Title
Thirteenth International Conference on Cyclotrons and Their Applications

Author
Clark, D.

Publication Date
1992-07-01

LBL-33247
UC-413

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

XIII International Conference on Cyclotrons and Their Applications, Vancouver, Canada, July 6–10, 1992

Conference Summary

D. Clark

July 1992

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL - 33247

XIII INTERNATIONAL CONFERENCE ON CYCLOTRONS AND THEIR APPLICATIONS

Dave Clark

Nuclear Science Division, Lawrence Berkeley Laboratory
University of California, Berkeley, California 94720, USA

July, 1992

This work was supported by the Director, Office of Energy Research Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

CONFERENCE SUMMARY*

D. J. Clark
Nuclear Science Division, Lawrence Berkeley Laboratory, Berkeley
CA, 94720, USA

1. CONFERENCE ORGANIZATION AND SETTING

The TRIUMF group put together an interesting and smooth-running conference. Mike Craddock served as Chairman of the Conference and of the International Organizing Committee. He was also chairman of the Local Committee, which coordinated the secretariat, exhibits, budget, proceedings and social events. Gerardo Dutto was Chairman of the Program Committee, which held a number of meetings to select the invited and other oral papers. This committee even had a newsletter to keep members up to date.

The setting was the beautiful city of Vancouver, surrounded by mountains, rivers, inlets and the sea. The Hotel Vancouver had good conference and poster rooms on the same floor. It had comfortable rooms, fast elevators and a health club and pool. Its breakfast buffet served an international fare of exotic delicacies such as pickled prawns and Pepsi-Cola glazed ham. The opening welcome address by Erich Vogt (Dr. KAON), invited the audience to tear up their return tickets and stay in this magical area of Vancouver, which was Indian territory not so long ago.

The TRIUMF tour on Monday afternoon was preceded by talks by Dutto on developments at TRIUMF, and by Craddock on the proposed KAON Factory. The cyclotron has been improved by the addition of a cavity at large radius, which has been shown to increase the energy gain per turn and thus reduce the electromagnetic stripping. It can also be used in the flat top mode to improve beam quality and H^- extraction. The support for KAON has been growing, with the assistance of Dr. KAON, Mr. KAON and KAON Kim. The tour was organized in a flexible way to allow people to either follow a guide to all the stations or take a self guided tour, spending more time at points of individual interest by following the map provided. The magnetic field strength of the TRIUMF magnet was demonstrated by a guide on top of the cyclotron shielding, who suspended a quarter and a dime from another quarter. (This doesn't work with U.S. money).

2. TECHNICAL PROGRAM

The following summary of the Conference covers the larger projects or those having some new design feature. It thus omits discussion of many interesting results and important contributions of the more than 190 papers, which can be found in these Proceedings.

The early sessions were devoted to papers describing the initial operation of new or upgraded cyclotron facilities. The facilities which were completed since the last International Conference in Berlin in May 1989, are listed Table 2. A superconducting isotope production cyclotron without a return yoke, similar to that of the Oxford Instruments design, was proposed in an abstract by the Belgrade group, but the paper was not submitted to the Conference. In Table 3 are found projects which were completed before the Berlin Conference but have undergone important commissioning work since that time. Table 4 shows projects which are under construction and Table 5 shows new projects which are proposed or under study. Table 6 lists the storage rings and synchrotrons injected with cyclotrons. There are of course many other rings with other types of injectors. In Table 7 are listed radioactive beam projects associated with cyclotrons. Finally a list of cyclotrons shut down since the Berlin Conference is given in Table 8. They have lived productive careers.

2.1. Invited Review Papers

There were a number of invited review talks on topics of interest to the cyclotron community. The speakers were selected for their experience in their areas and their ability to present the topic to the audience. They are listed in Table 1.

