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News about Chalk River's Tandem Accelerator Superconducting Cyclotron facility for users and potential users

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Year-end review

Director's Report – John Hardy

TASCC has had another very successful year. Beam was available for experiments for a total of 5794 hours, a 6% increase over last year. Including beam-development time, the accelerators operated for 92% of their scheduled operating time, or 81% of the total time available. These are all performance records of which we are very proud.

No doubt as a result of the accelerators' reliability, we have had more outside users in 1993 than in any previous year – a total of 80, with 47 from Canada and 33 from abroad. The results of their efforts and those of our own staff speak for themselves in the following reports. Much has been accomplished in both basic and applied research!

This year saw a major long-range planning study in Canadian sub-atomic physics. The Nuclear and Particle Physics Advisory Panel (NPPAP) made a series of site visits – one to Chalk River – and wrote a report with recommendations for the future. We were very gratified to find TASCC described in their report as an "outstanding nuclear physics facility." One of the committee's principal recommendations was for the funding of TRIGAM, a third-generation γ-ray spectrometer to be sited at TASCC.

TASCC continues to be an efficient and lively laboratory, at the peak of its form. However, like other national labs in the 1990's, we are concerned about the long-term financial future. This issue is a personal priority and has also received attention from many other people in recent months. I am optimistic that as long as the scientific output of TASCC matches its current pace, the facility will continue to serve the Canadian research community with distinction.

Negative Ion Injectors

A number of ion source developments took place during the year:

❶ Our duoplasmatron source was returned to regular use again, to produce ^{3}He and ^{4}He beams.

❷ The conical-ionizer version of the model 860 sputter source provided more intense heavy-ion beams than ever before.

❸ At year-end, the first beams from a new ECR source (^{16}O and ^{3}He) were accelerated.

❹ Three new beams (^{52}Cr, ^{69}Ga and ^{209}Bi) were developed and injected into the Tandem.

❺ Eighteen other beams were injected into the Tandem with higher intensities than before.

Facility report for December

Four beams were produced this month for physics experiments and two new beams were developed from the cyclotron.

A highlight was the successful performance of a new ECR source, recently developed at CRL. Installed in the beamline system, it generated beams of O^- and He^-. The helium beam was subsequently accelerated to 50 MeV per nucleon and extracted from the cyclotron. This constitutes a double highlight, since this beam has a stripping ratio of 1: 2, which is outside the range used for all other cyclotron beams to date.

Beams produced by the facility in December were:

Ion	*Energy (MeV)*
^{3}He	150
^{12}C	540
^{33}S	172
^{35}Cl	1505
$^{35-37}Cl$	100
^{74}Ge	298.2

The accelerator, ion injectors and cyclotron were shut down during the CRL Christmas break for scheduled maintenance and modifications.

ECR Source

A high-current Electron Cyclotron Resonance (ECR) source, originally developed by CRL's Accelerator Physics Branch, was modified by TASCC personnel (see October newsletter) to produce intense negative-ion beams for experiments. The source has been operated with both gaseous and non-volatile feeds and the beams produced included H^{1+}, Bi^{1+}, O^- and He^-. We produced the negative-ion beams by coupling the source to a standard charge-exchange canal which used a potassium metal-vapour target.

In December a compact, permanent-magnet version of the source with a charge-exchange canal was installed on an injector deck for bunching and transmission tests. The output current was sufficiently high to permit acceleration of ^{18}O from natural oxygen feedstock (0.2% ^{18}O). In addition, a ^3He beam was developed to the cyclotron and subsequently accelerated to 50 MeV per nucleon.

Future plans for the ECR source include development of a more compact, efficient version.

Tandem Accelerator

The accelerator has successfully met the ever-increasing demands of the TASCC research community. At the same time, new records were set in every major aspect of performance during 1993.

Beam availability, at 75%, was the highest ever, during a period in which 37 ion species were accelerated, 8 more than during the previous best year.

The Tandem was also operated at higher terminal voltages than ever before:

❶ Voltages greater than 14.5 MV were run on 27 days; the previous best record was 8 days.

❷ A beam was run to an experiment at 15.27 MV and the machine was conditioned to 16 MV without beam. (The previous high was 15 MV with or without beam.).

These performance records were established with fewer voltage breakdowns, fewer tank openings and less downtime than ever before.

Tandem performance is summarised below, with values given for the previous four years for comparison.

