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OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2003

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)

Once again there was considerable demand for beam time for proton irradiation work with six scheduled beam periods during the year. A group from Sandia National Laboratories and CEA in France carried out Expt. 919, "Proton irradiation effects in SOI devices", in two beam periods, one on BL2C at lower energies and then on BL1B at energies up to 500 MeV. This experiment aimed at determining which laboratory radiation source, Co-60 gammas or low energy X-rays, best simulated proton-rich space environments. The ATLAS group from the University of Alberta also used two sessions for further testing of the readout electronics for the liquid argon calorimeters for the high radiation environment at the LHC.

In order to satisfy the demand for higher fluences from several groups who wished to carry out displacement damage tests of harder devices, such as GaN devices and GaAs light emitting diodes, several improvements were made to enable more efficient use of protons. The maximum proton beam current is limited by neutron shielding to about 10 nA at 70 MeV and 2 nA at 500 MeV. As the devices to be tested are typically a few mm or less in size, smaller beam spots can be used. However, using a smaller beam spot makes it more important to have the beam well centered on the device during irradiation. This has been made easier by fabricating a new multiwire profile monitor which is located and aligned to the device under test. The beam profile and shape can be continuously monitored, both by the experimentalist and the cyclotron operators, during the irradiation. In addition, improved MATLAB software was developed by a summer student for analyzing the scanned images of the beam from Gafchromic (radiosensitive) film. Figure 161 shows a small beam profile from BL2C. The high intensity capability is available on both beam lines as the new profile monitor is portable and can be moved from one beam line to the other. Proton rates of 10^{10} protons/cm^2/s have been achieved. Groups from Defence Research and Development Canada (DRDC), previously called DREO, the Naval Research Laboratory, Oregon State, and the Canadian Space Agency made use of this capability during the year.

The neutron flux and energy spectrum was measured 1.4 m downstream of a 20 mm thick lead absorber for 110 MeV protons from BL2C. The measured and calculated neutron energy spectrum is shown in Fig. 162, together with the sea level neutron spectrum due to cosmic rays. For neutrons above 10 MeV the BL2C neutron flux is a factor of 2.5×10^6 per nA of

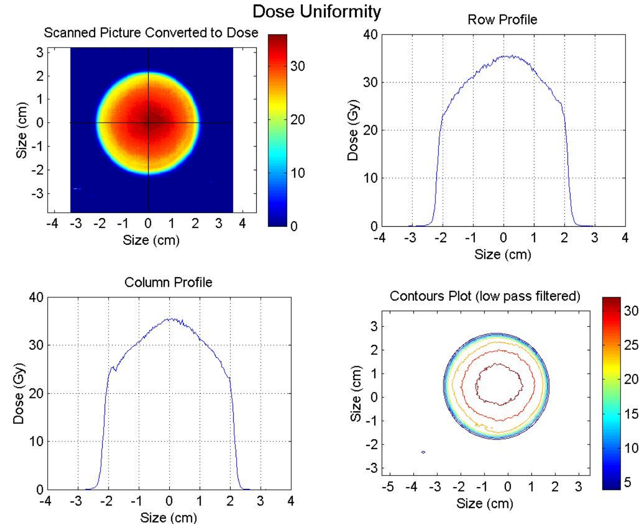

Fig. 161. Beam profile for 105 MeV protons at the BL2C high intensity test location.

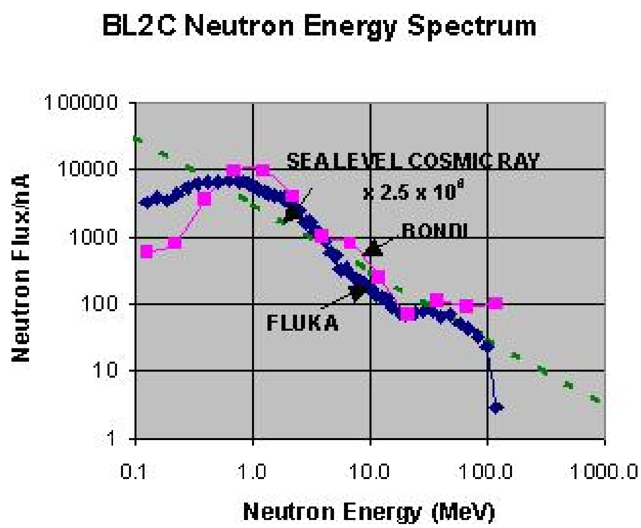

Fig. 162. The measured and calculated neutron energy spectrum.

protons above the sea level neutron flux. This beam was used by a Vancouver power supply company to test if an observed failure of power MOSFETS in certain types of their power supplies was due to cosmic ray neutrons. This was established quite convincingly and helped to solve a reliability problem that had been perplexing the company.

Other groups that used proton beam time during the year included MD Robotics (three occasions), Dynacon and UTIAS (three occasions) and QinetiQ, Farnborough, UK. In addition there were two series of irradiations for other applications. In one case samples of palladium were irradiated at three proton energies to determine certain radioisotope production rates from activation analysis. In another a group from Los

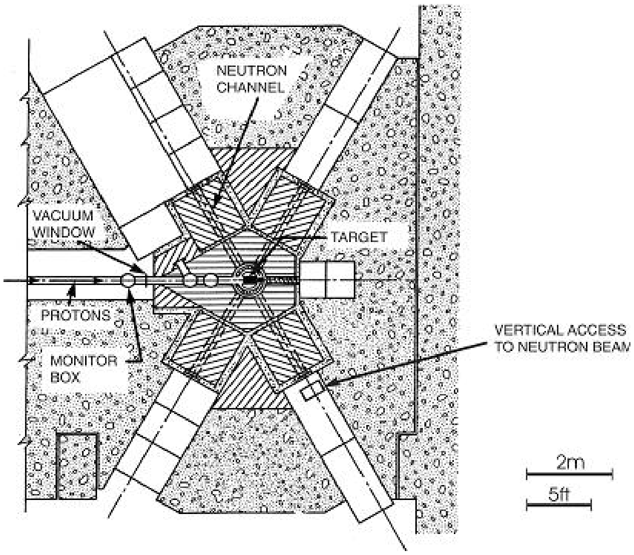

Fig. 163. Plan view of the TNF showing the vertical access to the neutron beam.

Alamos and UCLA carried out a proton RBE measurement in collaboration with the BC Cancer Research Agency. For this measurement a simple 2-step modulator was designed to give a spread out Bragg peak of 3 mm at 70 MeV. This measurement was requested by the CERN program committee to demonstrate the technique to be used in a future experiment to measure the RBE of antiprotons.

The BL1A beam dump (previously called the thermal neutron facility (TNF)) was designed with several neutron channels for thermal neutrons. These thermal neutrons were used for neutron scattering experiments in the 1980s when there was a lead beam stop and a heavy water moderator in the TNF. The beam dump is now aluminum and the moderator is ordinary water. A series of activation and other measurements were carried out in the summer to determine the flux of high energy neutrons (greater than 1 MeV) in this channel. There is vertical access to the southeast neutron channel as shown in Fig. 163, and a track with a pulley system was installed to allow measuring instrumentation to be lowered to beam level. This study has been documented in "Use of the TNF neutron beam for radiation damage studies" [TRI-DN-02-16] and shows that there is a significant high energy neutron flux corresponding to a 1 MeV equivalent flux of 1.2×10^7 neutrons/cm^2/s with 140 μA extracted down BL1A. As this neutron beam is available parasitically for about 3000 hours per year, there is a good possibility that it could be useful for SEU tests with neutrons. The only other neutron irradiation facility for electronic device testing available in North America is at LANSCE in Los Alamos and it is heavily booked. The TRIUMF neutron rate is similar to LANSCE although the testing area that is presently available at the TNF is smaller.

Proton Therapy Facility
(E.W. Blackmore, TRIUMF)

During the year, 9 patients were treated with protons, bringing the total number of patients treated at TRIUMF to 77. This total is made up of 75 treated for choroidal melanoma, 3 with tumours of the iris, and 2 with hemangiomas.

Dr. K. Paton and E. Blackmore attended the PTCOG meeting in Catania, Italy, May 29–31, and presented a paper on the results of proton and plaque therapy on ocular tumours treated in Vancouver. For that report a summary of the patient and tumour statistics was prepared for the first 70 proton patients (Table XIV).

Since 1995 the treatment planning program EYEPLAN has run on the VAX computers ERICH/REG which were part of the TRIUMF cluster running VMS. These computers were retired and the planning software transferred to one of the Central Controls System computers which use the VMS operating system. This is an interim measure only as a PC version of EYEPLAN has been obtained from Clatterbridge, UK, and it is presently being tested at the BC Cancer Agency.

The iris tumours typically require thinner modulators than used for choroidal melanomas. A new series of modulators from 5 mm to 10 mm were machined for this application.

Table XIV. Proton patient and tumour statistics. Total patients: 70 (67 choroidal melanoma, 2 iris, 1 hemangioma). Ages 17–80, 40 M, 30 F.

	Max. width	Min. width	Height mm	Volume cc	Range mm	Modulator mm
Maximum	23.0	19.1	12.6	1.68	31.4	23.8
Minimum	8.2	6.7	1.5	0.12	10.1	10.1
Mean	15.1	12.6	6.0	0.62	21.5	17.6

Location: 45% $<$2 mm macula, 55% $<$ 2 mm optic desk

μSR User Facility

(S. Kreitzman, TRIUMF)

Overview

Operational snapshot

μSR user facility operations in 2002 reflected the availability of the 500 MeV proton beam and the operational status of the secondary beam lines. To that end, 66 beam weeks of μSR experiments were carried out. This number was somewhat reduced from the previous year's (70 beam weeks) insofar as the proton beam was off for a week during schedule 102a and the high momentum M9B channel was lost during schedule 103a due to a failure of a He turbo compressor. The major spectrometer utilization was found to be (given in weeks) LAMPF 22, Helios 13, HiTime 11, DR 8, OMNI 7, and SFUMU/OMNI′ 10.

