# TRIUMF

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**FOR PARTICLE AND NUCLEAR PHYSICS**

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2002

*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.*

## Proton Irradiation Facility

*(E.W. Blackmore, TRIUMF)*

There was an increased demand for beam time on the TRIUMF proton irradiation facility (PIF), with several new groups of users requesting testing time. There were five scheduled beam periods, three with only the low energy beam BL2C available and two with both beams available. The September 13–18 beam period was not fully used as the unfortunate events of that week prevented travel for some of the users. Some of this work was rescheduled later in September and then during the December 12–18 run, when once again both beams were available.

Table XIII lists the laboratories and companies that have used beam since PIF was developed in 1996, and the types of devices that were tested. Typically many of these users are repeat customers, with seven of these groups using beam during this past year.

Table XIII. TRIUMF PIF users (1996–2001).

| Organization/company | Typical testing programs |
|---|---|
| Canadian | |
| DREO, T&N, CAL Corp. EMS Passat, Crestech, SFU | SEE in SRAM, DRAM; DD in GaAs & QW LEDs; neutron and proton dosimetry; TID in MEMs |
| DREO/Health Canada | Biological samples |
| MD Robotics (SPAR) | SEE, TID in Pentium computers, monitors, cameras |
| Bubble Technology, RMC | Bubble detectors for neutron and proton dosimetry |
| ABB Bomem | DD in laser diodes |
| Dynacon Enterprises Ltd. | SEE, TID in micro-satellite components, attitude control |
| Canadian Space Agency | SEE, TID in microgravity experiment components |
| ATLAS (UofA) | SEE, TID in calorimeter readout electronics |
| Foreign | |
| NASA/GSFC | SEE, TID, SET, DD in optocouplers, spacecraft electronics |
| DERA (UK) | SEE in SRAM, DRAM |
| Vanderbilt University | DD in GaN devices |

The flexibility in the beam delivery system was again demonstrated with DREO carrying out single event upset (SEU) studies at energies increasing from 20 to 500 MeV, BTI/RMC requiring proton fluences of $10^3$/s over a 10 cm diameter to test the response of bubble detectors to 100 MeV protons, and several other users requiring dose exposures to $10^{13}$ protons/cm$^2$ for total dose and displacement damage studies.

Vancouver was the host city in July for the Nuclear and Space Radiation Effects Conference, the IEEE sponsored conference for this field in North America. About 500 delegates attended, mostly from the United States and Europe. On the last day of the conference a tour of the proton irradiation facility at TRIUMF was provided, with a lot of interest generated. Several papers at the conference were presented on data taken at TRIUMF.

A Faraday cup for measuring the proton beam current at the test position was designed and commissioned during the year. The thickness of the copper absorber in the Faraday cup was made compatible with energies up to 225 MeV to allow calibrations to be carried out on both beam lines. With careful design of the insulator arrangement, the biased electron suppressor, and good vacuum, the Faraday cup had a dark current of less than 1 pA at a bias voltage of 300 V. Figure 119 shows the current calibration on the low energy beam line, comparing the three methods of fluence calibration: the Exradin T1 ion chamber, the Faraday cup, and direct proton counting at low intensity.

A number of users have indicated an interest in having calibrated neutron beams. Previously, the neutron flux and energy spectrum were measured downstream of a beam stop which was just thick enough to stop the incident proton beam. The measurements were made using Bonner Spheres, supplemented with carbon activation for higher energies. With the help of a visitor from Australia, a more careful measurement was

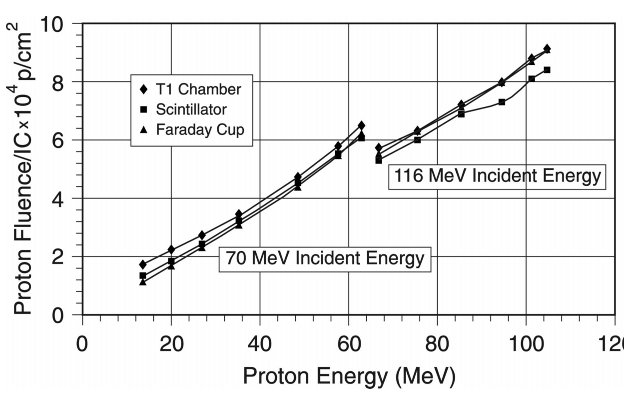


Fig. 119. Calibration of proton fluence.

carried out in May for incident 110 MeV protons on a 20 mm thick lead stop. The neutron dose equivalent rate is limited to about 0.1 to 0.2 kRad/hr using this technique due to the proton beam current limits in the PIF area. This is useful for neutron dosimetry work and possibly some SEU studies. For total dose and displacement damage studies, an absorbed dose of 10–100 kRad (1 MeV neutron equivalent) is required, which is not feasible at PIF. However, some initial neutron activation studies on the most easily accessible neutron beam at the TNF high intensity beam dump at TRIUMF have given some encouragement that neutron damage studies could be carried out in this location.

**Proton Therapy Facility**

*(E.W. Blackmore, TRIUMF)*

During the year, 8 patients were treated for ocular melanoma with protons, bringing the total number of patients treated at TRIUMF to 68. Figure 120 shows the patient numbers per year since the facility started. This year there was one patient from Oregon, the first U.S. patient, with the remaining patients from western Canada. There is some hope of attracting patients from eastern Canada once the results of the treatments to date are published.

Control and monitoring of proton therapy equipment and dose delivery is carried out using a dedicated computer, PTCS0, which is part of the TRIUMF cyclotron control system. The dedicated computer which previously was a VAX 4100 running VMS was replaced with an ALPHA Station Model 600, also running VMS. The controls software was transferred to this new computer and, after extensive quality assurance testing, was used for patient treatments in December.

Since 1995 the treatment planning program EYEPLAN has run on the VAX computers ERICH/REG which are part of the TRIUMF cluster running VMS. A decision has been made to retire these computers by the summer of 2002. Work has begun to transfer the planning software to the dedicated PTCS0 computer. This may require a change to the graphics packages or to the method of digitizing the X-ray positioning films.

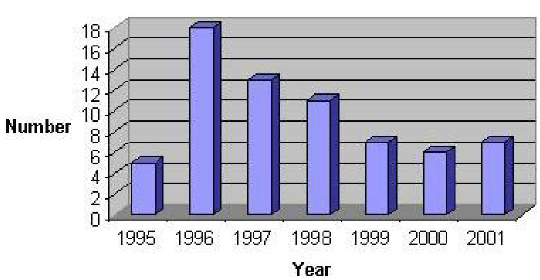


Fig. 120. Number of patients treated per year with protons at TRIUMF.

**$\mu$SR User Facility**

*(S. Kreitzman, TRIUMF)*

$\mu$SR user facility supported operations ran very smoothly during 2001. This, coupled with an almost undisturbed proton beam production schedule, resulted in the delivery of over 70 weeks of beam to 46 experiments carried out by approximately 20 groups. The major spectrometer usage (in weeks) was LAMPF (22), DR (15), Belle (now HiTime) (12) and Helios (8). Of note is that the DR (dilution refrigerator; 12 mK base temperature) ran for 11 weeks continuously without any significant problems. The technical aspects of the $\beta$-NMR experiment were also in good shape with the commissioning of rf technology allowing for frequency selective adiabatic polarization inversion.

On the political side, NSERC, the funding agency that is responsible for the $\mu$SR user facility MFA (major facility access) grant, unilaterally extended that grant (at the previous 1999 funding level) for two additional years. Since this grant exclusively supports the salary component of the facility's operation, and we were expecting to reapply (to cover, in part, the costs of salary inflation), we were forced to request an extraordinary supplement to this funding level in order to re-establish a financial environment which would allow staff retention. The results of this submission will be known in 2002.

Major facility developments which highlighted the year were:

- Delivery and commissioning of new American Magnetics 7 T high field magnet, HiTime.
- Fabrication of the new Helios spectrometer stand.
- Testing and finalization of the prototype uLB (ultra low background) insert.
- Installation (as yet uncommissioned) of new Linux data acquisition computers in all beam lines.
- Commissioning of $\beta$-NMR rf hardware that allows for adiabatic frequency selective excitation pulses.
- Reconstruction of the Miss Piggy 1.6 K cryostat to make it much more responsive.

The following material outlines these and related developments more fully.

**Spectrometers**

**HiTime**

The major functional spectrometer upgrade was that of the delivery and installation of a new American Magnetics designed 7 T magnet for the HF (high field/frequency) spectrometer. This magnet and spectrometer, now christened HiTime, shows significant

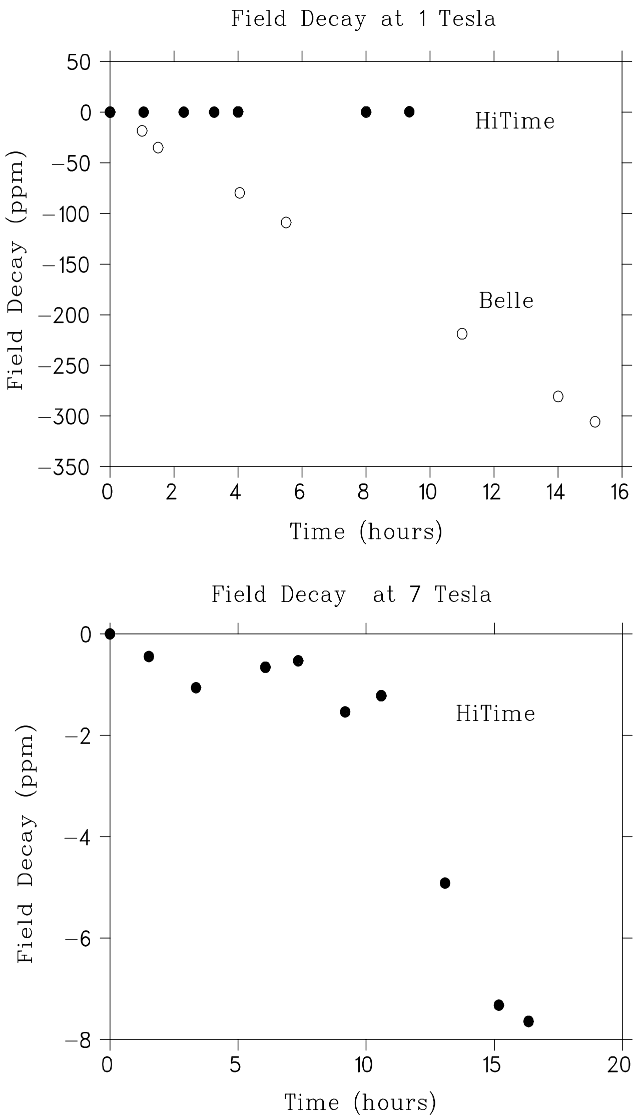


Fig. 121. Drift of the new HiTime magnet as compared with the original Belle magnet. The improvement is about a factor of 300.