	1989	*1990*	*1991*	*1992*	*1993*
Beam Available %	62	72	63	71	75
Beam development	15	11	13	13	10.6
Total Shutdown %	23	17	24	16	14.4
Ion Species Run	23	27	29	27	37
Days ≥14.5 MV	6	0	8	2	27
Voltage Breakdowns	285	198	540	225	151
Tank Openings	10	7	14	10	5

Superconducting Cyclotron

Twelve new beams were developed in 1993, bringing the total now available to 72. Sixteen different beams were produced for physics experiments.

Highlights in a very successful year included:

❶ Extraction of several beams beyond the limits of the "original" mass-energy diagram. These were: ^3He at 50 MeV/u, ^{12}C at 52.5 MeV/u, ^{35}Cl at both 43 and 46 MeV/u, and ^{70}Ge at 35 MeV/u.

❷ Development of a septum for the electrostatic deflector capable of handling higher beam currents.

❸ Development of an interactive beam-centering program for two radial probes.

❹ First commercial marketing of r.f. products to other labs.

Control Computer System

❶ During the first half of 1993, a shallow hierarchy of operator displays was devised for the Vsystem software. A series of displays has now been constructed for the injection beamline and partially tested.

At the same time, a means of dealing with CAMAC system errors under Vsystem was developed and two special-purpose programs were converted from the PDP-11 computer to the VAX cluster.

❷ Early in September, well-received presentations were made to the first Vsystem User's Meeting at Brookhaven National Lab. Information from that meeting, combined with a detailed evaluation by experts from VISTA of our conversion program, led

us to revise our handling of status information under Vsystem.

By the end of the year, new status handling had been developed and thoroughly tested. The benefits are: a 50% reduction in the size of the database; a corresponding improvement in system response; and status displays which are much easier to develop, maintain and test.

❸ During the last quarter, PID (Proportional-Integral-Derivative) control of one helium liquefier engine was demonstrated through Vsystem and a decision made to implement all the proposed closed-loop controls of the cryogenic helium plant through Vsystem.

❹ The PDP-11 control system has assumed a higher profile with experimental users at TASCC in the areas of AMS, delivery of secondary-particle beams, and delivery of highly-stripped beams for atomic physics studies. Computer control of these three areas was upgraded during the year. For instance, AMS experiments are now completely controlled from the PDP-11 once the injector, Tandem and beamline are set up for the three isotopes of chlorine.

❺ The system of bypass and repeater hardware in the CAMAC highway allowed automatic isolation of a CAMAC fault for the first time.

Data Acquisition

Experimenters used the Concurrent CCUR3230 and CCUR3280 computer systems extensively during 1993 for data acquisition and analysis. To assist users we upgraded documentation of the on/off-line acquisition software.

In addition, the new on-line graphics program OLGA was made available on the SPARC2 workstations, as reported in the September newsletter.

We also expanded the SUN network by adding four colour-terminals, a SPARC10 dual-processor workstation and a HP LaserJet network printer. Conversion of SUN software to run with the new SOLARIS 2 operating system is currently in progress.

8π Gamma-Ray Spectrometer

During 1993 there were 24 separate experiments on the 8π spectrometer, for a total of about 2500 hours of research time. In addition to the long-standing collaboration amongst the Canadian groups of TASCC, McMaster University and the Universities of Toronto and Ottawa, we also hosted international groups from the University of York (UK), the Australian National University (Canberra), Stony Brook, and the University of Notre Dame.

We welcome Stephane Flibotte (most recently of Strasbourg) to the newly created TASCC Professorship at McMaster University, and congratulate Victor Janzen on his appointment to the staff at Chalk River Laboratories.

During the summer we enjoyed extended and productive visits by theoretician Ingemar Ragnarsson (Lund, Sweden) and by experimentalist Eddie Paul (Liverpool, UK).

The Canadian 8π-spectrometer group participated in three experiments at the GAMMASPHERE spectrometer in Berkeley and proposals have been submitted to EUROGAM 2 (Strasbourg) for experiments there.

The TRIGAM proposal for a 3rd-generation array to be sited at CRL was reviewed in January 1993 and received an excellent report from an international visiting committee. Unfortunately, NSERC was unable to find funds for the project in 1993. The proposal was resubmitted in October 1993 for consideration in 1994.

Scientific highlights of 1993 included:

❶ Discovery of a staggering-effect in the energy spacing of the lowest-lying superdeformed band of ^{149}Gd. This observation was made with EUROGAM 1 data from last year and could have important implications. The principal researcher was Stephane Flibotte from McMaster University.

❷ First observation of a discrete superdeformed band in ^{145}Tb. Discrete bands have now been observed in four N=80 isotones, namely: ^{142}Sm, ^{143}Eu, ^{144}Gd and ^{145}Tb. The principal researcher was Simon Mullins from McMaster University.