Proposals and personnel

The μSR science program continues to flourish, with 19 new proposals submitted during the two semiannual Experiments Evaluation Committee reviews. A change of staff in the facility has also occurred with a new design technologist joining the group. This individual has extensive 3-D design experience and comes with a strong background in mechanical design previously applied to the field of fuel injector design/manufacture for the liquid natural gas industry.

Funding and planning

As mentioned in the 2001 Annual Report, the Natural Sciences and Engineering Research Council (NSERC) unilaterally extended the μSR facility's funding that year (for an additional two) so that it could be put onto a 5 year funding cycle, replacing the 3 year cycle previously used. At that time, we petitioned NSERC to also grant us an inflationary supplement for that 2 year period so salaries, which are supported by the relevant Major Facility Access (MFA) grant, could manage to keep pace with inflation and the normal career progress of the facility staff. We are pleased to report here that NSERC granted our request for the required supplement thereby allowing us to maintain the necessary staffing levels. A further result of the shift to 5 year MFA funding is that now the μSR Facility will be making its funding case to NSERC in synchronization with the 5-year planning cycle that TRIUMF itself maintains. An imminent example of this correlated planning will be found in the upcoming MFA 2004–9 proposal, due to be submitted in the fall, 2003. The proposal in question will envision a significantly increased scope for the Facility operations so that the aggressive μSR expansion plans which TRIUMF will be putting forth in its 5 Year Plan can be adequately supported.

Facility developments

The major facility developments which highlighted the year were:

- Design of the OMNI′ spectrometer.
- Reconfiguration of the Helios spectrometer front end.
- Design and construction of an in-house VME timing/gating/counting module.
- Commissioning of new Linux data acquisition computers.
- Introduction of β-NQR capabilities in ISAC.

The following material outlines these and related developments more fully.

Spectrometers

OMNI′

OMNI′ is the last of the traditional facility spectrometers to undergo its rebuild into an instrument suited for the requirements of modern μSR research. It has been designed to be the instrument of choice for zero and longitudinal field studies on the high momentum M9B channel. Insofar as the Japanese μSR research community makes heavy use of this beam line, the spectrometer makes the facilitation of their traditional experimental set-ups very easy. In addition, the standard experimental configurations which the facility provides are also built into the design for straight forward installation. A new feature in this spectrometer

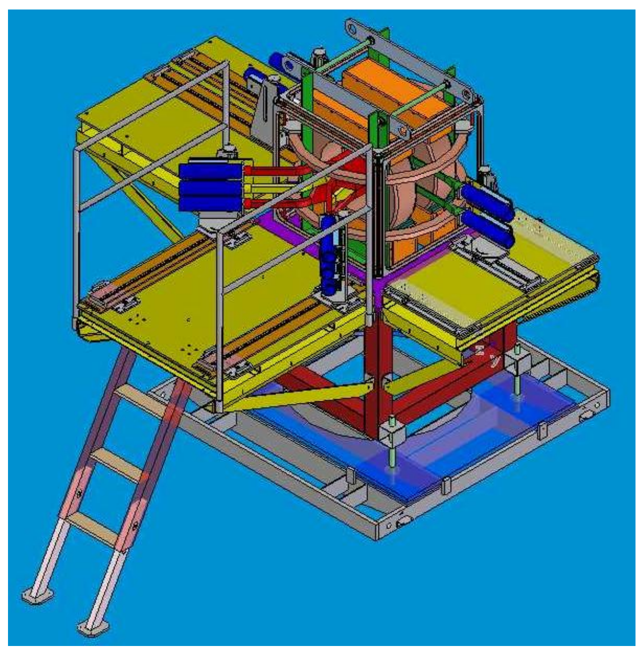

Fig. 164. A 3D rendering of the new OMNI′ spectrometer with a standard set of counters. The spectrometer is also fitted with specialized counters and mounting systems to accommodate experimental set-ups for the Japanese μSR research community which often utilize M9B.

is the use of carefully designed saddle coils to provide to a weak (up to 20 G) horizontal field perpendicular to the main field direction. The use of saddle coils best utilizes the available real estate inside the magnet and does not restrict either counter, cryostat or other cell access into the central field region. Finally, in addition to the large Z axis coils (3.5 kG) and weak (20 G) X/Y axis transverse field coils, the spectrometer has an independent set of zero field coils to remove small magnetic contributions from the earth and the cyclotron.

Helios front end

In 2001 the 7T solenoid workhorse spectrometer Helios was rebuilt to accommodate the current needs of the μSR research community. Envisaged at the time was a short large diameter front end geometry that had a significantly higher solid angle acceptance to the muon beams that could be injected into the apparatus. This front end has been implemented in 2002, resulting in an increase of 25–40% (a field dependent value) in the available muon luminosity at the sample position.

Data acquisition

Hardware – GGL VME module

The correct set-up of a μSR time-differential experiment requires defining a time domain of interest (the Data Gate), and then ensuring (to within a reasonable probability) that only one muon is in the sample during that time. This requirement, and the way in which the TRIUMF μSR TDC (time-to-digital converter) operates, necessitates that a series of gates are set up which all depend on the data gate in a well defined manner. In the past, when the time of interest needed to be altered, manual intervention was required to appropriately change the data gate and its derivative TDC and reference gates. With the advent of the TRIUMF designed μSR gate generator logic module (i.e. GGL, pronounced “giggle”), these operations are

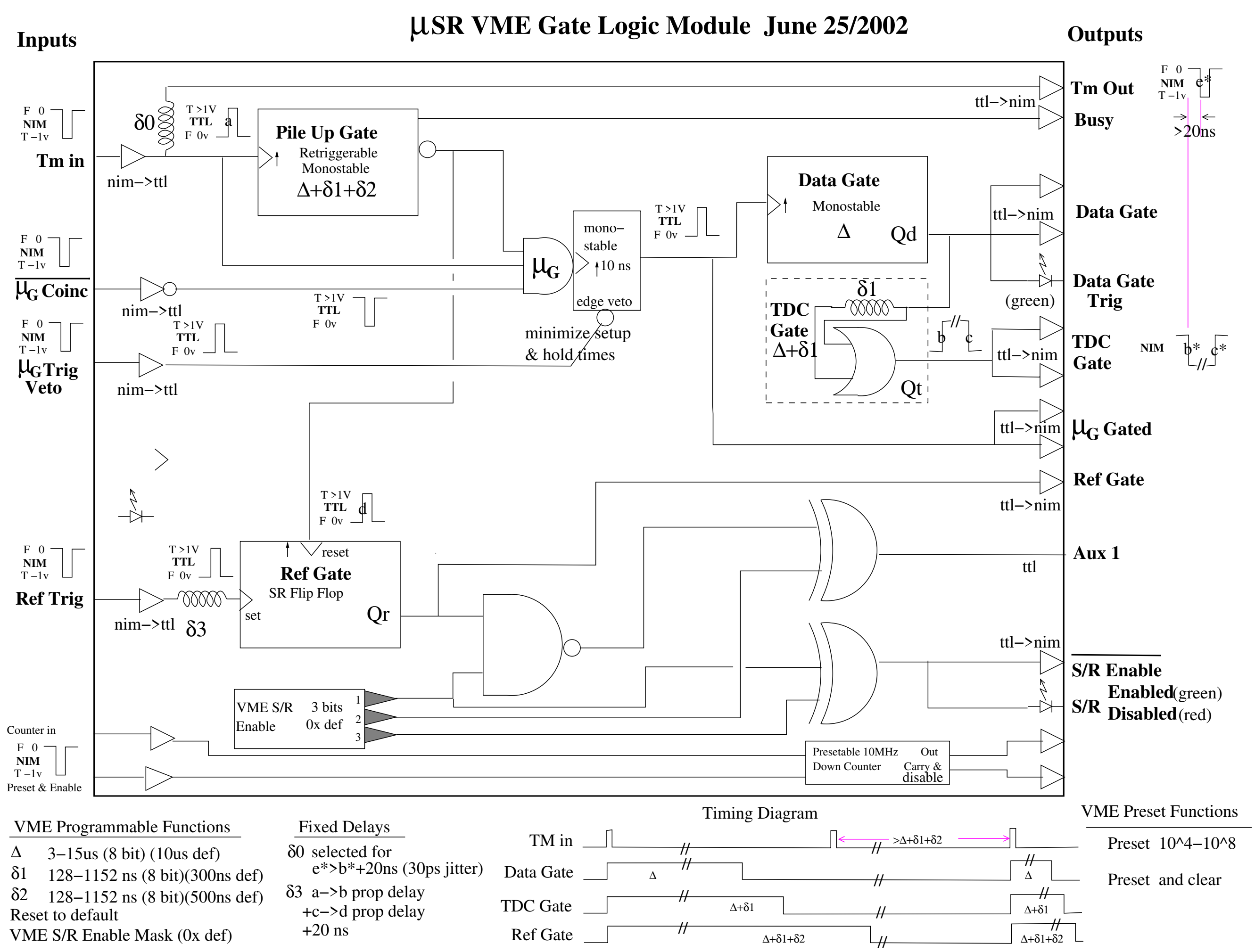

Fig. 165. The logic diagram of an integrated VME module that provides all the gating and timing delays required for the TRIUMF μSR time differential data acquisition mode. The module is meant to work efficiently with the μSR TDCs and the data acquisition software to remove the previous requirements for direct user intervention in the setting of the required gate intervals.

now automated by the DAQ system thereby obviating the requirement for any manual intervention after the initial electronics set-up. A further functionality of this board for TD μSR is that it supports the logic to switch to the so-called μSR $\times 2$ mode, in which sample and reference spectra are simultaneously acquired.

In addition to providing TD μSR mode support, the GGL module also contains preset scalers and DAC capabilities that allow I μSR (integral μSR) experiments to proceed solely with VME system support. Therefore the venerable CAMAC nuclear instrumentation interface is now being removed from the μSR DAQ configurations at TRIUMF.