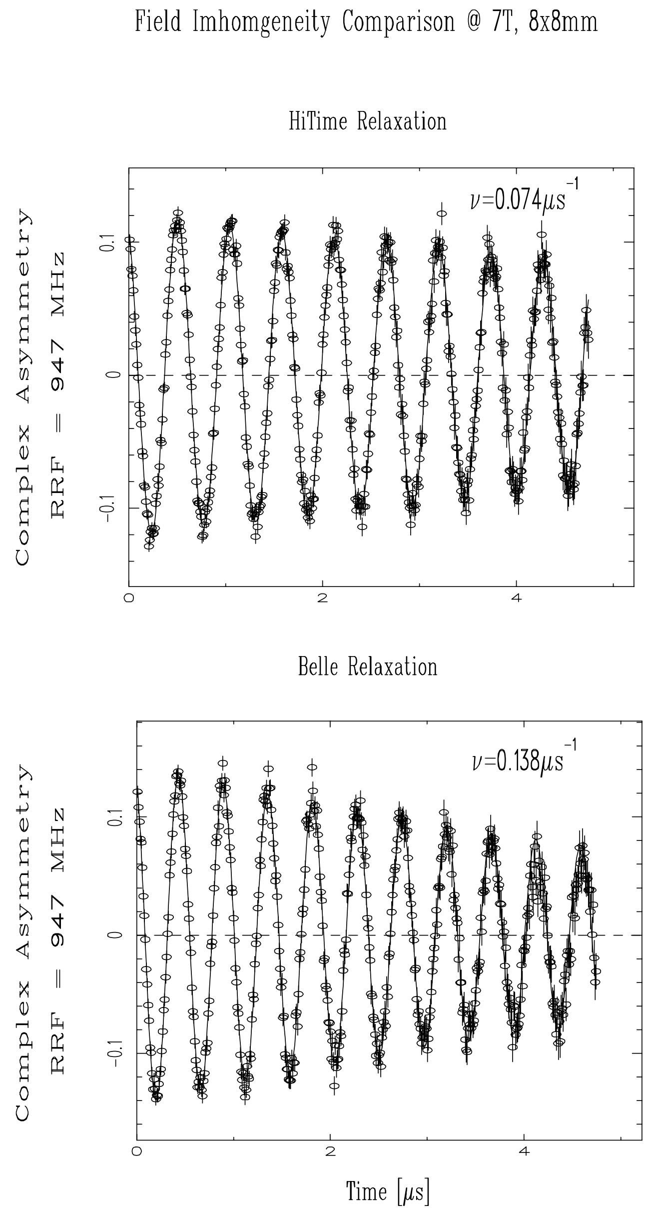


Fig. 122. Relaxation rate of the new HiTime magnet as compared with the original Belle magnet. The sample is an $8 \times 8$ mm pure Ag, which has an undetectable intrinsic relaxation rate. The decay of these spectra is then a measure of the external field's inhomogeneity. Even though the positioning in the HiTime magnet was not optimized, its decay time and hence homogeneity is at least twice that found in the old Belle.

improvements (see Figs. 121 and 122) in the two magnetic field parameters that count in high field $\mu$SR, namely field stability and homogeneity. The vastly improved stability will allow very long runs (lasting over a day if required) in which the field drift will still be well within the static distribution imposed by the magnet's (smaller) inhomogeneity.

**Helios**

From an operational point of view, the fabrication of a new Helios stand will allow much more rapid and reliable set up of this spectrometer. All counter sets have full skeletal support mounted on a heavy duty platform and rail system. Cryostat mounts have been redesigned with the goal of simple reliable and reproducible user adjustment. In addition, a design implementation with safety concerns taken into account from the outset now makes Helios very accessible regarding cryogenic management procedures.

**Inserts**

The capability to carry out experiments on samples (historically) considered too small for $\mu$SR has been addressed by the commissioning of our newest generation low-background insert. The distinguishing feature of this in-cryostat device is that it contains a muon aperture and active muon collimator in very close proximity to the sample, thereby keeping stray muons to a minimum. Coupled with a veto for muons which miss the sample, and position selective positron coincidence for the up, down and backward counters, this results in raw background rates that are about 1/1000 of the incoming muon rate. This low background rate allows small samples to be measured without the spurious background signals overly obscuring the physics being probed.

**Cryogenics**

**Miss Piggy**

A major redesign of the internals of the cryostat originally provided by Quantum Technologies had resulted in greatly improved cycle and stabilization times. Although a complete 290 K cool down from warm takes about 2.5 hours, once the outer shields have been cooled (often needs to be done only once) 200 K temperature traversals take less than 30 minutes.

**New horizontal gas flow**

A new HGF cryostat had been added to the cryogenic arsenal. It is almost an identical copy of our venerable existing HGF but with the additional feature of having a side access beam window. This increased versatility has already been put to good use in a series of experiments that required beam injection perpendicular to the cylindrical axis of cryogenic high pressure cells.

**$\beta$-NMR**

Further technical progress in the $\beta$-NMR program has been logged with the installation and testing of rf excitation capabilities (quadrature modulation), that allow for the application of frequency selective adiabatic pulses. These are the pulsed equivalent of an CW (continuous wave) polarization inversion in a limited frequency range. The pulsed equivalent of such capability greatly increases the experimental flexibility of the $\beta$-NMR experiment to map out line shapes accurately. The interested reader can refer to the recent article in the Journal of Magnetic Resonance, **153**, 155-177 (2001) or online at http://www.idealibrary.com/links/toc/jmre/153/2/0.

**Facility information and documentation**

Please refer to our Web site http://musr.triumf.ca for full access to a broad range of facility resources and information.

## Beam Lines

*(C. Ballard, TRIUMF)*

The Experimental Support group, which includes the Beam Lines group, is part of the Science Division and is responsible for the installation, alignment and maintenance of the experimental facilities at TRIUMF as well as the primary beam lines. As in 2000, the group supplied technical assistance to the existing experiments, primary and secondary channels in the meson hall as well as technical support to ISAC and CERN. The group also supported two co-op students and two summer students during the year.

In ISAC, the end of 2000 saw the completion of the MEBT and HEBT installations resulting in beam through DTL. In the year 2001, the group assisted on the LEBT installation including the polarimeter leading to the Osaka experiment and the $\beta$-NMR high voltage platform. The $8\pi$, DRAGON and TUDA experiments were installed and were taking data by the end of 2001. The success in ISAC was, in part, achieved through the coordinated efforts of Science Division, Cyclotron Division and ISAC Division. The planning of ISAC-II took place in the latter half of 2001.

In the vault, January's efforts were focused on the upgrade of beam line 1A. After 25 years of service, elements on the beam plane at the head end of 1A required an overhaul. The maintenance involved electrical and water header reconstruction. The upgrade went remarkably well.

In the meson hall, the group was also involved in completing the installation of the TWIST experiment in M13, which involved an area reconfiguration, the assembly of a 70 ton steel yoke for a large (1 m bore) superconducting solenoid, analogue and digital cable booms and a rolling platform for electronics racks.

Other projects in the meson hall included the continuation of the overhaul of the M9 separator, repairs to the M15 separator, M13 beamblocker, M9 beam blocker, upgrades to the M11 area and the TNF. The group also performed preventative maintenance on the water packages, vacuum systems and magnet power leads as well as the ongoing technical assistance to the proton irradiation facility, proton therapy, PET, ATLAS, $\mu$SR, and experimental support in the proton hall.

The CERN collaboration involved two technicians and a summer student on the assembly of nine PFN (pulse forming network) tanks. The tanks will be used in the LHC collider at CERN. Each tank weighs over 2 tons and consists of a bank of capacitors and resistors bathed in a silicon-based oil. The assembled tanks will be tested at TRIUMF and sent to Geneva.

The Beam Lines group continued to provide alignment assistance to ISAC, TWIST, Remote Handling and the RF group.

## Cryogenic Targets

*(C. Marshall, TRIUMF)*

A major construction project was the design, construction and testing of a new target for Expt. 744. The liquid hydrogen target was required to have low-mass walls in order to keep to a minimum the interaction with the electrons emitted by the nuclear reaction under study. In addition, the target and its supports had to fit into a small volume in the middle of a large magnet while allowing free entry and exit of the beam.

After extensive testing, a Divinycell and Kapton composite was utilized for the low-mass outer windows of the cryostat. A horizontal "wicking" heat pipe was designed to cool the tightly constrained target cell. However, its performance proved more development time was required, and it had to be abandoned. The work of design, fabrication, testing and installation was completed in time for a run with beam in early December, with the target operating successfully.

The second new target project was a liquid hydrogen cell for Expt. 875, a study of muon scattering. A dual length target cell (rotatable) with cooling system was designed and built to be mounted in a vacuum chamber supplied by the experimental group. The experiment did not run in 2001 due to delays in assembling other parts of the experiment.

Work was begun on reviving the polarized proton target for use in the CHAOS spectrometer (Expt. 862). The work involved upgrades to the control system, electrical services, and piping. Many of the components of the dilution refrigerator and its gas handling systems, having been out of service for years, required servicing and repairs. A new target angle will require modification of the cryostat and target cell.

## Computing Services

*(C. Kost, TRIUMF)*

### Overview

The new gigabit backbone has been extremely stable in supporting the over 800 networked devices connected to it. The FDDI ring has been removed. The increase in PC-based Linux systems continues unabated. Security concerns, hardware maintenance/upgrades, software management, etc. are largely mitigated by requiring adherence to site standards – although there is still a strong desire to reduce the number of flavours of Redhat Linux. Some local experience with configuring small clusters, along with acquiring information on mass tape and disk storage systems, has taken place in anticipation of a positive response to a Canadian Foundation for Innovation (CFI) application to fund a major (1500 cpu, 7Tb disk, 70Tb tape) farm to be located at UBC and used by several UBC departments (including TRIUMF). The phase-out of legacy hardware continued.

#### Modular approach

TRIUMF has taken a modular approach to provide an integrated computing environment. Enhancements to several modules took place this year:

- Linux backup facility is now based on a Super DLT tape system – with one drive and seven slots for an uncompressed capacity of about 770 Gbytes.
- Addition of a dual-cpu (1.0 GHz) PC running Windows-2000, to provide 20 more X sessions (mostly NCD terminals and Linux boxes) with the ability to run Windows applications.
- Windows print/file server/master domain controller upgraded from NT-4 to dual 1 GHz P3 Win2000.
- Replaced name and SNMP server with a faster PC.
- Replaced some colour X Window (NCD) terminals with PCs running Linux.
- Added 2 more colour laser printers to provide improved support for production of presentation transparencies.
- Added more memory and disk space to our central mail facility (which will see a complete upgrade next year).
- Wireless access (with minimal 56-bit encryption requirements) has been put in place in several key site locations.

