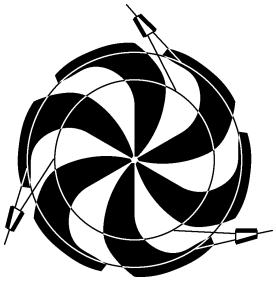
TRIUMF



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CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2005

The contributions on individual experiments in this report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission from the authors.

CONFERENCES, WORKSHOPS AND MEETINGS

FFAG 2004 WORKSHOP

Fixed-field alternating-gradient (FFAG) accelerators, which were intensively studied in the 1950s and '60s but never progressed beyond the model stage, have in recent years been the focus of renewed attention. Two proton machines have now been built, three more (plus an electron FFAG and a muon phase rotator) are under construction, and a variety of designs are under study for the acceleration of protons, heavy ions, electrons and muons, with applications as diverse as cancer therapy, industrial irradiation, driving subcritical reactors, boosting high-energy proton intensity, and producing neutrinos. These advances have been underpinned by a series of international workshops held at CERN, KEK, LBNL, BNL and now TRIUMF (April 14–21). A valuable feature of these workshops has been their small and informal nature, with as much time as possible allocated to work and discussion. At TRIUMF, the 23 participants were certainly hard-working, giving no less than 36 talks between them. Their presentations can be found at the workshop Web site: http://www.triumf.ca/ffag2004. The workshop was very capably organized by Shane Koscielniak and Elly Driessen.

With their fixed magnetic fields, modulated rf, and pulsed beams, FFAGs operate just like synchrocyclotrons – with the central region removed and the magnet broken into radial or spiral sectors to provide edge and strong focusing. The fixed magnetic field leads to a spiral orbit, so the vacuum chamber and magnets tend to be larger than for synchrotrons, but the repetition rate (and hence beam intensity) can be much higher, as it is set purely by rf considerations. High rep rate and large momentum acceptance are the two features where FFAGs offer advantages over synchrotrons, and it is applications needing one or both of these features that have driven the current surge of interest.

In order to avoid the slow crossing of betatron resonances associated with conventional low energy-gain per turn, all FFAGs so far constructed have been based on the "scaling" principle, which means keeping the orbit shape, optics, and betatron tunes fixed, independent of energy, just as in synchrotrons. This requires magnets with constant field index (log gradient) over a wide radial aperture, and either constant spiral angle or, for radial-sector designs, focusing (F) and defocusing (D) gradient magnets with equal and opposite fields.

Y. Mori described the two proton FFAGs recently built at KEK using DFD radial-sector triplets. The 1 MeV 6-sector POP (proof of principle) FFAG came into full operation in 2000, while the 12-sector, 5 m radius, 150 MeV ring, a prototype for proton therapy and neutron production, recently reached full energy.

Another 150 MeV FFAG of the same design is being installed at the Kyoto University reactor (KURRI), in collaboration with Mitsubishi, to test accelerator-driven sub-critical reactor operation. Two further FFAGs act as injector (a 2.5 MeV betatron with 8 spiral sectors) and booster (20 MeV with 8 radial sectors). Initially the rep rate will be 120 Hz, yielding a 1 μA beam, later 1 kHz, providing 100 μA.

FFAGs are also of interest for muons at both low and high energies. Y. Kuno described PRISM (phase-rotated intense slow muon source), a 10-cell DFD radial-sector FFAG of 6.5 m radius, now under construction at RCNP Osaka for eventual installation at J-PARC. It will collect 5-ns-wide bunches of 68 MeV/c $\pm$30% muons and use a sawtooth rf field to rotate them in phase space, reducing the momentum spread to $\pm$3%. With a rep rate of 100–1000 Hz the muon intensity will be $10^{11} - 10^{12}$/s, making possible ultra-sensitive rare-muon-decay studies. PRISM will also be used for ionization cooling of muons. Another scheme for ionization cooling came from Garren (UCLA) and Kirk and Kahn (BNL), who proposed a small 12-sector gas-filled FFAG (1 m radius) for cooling 250 MeV/c $\pm$30% muons, using superconducting magnets.