Software – Linux DAQ

The new μSR Linux based DAQ and user interface continues to be refined. Automatic logging of the statistics of monitored CAMP variables (like temperatures, fields) is fully functional as is the automation of the gate generation mentioned in the previous section. A user friendly interface for I μSR (similar in look and feel to its TD counterpart) has been under development, to be deployed in the spring/summer schedule of 2003.

β-NQR at ISAC

Because ^{8}Li is a spin 2 nucleus, in principle it can (and often will) be found in a non-cubic microscopic environment after implantation. The existence of an electric field gradient makes it therefore natural to extend the β-NMR capabilities into the regime of NQR experiments in zero or low magnetic fields. To this end, the facility has expanded its support for the β-NMR program to assist in the magnetic excitation and control of samples in the 1–500 kHz frequency domain, which is the domain of typical β-NQR studies.

The near future: planning for an broad community spectrometer

Background

The field of μSR research in Canada has of late entered a significant growth phase earmarked by the appointment of a number of young professors (with extensive post graduate μSR experience) to universities across the country. Not only have these new faculty members invigorated (and indeed overburdened) the demand for current facilities, but they have catalyzed a broader interest in the field by providing their local university research colleagues with a knowledge and insight that is prompting some to utilize μSR as a research tool in their own studies. To meet this growing demand, we envisage developing a turnkey μSR spectrometer/system to be used as a tool which is easily accessible to the general research community.

The rig and the beam line

In accordance with TRIUMF's plans, the beam line to be utilized will be a refurbished version of M9B. It will contain dual achromatic spin rotators to achieve both 90° spin rotation, muon/positron separation and high flux transmission. Also featured will be an intermediate focus prior to the last triplet allowing for remote collimation of the beam spot. The spectrometer itself will consist of a 2T split coil magnet, with access into the field from both the axial and side directions. The former geometry is ideal for TD μSR while the latter will be optimized for LF and ZF studies. Counters and cryostats associated with both entry directions can be selected and controlled remotely into their experimental positions so that the optimal experiments can be switched in with ease.

Philosophy

Save for the sample mounting, the entire operation will be remotely controlled. It is envisioned that a full time liaison scientist will assist in the data-taking and analysis so that the visiting scientists involved can go back to their home institution with a complete set of analyzed data relevant to the system they are investigating. This planned ease of use will emulate the experimental environment that is found in modern neutron user facilities.

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.

Computing Services
(C. Kost, TRIUMF)

Overview

A major accomplishment was the successful transfer of over a Tbyte of ATLAS Monte Carlo simulated data from TRIUMF to CERN, disk to disk, using a record spanning (12,000 km) end-to-end (single-hop) lightpath at record transfer rates (corresponding to transferring some 1500 CDs full of data at a rate of one every 8 seconds). This test was successfully demonstrated at the iGrid 2002 conference held in Amsterdam. It was the culmination of 3 months of intensive effort involving a partnership with CANARIE Inc., ATLAS Canada and other organizations, in addition to the tireless efforts of the 4 member research team – Corrie Kost, Steven McDonald, Bryan Caron, and Wade Hong. Besides the obvious spin-off benefits to TRIUMF, our network speed to BCNET was improved by a factor of 40. With WestGrid coming on stream by mid-2003, the rapid acquisition of small Linux based clusters at TRIUMF, the preparations under way to move into ISAC-II in early 2003, the retirement of our

VAX/VMS data analysis cluster, as well as the continued expansion of the local network, it has meant that our small group was under severe strain. Nevertheless we are optimistic that 2003 will herald in a new and substantially improved era in computing as we reap the rewards of extraordinary efforts made in 2002.

Modular approach

TRIUMF continues to take a modular approach in providing an integrated computing environment. Enhancements to several modules took place this year:

- Replacement of some colour X Window (NCD) terminals with PCs running Linux.
- Our central mail facility was upgraded with new hardware and new software packages including the Webmail service, antivirus program, LDAP server etc., and a Web-based version of the user configuration tool.
- The TRIUMF Router has been replaced with a Nortel Passport 8003, enabling gigabit routing. A second unit will be installed in early 2003, to increase capacity and provide some redundancy.
- Hardware for a new central Web server was installed. The new site, developed to enhance public exposure of TRIUMF, with suggestions for sitewide standards, should be released early in 2003.

Hardware/network

The TRIUMF network backbone configuration remains much like it was illustrated in the 2001 Annual Report, albeit with more BayStack switches. There are currently some 1850 nodes defined in the domain name server, with only about 50% (896) in active use. Most of those active ports are managed by the over 900 ports connected via Nortel BayStack switches. Some additional switches will be required to address capacity overloads in certain areas – the goal being to have all devices (with the exclusion of compute farm nodes, which should be on private networks) connected to managed ports.

Computer security

The number of network worms continues to grow. Code Red and Nimda are still active and show a marked monthly periodicity. In September a new worm, "Opaserv-A", started propagating across Windows networked disks and generated enough scan activity to overwhelm our reporting mechanism. We have not yet restarted the full reporter. We see more wide scan activity for proxy servers and other services. Some of this may be done by external people looking to send spam anonymously as proxy servers allow the original sender to be hidden from the recipient. We continue to operate the LaBrea "tarpit" program to slow these scans and hide real TRIUMF addresses, though the amount of traffic has caused problems with ARP cache on the router so we have had to scale back this effort.

In April we wrote a custom interface for the AVP antivirus product running on trmail. This was used to generate more complete virus reports, and also to discard worm-generated e-mail rather than deliver it to the recipient (it generally has no useful content and is sent from a forged address).

The most significant e-mail virus of 2002, in terms of amount of traffic seen at TRIUMF, was Klez. We had few actual virus infections, though an Opaserv infection over the Christmas vacation caused us to block outgoing Windows traffic (incoming was already blocked).

TRIUMF continues to receive an ever-increasing amount of unsolicited commercial e-mail, or "spam", some of it distasteful in nature. Some spammers using a dictionary attack against the site allowed them to discover seldom-used addresses that were not available anywhere on the Internet. There is no easy way to prevent this.

The anti-spam tool "SpamAssassin" was installed in November. This augments the Razor spam signature system by performing rule-based analysis of incoming mail. Internal TRIUMF mail and mail from affiliate institutions is "whitelisted" to avoid misplacing genuine messages. Users can customize their accounts by adjusting the reporting threshold and by adding personal "whitelists" for commercial newsletters (which are often reported as spam).

A number of "spamtrap" e-mail accounts, such as "games" or "ftp" were created. Mail to these spamtrap accounts is fed into the Razor signature database. In August a couple of Solaris machines were hacked and used for IRC activity. They were taken off-line and updated.

Videoconferencing

An ISDN-based computer is still used for a number of conferences as is the VRVS reflector set up for use by the HEP community. The Webcast server "video" was used to record and transmit a number of meetings, including the TRIUMF Users' Group and high school teachers' Pro-D day. Work on setting up an AccessGrid advanced videoconferencing facility (funded by WestGrid) at TRIUMF is in progress.

Network measurements

We continue to participate in the SLAC Pinger and the Oxford Traceping projects for WAN monitoring, as well as monitor the internal TRIUMF network for device availability and location using arpwatch. The search for a comprehensive, affordable, sitewide network monitoring tool continues.

Network data transfer trial

In line with networking requirements of future experiments such as ATLAS at CERN in 2007, CANARIE, Canada's advanced internet development organization, suggested that we participate in iGrid 2002 in Amsterdam by utilizing an international multi-gigabit experimental optical testbed to:

- Demonstrate an end-to-end lightpath between TRIUMF and CERN.
- Experiment with 10 gigabit Ethernet technology and Ethernet channel bonding over such distances.
- Transfer 1 Tbyte of ATLAS Monte Carlo data, single-host to single-host, disk-to-disk, at record speeds.

This required the extension of the end-to-end lightpath from its terminus in downtown Vancouver (BCNET) to TRIUMF – a distance of 20 km. Figure 166 illustrates the solution that was implemented – namely, the use of a coarse wave division multiplexer (CWDM) to provide 2 bonded GbE in an etherchannel, with 10 GbE technology, whose IEEE 802.3ae specification had just been finalized, at the end-points.

Intel generously supplied alpha versions of their Pro GbE LR server adapters for our end hosts. Extreme Networks enthusiastically loaned two of their Black Diamond 6808 switches with the new 10 GbE Lri blades. This enabled a high speed single stream of data from an end host to the Extreme Switch which could then be switched across to two channel bonded GbE interfaces. The dual GbEs were connected to a Cisco ONS15454 mapped to dual OC-24s and transported end-to-end as shown in Fig. 167.

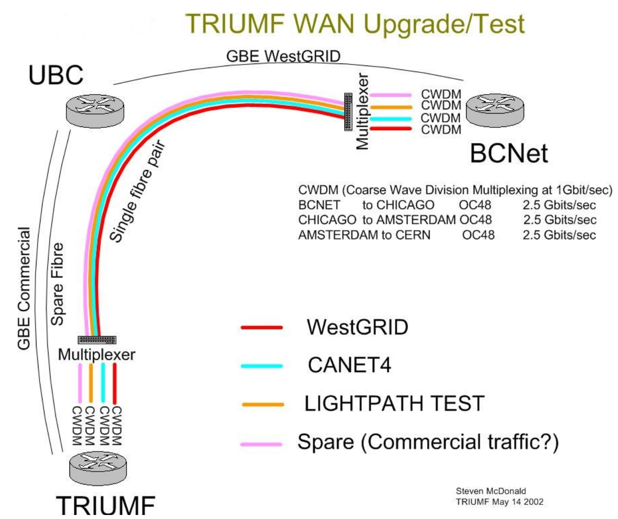

Fig. 166. TRIUMF WAN upgrade/test.