#### Linux

Redhat Linux 6.2 and 7.2, the recommended standard at TRIUMF, continues to increase its dominance at the lab. Automatic nightly updates (mostly security related) are now regularly performed for more than 70 machines (representing the majority of Linux machines).

#### Hardware

TRIUMF collaborated as part of the UBC proposal for a 1500 CPU Linux farm, with 7 Tbytes of disk storage and 70 Tbytes of tape storage – which was part of a Canadian Foundation for Innovation (CFI) application put forth by a WestGrid consortium of several universities and other institutions located in BC and Alberta. TRIUMF would use about 25% of the UBC resources. It would prototype the much larger resources required to do future collaborative analysis of the ATLAS (CERN) experiment. A positive response is anticipated early in 2002.

Figure 123 shows the continued expansion (to a total of 32) of the use of Nortel Networks Baystack 450-24T switches strategically located around the site.

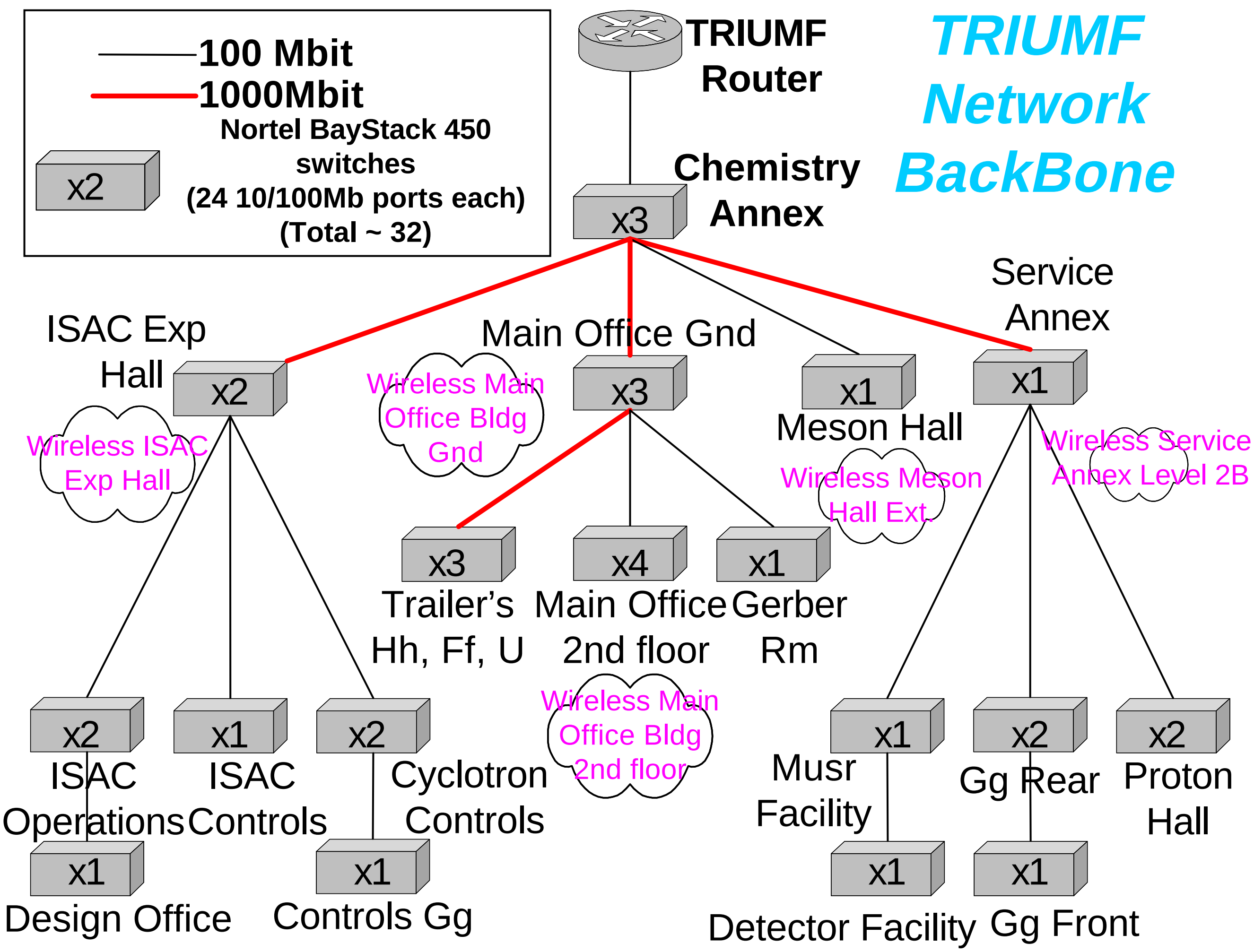


Fig. 123. TRIUMF network backbone.

**Computer security**

This was a significant year in that the entire Internet was hit by the Code Red and Nimda worms, which generated an unprecedented amount of network traffic and have still not been eradicated. TRIUMF was fortunate in having few Microsoft Web servers, but of those we have, half were infected (and found fairly quickly). We continue to run an automated scan reporter which contacts ISPs and machine owners about significant network scanning events. The reporter receives automated replies and occasional "thank you" notes. Subsequent to the Code Red worm, we started another reporter designed to alert owners of infected Windows PCs directly via a popup box. Some visualization tools were written for tracking worm progress and looked at the theoretical limits of worm propagation.

2001 also saw a large increase in the number of e-mail-borne viruses. Of note were the SirCam virus which targetted addresses found in Web pages as well as in address books, and the Magistr virus which continues to be found on a regular basis. The antivirus software reports to the sender where possible and again we receive occasional "thank you" notes and questions.

There has also been a significant rise in the amount of unsolicited (spam) mail arriving at TRIUMF, some having content beyond publicly accepted standards. The greater use of e-mail by staff has meant that more people are exposed via deliberate or inadvertent publishing of their address. A filter system, based on a number of on-line "blacklists", allows users to filter mail from tagged domains.

In response to the increase in socially unacceptable material spams, we have created an experimental keyword-based filter to augment the domain-based one. We have also moved to a pro-active anti-spam measure – all sites sending us mail are tested for open relay and immediately added to an on-line blacklist. The process also tries to contact machine owners or ISPs. The process also detects some open "contact forms" which have been used to send pornographic spam in particular. A "desktop security" committee was set up which meets regularly to discuss security concerns on different computing platforms with a view to formalising a security policy for TRIUMF and getting formal authority to control Internet access to devices at TRIUMF.

**Video conferencing**

A new computer was installed, dedicated to Internet based VRVS conferencing. An ISDN-based computer is regularly used for a number of conferences. A VRVS reflector was set up for use by the HEP community. A new computer, using RealVideo, and dedicated to Web casting, was used successfully to broadcast the annual meeting of the TRIUMF Users Group.

**Network measurements**

We continue to participate in the SLAC Pinger and the Oxford Traceping projects for WAN monitoring, as well as participating in the Bandwidth Challenge for SC2001. We also monitor the internal TRIUMF network for device availability and location using arpwatch, and extended this to gather data from the Baystack switches.

**Software developments**

**Physica**

This internationally popular, general purpose data analysis/display program continues to improve as reported bugs were fixed and requested enhancements were added – such as removing practical limits to the number of lines, DO loops, IF statements, and labels in a macro script.

- Increased flexibility of logarithmic axes.
- Enhanced unformatted file reading.
- Newfile qualifier on Write allows for unique file names in UNIX.
- Contour plots without axes can now have legends.
- Support for writing, reading, digitizing, and overlaying PNG bit-maps.

Much progress has been made for porting Physica to Windows, with about 30 new functions, 5 new operators, and about 20 new commands in place. The on-line help feature was completely redone, replacing the traditional Windows help structure with the newer and more flexible compiled html structure. Every new feature in the program has been documented in the on-line help.

A proof of principle Web based version of an on-line form of Physica was successfully implemented. It uses a modified Physica for Linux executable, together with a cgi script, and perl scripts to interpret the output of the Web based forms, allowing the browser user to interactively create Physica scripts and produce PNG graphics which are then displayed in the browser. PostScript hardcopy of the graphics is available.

An external user, Dr. Edward Sternin of Brock University, has already utilized the Web based version for "Physica-based data acquisition and analysis" for use by the undergraduate physics labs. For details refer to http://ohm.labs.brocku.ca/physica/.

**GEANT4**

An overview and survey paper on the GEANT4 project and software is expected to be published in a peer-reviewed journal in 2002. A member of our group edited chapter 3, "Software Process", composed of contributions from six section authors, as well as writing a new Introduction to the paper and participating in numerous teleconferences and author consultations.

Continuing last year's introduction of Tinderbox, an automated distributed Web based system testing framework, a series of cookbook recipes, detailing non-invasive changes to test scripts allowing Tinderbox monitoring and archiving of GEANT4 test jobs, were developed in collaboration with people at CERN. This work is scheduled for completion in 2002.

**GEANT4 hadronic physics**

Two new physics process classes, G4LEpp and G4LEnp, implementing $p{-}p$ and $n{-}p$ elastic scattering in the energy range 10 MeV to 1.2 GeV were written in consultation with L.G. Greeniaus and P. Wellisch. The classes are self-contained and incorporate differential cross section data obtained from the SAID database. These classes were then included in the GEANT4 4.0 release.

**TRIUMF-CERN LHC collaboration**

As part of our collaboration with CERN, we successfully applied the TRIUMF developed hybrid fast-multipole technique to the computation on beam-beam forces in the LHC. New results obtained for head-on and parasitic collisions were reported in a Phys. Rev. ST-AB paper.

In conjunction with a visit to CERN work was begun on extending the simulation code to include longitudinal effects, which had not previously been included in such studies. Presentations were given at CERN and TRIUMF group meetings to explain the physical and computational aspects of the problem and to get comments on it. This new study requires extensive (multiprocessor) computing resources and can act as one of the seed applications for developing and testing parallel commodity cluster facilities at TRIUMF.

**Beam dynamics**

The multiparticle simulation code ACCSIM continues to be used in a wide variety of accelerator applications including, most recently, proton driver studies for neutrino factories and internal cooling simulations for muons in FFAG's.