Mori also described the ambitious plan to build a neutrino factory at J-PARC based on a sequence of four muon FFAGs with top energies of 1, 3, 10, and 20 GeV. The largest would have a radius of 200 m (total orbit spread 50 cm) and consist of 120 cells, each containing a superconducting DFD triplet. Most cells would also contain rf cavities to provide an overall energy gain of $\approx$1 GeV/turn, restricting the muon decay loss to 50% overall. The use of low-frequency rf (24 MHz) keeps the buckets wide enough to contain the phase drift occurring as the orbit expands. A major advantage of FFAGs over linacs – either single or recirculating – is that their large acceptance obviates the need for muon cooling or phase rotation. There are also significant cost savings.

The rapid acceleration essential for muons allows betatron resonances no time to damage beam quality. Scaling can therefore be abandoned, the betatron tunes allowed to vary, and lattices explored for properties favourable to muons. In particular, in 1999 C. Johnstone (FNAL) showed that it would be very advantageous to use constant-gradient magnets, with positively bending Ds stronger and longer than the Fs. The circumference could be shortened, the radial orbit

Fig. 255. Attendees at the FFAG2004 Workshop at TRIUMF, including AG pioneer Ernest Courant and FFAG pioneer Andy Sessler (4th and 5th from left).

spread reduced (allowing the use of smaller vacuum chambers and magnets), and the orbit length made to pass through a minimum at mid-energy (instead of rising monotonically), thus reducing the variation in orbit time with energy – a vital consideration since there is no time for rf frequency modulation. Moreover, constant field gradients could be used (rather than constant field index), simplifying the magnet design and rendering non-linear resonances harmless.

Lattices along these lines were described by Johnstone, by Berg, Courant, Trbojevic and Palmer (BNL), by Keil (CERN) and Sessler (LBNL), and by Koscielniak (TRIUMF). The latest results from an ongoing cost-optimization study by Berg *et al.* favoured the use of linacs up to 2.5 GeV followed by 2.5–5, 5–10 and 10–20 GeV FFAGs; the main ring, composed of ≈100 doublet or FDF triplet cells, would have a circumference of ≈700 m, with orbit lengths varying by only 20 cm.

With the orbit time first falling and then rising, Koscielniak and Berg have shown that, by exceeding a critical rf voltage, an acceleration path can be created which stays close to the voltage peak (crossing it three times), snaking between neighbouring buckets (rather than circulating inside them). Their latest results showed that by using high-field superconducting 200 MHz cavities it should be possible to accelerate from 10 to 20 GeV in 16 turns, with decay loss 10% (25% in the three rings).

Several presentations were dedicated to particular technical features, including resonance crossing, injection and extraction, and magnet and rf hardware design. Some novel features of non-scaling designs - particularly acceleration outside buckets and the crossing of many integer and half-integer resonances - were felt to deserve demonstration in an electron model (probably 10–20 MeV/c) and some preliminary studies of lattices and hardware were presented.

A different non-scaling approach has been taken by Ruggiero (BNL), who described a design for a 1.5 GeV proton FFAG to replace the AGS booster, or for high-power applications up to 4 MW. Here acceleration is relatively slow (>1000 turns) so that resonances must be avoided. The tune is therefore kept essentially constant by using a non-linear field profile for which the changes in gradient balance those in flutter, while the non-scaling virtue of low dispersion is retained by using FDF cells with stronger D than F magnets. The 136-cell FFAG, located in the AGS tunnel, would accelerate 10^{14} ppp at 2.5 Hz, providing a 40 μA beam.

With this wide variety of new ideas and new projects, FFAGs seem at last to have come into their own. These matters were to be followed up at the next workshop, held at KEK in October, 2004.

TRIUMF SUMMER INSTITUTE

The TRIUMF Summer Institute (TSI) has a long standing tradition, and has over the years attracted many students from Canada and around the world to lectures on a wide variety of topics, all in direct relation to forefront physics pursuit at TRIUMF. The 2004 TSI was the 16th in the series, and took place at TRIUMF from the July 5–16. It was entitled Lectures in Nuclear Astrophysics: Experiment, Theory, and Observations. The Institute is tailored towards graduate students and young researchers in the field. This year's Institute was organized to go hand-in-hand with a major international conference, also organized by TRIUMF: the 8th International Symposium on Nuclei in the Cosmos (NIC 8), which started the following week. This combination of the summer school together with the conference allowed for an excellent introduction

to the field and attracted 38 students from 4 continents. The Institute is structured with formal lectures in the morning and a tutorial session in the afternoon, where open discussions were encouraged. The presence of various lecturers during these open sessions made for interesting discussions and allowed the students to tackle a broad variety of questions from different viewpoints, both experimental and theoretical. In addition to the formal part, 3 excursions were organized, including an ocean kayak trip, which allowed for excellent interaction between the lecturers and students, leading to many interesting and enlightening conversations (and unwanted swimming actions). Nevertheless, the Institute is recognized by many universities as a formal course and students used this opportunity to arrange for credit, which is given based on homework. The lecturers and topics this year were:

- T. Beers (Michigan State University, USA) Astrophysical Observations
- F. Bosch (GSI Darmstadt, Germany) Mass Measurements of Astrophysical Interest
- A. Cummings (McGill University) Explosive Nucleosynthesis
- B. Davids (TRIUMF) Indirect Reaction Studies Relevant for Nucleosynthesis
- C. Illiadis (University of North Carolina, USA) Direct Reaction Studies
- T. Kajino (National Astronomical Observatory of Japan) Big Bang Nucleosynthesis
- B. Mayer (Clemson University, USA) Stellar Evolution
- A. Mezzacappa (Oak Ridge National Lab, USA) Supernovae and Gamma-Ray Bursts

The organizing committee was chaired by Jens Dilling and included Lothar Buchmann, Barry Davids and Byron Jennings.

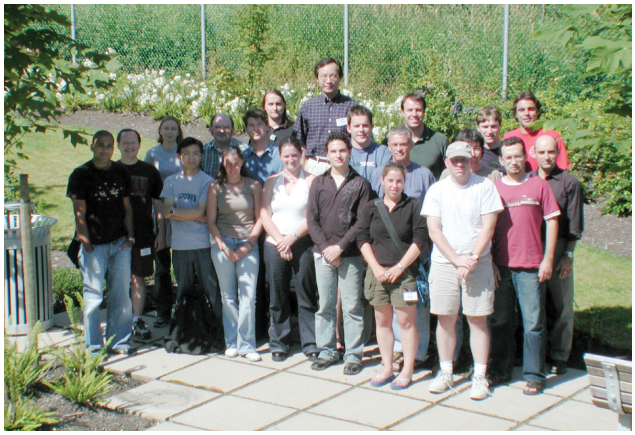

Fig. 256. Group photo of the TRIUMF Summer Institute participants and lecturers in the TRIUMF backyard.

NUCLEI IN THE COSMOS

The 8$^{\text{th}}$ International Symposium on Nuclei in the Cosmos was held from July 19–23 at the Coast Plaza Hotel, located in the West End of Vancouver. There, two hundred and thirty-seven participants were treated to the latest news from the world of nuclear astrophysics and related fields as well as a multitude of other means to keep the body and soul refreshed. This series of conferences was established under its present name in 1990, with the inaugural meeting being held in Baden, Austria. The initial emphasis on experimental nuclear astrophysics has now been extended to include a wide range of topics from observational astronomy to stellar modelling of extreme conditions, all bound together by the common subject of interest which is how elements are produced and distributed in the cosmos.

After an introductory address by Sam Sullivan, the deputy mayor of Vancouver, the conference was opened for talks with Tom Lehrer's rendition of "The Elements", as the focus of these meetings is the origin of the elements in the universe. Opening talks on core collapse supernovae reported significant advances in understanding these mechanisms which have led to (nearly) working models of such SN explosions; impressive colour movies of such explosion simulations were shown. Additional data on many processes, e.g. electron capture rates for medium mass nuclei in the iron region are, however, needed. The observation by satellites of the γ emitting isotope ^{26}Al ($t_{1/2} = 7.4\times10^5$ yr), most likely resulting largely from core collapse supernovae (and maybe other explosive events), has stimulated the drive to measure reaction rates for its production and destruction in such events. Such reactions involve both stable and radioactive heavy ion beams. As not all reactions can be measured directly, there is a strong need for nuclear theory input, a topic that was discussed extensively.