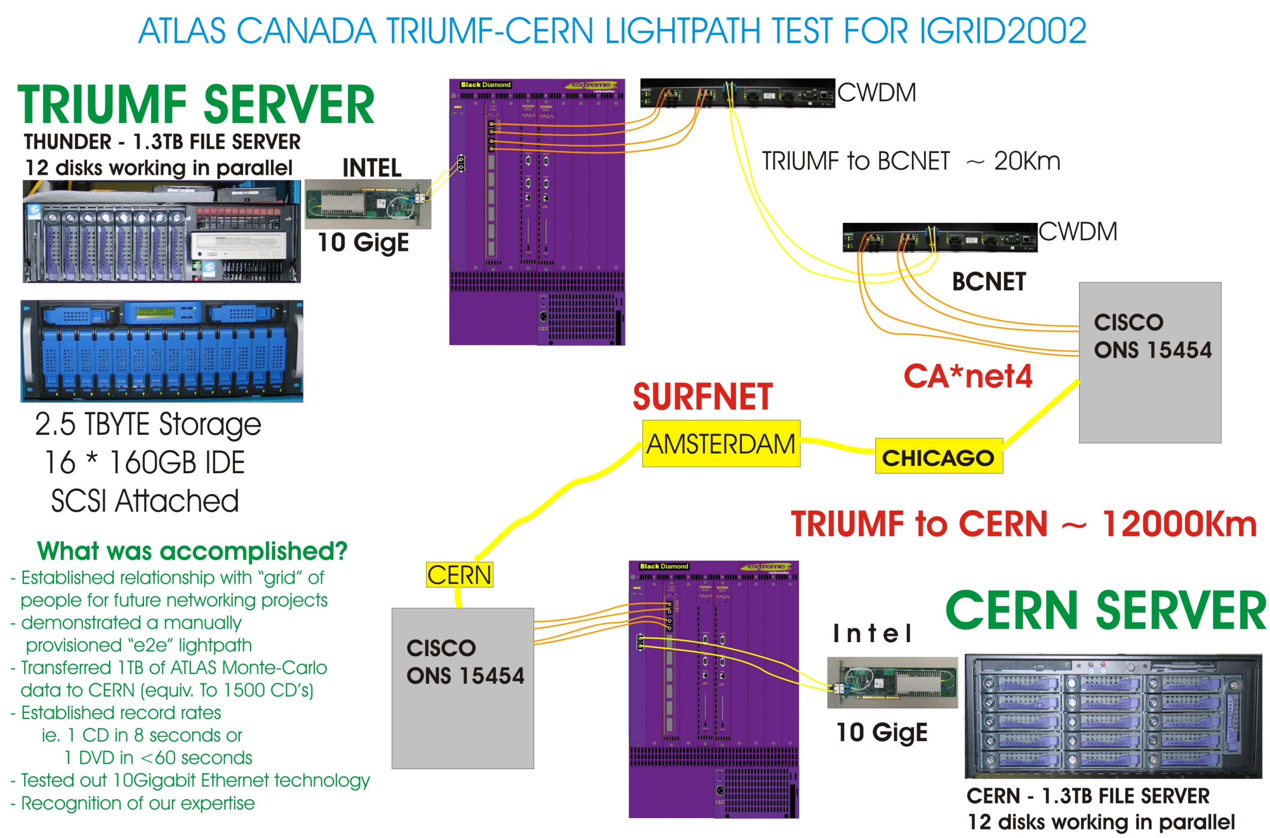

Fig. 167. ATLAS Canada TRIUMF-CERN lightpath test for iGRID2002.

With this configuration we were able to sustain an average rate above 1000 Mbits/sec in the transfer of about 10 Gbytes from disk at TRIUMF to memory in the machine at CERN. Figure 168 shows the transfer rate and total amount transferred as a function of time.

For disk-to-disk transfers, sustained/peak rates using bbFTP were 666/737 Mbps, while using the Tsunami transfer codes they were 700/824 Mbps. Figure 169 illustrates the transfer rates observed on each of the two bonded GbE channels during the successful transfer of over a Tbyte of ATLAS data.

Software developments

Physica

This internationally popular, general purpose data analysis/visualizaton program running on UNIX/Linux platforms has become quite stable. Even so, it continues to improve as reported bugs (now few and far between) were fixed and requested enhancements were added – such as increasing the maximum number of curves that can be replotted. The port of Physica to the Microsoft Windows platform has progressed from beta testing to the release stage. The list of features in the UNIX/Linux version of Physica that are not in the Windows version has grown short. The Windows version has new improved features not found in the UNIX/Linux versions, such as: more control over the appearance of a graph; true area fill; PostScript Language Level 2 bitmaps; use of TrueType fonts; JPEG output; an integrated graphical user interface; complete session save and restore.

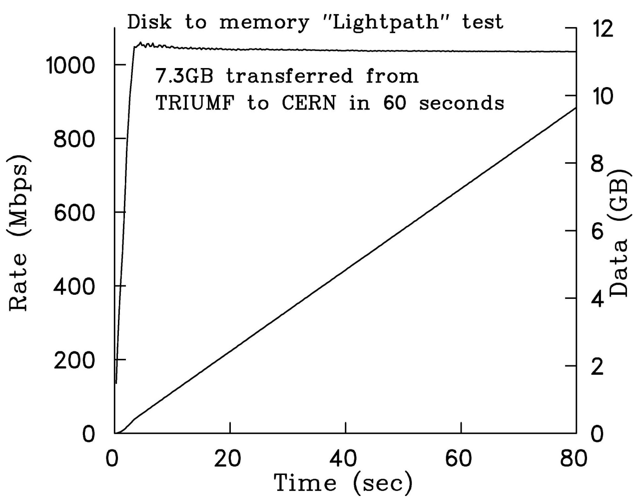

Fig. 168. Record disk to memory transfer rate.

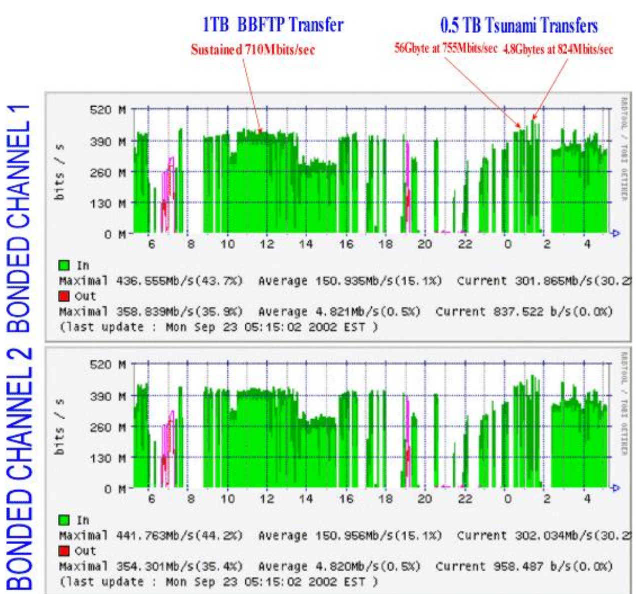

Fig. 169. Record disk to disk transfer rates.

Beam dynamics

GEANT4 – Testing and quality assurance

This year we made further contributions to GEANT4 in the area of Web-tools associated with software testing, debugging, and application development. New facilities installed on TRIUMF's GEANT4 WWW server include ViewCVS, a CVS browser allowing access to the GEANT4 source code repository with displays of revision histories, an excellent graphical diff utility showing changes between versions, and hyperlinked activity logs. Unlike the older CVSWeb package, ViewCVS is tags-aware and therefore a better fit to GEANT4 needs. Also available through ViewCVS is CVSGraph, which creates a hyperlinked graphical representation of the revision tree for any file in the repository, offering a clear view of all main trunk and branch tags. CVSView can be accessed as a stand-alone facility or from LXR, which is a Web-based browser for the GEANT4 source code. These tools can be accessed at http://geant4www.triumf.ca/.

GEANT4 – Visualization

Our Linux-based dual-cpu server for GEANT4 development also functions as a visualization workstation and is configured with a 22 in. flatscreen monitor, 3dLabs high speed graphics card with hardware geometry engine, and Xi Graphics Accelerated X Server software. The latter software, allowing hardware-accelerated graphics to efficiently coexist with the X Window environment on Linux, was definitely "bleeding edge" when we first acquired it, but Xi Graphics has followed through with completely rewritten and much enhanced drivers. This free upgrade was installed and extensively tested, showing improved performance and excellent stability.

ACCSIM

The multiparticle simulation code, ACCSIM, continues to be used in a wide variety of accelerator applications, principally for high-intensity proton synchrotrons and accumulator rings. This year, the work

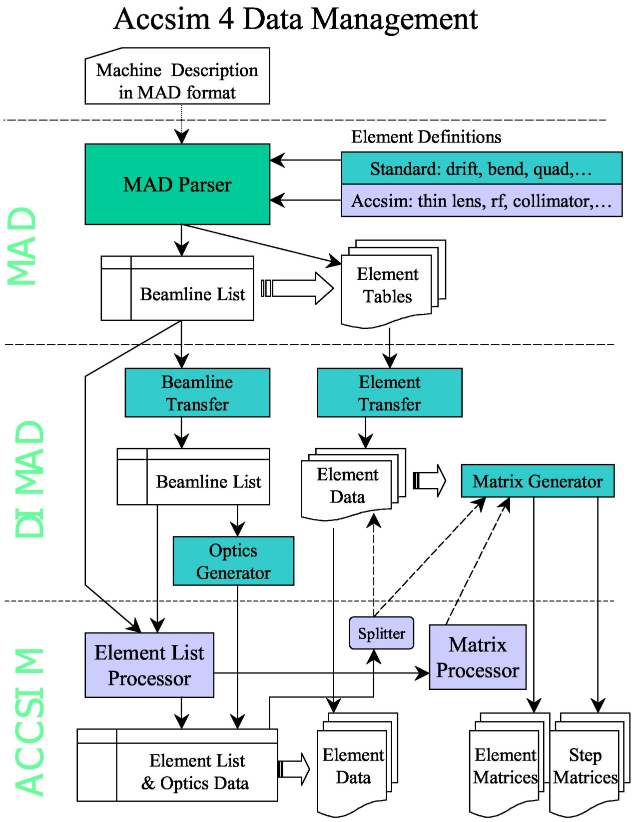

Fig. 170. Part of the architecture of the new ACCSIM. Components from MAD and Dimad are used by permission of the authors.

on "ACCSIM 4" (Fig. 170) was substantially complete and pre-release versions were distributed to users at CERN, KEK, JAERI, and Fermilab. This allowed a few remaining bugs to come out of the woodwork and be fixed, as well as some fine-tuning of features using current applications. The new code is completely stand-alone and allows the input of lattice descriptions in the standard MAD format, with automatic computation of the lattice optics, tunes, chromaticity, and transport coefficients, including step-matrices for space-charge tracking within magnetic elements. This represents a step forward in user convenience for this type of simulation code, which typically relies on a separate program such as MAD or Dimad to process the lattice description and compute the necessary machine data for input to the simulation.