This year's goal was to make ACCSIM a standalone program, free of the need to use Dimad as a preprocessor for calculating lattice parameters and matrices. There were many good reasons for doing this, not least of which was the difficulty of working with transverse space charge, where the Dimad lattice elements had to be laboriously split into small pieces to allow ACCSIM to do space charge calculations within the elements.

Careful consideration of the various ways to proceed with this project, taking account of the present code and the ACCSIM user community, many of whom are not familiar with C++ and F90, led us to the solution of adapting Fortran code from MAD and Dimad, which had the bonus of being field-proven through many years of use.

With the permission of the Dimad and MAD authors, we incorporated the necessary routines for (1) parsing lattice input and generating data structures, (2) calculating lattice optical functions, and (3) computing element transfer matrices. To keep a maintainable architecture for ACCSIM, modifications to the new routines were kept to a bare minimum, and data were transferred cleanly from MAD to Dimad to ACCSIM data structures for the successive stages of input, run preparation, and simulation.

The expanded program has performed well in all tests so far, and in particular the automation of intra-element space charge was found to agree closely with previous results for various rings. Pending further refinements and new documentation, it is now in "beta testing" and is available to users by request.

The new ACCSIM was promptly put to work to study coherent space-charge resonances. We set up a simulation framework for the Fermilab Booster using ACCSIM, TRANSOPTR, and Matlab, to demonstrate that coherent (envelope) resonances present practical intensity limitations in such rings. A paper on this work was presented at PAC 2001.

**Miscellaneous**

- A Windows C++ version of the two-body kinematic program, Kin2Body, is now available.
- TRMAIL now facilitates Web browsing, filtering, vacation default/forwarding, and disk space usage analysis.
- VMS mail on the DAC VMS cluster was shut down. Plans are to de-activate this cluster in 2002.
- Most Linux systems are now reasonably secure.
- A complete TRIUMF Web pages redesign is scheduled for 2002.
- Plans were completed to move our central computing support hardware and personnel to the new ISAC-II building scheduled for occupancy in early 2003.

## Data Acquisition Systems

*(R. Poutissou, TRIUMF)*

**Overview**

The TRIUMF data acquisition system MIDAS is now deployed over 20 stations around the laboratory. These machines also provide significant off-line analysis resources and disk storage.

Table XIV. Computer systems with MIDAS software managed by the DAQ group.

| Name | Location | Type |
|---|---|---|
| isdaq01 | ISAC-LE, $\beta$-NMR, TRINAT | 2xPII/450 |
| isdaq02 | ISAC-LE, GPS, LTNO | PIII/500 |
| isdaq03 | ISAC-HE, TUDA | 2xPIII/550 |
| isdaq04 | ISAC-HE, DRAGON | 2xPIII/550 |
| isdaq05 | ISAC-LE, Osaka | PIII/1000-256 |
| isdaq06 | ISAC-HE | PIII/1000 |
| isdaq08 | ISAC-HE, $8\pi$ | 2xPIII/1000 |
| midtis01 | TRINAT DAQ | 2xPIII/550 |
| midtis02 | Detector Facility | PPro/200 |
| midtis03 | LTNO platform DAQ | PII/350 |
| midtis04 | GPS DAQ | 2xPIII/550 |
| midtis05 | DRAGON floor DAQ | PII/350 |
| midmes01 | Detector Facility | PIII/500 |
| midmes03 | RMC DAQ | 2xPIII/550 |
| midmes04 | Meson hall tests | PII/350 |
| midmes05 | Detector Facility | PII/350 |
| midmes06 | $8\pi$ Slow Control | PII/166 |
| e614slow | TWIST Slow Control | PII/400 |
| midtwist | TWIST DAQ | 2xPIII/1000 |
| midm9b | M9B $\mu$SR DAQ | 2xPIII/600 |
| midm15 | M15 $\mu$SR DAQ | 2xPIII/600 |
| midm20 | M20 $\mu$SR DAQ | 2xPIII/600 |
| dasdevpc | DAQ development and Web server | PIV/1700 |

**MIDAS software**

The software development effort for MIDAS this year has been focused towards: a) support for newer hardware modules such as Hytech PCI/CAMAC, Wiener PCI/VME interfaces and other VME modules, b) improved user interface for experiment control through the Web browser, c) Web documentation, d) driver portability across different operating systems.

The DAQ group has also contributed to the 12$^{th}$ IEEE Real Time Congress on Nuclear and Plasma Sciences, Valencia, June, 2001, with a paper entitled *Real time control/monitoring and data acquisition system for nuclear polarization experiments with implanted radioactive ions.*

There was a significant effort on documentation (see http://midas.triumf.ca/docmidas/index.html).

**NOVA software**

Version 2.2 of the NOVA analysis system was released during 2001. Several experiments at TRIUMF (and elsewhere) are using NOVA both for real-time monitoring of their experiment and subsequent data analysis. An interface/data unpacker was developed for the DRAGON experiment, and the TRINAT analysis code was modified to allow them to upgrade to the newest version of the software.

**ISAC systems**

Support for new experimental zones has been provided, in particular for TUDA, where specific software code has been written to accommodate the private event analyzer running on Solaris computers. DRAGON, TOJA and Osaka are other experiments where the DAQ group has been involved in set-up and running support.

The six DAQ machines in the two counting rooms are organized in a NIS cluster to allow each group access to all CPUs, data disks and logging facilities transparently. We presently offer a CDrom RW drive, Exabyte 8500 drives and a DLT 4000 drive.

**$\beta$-NMR at ISAC**

Further modifications and improvements were made to the $\beta$-NMR data acquisition system. In particular, problems with stepping the voltage of the sodium cell (via EPICS) were investigated and solved. Several new features required by experimenters were added. The process of changing between different experimental modes was simplified, and extensive documentation was written.

**TWIST**

The full TWIST DAQ with two front end FASTBUS crates was commissioned. A special MIDAS task called the Event Builder was developed to combine a portion of events from each of the FASTBUS crates. Sustained data rates of 2500 events/sec and 5 Mbytes/sec were obtained. Logging is done to a DLT8000 drive.

A completely functional implementation of the slow controls system for the TWIST experiment was completed during 2001. The system includes multiple front ends, interfacing several programmable digital voltmeters, a CAMAC branch and a custom serial interface responsible for control and monitoring of the 260 post-amplifier boards required for the experiment. High voltage control and monitoring is carried out via CAMAC. In addition, several parameters of the proton beam are provided by the TRIUMF Controls group via a CAMAC memory unit.

All slow controls data are maintained in the MIDAS on-line database (ODB), where they are immediately available (via a Tcl interface) to the experimenter. Parameters are continually monitored and checked against user-selectable limits. When a parameter goes outside these limits, an alarm is immediately raised, informing the shift crew of the problem. The system worked well during engineering runs in 2001, and is being upgraded in preparation for physics runs in 2002.

A preliminary version of a similar system was implemented for DRAGON, providing them with access to many of their beam line elements.

**$\mu$SR systems**

For $\mu$SR, work continued on the new MIDAS-based system. A prototype MIDAS front end was written to replace the present front end (running on a PowerPC under VxWorks). Our student returned and incorporated support for a SIS3803 scaler into the new front end, and added the histogram readout. He also modified the Tcl/Tk user interface.

**Other experimental stations**

In the meson hall, both the RMC and the CHAOS DAQ were in use during 2001 and required support from the DAQ group. JLAB Hall D detector studies by the Regina group and aerogel tests by the Manitoba/CalTech $G\emptyset$ group used the meson DAQ facilities.

Three DAQ stations are provided in the detector facility. They were used in turn for detector developments by the BNL E949 group, the KOPIO group, the DRAGON group, the TWIST group and the HERMES group.

## Detector Facility

*(R. Henderson, TRIUMF)*

This year has been a very active and successful year for the Detector Facility. The facility has been almost fully occupied with the Expt. 614 project (TWIST).

The TWIST project is a sophisticated experiment which hopes to measure the Michel parameters to ten times the precision they are now known. TRIUMF members are playing a central role in this collaboration. Robert Henderson has designed the various detector modules and was largely responsible for the design of the complex "cradle" that holds, aligns and services the nineteen modules in the experiment. Robert Openshaw designed and commissioned the complex gas system. Wayne Faszer designed and built the high precision wire surveyor, and oversees module assembly, testing and QC. In December, the TWIST project finished a highly successful commissioning run of the full detector stack (19 modules) in the solenoid at full field (20 kG). The cradle and detectors were then returned to the Detector Facility for module cleaning, minor repairs and axial compression tests. The cradle will return to M13 in April, 2002 for further commissioning and the start of data-taking.

The TWIST detector module used so far is not the final design. It will be used for the first year of commissioning and data-taking. A final target module with a 6-position wheel is being designed. A low pressure TEC (time expansion chamber) is also being designed. This detector will be placed upstream of the solenoid yoke, to measure incoming muon polarization. All 19 TWIST modules are in operation, spare modules are being completed. This has been a major effort of the Detector Facility and an extremely successful one. The new target module and TEC will be fabricated and tested in the facility, but the group's contribution to TWIST will taper off in the next six months.

In the scintillator shop, the large NC machining effort for TWIST is nearing completion. In addition, a variety of scintillators have been built, the biggest customer being the $\mu$SR group. E929 at BNL also required several scintillator jobs. Two of these were small, but highly complex assemblies. This year fewer scintillators were required at TRIUMF and the shop committed to making a large number of scintillators for the $G\emptyset$ experiment at CEBAF, this involves about 0.9 man-years of shop time over an 18 month period. After significant delays, the $G\emptyset$ group finalized the design and these scintillators are now in production.

The construction of the ATLAS modules is expected to be finished by June, 2002, concluding a highly successful production and testing program at TRIUMF. The ATLAS project has been using most of the Detector Facility's large clean room (originally called the HERMES and then BABAR clean room). The Detector Facility did a great deal to set up ATLAS for production. Since then we have only needed to contribute 100% of Rich Maharaj's time and 30% of Peter Vincent's time. Production and shipping of ATLAS modules to CERN has been steady. The end of module production completion will free up two clean rooms and their shared use of the "semi-clean" room near RMC.

Our other major activity has been design and prototyping work for the KOPIO experiment. This is a very large project planned for BNL and has enthusiastic support from DOE. Doug Bryman is head of the TRIUMF/KOPIO group and Robert Henderson has joined the collaboration. It is expected that TRIUMF will be responsible for design, fabrication and testing of the large pre-radiator modules required. The experiment will require 32 modules, plus two spares. Each module has an area of 2.5 × 2.5 m and consists of 8 wire-planes sandwiched between 9 scintillator layers. The wire-planes have anode and cathode-strip readouts and the scintillator layers use wave-shifting-fibre readout. Each module weighs approximately 2 tons.