The focus of the conference then shifted to observation of specific isotopes by non-optical means. An exciting development is the observation of ^{60}Fe ($t_{1/2} = 1.5 \times 10^6$ yr) in ferromanganese crust in the Pacific. This isotope can only have been produced in a SN explosion which occurred in the solar vicinity about three million years ago. The Cosmic Ray Isotope Spectrometer (CRIS) on the ACE spacecraft, which is measuring the isotopic composition of cosmic rays, observes a source similar to the elements in the solar system except for a few, not well understood isotopes. Since 2002 the European Space Agency's INTEGRAL satellite has been observing γ-rays emitted from specific isotopes in our galaxy, including those from positron annihilation radiation and from the decay of ^{26}Al. Since in many core collapse supernovae models ^{60}Fe is produced at

about the same rate as ^{26}Al, the fact that its decay has not been observed by satellites has become critical.

A large fraction of the conference was dedicated to the observation of early nucleosynthesis in the atmospheres of old, small halo stars and the modelling of the galactic chemical evolution. There is remarkable evidence that early r-process nucleosynthesis and the distribution of iron peak elements is often close to solar, closer than models would predict. Early s-process nucleosynthesis leads to a relative enhancement of lead, while some isotopes show not well understood irregularities.

The measurement of nuclear reactions with stable isotopes is still at the forefront of research. In particular, the reaction considered to be the most important for understanding the production of medium mass elements in stellar environments is $^{12}C(\alpha,\gamma)^{16}O$. It was the subject of many experimental studies reported at the symposium which attempt to determine its rate at stellar temperatures with greater precision. While significant progress has been achieved by various groups, more work is needed. The LUNA (Laboratory Underground for Nuclear Astrophysics) facility, located in the Gran Sasso tunnel in Italy, allows measurements of important reactions such as radiative proton capture on ^{14}N at very low energies where the stellar reaction rate has lately been lowered considerably. With the reduction of cosmic ray background, studies down to the Gamow energy window can be achieved.

A highlight of the conference was the series of talks on SN and γ-ray bursts (GRBs), exhibiting total energy outputs of $\approx 10^{52}$ ergs and more. Overwhelming evidence over the last 6 years indicates that a large fraction of GRBs are accompanied by SNIc events, although the inverse is not necessarily true. Models of such violent explosions, known as collapsars, were presented as a work in progress; the role of rotation and the formation of jets are important aspects of such scenarios. Of equal importance is a good understanding of SNIa, which are excellent cosmological distance indicators (standard candles). The maximum light output versus decay width calibration seems to be understood now theoretically; however, second order variations in models and the exact deflagration mechanism need more attention.

Considerable progress has been made in understanding the s-process but more work is needed, especially with initiation reactions and for reactions of low cross section and at very low energies as the paradigm for s-process nucleosynthesis has moved to low mass stars. A new facility, the n_TOF system at CERN, is now operational and providing valuable (n,γ) cross sections over a wide mass range.

A number of talks were centred on the r-process, which is believed to be the mechanism responsible for the production of half of the elements heavier than those in the iron peak. Identification of the astrophysical site and the specific conditions under which the r-process takes place remains a major mystery, along with predictions of properties of very neutron-rich exotic nuclei involved in this process. Studies on presolar grains are also providing a wealth of new information and setting constraints on models of nucleosynthesis and stellar evolution for a multitude of stellar scenarios.

Originally, this conference series sought to bring together experimentalists to discuss programs in nuclear astrophysics. This is still a main focus of attention and there were a number of overview talks on studies with both stable and radioactive heavy ion beams. Areas of focus for radioactive isotope studies are measurements related to the r-process, the rp-process and the p-process. The combination of these data coupled with improved stellar models leads to a better understanding of nucleosynthesis in stellar environments prior to and during explosive scenarios. Therefore mechanisms for cataclysmic stellar events, including novae and X-ray bursts, were the subject of various talks at the conference. New techniques involving radioactive beams and recoil separators are providing new avenues to obtain necessary information previously considered inaccessible. Additional reaction rates involving exotic nuclei are still required for a clearer understanding of the mechanism leading to the production of particular isotopes.

In addition, there were talks on reactions occurring in the sun, measurements of the solar neutrino flux using the Sudbury Neutrino Observatory (SNO) which have led to a clear confirmation of neutrino flavour mixing, and the status of information on reactions in big bang nucleosynthesis.