Japanese Hadron Facility

A member of our group visited the Japan Atomic Energy Research Institute (JAERI), the site of JHF (later rechristened as J-PARC), the high intensity proton accelerator facility being built in partnership with KEK. The main objective was to introduce the ACCSIM code to JAERI accelerator physicists and to develop new simulations for the JHF 3 GeV synchrotron, whose design has been substantially revised since the original JHF proposal.

ACCSIM 4 was installed on several machines at JAERI and KEK and informational seminars were given at both labs. Further development work included a new treatment of bump dipoles, allowing the off-axis orbits and fringe fields to be computed correctly while still maintaining a conventional (local, on-axis) coordinate system for tracking. This will be used to model the 3 GeV machine's sophisticated injection region incorporating 8 orbit-bump dipoles and 2 quadrupoles. Loss management is also a primary concern for this machine. Using ACCSIM 4, a simulation with collimator elements, including proton interactions with the materials, could be rapidly set up and was found to give distributed loss estimates that were in good agreement with MARS code results previously obtained at JAERI.

Parallel computing

Using a small commodity Linux cluster set up originally as a test-bed for cluster management software, this year we inaugurated parallel computing at TRIUMF, at least on a small scale. In conjunction with the collaboration with CERN on LHC beam dynamics, a multiparticle beam-beam simulation code, BeamX, was extended from a 2D beam interaction model to a 3D scenario involving longitudinal subdivision ("slicing") of the counter-rotating proton bunches. The low-cost cluster of 6 CPUs, configured as a private network, provided an excellent development platform on which to parallelize this code using the MPI and LAM toolkits (standard with Red Hat 7.3) and to work out an effective algorithm for the inter-process communication which maintains consistent information between processors as each computes the interaction between particular slice pairs.

In search of additional resources, BeamX has since proliferated to the THOR cluster at the University of Alberta, while production runs also continue at TRIUMF. BeamX is a useful "seed" application for future parallel computing on the larger cluster (WestGrid) soon to come.

Miscellaneous

To underscore the advances in computing power, our standard floating point intensive application ACCSIM, which took 187 minutes on a VAX-780 now takes about 9 seconds on a 2.8 GHz Xeon based machine (using the Intel compiler which reduced it from 15 seconds using g77).

Data Acquisition Systems

(R. Poutissou, TRIUMF)

Overview

In 2002, the DAQ group continued to support a wide array of experimental groups and test stations. Peter Green, who had been with the group for many years, retired at the end of June. He has been replaced by Konstantin Olchansky who had come to TRIUMF two years ago to work with the TWIST group after several years at Brookhaven National Laboratory in data acquisition systems, software analysis and Linux system management.

The TRIUMF data acquisition system MIDAS is currently deployed over 26 stations managed by the DAQ group around the laboratory. These machines also provide some off-line analysis resources and disk storage.

MIDAS software

The MIDAS software continued to evolve and mature. Stefan Ritt, the main author of MIDAS software, spent two weeks at TRIUMF in the early summer to discuss and implement improvements of interest to the TRIUMF systems in collaboration with Pierre Amaudruz. Konstantin Olchansky joined the effort in July. The work on the MIDAS software during this year has been focused on the integration of an event builder, current MIDAS tools optimization and Web interface improvement integrated in a new release of MIDAS version 1.9.1

This new release specifically addressed the following tasks: mevb, logger, lazylogger, mhttpd, elog, history and upgraded error handling in the RPC portion of the code. Most of the software improvements have been suggested and tested by the TWIST experiment where MIDAS has been put to stringent use with data collection up to 8 Mb/s and over a dozen slow control devices.

The number of hardware devices supported by MIDAS keeps increasing. New MIDAS drivers for GPIB and USB devices were added as well as support for a SCSI Camac interface. The success of the USB driver has prompted a study to replace the connection of RS232 devices through old Emulex terminal servers by USB serial adapters.

Evaluation of other DAQ hardware such as PCI/VME interface, VME frontend modules (Flash ADC, AMT deadtimeless multihit TDC) and a new VME processor (a Pentium 3 VMIVME 7750 from VMIC) is in progress.

Study of the new MSCB slow control system developed by Stefan Ritt at PSI has been started in order to evaluate its possible implementation and use within TRIUMF for control and monitoring of experimental devices.

Information about MIDAS can be found at http://midas.triumf.ca/docmidas/index.html.

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

Name	Location	Type
isdaq01	ISAC-LE, βNMR, TRINAT	2xPII/450
isdaq02	ISAC-LE, GP2, LTNO	PIII/500
isdaq03	ISAC-HE, TUDA	2xPIII/550
isdaq04	ISAC-HE, DRAGON	2xPIII/550
isdaq05	ISAC-LE, ISAC users	PIII/1000-256
isdaq06	ISAC-HE ISAC users	PIII/1000
isdaq08	ISAC-LE, 8π	2xPIII/1000
midtis01	TRINAT DAQ	2xPIII/550
midtis02	Detector Facility	PPro/200
midtis03	LTNO platform DAQ	PII/350
midtis04	GP2 DAQ	2xPIII/550
midtis05	8π cryo	PII/300
midtis06	ISAC floor DAQ	AMD/XP/350
midmes01	Detector Facility	PIII/500
midmes02	DRAGON	2xPIII/550
midmes03	RMC DAQ	2xPIII/550
midmes04	Detector Facility	PII/300
midmes05	Detector Facility	PPro/200
midmes06	8π cryo backup	PII/166
daqtest	M11 users	PII/400
e614slow	TWIST Slow Control	PII/400
midtwist	TWIST DAQ	2xPIII/1000
midm9b	M9B μSR DAQ	2xPIII/1000
midm15	M15 μSR DAQ	2xPIII/1000
midm20	M20 μSR DAQ	2xPIII/1000
dasdevpc	DAQ development and Web server	PIV/1700

On-line analysis software

The DAQ group had been supporting two on-line analysis packages. The first one is called NOVA, developed and maintained by Peter Green. The second one is the MIDAS analyzer using the HBOOK/PAW/CERNLIB histogramming software suite.

With the retirement of Peter last June, the development of NOVA has stopped. Limited support for this package is expected to last until the end of 2003. With the development of HBOOK also being static, it was time for the DAQ group to embark on a new avenue. After consultation with the 8π group, Stefan Ritt and TRIUMF computing services, it was decided to begin a development effort using ROOT which is a new C++ analysis framework supported at CERN and widely embraced by the high energy physics community as well as by GSI. The 8π group put in a big effort to develop a GUI and macros for ROOT while Konstantin provided a MIDAS analyzer capable of producing ROOT histograms via shared memory and integrated MIDAS RPCs into ROOT. In 2003, the effort will continue in collaboration with Stefan Ritt to provide a full interface to ROOT as well as a versatile GUI to satisfy the on-line analysis needs of former NOVA and HBOOK users.

DAQ systems

POL and βNMR at ISAC

Further modifications and improvements were made to the βNMR data acquisition system. Support has been added for various scans of devices controlled by Epics (from the ISAC control system) and by CAMP systems (specific βNMR slow control systems). Extensive documentation accessible through any Web browser is now available for this experiment.

A second DAQ called POL was installed on the second leg of the βNMR beam line. It supports a polarimeter for beam studies. The software had to be made versatile enough for use by βNMR users and other experimenters (Osaka) setting their experiment in that area. The experience gained in developing reliable scans of EPICS devices was made available to other MIDAS experiments, specifically to the Osaka group.

μSR systems

The new Linux-based TD-μSR DAQ system was completed (including a graphical user interface written by Donald Arsenault). It has been installed on all three μSR beam lines and was successfully used during the fall beam periods.

A large part of a prototype Linux-based system to replace I-μSR has been written and debugged.

TWIST

Development continued on the TWIST DAQ system. To boost the data rate, the logging media was changed from a DLT8000 to a Super DLT III drive bringing the data rate to the level of 10 Mb/s sustained while lowering the tape costs by a factor of 2.

As mentioned above, this demanding DAQ required a number of MIDAS improvements in all aspects of MIDAS. Much work was done, mainly in the slow control category, in particular, the implementation of M13 B1 and B2 magnet regulators and improvement of the USB camera readout for the TWIST alignment system (including modifications to the Linux ov511 driver). Three of the FASTBUS TDCs had failed and required repairs. One had to be sent to an external company but Andrew Daviel was able to diagnose the problem FPGA in the other cases. Replacement of the chip was done in-house by the Electronics group.

The TWIST experimental group is now exclusively using Elog, the MIDAS electronic logbook facility, instead of a paper logbook. Elog is accessible through any Web interface making it possible for all members of the group, locally or externally based, to follow the progress of the experiment and make timely contributions.

Other experimental stations

The 8π group switched from a VMS based DAQ to VME and MIDAS in the first half of the year with the help of the DAQ group. They also developed a ROOT on-line analysis package as mentioned above.

Half a dozen other requests for DAQ ranging from small test bench set-ups to real experiments have been handled. Support for external MIDAS users has been strong with more than 10 labs around the world requesting help on DAQ hardware selection and/or installation.

Detector Facility

(R. Henderson, TRIUMF)

This year has been an active one for the detector facility.