This project (if NSERC approved) will be of comparable size to the ATLAS calorimeter work at TRIUMF and will be the major project in the Detector Facility for the next four years. At present it represents a significant design and prototyping effort with a goal of first pre-production module by mid-2003.

## GEANT4

*(P. Gumplinger, TRIUMF)*

Modern high energy physics experiments pose enormous challenges in software engineering. Of particular importance is the ever-increasing demand for large-scale, accurate and comprehensive simulations of the particle detectors used in these experiments. The demand is, in part, driven by the escalating size, complexity, and sensitivity of the detectors and, in part, by the availability of moderate-cost, high-capacity computer systems on which larger and more complex simulations become possible. Similar considerations arise in other disciplines, such as: radiation physics, space science, nuclear medicine and, in fact, any area where particle interactions in matter play a role.

In response to this, a new object-oriented simulation toolkit, GEANT4, has been developed. The toolkit provides a diverse, wide-ranging, yet cohesive set of software components which can be employed in a variety of settings. These range from simple one-off studies of basic phenomena and geometries, to full-scale detector simulations for experiments at the Large Hadron Collider and other facilities.

In defining and implementing the software components, all aspects of the simulation process have been included: the geometry of the system, the materials involved, the fundamental particles of interest, the generation of primary events, the tracking of particles through materials and electromagnetic fields, the physics processes governing particle interactions, the response of sensitive detector components, the generation of event data, the storage of events and tracks, the visualization of the detector and particle trajectories, and the capture and analysis of simulation data at different levels of detail and refinement.

Early in the design phase of the project, it was recognized that while many users would incorporate the GEANT4 tools within their own computational framework, others would want the capability of easily constructing stand-alone applications which carry them from the initial problem definition right through to the production of results and graphics for publication. To this end, the toolkit includes built-in steering routines and command interpreters which operate at the problem set-up, run, event, particle transportation, visualization, and analysis levels, allowing all parts of the toolkit to work in concert.

At the heart of this rather diverse collection of code is an abundant set of physics models to handle the interactions of particles with matter across a very wide energy range. Data and expertise have been drawn from many sources around the world and in this respect GEANT4 acts as a repository that incorporates a large part of all that is known about particle interactions; moreover it continues to be refined, expanded and developed. A serious problem with previous simulation codes was the difficulty of adding new or variant physics models; development was difficult due to the increasing size, complexity and interdependency of the procedure-based code. In contrast, object-oriented methods have allowed us effectively to manage complexity and limit dependencies by defining a uniform interface and common organizational principles for all physics models. Within this framework, the functionality of models can be more easily seen and understood, and the creation and addition of new models is a well-defined procedure that entails little or no modification to the existing code.

GEANT4 was designed and developed by an international collaboration, formed by individuals from a number of cooperating institutes and universities, including from Canada: TRIUMF, UBC, University of Alberta and the University of Montreal. It builds on the accumulated experience of many contributors to the field of Monte Carlo simulation of physics detectors and physical processes. While geographically-distributed software development and large-scale object-oriented systems are no longer a novelty, we consider that the GEANT4 Collaboration, in terms of the size and scope of the code and the number of contributors, represents one of the largest and most ambitious projects of this kind. It has demonstrated that rigorous software engineering practices and object-oriented methods can be profitably applied to the production of a coherent and maintainable software product, even with the fast-changing and open-ended requirements presented by physics research.

For example, GEANT4 is an ideal framework for modelling the optics of scintillation and Čerenkov detectors and their associated light guides. This is founded in GEANT4's unique capacity of commencing the simulation with the propagation of a charged particle and completing it with the detection of the ensuing optical photons on photo sensitive areas, all within the same event loop. This functionality of GEANT4 was developed exclusively at TRIUMF and is now employed world-wide in experimental simulations as diverse as ANTARES, AMANDA, LHCb and HARP.

In GEANT4 the concept of *optical photons* is a class of particles detached from their higher energy *gamma* cousins. This implementation allows processes to be associated to them arising from the wave like property of electromagnetic radiation. Optical photons are produced in the simulation as a result of Čerenkov radiation, scintillation, or transition radiation, and the GEANT4 catalogue of processes at optical wavelengths includes refraction and reflection at medium boundaries, bulk absorption and Rayleigh scattering.

The collaboration provides user support and documentation for the toolkit. The documentation includes installation, user and reference guides, and a range of training kits. User support covers help with problems relating to the code and assistance with using the program. We welcome and respond to enhancement requests, and of course, a user may expect assistance in investigating anomalous results. To facilitate the communication, a Web-based reporting system and a list of frequently asked questions (FAQs) are available on the public GEANT4 Web page.

GEANT4 employs the concurrent versions system (CVS) which maintains a central repository for all documents and source code and provides all the necessary functionality for change management. When new or modified code is tagged for testing, CVS automatically sends the relevant information to an extended version of Bonsai, a Web-based CVS query and database system. Bonsai has been modified to support tags-based processing and to provide an on-line form where developers can submit new tags for system testing. Another Web-based tool, Tinderbox, is being expanded and adapted to GEANT4 and will provide automated monitoring, logging, and problem detection and reporting (including hyperlinks to suspect source code) for all system tests, both completed and in progress. To aid with both development and testing, we maintain an indexed and cross-referenced source code browsing facility based on LXR. The bug reporting system is a customized version of the open source reporting tool Bugzilla. Besides routing the problem to specialists, it tracks and documents the responses until the problem is resolved. The Collaboration also maintains a Web-based user forum, G4Hypernews, with sub-forums according to areas of different interest.

TRIUMF collaborators have been active in almost all areas of user support, documentation, testing and quality assurance, and in particular the development of associated tools. We continue to make upgrades to the most venerable hadronic physics package provided with GEANT4. In 2001, we added classes describing $p-p$ and $n-p$ elastic scattering in the energy range of 10 MeV to 1.2 GeV. The classes are self-contained and incorporate differential cross section data from the SAID database.

We have assisted Rachid Mazini, from the University of Montreal, in the comparison of GEANT4 with ATLAS test beam data for the Hadronic Endcap Calorimeter and Forward Calorimeter. One of us traveled for this purpose to Montreal in January, 2001. In the fist quarter of last year, we supervised a co-op student, Yong Liang Zhao, who developed a GEANT4 based simulation program for the TWIST experiment. This work produced remarkable results for the prediction of how surface muons range out in the detector and come to rest in the stopping target. We have also assisted over a period of four months, and mostly by e-mail, an undergraduate student at the University of Montreal, David Cote-Ahern, to develop and test the correctness of spin tracking in GEANT4.

TRIUMF collaborators have been responsible for obtaining and editing contributions from section authors of two chapters in the GEANT4 General Paper. We have also authored several sections. The paper is now in semi-final draft and is expected to be submitted for publication in early 2002. We have contributed to the general review of the structure and content of GEANT4 documentation on the Web. For these and Technical Steering Board matters, we participated in numerous video- and teleconferences throughout the year and two of us attended the annual GEANT4 workshop in Genoa, Italy, in July.

Collaboration development highlights in 2001 include two incremental releases in April and June, and a major new release, 4.0, in December. The program now supports secondary particle production cuts per material, random number generator seeding per event, and magnetic fields assigned to volumes. The TRIUMF team helped prepare the requirement for some of these improvements. Finally, the full migration of GEANT4 to CLHEP 1.7 has been achieved.

The GEANT collaborators are: J. Chuma, P. Gumplinger, F.W. Jones, C.J. Kost, M. Losty, TRIUMF; L.G. Greeniaus, University of Alberta.

**Scientific Services**
*(M. Comyn, TRIUMF)*

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 2001 included: producing the 2000 Annual Report, the TRIUMF preprints, and the KOPIO draft technical design report; refining the new database system for the Library; updating the display material in the front lobby; and supporting eleven past, present and future conferences and workshops.

**Publications Office**

The TRIUMF Annual Report Scientific Activities has been truly electronic since 1998. Electronic files have been used throughout, from initial contributor submission, through editing, transmission via ZIP disk to the printer, and subsequent direct printing on a Xerox Docutech system. The same files are used for the WWW versions of the report which are available at http://www.triumf.ca/annrep in both Portable Document Format and PostScript file formats. Unlike the monochrome paper version, the electronic versions allow those figures which were submitted in colour to be both viewed and printed in colour. The WWW version of the 2000 report was available to readers five weeks before the printed version. During the last two months of 2001, over 300 people accessed the 2000 Annual Report via the WWW. The Annual Report mailing list has been reduced and the trend is expected to continue as people become more accustomed to accessing the information over the WWW. This will result in less copies having to be printed, with subsequent cost savings.

In an attempt to aid and encourage authors to submit Annual Report contributions in the correct format, the instructions available on the WWW were refined. The LaTeX $2_\varepsilon$ skeleton file was upgraded to introduce new features, and the instructions document which all authors should consult was expanded to include details of these new features, plus additional information on the correct production of Encapsulated PostScript files for the figures.

Illegal code embedded in Encapsulated PostScript files continues to be a major problem in electronic publishing. Some software packages, such as the TRIUMF graphics routines, fully conform to the Encapsulated PostScript specifications, whereas many do not. In order to alert authors to problems encountered with files they submitted the previous year, and in an attempt to prevent similar problems recurring, a postmortem of the 182 figures in the 2000 Annual Report was produced and included on the Web site to supplement those for the 1998 and 1999 Annual Reports. This analysis and explanation of solutions is viewed as an ongoing project which will evolve as new procedures are devised and software packages become available for editing bad PostScript code. Superior TRIUMF scientific publications should result. See http://www.triumf.ca/annrep/figures.html for details.

TRIUMF preprints are now only produced electronically, and immediately posted on the WWW at http://www.triumf.ca/publications/home.html to allow rapid dissemination of the publications. This has replaced the traditional distribution of paper copies by mail, resulting in significant savings of both cost and labour.

Considerable effort was expended producing the KOPIO draft technical design report for review by the U.S. National Science Foundation.

A $\LaTeX\,2_\varepsilon$ skeleton file was produced, based on modifications to the book document class and other style files, to allow future volumes of Advances in Nuclear Physics to be published with almost exactly the same format as previous editions which were produced using proprietary and extremely complex $\TeX$ code. Superior automated features were also introduced.

Work for the Joint Accelerator Conference Website (JACoW) committee included refining the $\LaTeX\,2_\varepsilon$ templates for use initially at the Particle Accelerator Conference (PAC2001), which was held in Chicago in June, and later at future conferences in the JACoW series. An invited review talk on trends in electronic publishing over the last five years and predictions for the future was given at the JACoW Workshop held in Frascati in March.