❸ Demonstration of very significant gamma-ray

energy resolution improvements by kinematic reconstruction based on identified evaporated light ions detected in the miniball. The principal researcher was John Cameron from McMaster University.

❹ First recoil-distance lifetime measurements for the known oblate structures in the mass A≈200 region were made in collaboration with groups from the University of York and the University of Toronto.

❺ An experiment was performed to test the recent prediction of hyperdeformation in mass A≈180 (specifically ^{180,181}Os). The null result may imply that hyperdeformed shapes lie at higher excitation energies than predicted. The principal researcher was David Ward of TASCC.

❻ A concentrated effort was made to determine the properties of an anomalous band in ^{131}Pr that has many characteristics of superdeformed bands in the mass A=130 region but decays principally by dipole emission between signature partners.

The band is observed only at low rotational frequency (190 keV $<\hbar\omega<$ 400 keV) rather than the more typical value (300 keV $<\hbar\omega<$ 800 keV), which is seen, for instance, in ^{131}Ce.

The collectivity of this band has been measured by DSAM and first analyses seem to confirm a deformation typical of superdeformed bands in the region. The principal researcher was Alfredo Galindo-Uribarri of TASCC.

❼ The study of collective structures near the Z=50 shell closures has been vigorously pursued with new bands discovered in ^{112}Te, ^{115}I and ^{113}In.

The concept of soft band termination now appears to be on a firm footing. However, it has become apparent that the properties of these intruder bands vary, from case to case, in as-yet unexplained ways.

The principal researchers were Victor Janzen of TASCC with collaborators from York, Liverpool, Stony Brook and Notre Dame.

ISOL On-Line-Isotope-Separator

We performed nine experiments in collaboration with researchers from the University of Manitoba, Queen's University, McGill University, Los Alamos National Laboratory and Tohoku University in Sendai, Japan. Highlights include:

❶ In our weak-interactions program, we searched for a non-analogue $0^+ \rightarrow 0^+$ beta transition in the decay of ^{38m}K but we could only establish an upper limit of 19 parts per million (ppm).

A letter was written on our observation of such transitions in the decays of ^{46}V and ^{54}Co as well as the limits established for ^{38m}K and ^{50}Mn. These data provide the only possible test of the isospin-mixing calculations used to determine the weak vector-coupling constant from superallowed beta-decay studies.

Comparisons with two theoretical models of isospin mixing effects show that one model agrees with the experimental data better than the other. More importantly, we have provided for the first time a sound basis for trusting the calculations of these effects and thus the necessary corrections to the determination of the weak vector-coupling constant.

❷ We measured a previously unobserved Gamow-Teller beta transition in the decay of ^{46}V. This is the only beta branch observed in addition to the superallowed one and has a branching ratio of 113 ppm. Its presence necessitates a significant correction to the superallowed branch decay rate.

❸ Lack of precise measurements of the branching ratio of the superallowed beta transition in the decay of ^{10}C prevents this nuclide from being used for precise weak-interaction tests. If the branch were well known, this case would provide the best test for the possible presence of a residual Z dependence in the corrected ft-values of the precisely measured superallowed beta emitters. The determination of this branching ratio requires a measurement of the intensity ratio between two different gamma rays.

A very promising test experiment was done with the 8π gamma-ray spectrometer, which avoided pile-up problems experienced by other experimenters. Results indicate that the required precision can be reached in a measurement of one-week's duration.

❹ We studied the previously unknown beta-delayed

gamma-ray decays of two T_z=–1 nuclides, ^{44}V and ^{52}Co. Gamma singles and gamma-gamma coincidence data were obtained in two separate experiments. In both cases we were able to locate precisely several states in the daughters, including the isobaric analogue state.

Since both cases are amenable to shell-model calculations, comparisons of calculated and experimental GT strengths were started.

❺ A collaboration between the University of Manitoba, McGill University and Chalk River Laboratories worked during the year to design and test parts of a proposed Penning-Trap mass spectrometer.

If funded, the instrument will be located at TASCC and be coupled to our He-jet transfer system with a selective laser-desorption and ionization stage. It will be able to measure masses of isotopes of practically all elements, a significant advantage over similar types of instruments elsewhere.

A proposal for funding was submitted to NSERC in September, as detailed in our October newsletter.

❻ We studied the efficiency of our He-jet transfer system under varying conditions to find out if radio-activities could be transferred efficiently over long distances and in a reasonable time.

The interested parties in these studies were the Penning Trap collaborators mentioned above and Sudbury Neutrino Observatory (SNO) collaborators. The tests were generally promising; as an example, it was shown that activities could be transported 60 meters in 2 seconds with an efficiency of 35%.