The reviews of non-medical and medical applications gave cyclotron designers an insight into the beam requirements in these fields. The review of compact cyclotrons showed the important application of cyclotron principles to compact commercial machines, where negative ion acceleration is becoming more important because of its easy extraction of high beam currents. New designs or operation of compact cyclotrons for isotope production, some with both proton and deuteron beams, are reported at this Conference. They include the Kurchatov MPC-10 for 10 MeV p using H^-, the EBCO TR-30 and TR-13 for 30 and 13 MeV p using H^-, the 16 MeV proton Scanditronix PETtrace 2000 using H^-, the Nagoya/Japan Steel 22 MeV proton machine, the Dubna/Tashkent 20 MeV proton design with internal target, and the IBA Cyclone-3 with 3.6 MeV deuterons. The review of beam instrumentation for cooler facilities described the feedback

Table 1. Invited Review Papers

BECHTOLD	Commercially Available Compact Cyclotrons for Isotope Production
ZIEGLER	Material Research with Beams at Cyclotron Energies
WAGNER	The Clinical use of Radioisotopes
RUTH	The Production of Radionuclides for the Biosciences
PEDRONI	Accelerators for Charged Particle Therapy: Performance Criteria from the User Point of View
THORNTON	Current and Potential Clinical Indications of Proton Irradiation
ELLISON	Beam Instrumentation for Cyclotron-Based Cooler Synchrotron Facilities
LYNEIS	ECR Ion Sources for Accelerators
SCHMOR	A Review of Polarized Ion Sources for Cyclotrons
DAVIES	Advantages of Differential-Algebra and Lie-Algebra in the Orbit Dynamics of Cyclotrons
PAGANI	Advances in Rf Technology for Cyclotrons
BUSSE	Integrated Tools for Cyclotron Operation
NITSCHKE	Accelerated Radioactive Nuclear Beams: Existing and Planned Facilities
BLOSSER	Future Cyclotrons
HARDY	The Use of Cyclotrons for Physics Experiments, Past, Present and Future
POLLOCK	Physics with Storage Rings

Table 2. Projects with First Operation since Berlin Conference.

Laboratory	Facility	Description
RCNP, Osaka	K400 6-sector ring cyclotron	First beam 12/91. Protons accelerated to 300 MeV. Designed for 400 MeV protons and He^{2+}. Injected by older K140 cyclotron.
Dubna, Russia	U400M cyclotron	First beam 5/91 with a He^{1+} beam accelerated to 30 MeV/u. Coupled to U400 it will accelerate all ions, with uranium going to 20 MeV/u.
Jyvaskyla, Finland	K130 cyclotron	First beam 1/92. Design is for heavy ions and 85 MeV protons. Furthest north cyclotron.
JAERI, Japan	K110 cyclotron	First beam 3/91. Designed for heavy ions and 90 MeV protons.
MEDICYC, Nice, France	K65 cyclotron	First beam 12/90. Using 65 MeV protons for proton therapy and will also do neutron therapy.
KFA, Julich	K180 cyclotron	Upgrade, including RF and trim coils, as injector for storage ring COSY.
Uppsala, Sweden	K200 cyclotron	FM mode now in operation in addition to CW mode, giving 180 MeV protons at up to 60% duty factor. Only FM/CW cyclotron.
PSI, Switzerland	Injector II cyclotron for ring.	Increased average beam current to 1.5 mA at 72 MeV, with special attention to defining slits, bunching and space charge.
Oxford Instruments	K12,17 cyclotrons	Superconducting without return yoke. NMR magnet technology. For isotope production and neutron radiography. Not reported at Conference.

and operator assistance systems needed for these machines. The ion source reviews gave surveys of this important area. The addition of an ECR source can increase the heavy ion performance by an amount approaching that of another acceleration stage. ECR developments include the unique high field 10 GHz source CAPRICE at Grenoble, the superconducting source at MSU, and electron injection with either a biased disk as at Grenoble or with an electron gun as at LBL. With the electron gun the LBL AECR source has produced 1 eμA CW beam for each of Ar^{16+}, Kr^{26+}, Xe^{31+} and Bi^{35+}. Polarized source developments include ECR ionizers for atomic beam sources. Differential and Lie Algebras are an alternative formalism to the conventional orbit analysis, and a lively discussion was held after this talk. The reviews of rf and control

Table 3. Projects with Major Commissioning since Berlin Conference.