**Library**

The Library budget was increased in 2001 to compensate for rising journal subscription costs and unfavourable exchange rates for 2002 renewals, thereby maintaining the list of journals which have been acquired since the last cutbacks in 1998. However, the journal subscription budget and electronic access alternatives are constantly under review.

The Library made very few book purchases in 2001 and continues to rely on donations for most of its acquisitions.

The Oracle database system implemented in 2000 was refined to facilitate efficient Library operations. It allows accurate tracking of the journal subscription acquisitions and hence aids subsequent timely requests to publishers for any missing volumes. It also identifies any volumes which have been illegally removed from the Library prior to the annual spring bookbinding exercise. All books loaned from the TRIUMF Library are entered in the database and automatic e-mails are sent to borrowers who fail to return a book after a month, followed by weekly reminders. This system has proved to be extremely successful at ensuring the prompt return of books, with the added advantage that several borrowers have also returned books which have been out for extended periods. Records for books acquired before 1970 have to be entered manually whenever they are first loaned, and all new acquisitions have to be entered. Outstanding loan reports can be generated easily.

The Library operates on a self-serve basis and manages with minimal support for day-to-day operations.

**Information Office**

Following a resignation early in the year, the Information Office and Conference functions were combined.

The Information Office coordinated tours for over 1,900 people during 2001. The general public tours were conducted by a summer student during the June to August period when tours were offered twice a day. Compared to recent years, a record number of people (290) took a record number of tours (68) during the three month period. Throughout the remainder of the year for the twice weekly general public tours, and for the many pre-arranged tours given to high school students and others, a small, dedicated group of TRIUMF staff acted as tour guides.

During the year new display panels for PET were produced as part of an effort to gradually redesign the layout of the lobby. The ISAC model was also upgraded to show new low and high energy beam lines and facilities.

The TRIUMF Welcome Page, which is accessible directly at http://www.triumf.ca/welcome or via the TRIUMF WWW Home Page, continues to receive over 5,000 visits each year. The series of WWW pages were developed by two co-op students. They are intended to provide an overview of TRIUMF in a format understandable to the general public. The virtual tour of TRIUMF allows people to "visit" from anywhere in the world via the WWW, or to gain a good introduction before coming to TRIUMF for a real tour. The latter is particularly intended for students using TRIUMF and its science as part of school projects. The Information Office responds to any questions posed by visitors to the site. Some of the pages were updated during the year. At year end efforts began to use outside resources to totally overhaul those parts of the TRIUMF Web site directed at the general public.

Various TRIUMF images found on the WWW pages continue to be in demand for use in text books and on other Web pages.

Use of the Sony VPL-PX20 LCD data projector purchased in 2000 increased rapidly as more speakers gave seminars and presentations using MS PowerPoint, Star Office, and other applications.

Support was provided to the TRIUMF Users' Group throughout the year by the TUEC Liaison Officer.

**Conferences**

During 2001 support was provided for the following conferences and workshops.

- $38^{\text{th}}$ Western Regional Nuclear and Particle Physics Conference (WRNPPC'01) and Workshop on Experimental Facilities for ISAC-II, Lake Louise, AB, February 15–18 (58 delegates).
- Summer Nuclear Institute at TRIUMF (SNIT 2001), TRIUMF, July 9–20 (24 delegates).
- Low Temperature Nuclear Orientation Workshop, TRIUMF, August 9–10 (25 delegates).
- Future Opportunities for Neutrino Physics Workshop, Dunsmuir Lodge, Sydney, Vancouver Island, BC, November 8–11 (75 delegates).
- TRIUMF Users' Group Annual General Meeting, TRIUMF, December 12 (49 delegates).

In addition, preparations were made for the following future conferences and workshops.

- Joint Belle-BaBar Worshop on Detector Issues, TRIUMF, February 14–16, 2002.
- Workshop on Low Energy Precision Electroweak Measurements (LEPEM2002), TRIUMF, April 4–6, 2002.
- TITAN Workshop, TRIUMF, April 11–13, 2002.
- Alpha Therapy Workshop, TRIUMF, April 29, 2002.
- $14^{\text{th}}$ International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications (EMIS XIV), Victoria, May 6–10, 2002.
- Summer Nuclear Institute at TRIUMF (SNIT 2002), TRIUMF, June 10–21, 2002.
- Big DRAGON Workshop, TRIUMF, July 18–19, 2002.

## Sudbury Neutrino Observatory

*(R. Helmer, TRIUMF)*

The first physics results from the SNO experiment were published this year, including the fluxes measured with the charged current (CC) reaction with deuterium and the elastic scattering (ES) reaction with electrons. SNO measured

$$\phi^{\text{CC}}_{\text{SNO}}(\nu_e) = 1.75 \pm 0.07(\text{stat})^{+0.012}_{-0.011}(\text{syst}) \pm 0.05(\text{theor}) \times 10^6\ \text{cm}^{-2}\text{s}^{-1}$$

and, assuming no flavour transformations,

$$\phi^{\text{ES}}_{\text{SNO}}(\nu_x) = 2.39 \pm 0.34(\text{stat})^{+0.16}_{-0.14}(\text{syst}) \times 10^6\ \text{cm}^{-2}\text{s}^{-1}.$$

The difference between the $^8$B flux measured with the ES and CC reactions is $0.64 \pm 0.40 \times 10^6$ cm$^{-2}$s$^{-1}$, or 1.6 $\sigma$.

The rate of ES reactions has been measured to much higher statistical and systematic precision by the Super-Kamiokande collaboration [Fukuda *et al.*, Phys. Rev. Lett. **86**, 5651 (2001)], and, again assuming no flavour transformations, leads to

$$\phi^{\text{ES}}_{\text{SK}}(\nu_x) = 2.32 \pm 0.03(\text{stat})^{+0.08}_{-0.07}(\text{syst}) \times 10^6\ \text{cm}^{-2}\text{s}^{-1}.$$

The SNO result is consistent with this flux measurement. The difference between the Super-Kamiokande ES measurement of the $\nu_x$ flux and the SNO CC measurement of the $\nu_e$ flux is $0.57 \pm 0.17 \times 10^6$ cm$^{-2}$s$^{-1}$, or 3.3 $\sigma$. This result provides strong evidence that part of the flux measured by Super-Kamiokande consists of another active flavour distinct from $\nu_e$.

The total flux of solar neutrinos can be determined from the combined ES and CC measurements, assuming transitions to active neutrino flavours. Comparison with the ES results from Super-Kamiokande yields

$$\phi(\nu_{\mu\tau}) = 3.69 \pm 1.13 \times 10^6\ \text{cm}^{-2}\text{s}^{-1}$$

and

$$\phi(\nu_x) = 5.44 \pm 0.99 \times 10^6\ \text{cm}^{-2}\text{s}^{-1}.$$

This total is consistent with theoretical expectations ($5.05 \pm 1.00 \times 10^6$ cm$^{-2}$s$^{-1}$) [Bahcall *et al.*, Astrophys. J. **555**, 990 (2001)].

SNO is now firmly into the data-taking phase of the experiment, and the need for infrastructure support from TRIUMF is greatly diminished. During the past year only some small parts required for the deployment of one of the calibration sources were fabricated here.

## DRAGON Facility

*(D. Hutcheon, TRIUMF)*

DRAGON (**D**etector of **R**ecoils **A**nd **G**ammas **O**f **N**uclear Reactions) is a facility for the study of radiative capture reactions with unstable beams, of interest in nuclear astrophysics. Its principal components are: a windowless gas target; an array of scintillation counters to detect the capture $\gamma$-rays; an electromagnetic mass separator to transport the heavy product of the reaction and separate it from the beam; and a detector of the heavy recoil particles.

During 2001 the major components of the separator and gamma array were installed, commissioning measurements carried out using stable beams, and a first experiment run with unstable beam (Expt. 824). The facility demonstrated an ability to detect reactions as rare as one per $10^{12}$ incident particles in a $^{21}$Na beam. When combined with the intense beams available from ISAC, DRAGON provides capabilities unmatched anywhere else in the world.

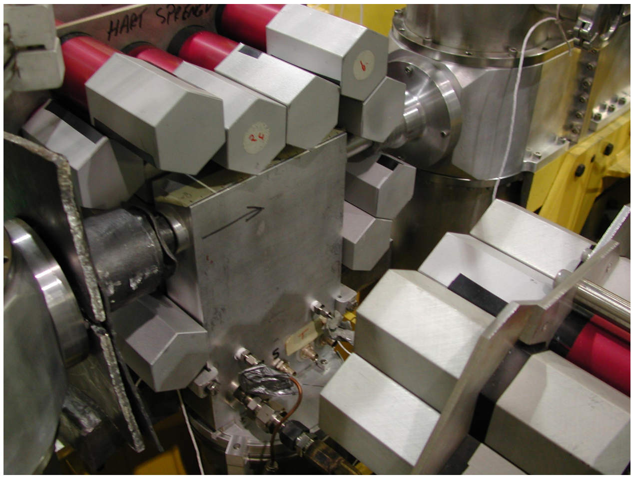

Fig. 124. The DRAGON array of BGO detectors with one half of the array pulled back to show the vacuum box of the gas target.

**Installation**

The gamma array consists of 30 hexagonal BGO scintillators, close-packed around the vacuum box of the gas target. The solid angle coverage is ≈80% and the efficiency for detecting a $\gamma$-ray in the full-energy peak is calculated to be 45–55%. The 30-fold segmentation was chosen because of the expected background of 511 keV annihilation quanta due to beam-spill at the target – most beams of interest decay by positron emission. The BGO scintillators are mounted horizontally on two frames, each frame mounted on a trolley which can be rolled aside to provide access to the gas target.

The electromagnetic separator, 20 m long, consists of 2 large magnetic dipoles, 2 electrostatic dipoles, 10 quadrupoles, 4 sextupoles and 4 pairs of steering magnets. Faraday cups and X-Y slits are located in diagnostics boxes at 3 focus locations, and beam-centring monitors at 6 additional places. Installation of electromagnetic components was completed and the assembly of the vacuum/diagnostics system took place in stages during the first 8 months of the year. The only significant problem was the inability of a supplier to produce all of the required ceramic insulation tubes for the high-voltage supplies of the electrostatic dipoles, which are intended to run at up to 200 kV; substitute tubes made of nylon were installed on one of the two EDs, and have proven adequate for experiments to date (up to 155 kV). Further details about the installation of diagnostics and the ED units appear in the Engineering section of the Accelerator Technology Division chapter of this Annual Report.

The DRAGON control system is based on EPICS, the ISAC site standard. Through a graphical interface the user has an integrated view of the separator magnets and diagnostic devices (Faraday cups, slits, beam-centring monitors), and of the pumps, valves and gauges of the gas target and separator vacuum systems.