Applied Science Programs

❶ The largest program of this nature is the Accelerator Mass Spectrometry program carried on as a collaboration between Nuclear Physics and TASCC A&D branches and the Environmental Research Branch.

Studies concentrated on ^{36}Cl measurements. Groundwater studies relevant to underground waste repositories and environmental studies of the CRL site area are major program components. Measurements were also performed for a large number of outside earth-science groups.

Some developmental work was done on perfecting AMS techniques for studies of ^{129}I and ^{59}Ni and an Isotrace/Nuclear Physics Branch collaboration studied the effects of electric fields on negative-ion lifetimes.

❷ A variety of nuclear techniques was used for depth profiling of light elements in heavy substrates by scientists from Nuclear Physics Branch, Reactor Materials Research Branch, and McMaster University. In particular, developmental work was done on the Elastic Recoil Detection (ERD) technique with very heavy beams such as ^{127}I and ^{197}Au.

In addition to work done at TASCC, members of Nuclear Physics Branch and Systems Chemistry and Corrosion Branch, in collaboration with Queen's University scientists, studied deuterium uptake in Zr and its alloys using the Queen's University Van de Graaff accelerator.

❸ Systems Chemistry and Corrosion Branch and Nuclear Physics Branch continued to collaborate in radiolysis work aimed at determining rate-parameter values for input into modelling studies of radiochemical effects in CANDU reactor cooling systems.

❹ A Fuel Materials Branch /Nuclear Physics Branch collaboration used iodine beams from the Tandem to simulate fission-track damage in UO_2 and SIMFUEL to study its effect on gas release and on gas-bubble formation and resolution in these materials.

❺ A collaboration of Defense Research Establishment, Ottawa; Naval Research Laboratory, Washington; Rensselaer Polytechnique Institute, Troy, New York, with support from Nuclear Physics Branch staff, carried out single-event upset studies in semiconductor devices using cyclotron beams.

❻ Finally, an IBM group used cyclotron beams in flux pinning studies in high-T_c superconductors.

In all, 51 days of operation were scheduled for applied science work in 1993

Heavy-Ion Channeling

In 1993 we measured resonant coherent excititation (REC) for hydrogen-like ^{28}Si ions channeled in a thin crystal of Si. Excitation of the electron of the moving ion from the K-shell (n=1) to the L-shell (or higher levels) occurs when the transition frequency between the levels matches the frequency of the interaction of the moving ions with the atoms along the crystal axis.The frequency is kv/d, where v is the ion velocity, d is the spacing between atoms in the atomic row and k is the

harmonic number.

For channeling along the <112> axis, we measured the resonances: k=5, n=1→2; k=6, n=1→2; k=6, n=1→3; and k=6, n=1→ 4. For channeling along the <111> axis we measured k=7, n=1→2 and k=8, n=1→3 resonances. This is the first time that the higher-order resonances (n=1→3 and 1→4) have been observed. Also, Si is the heaviest projectile used to date in such experiments.

The channeling group from Oak Ridge National laboratory led an RCE experiment in planar channeling. We studied hydrogen-like 24Mg ions channeled along the (100) plane of a thin Ni crystal, the independent variable being the inclination of the ion trajectory with respect to the <100> axis. Anisotropy of the crystalline field leads to splitting of some of the resonances and to different alignments of the resonantly excited ion,reflecting different substate populations of the 2p hydrogenic state.

The RCE resonances were observed by measurement of the ratio of the hydrogen-like to hydrogen-like plus fully stripped ions in the transmitted beam. The ratio of K x-ray yields as observed in detectors placed at 45° and 90° to the beam direction was measured for a series of points spanning the partially resolved (2,0) resonance and was observed to differ significantly for the two major components of the resonance, confirming differences in the alignments.

Heavy-Ion Reaction Mechanisms

For the collaboration working on heavy-ion reaction mechanisms, highlights of the year include the arrival of a new postdoctoral fellow and the first 4π reactions experiment at TASCC, as well as the initiation of several new series of experiments.

Dan Fox took up a postdoctoral position with us in October. He obtained his Ph.D. at the National Superconducting Cyclotron Laboratory at Michigan State University, and comes to us after working at Los Alamos and Indiana University. Dan brings expertise in a number of areas, including the analysis of fragment-fragment correlations.

The 80-detector charged-particle array covering the angular range from 7° to 46° had been completed by the Laval/CRL collaboration in 1992. In 1993 it was coupled for the first time to the CsI miniball developed by the 8π spectrometer collaboration. Together, the arrays constitute a system of 104 detectors covering more than 80% of the complete solid angle in the laboratory rest frame. The setup was commissioned in December in an experiment that was part of a systematic study of the properties of highly excited nuclei. The success of the experiment has led the group to consider construction of a dedicated 48-element CsI/photodiode array, similar to the miniball, but optimized for reactions work.