Laboratory	Facility	Description
HIRFL, Lanzhou	K450 ring	Commissioning of ring and K69 injector cyclotron. Carbon beam at 75 MeV/u.
MSU/Harper Hospital	K96 cyclotron	Superconducting "flying cyclotron" in full operation for neutron therapy in a hospital on a rotating gantry. Uses pulsed rf.
RIKEN, Japan	K70 cyclotron	Developed as 2nd injector for K540 ring cyclotron. Light ion energies increased, with protons at 210 MeV.
GANIL	C02 injecting SSC1, SSC2 ring cyclotrons	Higher energies available from OAE and new metallic ions from ECR.
MSU, NSCL	K1200 cyclotron	Superconducting. New tuning methods and diagnostics, including TV probe. ECR source development includes super gas mixing and space charge studies. U^{39+} accelerated to 25 MeV/u.
Texas A&M	K500 cyclotron	Superconducting. Deflector development, main coil positioning, ECR first operation. Many new beams.
Chalk River	K520 cyclotron	Superconducting. Deflector development to study effect of insulators, materials and surface treatment. Many new beams.

Table 4. Projects under Construction

Laboratory	Facility	Description
Tech. Univ., Munich	TRITRON	Separated Orbit Cyclotron, x5 energy gain as post-accel. for tandem, superconducting magnet and rf.
Groningen and Orsay	AGOR	K600 superconducting cyclotron, reached 4 T in magnet.
Catania/Milan	K800 cyclotron	Superconducting cyclotron. Magnet cool-down measurements and tandem tests.
St. Petersburg and Tashkent	U250 cyclotron	K200 cyclotron. A/Q = 2-10. Heavy ion cyclotron.
Gatchina, Russia	2 m cyclotron	Heavy ions and 75 MeV H^-. Nuclear physics and isotope production.
NAC, Faure, South Africa	K11 injector	Injector cyclotron will use ECR and polarized sources.
Dubna, Russia	U400 plus U400M	Connection of cyclotrons will give ions H to U at 100-20 MeV/u.
PSI, Switzerland	Ring beam increase	Intensity will go from .5 mA to 1.5 mA for 590 MeV protons with upgrade of rf power.
LBL, Berkeley	K=0.05 cyclotron	First permanent magnet cyclotron. For cyclotron mass spectroscopy: ^{14}C, etc.

systems gave up to date information in this area. The review of radioactive nuclear beams described production methods and facilities planned and operating throughout the world. The talk on future cyclotrons described the challenges of new designs and showed a simple spread sheet program on a personal computer to do conceptual designs, parameter studies and preliminary cost estimates on proposed cyclotrons. The nuclear physics applications of cyclotrons and storage rings were described in the last 2 talks.

2.2. Challenges for the Future

The challenges for the future lie in the extension of the technology and of the limits of performance of present cyclotrons. These can be seen in the projects under construction and those in the proposal/study stages, Tables 4,5,6,7 and in some of the review papers, Sec. 2.1.

Table 5. Projects Proposed or under Study		
Laboratory	**Facility**	**Description**
HMI, Berlin KFA, Julich Bessy,Berlin	FFAG ring	Accel. from 500 MeV to 3 GeV, 1 mA, 50 Hz, for neutron spallation source. This is a type of synchro-cyclotron.
IBA - Sumitomo	K230 cyclotron	230 MeV protons for therapy. Energy variation by degrading to as low as 70 MeV. Zero hill gap at edge.
Alma Ata	K600 ring	Heavy ion cyclotron.
NAC, Faure South Africa	K200 cyclotron	Superconducting cyclotron with "S-Coils" in return yoke area, for proton therapy.