For the first six months the group was busy completing the spare detector modules for the TWIST project (E614). This project is a sophisticated experiment at TRIUMF which hopes to measure the Michel parameters to ten times the present precision. The various subsystems of this experiment are functioning superbly, including the 56 high-precision drift chambers and the complex gas system fabricated in the facility. A great deal of data has been collected already. A low pressure Time-Expansion-Chamber (TEC) has also been designed for use just upstream of the TWIST spectrometer. This TEC will be built and tested in the facility and will be used to measure the muon beam properties.

The last ATLAS modules have been shipped to CERN and the facility involvement in this project has finished. The completion of the modules frees up two of the facility's clean rooms, adjacent floor space and office space in the facility.

The scintillator shop continues to function as the heavily used machining centre for the facility. This year has seen a wide variety of scintillators fabricated for μSR, the $G\emptyset$ experiment (at JLab) and the 8π experiment. The larger mill in the scintillator shop was previously retrofitted as a 4-axis NC mill for the TWIST project, and this allows us to machine the complex curved scintillator pieces for $G\emptyset$. The $G\emptyset$ scintillator designs were significantly delayed by the $G\emptyset$ group. The first scintillator sector has been finished and we are waiting for the testing before producing the other seven sectors. More KOPIO prototype detectors continue to be fabricated in this shop.

Design and prototyping have continued for the proposed KOPIO preradiator modules. KOPIO is awaiting approval by the US funding agencies. Robert Henderson spent the majority of this year working in the KOPIO group. If approved, this project will be a very large detector project at TRIUMF – considerably larger and more complex than previous projects such as the ATLAS calorimeter fabrication, the BABAR drift chamber, or the HERMES TRDs.

CFI funding for LADD has been approved. This money will be used to boost the detector development infrastructure at TRIUMF. LADD will take considerable time and effort to set up and is planned to give TRIUMF a world class facility for continuing development of detector technologies, not just for physics experiments but potentially for a wide range of R&D projects including a variety of medical detectors.

Experimental Support

(C. Ballard, TRIUMF)

The Experimental Support group, which includes the Beam Lines group, is responsible for the installation, alignment and maintenance of the experimental facilities at TRIUMF as well as support for the primary beam lines and maintenance, repair and operation of the secondary channels. As in 2001, the group supplied technical assistance to the existing experiments as well as technical support to ISAC and the CERN collaboration. The Beam Lines group continued to provide alignment assistance to ISAC, TWIST, Remote Handling and the RF group.

Meson hall

In January, efforts were focused on the upgrade of beam line 1A. Other projects in the meson hall included the continuation of the overhaul of the M9 separator; repairs to the M15 separator, M13 beam blocker and 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 ongoing technical assistance to the proton irradiation facility, proton therapy, PET, ATLAS and μSR.

CERN collaboration

The CERN collaboration involved two technicians and a summer student on the assembly of nine pulse forming network (PFN) tanks. The tanks will be used in the LHC collider at CERN. Each tank weighs over 2 tonnes 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.

ISAC

2A beam line

The beam line to the east target station was installed and aligned. The first 15 degree bender was moved to a second position. The 2A Wye magnet was installed in its place with steering magnets and "bunny" quads also installed and aligned. The Wye magnet can switch beam from the west target station to the east target station. The overall project took about 2 months.

β-NMR

A permanent telescope mount was placed after the GPS 2 alignment port to align the cryostat in the β-NMR experiment. This allowed the position of the sample to be checked without compromising the vacuum.

DRAGON

Two lead shielding frames in the DRAGON beam line were installed to protect personnel from X-rays emitted from the diagnostic boxes inside.

A DRAGON target analysis telescope was designed and installed. An Opti-Cal program was used to calculate the lenses required for focusing on the DRAGON gas target. The photograph obtained using an astronomical colour camera illustrated the hydrogen gas target beam glow.

GPS 2

A beam tube in the LEBT line was modified with glass view-ports to see the polarimeter without breaking vacuum.

TWIST

The TWIST Hall probe alignment table for mapping the magnetic field inside the TWIST solenoid in M13 was assembled, installed and aligned. The project involved redesigning a linear guide rail parallel to the axis of the coil to achieve the tolerances required for the map. The automatic system consisted of Hall probes mounted to a rotating aluminum tube that travelled along the axis of the magnet via a ball screw. The location of the Hall probes was to be reproducible to ± 0.010 in. Special modifications were required to maintain the tolerances during rotation as well as translation.

M13 slits

These were installed back into M13 for the TWIST experiment. A cover plate was used off-line to test the mechanism, motor drives and alignment of the slits prior to installation. A temporary motor control was run to a panel where the slits could be operated until the final controls hardware was ready. The M13 beam blocker/gate valve was reassessed because the limit switches were apparently not engaging. It was decided to remove the valve from the M13 beam line and replace the actuator arm with a welded assembly. This could take place during the January shutdown.

Magnets

The old M8 bender magnet was rebuilt and installed in the off-line ion source test stand. The magnet needed new lifting lugs and the pole gaps were shimmed to meet the specifications for bending the beam into the analysis station after going through the charge state booster. The water manifolds and hoses were replaced as well as the thermo-switched interlocks. The magnet was field mapped and assembled on the stand and aligned in the test stand beam line.

GEANT4

(P. Gumplinger, TRIUMF)

The GEANT4 Collaboration was established in late 1998 with the purpose of transferring the results of earlier R&D activities of the CERN RD44 Project to a supported production service that would provide a software toolkit for simulation of the passage of particles through matter, and in particular would serve as a modern object-oriented (OO) toolkit to build particle detector simulation programs. To this end, a number of institutions from around the world signed a Memorandum of Understanding (MoU) taking specific commitments and pledging resources toward the common goal. The Collaboration, initially formed to provide the high energy physics (HEP) community with a flexible toolkit for simulation, has expanded to include institutions whose primary work is in space science, medicine, industrial research, and commercial applications. TRIUMF is represented in both the GEANT4 Collaboration Board (CB) which administratively manages the collaboration, and the Technical Steering Board (TSB) which manages the execution of the project.

GEANT4 has grown rapidly from the R&D phase to the production stage. The Collaboration is moving toward making GEANT4 a robust and performant simulation package. A fully operational product now exists with impressive capabilities in HEP and other fields. Attention to professional software engineering methods has led to a maintainable and high-quality software product. The investments early in the project to adopt modern software methods are clearly paying off. GEANT4's object-oriented design allows external code, e.g. visualization and Graphical User Interfaces (GUIs), to be more easily incorporated. Leveraging of external resources allows GEANT4 to rapidly expand its repertoire. One of the strengths of the GEANT4 design is its modularity and flexibility in the choice of physics processes. Since the physics processes are the primary focus of a detector simulation program, a comprehensive validation program is key to the success of the product. In fact, a satisfactory implementation of hadronic models is mission-critical for the LHC experiments.

GEANT4 is gaining widespread acceptance as the tool of choice. Over the past few years, the size of the user community has grown significantly faster than the collaboration itself and will undoubtedly continue to grow. Adoption of GEANT4 by an expanding community means there are many more novice users with no previous ties to the developers of GEANT4. The collaboration has addressed many of the issues in support of the novice user. The updated documentation, tutorials and Web publication of the set of standard physics lists for hadronic physics has also been a big step in helping the users inside and outside the collaboration get started with the code. The collaboration added a Web based user requirement entry and tracking system. Three user workshops in the span of one year, at SLAC, CERN, and the European Space Agency, and the addition of Hypernews has helped improve communication, in general, and the dialog with the LHC experiments, in particular.

The GEANT4 optical photon transport modelling of Čerenkov and scintillation detectors was developed by TRIUMF collaborators and has seen substantial improvements during the past year. This specific GEANT4 functionality is now employed worldwide in experimental simulations as diverse as ALICE, ANTARES, AMANDA, Borexino, Icarus, LHCb, HARP, KOPIO, the Pierre Auger Observatory, and the GATE (Imaging in Nuclear Medicine) Collaboration. In the near future, it will also be exploited as part of the investigation to understand the optical properties of extruded plastic scintillator tiles for KOPIO and for the Near Detector of the Long Base-Line Neutrino Experiment at J-PARC/SuperK. Since the GEANT4 Collaboration has been built on a model of distributed support, TRIUMF personnel are constantly responding to inquiries posted on the G4 User Forum regarding the optical photon tracking. Questions and feedback arrive from people working in medical PET research, cosmic shower research, neutrino detectors, HEP experiments and also from corporate research laboratories. We have also attended two of the three user workshops during the past year, as well as the annual GEANT4 collaboration meeting at CERN in October.

Locally, we have encouraged and supported the TIGRESS collaboration at ISAC-II to base their simulation studies on GEANT4. This initiative was mostly carried out by two undergraduate students, Mike Schumaker and Paul Finlay, and their supervisor Carl Svensson, from the University of Guelph, and generated a contribution to the recent G4 user's workshop at CERN.

The GEANT4 group maintains a Web server at http://geant4www.triumf.ca/ for use by GEANT4 collaborators, application developers and others interested in Web tools to help with the development and testing of large software systems. At present, the server is dedicated to the following facilities: LXR, ViewCVS, CVSGraph, and Tinderbox.

LXR provides a powerful source-code viewer and browser for the entire GEANT4 package including examples and tests. Searches are available through the full text, identifiers, and filenames. The C++ code is fully cross-referenced, with hyperlinks for identifiers such as class names and methods, allowing immediate access to their definitions and occurrences.

ViewCVS is a CVS browser which gives full visual query and browsing capabilities for the GEANT4 source code repository. It provides displays of revision histories, hyperlinked activity logs, source file contents, and an excellent graphical diff utility showing changes between versions. A key element for the adoption of ViewCVS, rather than the popular CVSWeb package, is its support for CVS tags. The tag annotations and tag-based queries are essential for GEANT4's scheme of version control.

CVSGraph also accesses the GEANT4 source code repository and provides, for any source file, a hyperlinked graphical representation of its revision tree and, in particular, the attachment of tags to revision numbers. This is a great help in dealing with the sometimes voluminous tag information kept by CVS.