The recoil ions from the capture reaction were detected at the end of the separator in a double-sided silicon strip detector (DSSSD) located 0.5 m beyond the slits at the final focus. Position resolution of 3 mm was set by the width of the front and back strips. The total area covered by the DSSSD was 48 mm × 48 mm.

**Gas target profile**

The profile of target gas density along the beam direction was measured using the $\gamma$-rays from de-excitation of the 4.43 MeV state of $^{12}$C, produced by the $^{15}\mathrm{N}(p,\alpha)^{12}\mathrm{C}$ reaction. Two arrangements of gamma detection were used. In the first, a partial BGO array, on only one side of the target, measured a resonance yield and calculated its position centroid for different beam energies. In the second method, a single detector was collimated so as to view a short section of the target, at 90° to the beam direction. The beam energy was set to an off-resonance region and yields measured as the collimated detector was scanned parallel to the beam direction.

The measurements showed that most of the gas seen by the beam lay within the central gas cell, but significant amounts of gas were in the target vacuum box and the nearest differential pumping tubes. This does not affect capture experiments with narrow resonances, but complicates the analysis of experiments looking at direct capture or at broad resonances.

**System performance**

Strong resonances at 270 keV/u and 762 keV/u in the $^{21}\mathrm{Ne}(p,\gamma)^{22}\mathrm{Na}$ reaction were a useful tool for studying the performance of DRAGON. The spectrum of $\gamma$-rays measured in coincidence with $^{22}$Mg ions from the 762 keV/u resonance is shown in Fig. 125.

Beam suppression by the separator depended strongly on the energy of the beam and on the opening of slits. The beam background came predominantly in a peak at nearly the full beam energy, clearly resolved from the recoil product at higher beam energies. Figures 126 and 127 show the heavy-ion energy spectra in the DSSSD for singles events and in coincidence with a $\gamma$-ray, for the 762 kev/u and 260 keV/u resonances. The separator suppression factors were $4 \times 10^{-10}$ and $3 \times 10^{-12}$ at 270 and 762 keV/u, respectively. Further suppression can be achieved by cuts on energy, position and timing in the DSSSD, the cuts being most effective at higher beam energies. No beam background was seen in the DSSSD energy spectrum for events with a coincident $\gamma$-ray.

The performance of DRAGON with unstable beam reactions is reported in the section on Expt. 824 in this Annual Report.

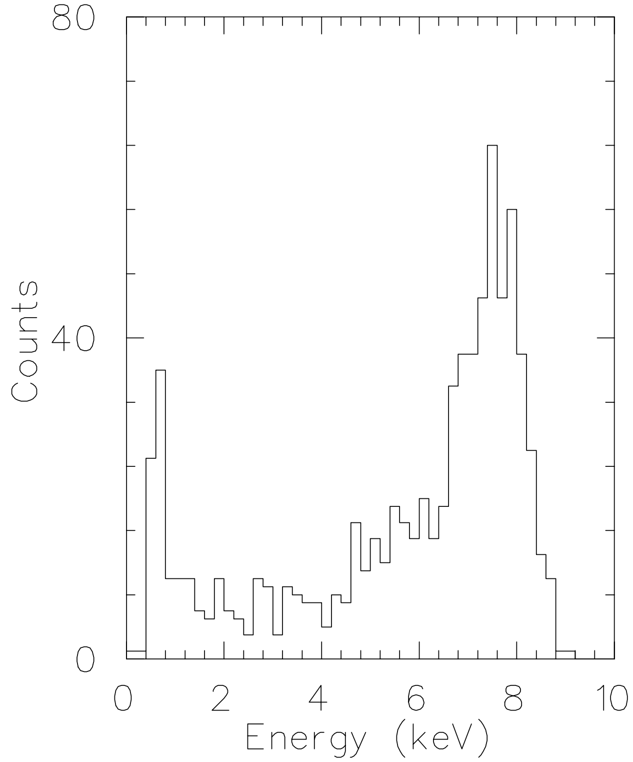


Fig. 125. Response of the BGO array to $\gamma$-rays from decay of the state at 7.47 MeV excited by the $^{21}Ne(p,\gamma)^{22}Na$ reaction.

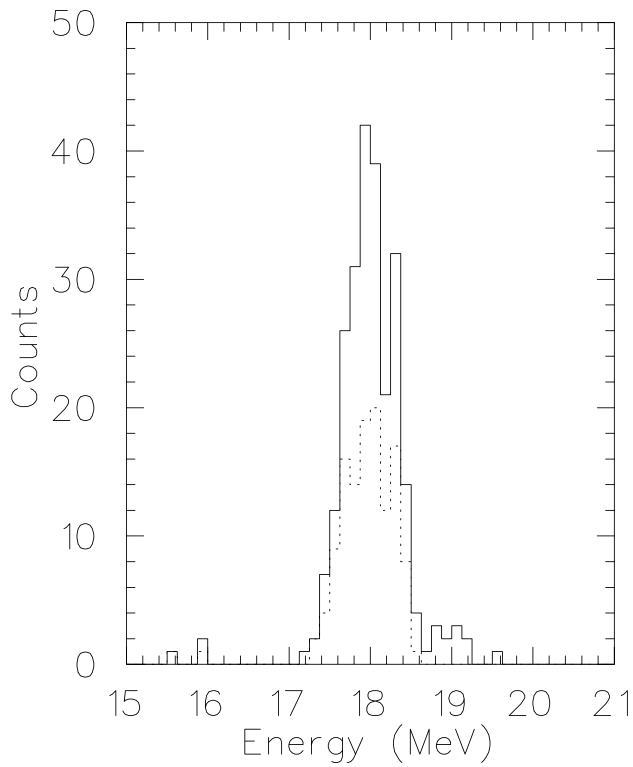


Fig. 126. $^{22}$Na recoils (peak at 18 MeV) and beam background (19 MeV) produced by a 767 keV/u $^{21}$Ne beam. The dotted histogram shows recoils in coincidence with capture $\gamma$-rays.

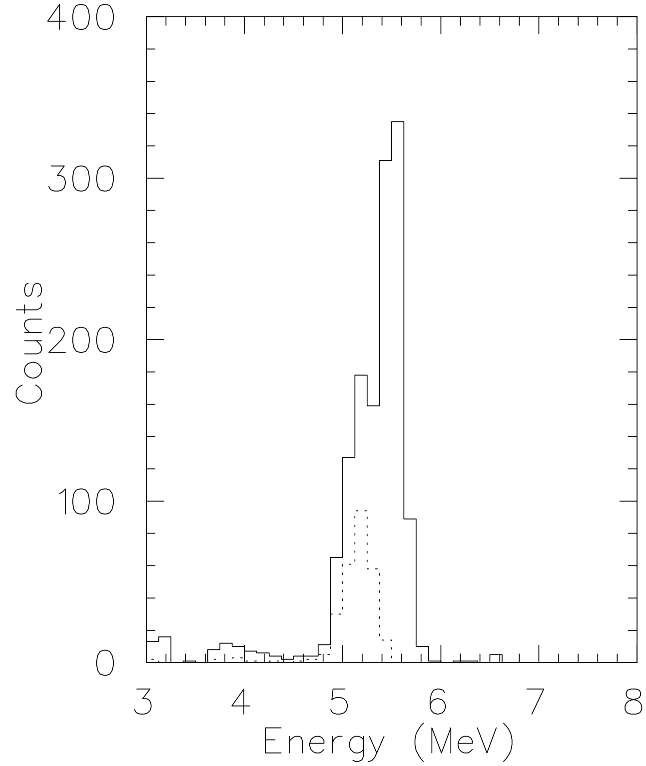


Fig. 127. $^{22}$Na recoils (5.2 MeV peak) and beam background (5.5 MeV) produced by a 265 keV/u $^{21}$Ne beam. The dotted histogram shows recoils in coincidence with capture $\gamma$-rays.

**8$\pi$ Spectrometer**
*(G. Hackman, TRIUMF)*

The 2000 Annual Report reviewed the 8$\pi$ spectrometer, its installation at TRIUMF, and the physics program to be carried out with it. In the year 2001, new mechanical support flanges and hevimet collimators were fabricated, and now all 20 Compton suppression shields and 17 HPGe detectors are installed in the close-packed configuration needed for the beta-decay program (see Figs. 128 and 129). The original signal-processing and acquisition system is now functional. The liquid nitrogen computer-control codes were ported to Linux on a Pentium-based PC, however, hardware conflicts within the PC have delayed final migration to that platform. The beam line was constructed and stable beam was delivered to the target location. For the large solid-angle inner beta array, several prototype fast-plastic scintillator detectors were tested leading to a new barrel-shaped geometry with light pipes.

There are currently three approved experiments using the 8$\pi$ spectrometer: "Isospin symmetry breaking in superallowed Fermi beta decays" (Expt. 909, C.E. Svensson), "High-K isomers in neutron-rich $A = 170$ to 190 nuclei" (Expt. 921, P.M. Walker, spokesperson),

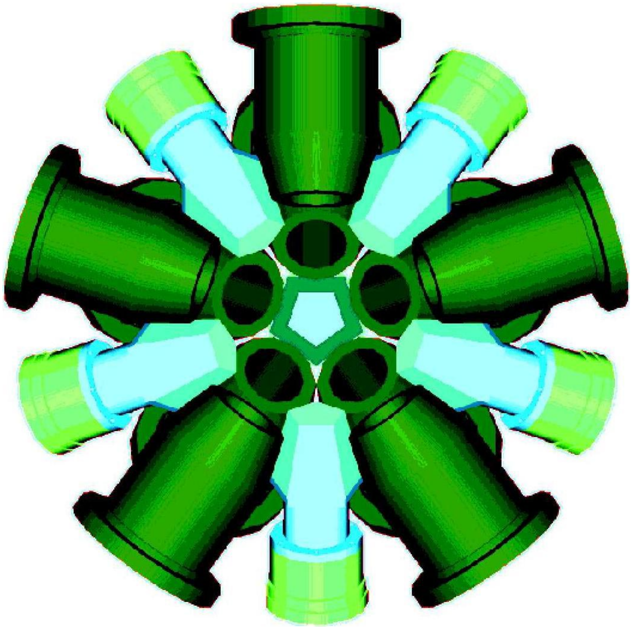

Fig. 128. Model of the close-packed $8\pi$ configuration.