Table 6. Storage Rings and Synchrotrons Injected by Cyclotrons		
Laboratory	**Facility**	**Description**
Operating		
Indiana	Cooler Ring	Electron cooling. Polarized protons. Injected by K215 ring cyclotron.
INS, Tokyo	Tarn II	Accel. to 220 MeV/u, electron cooling. Injected by K68 cyclotron
Uppsala	CELSIUS	Electron cooling. Injection by stripping and multi-turn. Can accel. protons to 1.3 GeV. Injected by K200 cyclotron.
Under Construction		
KFA, Julich	COSY	Electron and stochastic cooling, slow extraction, K2500. Injected by K180 cyclotron.
Proposed or under Study		
TRIUMF	KAON	Accel. 100 μA to 30 GeV with 2 synchrotrons and 3 storage rings. H^- extraction from TRIUMF cyclotron using auxiliary cavity.
RCNP, Osaka	K1800 ring	Ring injected by K400 ring cyclotron.
Kiev	2 rings	Booster synchrotron plus storage ring, with accel. up to 300 MeV/u, electron cooling, protons-xenon. Injected by U240 cyclotron. Radioactive beams.
Dubna	2 rings	"K4" storage ring and "K10" ring with electron cooling. Ring rigidities are 4 and 10 Tm. Injected by U400 plus U400 M complex.

We can look at projects under construction, Table 4. The TRITRON will be the first Separated Orbit Cyclotron (SOC), an idea that started in the 1960's with the "Beehive" three dimensional design of F. M. Russell of the U.K. TRITRON will also be the first cyclotron with superconducting rf. Like some other designs it has a superconducting magnet, but with the unusual feature of the return flux flowing between particle turns. Examples were given of designs up to 1000 MeV. Cyclotron intensity limits are being extended by the PSI cyclotrons, with the next challenge being the injection of the 1.5 mA available from Injector II into the Ring, and its acceleration from 72 to 590 MeV. A new technology for very small cyclotrons is being developed at Berkeley with a permanent magnet cyclotron.

We then have projects in the proposed/study status, Table 5. The FFAG ring proposed in Germany to accelerate protons from 500 MeV to 3 GeV would be the highest energy cyclotron, actually a synchro-cyclotron. This technology comes from the MURA studies in the U.S.A. The IBA/Sumitomo 230 MeV proton therapy design faces the challenge of fast energy variation by degrading, in competition with synchrotrons, and extracting the beam at high magnetic field by having zero magnet gap at the edge. The S-Coils proposed by NAC for a superconducting proton cyclotron at 200 MeV, are an interesting new coil configuration. In an abstract the Belgrade group proposed 2 large superconducting cyclotrons, 4 m diameter, without return yokes, for heavy ion acceleration, ISOL or acceleration/deceleration. Unfortunately this group did not attend the Conference and the paper was not received.

The challenge for storage ring and synchrotron systems, Table 6, is to fully develop electron and stochastic cooling, and target systems, and provide upgraded control

Table 7. Radioactive Beam Projects Using Cyclotrons		
Laboratory	**Facility**	**Description**
Operating		
TRIUMF	TISOL	ISOL facility with isotopes produced by TRIUMF cyclotron, ionized in ECR or surface ioniz. sources, used for physics expts. R&D to support proposed ISAC post accelerator and ISL facilities described below.
Louvain, Belgium	K30 plus Cyclone	ISOL primary beam with 500 μA p K30 cyclotron. ECR ionization and accel. with K130 Cyclone. $^{13}N^{1,2+}$, $^{19}Ne^{2,3+}$ to .6 MeV/u, up to 50 ppA. New post accel. K33 cyclotron funded.
GANIL	C02, SSC1, SSC2	Fragments produced by C02 + SSC1 are accel. in SSC2, identified and mass measured by SSC2 to 5×10^{-6}. Also LISE-3 and SPEG spectrometers.
RIKEN, Japan	K540 ring	Fragmentation beams up to 100 MeV/u. "RIPS" spectrometer to separate fragments. Energies down to 5 MeV/u with degrader.
MSU, NSCL	K1200 cyclotron	Fragmentation products separated by A1200 spectrometer for delivery to experimental area. Superconducting solenoid under construction for <50 MeV/u.
Under Construction		
Oak Ridge	OREB	ISOL facility using K100 ORIC cyclotron for production, negative ion source, 25 MV tandem for accel. Ion masses <80, >5 MeV/u, <10 pnA.
INS, Japan	ISOL facility	Primary beam from present K68 cyclotron: protons at 45 MeV. High resolution separator with m/Δm=5000. R&D for Japanese Hadron Project (JHP).
Osaka	K400 cyclotron	Fragment separation by secondary channel with degrader.
Dubna	U400 plus U400M	Fragmentation of all mass beams at 100-20 MeV/u. Analyzer "COMBAS". Later will use storage rings K4 and K10.
Proposed or under Study		
TRIUMF	ISAC	ISOL facility using TRIUMF or KAON beam, high-resolution separator, RFQ plus drift tube linac post-accel. to give 1.5 MeV/u for A<60.
ISL, North America	ISOL facility	Will produce all masses, with energies up to 10 MeV/u at $<10^{12}$ p/s. Primary accelerator for 100-200 μA light ions at 500-1000 MeV can be a cyclotron.
GANIL	ISOL facility	Primary beam of 100 MeV/u , 10 pμA for A up to 40, from present K400 coupled cyclotrons. Thick target, ECR source. Option for secondary accel. is a compact plus a ring cyclotron, similar to present GANIL designs.
PSI, Switzerland	ISOL facility	590 MeV p at up to 1 mA from ring, ECR source, existing K120 cyclotron secondary accel.
Moscow	ISOL facility	Linac primary accel. Coupled cyclotrons: K208 injecting K600 ring considered for secondary accel. to give >5 MeV/u for A<150.
Grenoble	PIAFE	Fission products, A=70-150, from ILL reactor to ECR source, charge +1 ions 450 meters at 30 kV to SARA coupled cyclotrons. Accel. to 2-20 MeV/u, $<10^9$ p/s.
Catania/Milan	K800 cyclotron	Fragmentation beams at 50-80 MeV/u. Also ISOL facility using cyclotron for production and 15 MV Tandem for acceleration up to 8 MeV/u.