At the banquet held at the University of British Columbia's Museum of Anthropology, all were treated to an introspective view of the early days of studies at the first centre for experimental nuclear astrophysics at Caltech by D.D. Clayton. His talk was entitled "Phive Years of Physics Phun with Phowler", presenting stories of working with Willie Fowler (Nobel Laureate in 1983). The talk can be found in the conference proceedings, including the Kellogg Laboratory's battle song.

A closing talk was given by Claus Rolfs with a particular emphasis on experimental measurements in Bochum. The next symposium, Nuclei in the Cosmos IX, will be hosted by CERN in Geneva, Switzerland in 2006.

The conference proceedings will be published as an edition of Nuclear Physics A early in 2005. The edi-

tors are Lothar Buchmann, Martin Comyn and Jana Thomson.

The following people are acknowledged for ensuring the successful staging of the conference. With her impressive organizational skills, Elly Driessen made the conference possible in the first place. Lorraine King's dedicated work on the proceedings helped ensure their timely publication. Thanks are extended to the staff of the Coast Plaza Hotel and to Mindy Hapke for taking the conference photographs. UBC Catering Services and the Romanza String Quartet, both involved with the banquet, are also gratefully acknowledged. The work of the Local Organizing Committee, in particular J. D'Auria, P. Gardner, K.P. Jackson, G. Jones, H. Leslie, J. Rogers and A. Shotter, deserves high praise as does the TRIUMF accounting office for help and personnel during registration, and the many tour guides who assisted at the TRIUMF tour on the Saturday morning following the conference. Finally, hosting the conference would not have been possible without the generous sponsorship provided by MDS Nordion, NSERC and TRIUMF.

VICTORIA LINEAR COLLIDER WORKSHOP

The Victoria Linear Collider Workshop was held July 28–31 at the Hotel Grand Pacific in downtown Victoria. This was a meeting in the series of North American workshops on the physics, detector, and accelerator issues of the future International Linear Collider.

The workshop was attended by 150 physicists, the large majority from the United States, but with many participants from Canada, Europe, and Asia.

Alan Shotter, TRIUMF director, opened the meeting by welcoming the participants to Victoria and giving a brief introduction to TRIUMF and its role in Canadian particle physics. The rest of the first day consisted of plenary talks on the status of linear collider plans around the world, the status of accelerator research and development, and on a number of theoretical developments. The closing talk of the first day, *The Linear Collider and the Rest of the Universe*, by Jonathan Feng, was very well received.

The second and third days had parallel sessions, typically five at any time, of the 21 working groups covering all aspects of physics, detector, and accelerator issues. In the late afternoon of the second day, a review of detector research and development was presented in plenary session.

In the afternoon of day three, the plenary session included a presentation by Barry Barish on the status of the International Technology Recommendation Panel (ITRP). That panel was charged to select between the two competing accelerator technologies, so that the world community could focus on a single design. At ICHEP in Beijing in August, the ITRP announced its recommendation to use superconducting accelerating structures. Subsequently, Barry has been asked to lead the organization to develop the single design of the International Linear Collider.

Other plenary presentations on the third day included talks from representatives of the US funding agencies, and from the leaders of the world wide physics and detector studies.

The final day of the program had a set of summary presentations covering some of the parallel sessions, and concluded with a fine talk by Michael Peskin from SLAC.

More information about the workshop, including all of the presentations given at the meeting, can be found on the Web at www.linearcollider.ca/victoria04.

The workshop was a great success. The participants and organizers were very pleased with the hotel services and staff. The chair of the organizing committee (D. Karlen) would like to acknowledge the financial support for this meeting from TRIUMF, University of Victoria, IPP Canada, and NSERC.

FIFTH INTERNATIONAL SYMPOSIUM ON RADIOHALOGENS

The Fifth International Symposium on Radiohalogens (5ISR) was held September 11–15 in Whistler. 5ISR was the most successful Radiohalogen symposium in the series with more than 70 attendees from Canada, Europe, Japan, China, and the USA. While most attendees were from academic research facilities, several participants came from companies such as Bristol-Myer Squibb, MDS Nordion, Merck, Nihon Medi-Physics, Schering AG, Theragenics, and Molecular Insight Pharmaceuticals. Topics discussed at the meeting included: production of radiohalogens, fluorine chemistry, iodine chemistry, bromine chemistry, radiohalogens in radiotherapy, drug development, and industrial issues. Sponsorship for the meeting came from the US Department of Energy (DOE), MDS Nordion, the University of Washington, TRIUMF, and the Society of Radiopharmaceutical Sciences (SRS). With the DOE and SRS contributions we were able to provide travel awards for 11 graduate students and postdoctoral fellows to attend the meeting. The 5ISR Web site (http://www.triumf.ca/5ISR) contains a PDF version of most of the scientific presentations, an attendees list, and various photos from the meeting.