The above three tools have been interconnected so that the user can quickly jump between different information displays for a given source file. Since the CVS repository for GEANT4 is maintained on AFS file space at CERN, to implement the Web tools requires a copy of it to be maintained on geant4www. This is updated frequently and efficiently using rsync, but there is necessarily a short delay before CVS checking becomes visible in the local repository.

Tinderbox is a Web-based testing and archiving facility that is supplementary to the main system testing activities performed continuously at CERN. By giving visual representation of test-job status, and hyperlinked logs of test results, it is useful for both problem diagnosis and debugging, and for testing on unsupported or variant platforms that are not part of the routine test cycle. There are now more elaborate Web-based testing systems to be considered, but we have found Tinderbox to be a lightweight and reliable design and will be pursuing further applications for it such as "Large N" tests and the evaluation of new compilers.

The GEANT4 Collaboration Board has decided to convene periodic external reviews to make an assessment of the collaboration activities and to provide feedback to the CB with the aims of improving the collaboration and guiding the choice of its future objectives. The first such review was held at CERN on June 18–21, 2001, followed by a Delta Review, also at CERN, on October 9–11, 2002. The two reports at http://wwwinfo.cern.ch/asd/geant4/geant4.html contain many recommendations but also compliment the collaboration on their tremendous success.

GEANT4 collaborators at TRIUMF include: P. Gumplinger, F.W. Jones, C.J. Kost and M. Losty.

Scientific Services

(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 2002 included: producing the 2001 Annual Report, the abstracts book and proceedings for the 14$^{\mathrm{th}}$ International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications (EMIS-14), and the TRIUMF preprints; updating the functionality of the database system for the Library; coordinating TRIUMF tours and assisting with the production of public relations materials; and supporting twenty past, present and future conferences and workshops. The primary focus of the group throughout the year concerned all aspects of hosting the EMIS-14 conference in Victoria in May.

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 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 2001 report was available to readers two weeks before the printed version. During the last two months of 2002, over 300 people accessed the 2001 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 unchanged but the instructions document which all authors should consult was expanded to include additional information on the correct production of Encapsulated PostScript files for the figures and the submission of original file formats.

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 post-mortem of the 204 figures in the 2001 Annual Report was produced and included on the Web site to supplement those for the 1998–2000 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.

In addition to the Annual Report and TRIUMF preprints, the Publications Office also produced the book of abstracts and proceedings for the EMIS-14 conference. Having produced a $\LaTeX 2_\varepsilon$ template and instructions for abstract submission and posted them on the EMIS-14 Web site in November, 2001, 155 abstracts were received by the February 1 deadline. These were processed, edited, entered on a database, and made available to the international advisory committee on a secure Web site to facilitate determination of which abstracts should be presented as contributed oral talks or as poster session papers. Once the conference program was finalized, authors were informed of their abstract designation and given manuscript preparation instructions. With assistance from the SFU TRIUMF secretary, a book of abstracts was produced for the conference delegates. The refereed conference proceedings were to be published by Elsevier Science as a dedicated issue of Nuclear Instruments and Methods in Physics Research Section B, Beam Interactions with Materials and Atoms. The functionality of the abstract database was extended to accommodate the many steps that would be necessary to track manuscripts from their initial submission, allocation and sending to the referee, return from the referee, possible return to author for correction and re-submission, and in some cases multiple loops of the procedure. A set of forms and a filing system were also produced that would be used to track the manuscripts. Most of the manuscripts were received at the conference proceedings office in May and wherever possible they were given to the referees during the conference. Some extremely diligent referees even completed their task before the end of the conference and returned their allocated manuscripts indicating whether they were approved with or without corrections. The task of tracking and chasing the manuscripts took until early December. Some manuscripts were in transit up to eight times between TRIUMF, referee and author. The 129 accepted manuscripts were sent to the publisher in both electronic and hard copy format before Christmas, along with the additional material to appear at the front and back of the proceedings. A May, 2003 publication date is anticipated.

Substantial Web site support was provided for the Summer Nuclear Institute at TRIUMF (SNIT 2002) held June 10–21. Apart from creating and maintaining the Web site, PDF files of all the lectures were created from a variety of original file formats and posted on the site.

Support was provided for the Italian-Canadian Interface for the Development and Exploitation of Stable and Exotic Ion Beams which was held at TRIUMF October 16–20, 2002. A conclusions and abstracts booklet was produced.

Work for the Joint Accelerator Conference Website (JACoW) committee included: presenting two papers at the 3$^{\text{rd}}$ JACoW Team Meeting held in Thoiry, France, in February; collaborating on the publication of the electronic proceedings of the European Particle Accelerator Conference (EPAC 2002), held in Paris, France, in June; and co-chairing the Database Workshop and presenting a paper at the 4$^{\text{th}}$ JACoW Team Meeting held at Lawrence Berkeley National Laboratory in November.

Library

The Library budget was increased in 2002 to compensate for rising journal subscription costs and unfavourable exchange rates for 2003 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 a few book purchases in 2002 and continues to rely on donations for most of its acquisitions.

The Oracle database system implemented in 2000 was upgraded 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

The Information Office coordinated tours for 2,178 people during 2002, the highest number since 1997. The general public tours were conducted by a summer student during the June to August period when tours were offered twice a day. 245 people took a record number of tours (77) 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.

Table XVI shows the number of people taking tours, the number of tours, and the number of tour guides required to conduct them (groups of more than 15 require multiple tour guides) for each of the years 1999–2002 plus the totals. A steady increase can be observed. The numbers are broken down into four categories:

- General public: tours provided for members of the general public twice a week September–May, and twice a day June–August on a drop-in basis.
- Science: pre-arranged tours conducted for university/college physics, chemistry or science students with a specific interest in TRIUMF, scientists at TRIUMF for a conference or workshop, and scientific groups.
- Students: pre-arranged tours conducted for elementary and high school students and university/college non-science students.
- VIP: Specific tours, often conducted by senior management personnel, arranged for VIPs, review/advisory committee members, and the media.

Table XVI. Breakdown of TRIUMF tour numbers for the period 1999–2002.

Category	1999	2000	2001	2002
General Public				
# people	350	368	421	499
# tours	96	107	110	131
# tour guides	96	107	111	134
Science				
# people	384	294	383	592
# tours	18	20	30	23
# tour guides	33	26	43	57
Students				
# people	794	612	839	894
# tours	46	40	30	40
# tour guides	70	53	60	70
VIP				
# people	145	171	258	193
# tours	37	37	59	53
# tour guides	38	40	65	55
Total				
# people	1,673	1,445	1,901	2,178
# tours	197	204	229	247
# tour guides	237	226	279	316

The summer student assisted with the production of a MS PowerPoint version of a slide presentation often given by TRIUMF staff to high school students. A Japanese translation was also produced.

The TRIUMF Welcome Page, which is accessible directly at http://www.triumf.ca/welcome or via the TRIUMF WWW Home Page, continues to receive well over 5,000 visits each year. The series of WWW pages were developed by two co-op students and are intended to provide an overview of TRIUMF in a format understandable to the general public. The Information Office responds to any questions posed by visitors to the site. Some limited maintenance of the pages was performed during the year. A Web site committee met frequently during the year in an effort 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 dramatically as more speakers gave seminars and presentations using MS PowerPoint, Star Office, Adobe Acrobat, and other applications. It was also used at the WRNPPC'02 and EMIS-14 conferences.

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

Conferences

2002 was an extremely busy year for conferences and workshops. Apart from the EMIS-14 conference, support was provided for twelve other conferences, workshops and meetings. Seven occurred within the busy April–July period. Registration databases were created and managed for most of the conferences.

In addition, support was provided in the electronic proceedings office of the European Particle Accelerator Conference (EPAC 2002), held in Paris, France, June 3–7.

TRIUMF hosted or supported the following conferences and workshops in 2002:

- Joint Belle-BaBar Worshop on Detector Issues, TRIUMF, February 14–16 (31 delegates).
- Workshop on Low Energy Precision Electroweak Measurements (LEPEM2002), TRIUMF, April 4–6 (68 delegates).
- TITAN Workshop, TRIUMF, April 11–13 (37 delegates).
- Alpha Therapy Workshop, TRIUMF, April 29 (72 delegates).
- 14$^{\text{th}}$ International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications (EMIS-14), Victoria, May 6–10 (159 delegates).
- Summer Nuclear Institute at TRIUMF (SNIT 2002), TRIUMF, June 10–21 (43 delegates).
- 5$^{\text{th}}$ International Conference on Hyperons, Charm and Beauty Hadrons (BEACH 2002), UBC, June 25–29 (116 delegates).
- Workshop on Big DRAGON: a Recoil Separator for ISAC-II at TRIUMF, TRIUMF, July 18–19 (35 delegates).
- Symposium on Symmetries and the Weak Interaction: in Celebration of the 80$^{\text{th}}$ Birthday of Sir Denys Wilkinson, TRIUMF, September 5 (52 delegates).
- TRIUMF Five-Year Plan Town Meeting, TRIUMF, September 21–22 (75 delegates).
- Italian-Canadian Interface for the Development and Exploitation of Stable and Exotic Ion Beams, TRIUMF, October 16–20 (36 delegates).
- Physics Teachers Professional Development Day Workshop, TRIUMF, October 25 (85 delegates).
- TRIUMF Users' Group Annual General Meeting, TRIUMF, December 11 (41 delegates).

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

- Functional Imaging PET Workshop, UBC, June 26–27, 2003.
- Summer Nuclear Institute at TRIUMF (SNIT 2003), TRIUMF, July 21 – August 1, 2003.
- GEANT4 2003 Workshop, TRIUMF, September 2–6, 2003.
- International Union of Pure and Applied Physics (IUPAP) Meeting, October 10–11, 2003.
- HEPiX-HEPNT Autumn 2003 Meeting, TRIUMF, October 20–24, 2003.
- Eighth International Symposium on Nuclei in the Cosmos (NIC8), Vancouver, July 19–23, 2004.
- Fifth International Symposium on Radiohalogens (5ISR), Whistler, September 11–15, 2004.