systems so that the potential physics can be fully realized. The KAON facility has the challenge of extracting 100 μA of H^- beam and matching it to the succeeding synchrotron rings at 3 and 30 GeV.

In the radioactive beam field, Table 7, the challenge is to provide usable beams of a wide variety of radioactive species, so that interesting physics can be done with them. A start has been made by TRIUMF, Louvain, GANIL, RIKEN and MSU. New beams will be provided by Oak Ridge, INS, Osaka and Dubna, and later hopefully by ISAC at TRIUMF, ISL, GANIL, PSI, Moscow, Grenoble and Catania/Milan.

The review papers of section 2.1 pointed out some challenges also. In applications, better communication is needed between the cyclotron "builder/operator" and the "user" so that new innovative uses and funding sources can be found. The ion source challenge is to improve beam intensities with an acceptable quality. For ECR sources better understanding is needed of rf coupling, electron injection, magnetic field and frequency optimization, so that higher charge states can be produced. Technical

Table 8. Cyclotrons Shut Down Since the Berlin Conference - R.I.P.		
Laboratory	**Facility**	**Description**
CERN	K600 synchro-cyclotron	600 MeV proton synchro-cyclotron. Decommissioning plan paper at Conference.
AERE, Harwell	K86 cyclotron	Heavy ion cyclotron, high beam intensities from internal source.
Groningen	K160 cyclotron	Heavy ion cyclotron. Shut down to prepare for installation of AGOR (Table 3). Will be used for shielding.
McGill	K100 synchro-cyclotron	p, d, He-3, He-4 beams.

challenges in cyclotron design and operation continue, such as producing higher magnetic fields and deflector electric fields, and improving operator controls.

3. SPECIAL AWARD

The Conference Summary speaker (DJC) announced a special award based on his experience as a member of the Program Committee in reading the abstracts submitted to the Conference. Its text is shown in Fig. 1.

4. SOCIAL EVENTS

The Conference social events included 2 receptions, 2 dinners and a choice of 5 excursions on Wednesday afternoon. The salmon barbecue was held on Monday evening at the picnic area of the impressive site of the UBC Museum of Anthropology, where guests could tour the Museum after dinner.