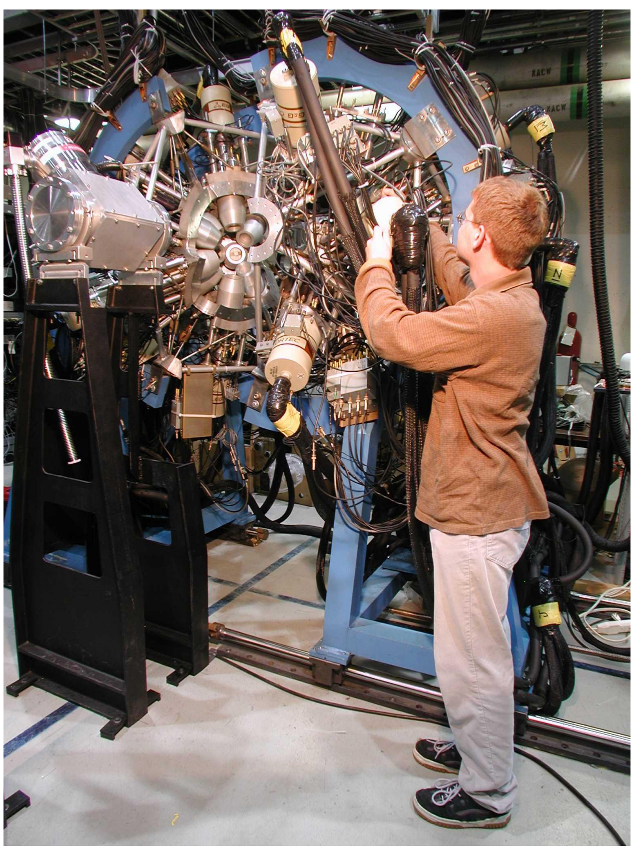

Fig. 129. Photograph of the $8\pi$ as of August, 2001.

"Octupole deformation and spin-exchange polarization of odd-$A$ radon isotopes: toward radon electric dipole moment measurements" (Expt. 929, C.E. Svensson and T.E. Chupp). The latter two were approved at the December, 2001 EEC meeting, where a letter of intent on the spectroscopy of neutron-rich $A \sim 90$ nuclei (G. Hackman) was also considered. To handle the event rates and obtain the precision needed for these experiments, the data acquisition system will be upgraded with FERA ADCs and bit registers and a high-precision 10 MHz clock.

Of the 19 collaborators who actively participated in reassembling the $8\pi$ spectrometer and designing the inner beta-detector array in 2001, eight were students and seven were from six foreign institutions: G.C. Ball, G. Hackman, P. Bricault, J. McDonald (TRIUMF), C.E. Svensson, A. Phillips, E. Vandervoort (U. Guelph), J.C. Waddington, R.A.E. Austin, G. Grinyer, P. Klages (McMaster U.), L. Stern (U. Victoria), J.L. Wood, D. Kulp (Georgia Tech. U.), E. Zganjar (Louisiana State U.), D. Hodgson (U. Surrey), P.E. Garrett (LLNL), D. Ward (LBNL), D.C. Radford (ORNL).

In addition to preparing the $8\pi$ for ISAC-I experiments, members of this collaboration prepared an NSERC major equipment grant request for a large "clover" detector as a prototype for TIGRESS, which will be a multi-detector Compton-suppressed HPGe array optimized ultimately for ISAC-II.

**Low Temperature Nuclear Orientation at ISAC**
*(P. Delheij, TRIUMF)*

The LTNO set-up is a facility to orient nuclei from the radioactive ion beam source TRIUMF-ISAC. In the past year considerable effort was devoted to arrive at NMRON measurements: the resonant change of the polarization as the frequency of the applied rf field is scanned through the Larmor frequency. Off-line sources of $^{60}$Co$\underline{\text{Fe}}$ and $^{54}$Mn$\underline{\text{Ni}}$ were fabricated in a reducing atmosphere of an argon/hydrogen mixture with a composition of 98/2. To check for possible (magnetic) contamination, some Fe foils were examined at SFU Physics by B. Heinrich and K. Myrtle in their auger electron spectrometer. This device provides the option to clean the surface by sputtering with an Ar beam. It was found that the foils were covered by a layer of carbon and oxygen with a thickness of approximately 5 nm. After removing this layer with the Ar ion beam an exposure of 3 minutes to ambient atmosphere restored this layer with a thickness that was very close to the original value.

In Fig. 130 the NMRON results are shown for $^{60}$Co$\underline{\text{Fe}}$. The off-resonance intensity in the direction parallel to the orientation axis is reduced by 44% due to the polarization of the $^{60}$Co at a temperature of 11 mK. Therefore, an intensity increase is observed when (partial) destruction of the polarization takes place if the frequency of the applied rf field equals the Larmor frequency. External magnetic fields of 2 kG and

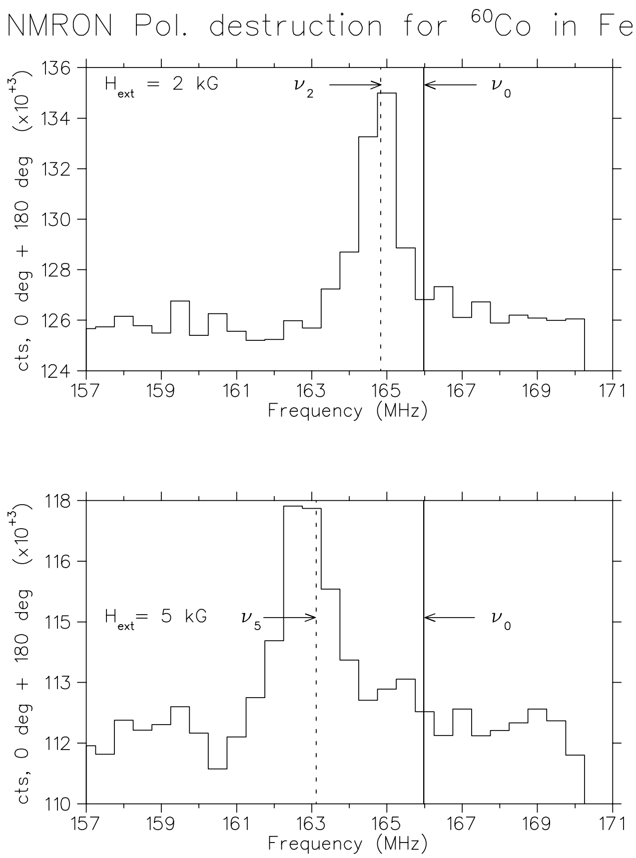


Fig. 130. Shown are two rf scans in an external magnetic field of 2 kG and 5 kG. The experimental data are in good agreement with the expected resonance frequencies $\nu_2$ and $\nu_5$.

5 kG cause shifts $\nu_2$ and $\nu_5$ respectively away from $\nu_0$ [165.957(5) MHz, Hagn and Eska in Proc. III Int. Conf. on Hyperfine Interactions, Karlsson and Wappling, eds. (Uppsala, 1974) p. 148], the Larmor frequency in zero external field. It should be noted that the resonance frequency is lowered because the hyperfine field is negative.

Approval for Expt. 893 was obtained, an experiment to resolve the discrepancy between the experimental result [+54 ± 10 kG, Allsop *et al.*, Hyp. Int. **15/16**, 313 (1983)] and the theoretical value [–261 kG, Cottenier and Haas, Phys. Rev. **B62**, 461 (2000)] for the hyperfine field of Rb in Fe. The data that are shown in Fig. 131 demonstrate that substantial anisotropies can be obtained for the gamma emission in the decay of $^{79}$Rb. By a judicial choice of gamma line intensity ratios (i.e. 688 keV/622 keV and 161 keV/155 keV), polarization effects up to 0.2 have been measured. Taking these ratios provides an internal normalization for beam intensity fluctuations. Furthermore, they are insensitive to beam motion effects. Part of the $\gamma$-rays

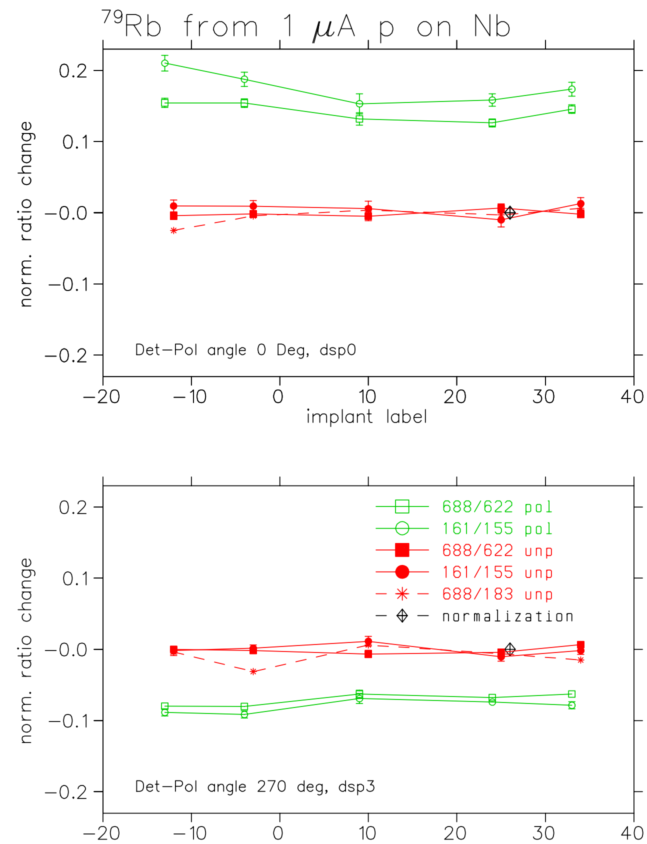


Fig. 131. The polarization effects in the gamma transitions following the decay of $^{79}$Rb are plotted versus time.

that reach the detectors are transmitted through the copper cold finger. The transmission varies with $\gamma$-ray energy. Selection of gamma transitions that are close in energy, 688–622 and 161–150, minimizes this possible error source. Conversely, selecting a large energy difference, 688–183, provides a check on the stability of the beam position over time. The last intensity ratio changes by 60% if the transmission length through the copper changes by 5 mm. Only about half the $\gamma$-rays are filtered in this way. Therefore, a maximum deviation in the ratio of 4% indicates that the beam spot movement is less than 0.7 mm.

The polarization results for $^{75}$Ga at LTNO are described by P. Mantica under Expt. 863 in this Annual Report.

Collaborators on the LTNO are: P.P.J. Delheij, C.A. Davis, TRIUMF; B. Turrell, J. Pond, R. Kiefl, Univ. of British Columbia; K.S. Krane, P. Schmelzenbach, J. Loats, C. Stapels, Oregon State University; J. Wood, D. Kulp, Georgia Institute of Technology; P. Mantica, A.C. Morton, A.D. Davies, D. Groh, Michigan State University; H. Haas, Hahn Meitner Inst.; S. Cottenier, K.U. Leuven.