A new series of measurements, in which the fragment-emission time scale for a heavy-ion reaction is deduced from the relative momenta between correlated intermediate-mass fragments, was initiated this year. Collisions of 35A MeV ^{70}Ge with relatively light targets of Al and Ti were exploited to produce "reverse-kinematics" reactions for optimum detection efficiency. Data sets of 10^6 or more fragment-fragment coincidences were collected for each reaction, permitting selections to be made on fragment momentum and event centrality. These data, along with other measurements at the same bombarding energy per nucleon, constitute the first study of the fragment-emission time scale as a function of the projectile-target mass asymmetry.

The Université Laval led experiments to study projectile breakup mechanisms and central collisions in ^{35}Cl-induced reactions. The former experiment measured the exit channels available for peripheral collisions on a gold target; the latter took advantage of reverse kinematics to focus the products of reactions with lighter targets ^{12}C, ^{24}Mg, and ^{27}Al into the forward-angle array.

In another new development, we searched for pionic fusion from the $^{12}C(^{12}C,^{24}Mg)\pi^0$ and $^{12}C(^{12}C,^{24}Na)\pi^+$ reactions at 23A MeV. The QDDD spectrometer served to separate A=24 recoils at 0° from the high flux of incident beam particles. An upper limit of 0.32 nanobarns was obtained for the π^0 cross section. Improvements to the focal plane detector are in progress to reduce background from pileup.

December experiments

Experiment Commission an experimental setup that coupled the miniball with the forward array to provide full 4π coverage for charged-particle reaction products. Data were accumulated for the reaction 43 MeV/u chlorine-35 on KCl.

Researchers G.C. Ball, D. Bowman, D. Fox, A. Galindo-Uribarri , E. Hagberg, D. Horn, M.G. Steer and T. Whan *(TASCC)*; L. Beaulieu *(Université Laval)*

Beam 43 MeV/u ^{35}Cl

Duration 7 days

Experiment First development of beams from a modified ECR source.

Species	*Available CUP1_Ad nA*	*Analyzed CUP1_1f nA*	*Terminal Voltage MV*	*Accelerated through Cyclotron nA*
^{16}O	1000	100	11.8	--
^{18}O	20	20	10.6	--
^{3}He	2500	260	12.4	14
^{4}He	8000	280	12.4	--

Researchers J.S. Wills, P. Dube, Y. Imahori and H. Schmeing *(TASCC)*

Beams ^{16}O; ^{18}O; ^{3}He;^{4}He

Duration 1 day

Experiment Irradiation of water samples to simulate neutron-induced reactor radiolysis.

Researchers A.J. Elliott, D.C.Ouellette and P.M. Chenier ***(System Chemistry and Corrosion Branch, CRL)***; V.T. Koslowsky *(TASCC)*

Beam 45 MeV ^{12}C

Duration 2 days

Experiment Study of high-energy gamma-rays in dysprosium-52.

Researchers S. Flibotte, J.C. Waddington and S. Mullins ***(McMaster University)***; S. Pilotte ***(University of Ottawa)***; D. Ward, D.C. Radford and A. Galindo-Uribarri *(TASCC)*

Beam 172 MeV ^{33}S

Duration 4 days

Experiment Cyclotron development of 50 MeV-per-nucleon helium-3 and 4.03 MeV-per-nucleon germanium-74. These are the 71st and 72nd beams, respectively, extracted from the superconducting cyclotron. Successful production of this ^{3}He beam is particularly gratifying since He ion acceleration was not seen to be possible by the designers of the TASCC cyclotron.

Researchers TASCC Beam Commissioning Team

Beams 50 MeV/u ^{3}He; 4.03 MeV/u ^{74}Ge

Duration 3 days

"An expert is a person who chooses to be ignorant about many things so that he may know all about one."
E.E. Schattschneider

Next month . . .

- Facility shut down until Jan 4 for scheduled maintenance
- Study of depth profiling
- Study of AMS sensitivity of CRL system for iodine-129
- High-spin study of thulium-164
- Study of gas release from simulated reactor fuel
- High-spin study of hafnium-167
- Materials analysis by elastic recoil method
- Development of new beams from the cyclotron
- Measurement of electron-capture decay of technetium-100

Facility operating record

Total Hours for Year	8760
Beam Available	
Tandem Only	4608.4
Tandem + Cyclotron	1185.8
Beam Development	1276.4
Planned Shutdown	1068.5
Forced Shutdown	620.9

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