The Conference Dinner was held on Thursday evening at the Hotel Vancouver. The master of ceremonies was Mike Craddock, who also filled in as banquet speaker. He extended the congratulations of the cyclotron community to Henry Blosser and Bob Pollock, who had been awarded the American Physical Society Bonner Prize for contributions which included superconducting cyclotron construction and a cyclotron-injected storage ring. In his speech Craddock pointed out that his research has revealed that there are two classes of accelerators, "proper" and "improper". The proper machines are of course cyclotrons, with their rotational periodic symmetry due to their sector structure. An example of an improper machine is the synchrotron, with its frequent deviations from symmetry due to straight sections of unequal length. He didn't explain how he got involved in a synchrotron project such as KAON. He also noted that the TRIUMF group had mystically arranged the weather at the Conference, so that the occasional rain fell at times during the sessions, while on the important social occasions such as the salmon barbecue and the Wednesday excursions the weather was fine. This kind of weather control is unknown outside Super, Natural British Columbia.

5. PREDICTIONS FROM THE PAST

In Henry Blosser's talk "Future Cyclotrons" at the last session of the Conference he made some predictions about future improvements in cyclotron design. Following the historians, it is useful to look to the past for important clues about the future directions for cyclotron development. We have often heard about ancient astronauts, but seldom hear of ancient cyclotron designers. Two examples will show the importance of this field of study.

The first is taken from Athens (Greece, not Ohio). Fig. 2 shows a design found on stone at an agora near the Acropolis[1]. This early design shows a three sector magnet whose spiral sectors are remarkably similar to those of modern designs such as the Jyvaskyla cyclotron, Fig. 3, which just came into operation (Table 2). It is also similar to other modern era designs such as the LBL 88-Inch Cyclotron and the MSU/Harper Cyclotron (Table 3).

The second example, Fig. 4, is a high-spiral design by the Maori people of New Zealand[3]. It was found on one of their meeting houses. The use of 2 sectors gives high flutter near the center. Apparently they had solved the problem of the NuR = 2/2 radial resonance which has caused more cautious later designers to believe that we need at least 3 sectors. Also this design appears to operate without an rf system.

So we have much to learn from these ancient cyclotron designers, and I suggest that we include Athens and New Zealand on our list of potential locations for future cyclotron conferences.

6. ACKNOWLEDGMENTS

The author wishes to thank M. Craddock and G. Dutto for their helpful comments on this paper.

7. REFERENCES

1) Courtesy of D. Stiver, LBL, member of the Voluntary (No DOE funding) International Historical Cyclotron Task Force for the Investigation of Ancient Cyclotrons.

2) Esko Liukkonen, "The Jyvaskyla K130 Cyclotron Project", in Proc. Twelfth Int'l Conf. on Cyclotrons and their Applications (World Scientific, Singapore, 1991) pp. 40-42.
3) Courtesy of D. Clark, Chairman of the Board of the Task Force of Ref.1).

*This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE- ACO3-76SF00098.

Fig. 2. Three sector design, Athens, Greece.
CBB 926-4955

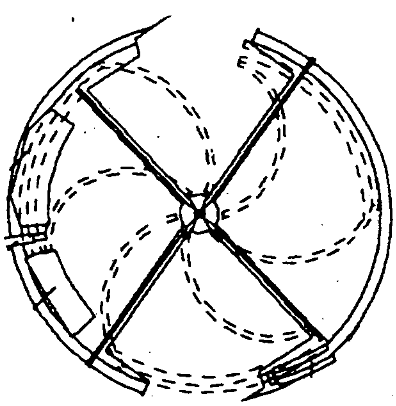

Fig. 3. Jyvaskyla K130 magnet pole[2]).
ZBL 926-4964

FIRST TRIENNIAL AWARD

FOR

THE MOST LIVELY ABSTRACT

TO

HENRY BLOSSER

FOR

"FUTURE CYCLOTRONS"

"..IN 1972 THE AUTHOR PREDICTED A MINOR ROLE FOR SUPER-CONDUCTIVITY IN .. CYCLOTRONS. NOW 20 YEARS LATER, .. ALL .. PREDICTIVE RESOURCES WILL .. BE USED (ORDERED TRANSPARENT SPHERES, ASTRONOMICAL SYNCHRONISITIES, 3D COMPUTER CALCULATIONS, TEA LEAVES, ETC.).. "

A subcommittee will determine the nature of the award.

Fig. 1. Special award.

Fig. 4. Maori high spiral design, New Zealand.
CBB 926-4953