CONCLUDING REMARKS

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Introduction

To begin with, it is a pleasure for me to say that there couldn't have been a better place and a better moment to hold this cyclotron conference than here and now. As a matter of fact, last October, some of us received the following announcement of a wedding (or should I say, an engagement) for the first time in the world, of two superconducting cyclotrons:

"We are happy to announce that the first beam was extracted from the NSCL coupled cyclotrons on October 10, 2000. An oxygen 3+ beam was accelerated to 12.5 MeV per nucleon in the K500 cyclotron, extracted and transported to the K1200 cyclotron, where it was fully stripped, accelerated to 140 MeV per nucleon and extracted. This critical milestone of the NSCL coupled Cyclotron Project was met ahead of schedule."

The authors of this message, F. Marti, P.S. Miller and R.C. York, as well as the whole NSCL team, have been "at home" during these last five days of conference, receiving a fair reward for their spectacular effort. On behalf of the cyclotron community, and although we'll forever puzzle over whether the bride is Kay 500 or Kay 1200, I wish this couple a long and fruitful life.

It sometimes happens to each of us to wonder "What is the cyclotron community heading towards?" In the very first talk (on the role of the cyclotron in recent nuclear physics), I. Tanihata gave us an imposing clue: "We want you to build higher energy machines with higher intensities". The first, but not the only, answer to this request was delivered immediately in the next talk by Th. Stammbach: ***2006*** is the Swiss-precision figure of the number of microamperes for the 590 MeV proton beam extracted recently from the PSIclotron[1]. And in addition, he gave consideration to a 1 GeV, 10 mA dream machine… On this way up, and hopefully also on sidetracks, let's ask ourselves the following question:

1 WHAT'S NEW WITH THE CYCLOTRON?

If I am allowed to tackle the question in a quite unconventional manner, not beginning at the source and ending with the extraction system, I will consider first what seems to help tremendously in the race to high intensities:

1.1 Beam dynamics

The continuing development of beam dynamics internal to cyclotrons (6D-matching, "round beams", etc.) has at least two causes:

- the needs generated by the race toward higher intensities and therefore the increasing importance of space charge forces; and
- the disappearance of internal, PIG-like sources from the heart of the machine, whether made possible through the emergence of separated-sector cyclotrons or of spiral-type inflectors for compact ones, allowing a much cleaner confrontation between measurements and numerical simulations based on theoretical considerations.

The possibility of defining initial transverse emittances before injection, of bunching and of properly calculating the transfer matrices of inflectors has brought drastic changes in the way the problems could be treated and compared with reality. Similar simplifications arose of course for beams injected into an SSC. What could once only be considered as refinements, like taking into account matching and correlations in the 6-D phase space, is now allowing us to go beyond previous intensity limitations.

1.2 Ion sources

The fact that ion sources are now in most cases outside of the cyclotron makes their improvement so much easier, not only because geometrical constraints are relaxed but also because modifications are tested faster in an environment independent of the cyclotron electromagnetic field. It also allows axial and DC extraction, which permit better emittance measurements to be made.

In the development of ECR sources, everybody is hopefully not going in the same direction.

- There is a strong trend to switch to superconducting coils in order to get stronger containment and to use higher RF frequencies. The results obtained on Venus at LBL, SERSE at LNS, and SHIVA at RIKEN show that higher intensities of higher charge states are at hand, although with new extraction and transport problems.
- Some installations, mostly RIB-dedicated like GANIL and MSU for instance, would rather benefit from high intensities of moderate charge states.
- As for RIB facilities, charge breeders (in which singly-charged exotic ions are injected into another source to get multicharged ions) already produce interesting efficiencies. A side aspect of this 1+/N+

[1] Cf. M. Craddock's talk: "Cyclotron, psyclotron ? What's in a name ?", these proceedings.

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference*, edited by F. Marti

scheme is that it could help also in the production of "metallic" ions, for which development is otherwise continuing through different methods.

1.3 Injection systems

Two examples of routine operation (at HMI and Riken) demonstrate that variable frequency RFQs work satisfactorily as injectors for cyclotrons. For injection directly from the ion source, large efforts are being made to master high intensities at low energies: H^- at Jyväskylä (TRIUMF collaboration) and high charge state ions at LBL.