TRIUMF USERS' GROUP ANNUAL GENERAL MEETING

The 2004 TRIUMF Users' Group Annual General Meeting was held in the TRIUMF auditorium on

Wednesday, December 8, prior to the Subatomic and Materials Science two-day EEC meetings. The meeting had 48 registrants and several users who were unable to travel to TRIUMF watched the live video stream on the Web. The video files are archived on http://video.triumf.ca/cgi-bin/archive/tug04.

The meeting began with the traditional set of talks by the Director and Division Heads reporting on the state of the laboratory, the science highlights and future beam schedule, the cyclotron status and plans for future refurbishing and upgrades, and the status of ISAC-I and ISAC-II. All of the presentations contemplated future developments outlined in the 2005–2010 Five Year Plan which was awaiting government approval.

In anticipation of the new funding, the TRIUMF Users' Executive Committee (TUEC) had conducted a long range planning survey as an initial step in developing a vision beyond 2010. Jeff Sonier, the TUEC Chair, presented a summary of the 43 responses received. Many were provocative and prompted a lively discussion from the floor, which extended into the lunch break. It was generally agreed that it had been a worthwhile exercise, and the collated responses were later given to the Director and Division Heads for their consideration.

After lunch, there were talks by Isao Tanihata of ANL and two TRIUMF graduate students, Julie Lefebvre and Dan Melconian.

In the TUEC Business Meeting, Jeff Sonier outlined what TUEC had achieved during 2004 and then announced the results of the election for the vacant 2005 TUEC positions. By acclamation, P. Garrett (U. Guelph) was elected as chair elect for 2005. For the first time in the history of the TRIUMF Users' Group (TUG), there was a second place tie in the vote for the two representatives. As the TUG by-laws did not specify what to do in such a situation, it was agreed by a majority of the members present that in this instance there would be three representatives for 2005/2006. They are G. Gwinner (U. Manitoba), M. Nozar (TRIUMF) and F. Sarazin (Colorado School of Mines). To avoid a recurrence in the future and, more importantly, to specify what to do in the case of a tied vote for chair elect, TUEC will propose an amendment to the by-laws early in 2005 and conduct a ballot which will require a two-thirds majority of the members voting in order to be adopted.

TUEC also nominates two members to represent the Users on the TRIUMF Operating Committee. In 2004 S. Yen (TRIUMF) and L. Lee (U. Manitoba) remained as the on-site member and alternate, respectively, while G.M. Luke (McMaster U.) and J.E. Sonier (SFU) remained as the off-site member and alternate, respectively.

This ended the formal part of the TUG AGM, but instead of finishing with a buffet dinner at TRIUMF, everyone moved to TRIUMF House for a reception and a final chance to reminisce and say farewell to the old building before the move to the new facility the following week.

Welcome	Jeff Sonier
State of the Laboratory	Alan Shotter
Science Division Report	Jean-Michel Poutissou
Cyclotron Status	Roger Poirier
ISAC Report	Paul Schmor
TUG LRP Survey Results	Jeff Sonier
Radii and Density Distributions of Nuclei	Isao Tanihata, ANL
Chemistry and Physics of Gold-Cyanide Coordination Polymers	Julie Lefebvre
Searching for Right-Handed Currents in the β-Decay of Laser-Cooled Polarized ^{37}K	Dan Melconian
TUEC Business Meeting	Jeff Sonier
Reception - Farewell to the Old TRIUMF House	

TUEC Membership for 2004

J.E. Sonier	SFU	*Chair*
J. Dilling	TRIUMF	*Chair Elect*
W.D. Ramsay	U. Manitoba	*Past Chair*
A.A. Chen	McMaster U.	2003/2004
T.A. Porcelli	U. Northern BC	2003/2004
P. Bricault	TRIUMF	2004/2005
A. Laird	U. York, UK	2004/2005
M. Comyn	TRIUMF	*Liaison Officer*