimetric precision achieved, the group has surpassed other groups from which they have learnt (PSI and MGH) and is currently in a leading position world-wide." However, the directors decided on the basis of the shutdown of ISL to stop the participation with this programme part in the programme oriented funding "Health". The excellent performance both in therapy and in associated research initiated a solution to continue the eye tumour therapy as described below.

CONTINUATION AS A SINGLE ENERGY, SINGLE ION MACHINE

In December 2006, the cooperation contract was signed between the Hahn-Meitner-Institut and the Charité to continue the proton therapy. A new department "protons for therapy" (PT) supplies the proton beam for the Charité. This activity belongs not any more to the HMI research programme. The financial circumstances lead to a reduction of the man-power for accelerator operation from about 20 full time equivalent positions to 6.5 (including the secretary). Therefore, operating the accelerators is only possible as most of the people involved work only partially for PT, whilst for the rest of the working time they have been assigned new duties at other departments of HMI. In order to manage with the available man-power, the accelerator operation will change from a three-shift to a two-shift mode. Over night the machine will idle simply monitored by new control programmes.

The high-energy target stations have been disconnected from the cyclotron. The control system is reduced to the remaining components. The RFQ was removed as it cannot provide protons.

The essential new development will be the installation of a new proton injector, delivering the necessary injection energy of 3.6 MeV. The new installation will eventually replace the 5.5 MV Van-de-Graaff, and, since it will be placed inside the cyclotron vault where the RFQ was situated, will reduce the length of the injection line by more than 20 m.

Though the original Van-de-Graaff accelerator ran reliably over more than 20 years, its capacity to provide a wide variety of ion species over a broad energy range including a RF bunching system lead to complicated operations. The source on the high-voltage terminal, the moving belt, and the complicated fast high voltage regulation system require careful maintenance.

A 2 MV tandetron accelerator has been purchased from the Bundesanstalt für Materialforschung und -prüfung (Federal Institute for Materials Research and Testing). It will be installed in the cyclotron vault, were the RFQ was situated. Thus, the installation of the tandetron can be executed without lengthy interruptions of the therapy schedule.

SUMMARY AND PERSPECTIVES

ISL fulfilled its duty to the users till the very end. All planned activities have been finished. In December 2006, a "final colloquium" was held. In four contributions, the broadness of the ISL activities was demonstrated as well as its impact on ion beam techniques, accelerator development and applications:

- S. Brandenburg (KVI Groningen): "Cyclotrons, versatile tools for science"
- A. Vredenberg (University Utrecht): "Ions as a shaping tool for the nano world"
- D. Wildung (Ägyptisches Museum Berlin): "Future in the cellar – paradigm shift in the museums"
- M. Foerster (Charité Berlin): "Eye tumour therapy".

Thus, a very fruitful phase of research using fast ions has come to an end. We thank our users for exciting experiments and the ISL accelerator crew for their endeavours.

We have now experienced the first nine months under the new boundary conditions. Although we are still in the conversion process, operation of the machine went quite smoothly. Already after nine months, we nearly reached the number of patients treated in 2005. With the new installations we will continue to provide unique therapeutic possibilities for the patients in Germany.

REFERENCES

[1] W. Bolse, Nuclear Instruments and Methods in Physics Research B 244 (2006) 8

[2] S. Klaumünzer, 14th International Conference on Radiation Effects in Insulators REI 2007, Caen, France