1.4 Extraction systems

High voltages inside cyclotrons still lead to sparking or instability problems, as reported for instance by LNS Catania and JYFL Jyväskylä. An alternative which may be developed whenever possible is extraction by stripping, which may offer in addition both 100% efficiency and a variable energy just by changing the position of the foil. Some high intensity projects are based on this principle. Finally, the demonstration of the validity of the self-extraction principle has been established at IBA.

1.5 Emerging

Two subjects were mentioned which will probably deserve more attention in the future: beam diagnostics for RIBs (B. Launé) and, although not belonging specifically to the field of cyclotrons, high power targets (TRIUMF) and the related radiation problems.

2 NEWS FROM NEW CYCLOTRONS

The enrichment of the field by newcomers is a sign of vitality of the field. Among others we have several new entries worthy of mention:

- The K500, NSCL-like superconducting cyclotron at VECC Calcutta is coming and should be commissioned in 2004. The present room-temperature cyclotron has been modified to serve as a driver for the new machine.
- At RIKEN, all parts of the IRC are ready and tested, to be installed in 2003 when the new building is completed.
- At SPIRAL, in the expectation of an authorization for start-up with exotic beams, the cyclotron CIME has been thoroughly tested with stable beams over the whole frequency range.
- At KEK, in addition to a proton POP model of FFAG, a 150 MeV proton FFAG for cancer therapy is to be built during the years 2000-2002.

… and commercial cyclotrons are coming in by the dozen!

3 VERY HIGH POWER CYCLOTRON PROJECTS

Accelerator Driven Systems for energy production and waste transmutation keep attracting the attention of the cyclotron community: for the MYRRHA project, IBA is proposing a single cyclotron solution, with a 1.75 MW $H2^+$ beam, while the Supercyclotron at JINR is based on a cascade of 3 cyclotrons, both project being based on room-temperature magnets. In order to provide 12 MW of beam power, Texas A&M introduces a new concept with stacked superconducting cyclotrons, a solution that should relax the beam current limititations.

4 RESURRECTION AND REVIVAL

After half a century of lethargy, and thanks to the growing interest in neutrino beams generated by fast decaying muon beams, FFAGs are staging a spectacular come-back. Their very large acceptance, and their capability of accelerating large intensities make them a cheaper alternative to linacs as regards acceleration of secondary beams, neutron spallation sources or drivers for ADS. The return of the FFAG illustrates the fact that no hope should be abandoned when an idea is left sleeping and, when noticing this, I can't help thinking of the TRITRON.

In a totally different field, ISL in Berlin has reached a cruising speed in its new life of a cyclotron-based center converted to eye tumor therapy and other various applications.

5 PRIDE OF THE CYCLOTRON COMMUNITY: MEDICAL APPLICATIONS

Already in very lively use in the production of radioisotopes for medicine, the cyclotron is still going ahead in the field of therapy. An impressive panorama of the Japanese centers using proton and heavy ion beams was painted by Y. Hirao. In Europe, PSI shows a deeper involvement in the subject through developments of spot scanning and gantries, and a declared acquisition of a dedicated, MSU-designed accelerator. Concerning the effectiveness of various treatment techniques, the "mixed-beam" protocol (photon plus neutrons) was vigorously advertised by J. Foreman.

6 THE CONFERENCE

It has certainly happened to most of us to find ourselves in a situation where a water leak pops up inside a power supply, usually not in the basement but on the top of the machine, and in addition the mains power goes off because of a gigantic spark somewhere. A similar crisis was brilliantly handled by the organizers on Tuesday night at the "Pig Roast" party: pouring rain and lightning

finally resulted in very close and warm contact between the participants under the tent.

On behalf of the audience, I would like to express many thanks to the local organizers for the welcome we received, for the visits to the Museum and to NSCL, and for the perfect timing of the sessions. Thanks also to the Program Committee who set up a perfectly balanced and very interesting scientific program, as well as to the authors and speakers who contributed to the success of this conference.