The DRAGON Facility
(J.M. D'Auria, SFU)

The primary purpose of the DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) facility, located in the ISAC-I experimental hall, is to measure the astrophysical S-factor or resonance strengths in sub-Coulomb barrier, radiative proton and alpha capture reactions. These reactions are studied using inverse kinematics with gaseous targets of hydrogen or helium bombarded with stable and radioactive heavy ion beams of energies from 0.15 to 1 MeV/u. The rates of such reactions are of interest to increasing our understanding of explosive nucleosynthesis phenomena in nova, supernova, and X-ray bursts. Funding for the DRAGON facility was received April, 1998 and DRAGON began taking data for Expt. 824 in October, 2001. Described herein are upgrade changes made to the facility over the last 12 months along with commissioning studies.

Figure 171 is a schematic representation of the DRAGON facility. It is composed of a windowless, recirculating gas (hydrogen or helium) target (with a cold trap) surrounded with a gamma detection array (30 BGO units), an electromagnetic separator (EMS) and a recoil detection system. The separator will accept heavy recoil products of radiative capture reaction. Their momentum is essentially the same as the beam itself. The design philosophy of the EMS is to select one charge state of the beam and reaction products to pass through slits located after the first magnetic dipole. Beam and reaction products are then separated in the first electrostatic dipole, due to their difference in kinetic energy. Additional separation/beam suppression is achieved in the second stage. In the focal plane detection system the main detector used has been a DSSSD (double sided silicon strip detector), which provided both energy and spatial information, both singly and in coincidence with the gamma system. More complete descriptions can be found elsewhere [Hutcheon *et al.*, Nucl. Instrum. Methods (in press); Liu *et al., ibid.*].

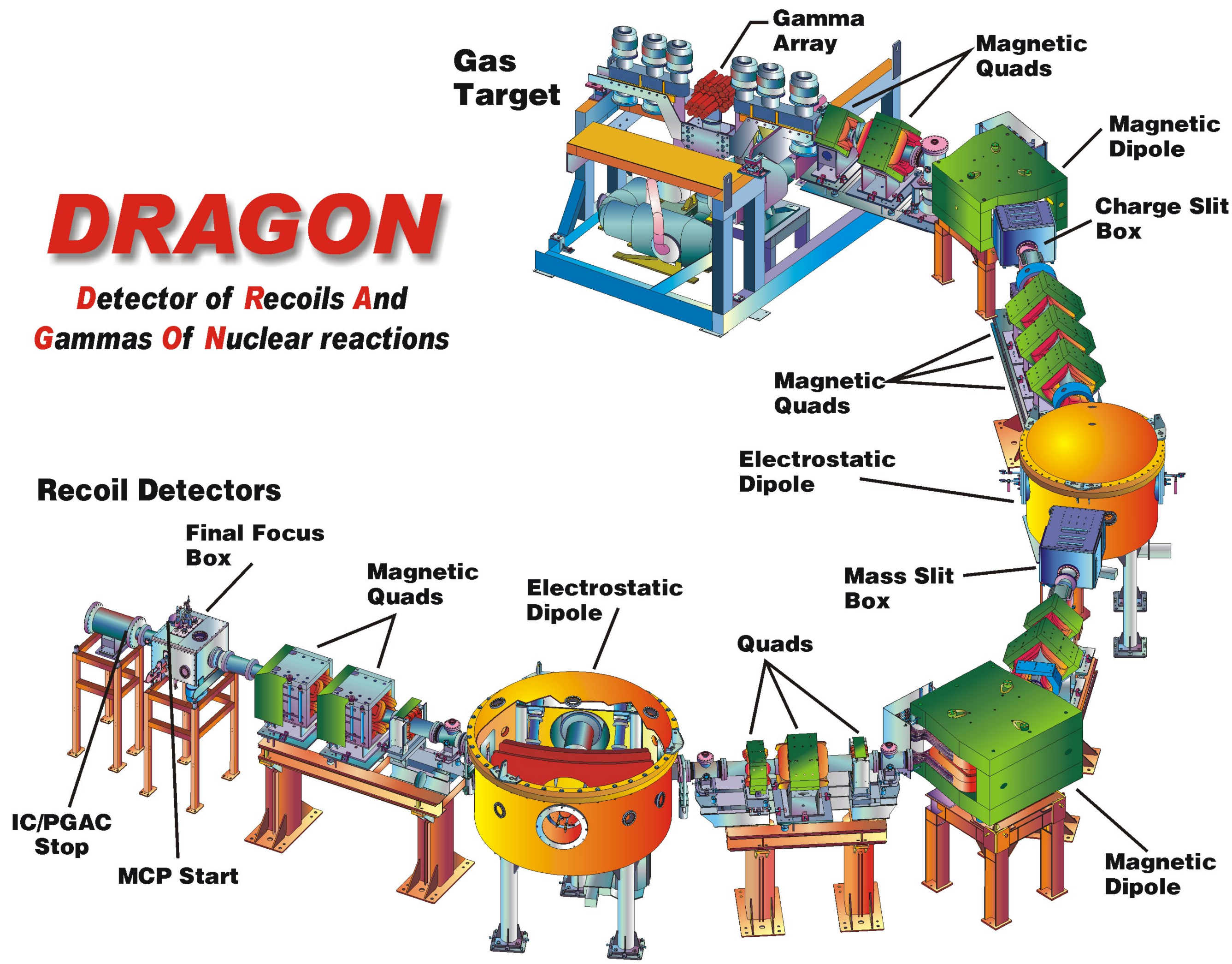

Fig. 171. Schematic view of DRAGON.

Synopsis of facility changes

A number of hardware improvements were made in 2002. These included:

1. Installation and testing of a segmented ionization chamber for detection and identification of the recoil products at the exit of the EMS.
2. Installation and testing of the microchannel plate system to be used at the focal plane for timing and position information.
3. Testing of a novel optical viewing system to allow tuning of the beam while it is intercepting the gas in the target.
4. Improvements in the EPICS-based DRAGON separator tuning program.
5. Replacements of older-model dipole power supplies.
6. Construction and installation of a safety fence around the complete facility.
7. Installation of lead-filled shields around mass and charge slit chambers.

Commissioning

Considerable time was devoted in the past year to using stable beams of ^{14}N, ^{20}Ne, ^{21}Ne, and ^{24}Mg over a wide range of energies to understand and improve the operation of the facility. Approximately 125 shifts in total, with runs in almost every month, were delivered to DRAGON. In particular these studies were devoted to:

1. Calibration of a technique of measuring the incident beam energy.
2. Calibration of the overall absolute efficiency of the DRAGON.
3. Studying the response of DRAGON for a wide resonance.
4. Testing focal plane detection systems.

Table XVII. Reaction resonances used for energy calibration studies.

Reaction	E_{lit} (keV)	E_{meas}(keV)	$E_{\mathrm{m}}/E_{\mathrm{l}}$
^{20}Ne$(p,\gamma)^{21}$Na	1112.6 ± 0.6	1110.9 ± 0.8	0.998
^{21}Ne$(p,\gamma)^{22}$Na	731.5 ± 1.6	732.1 ± 0.5	1.001
^{24}Mg$(p,\gamma)^{25}$Al	214.0 ± 0.8	214.5 ± 0.4	1.002

Table XVIII. Efficiency calibration studies.

Reaction	E_{cm} (keV)	$\omega\gamma_{\mathrm{pub}}$	$\omega\gamma_{\mathrm{meas}}$	$\omega\gamma_{\mathrm{meas}}/\omega\gamma_{\mathrm{pub}}$
^{20}Ne$(p,\gamma)^{21}$Na	1112.6	1.13 ± 0.07 eV	0.92 ± 0.17 eV	0.81
^{21}Ne$(p,\gamma)^{22}$Na	258.6	82.5 ± 12.5 meV	209 ± 35 meV	2.27
^{21}Ne$(p,\gamma)^{22}$Na	731.5	3.95 ± 0.79 eV	3.85 ± 0.50 eV	0.97
^{24}Mg$(p,\gamma)^{25}$Al	214.0	12.7 ± 0.09 meV	11.7 ± 0.2 meV	0.92
^{24}Mg$(p,\gamma)^{25}$Al	402.2	41.6 ± 2.6 meV	56.4 ± 8.7 meV	1.36
^{24}Mg$(p,\gamma)^{25}$Al	790.4	532 ± 41 meV	576 ± 39.3 meV	1.08

Beam energy

Beam energy at DRAGON is measured using the first dipole, MD1. Beam is centered through a 2 mm opening in the slits at a focus after MD1. Energies calculated from MD1 NMR magnetic field readings were checked against known resonance energies. The results are shown in Table XVII.

System efficiency

Since the DRAGON is used to measure the absolute resonance strength of unknown reactions involving radioactive reactants, studies were performed to understand the operation (transmission, etc.) under different settings (e.g. slit settings, tuning, etc.). A beam deflection magnet, temporarily replacing the gas target was used to study transmission properties. In addition, a number of known resonance strengths were measured using stable beams (Table XVIII). Such studies will continue.

Wide resonance

DRAGON was designed specifically to study resonances whose widths are much less than the energy loss in the gas target chamber. However, there is interest in broad resonances and non-resonant capture reactions also, and beam time was devoted to explore and measure the response of DRAGON in those cases. This study involved the ^{21}Na radioactive beam for the resonance at $E_{\mathrm{cm}} = 821$ keV and the results are displayed in Figure 172. The resonance strength, $\omega\gamma$, of this broad resonance was measured to be 556 ± 77 meV while the width, Γ, was estimated to be 16.1 ± 2.8 keV.

Focal plane detectors

The specially designed ionization chamber for detecting reaction products at the end of DRAGON was tested (for Expt. 811) using the ^{21}Ne$(p,\gamma)^{22}$Na reaction. Excellent separation was noted between neon and sodium ions at 0.5 MeV/u both singly and in coincidence with the gamma array.

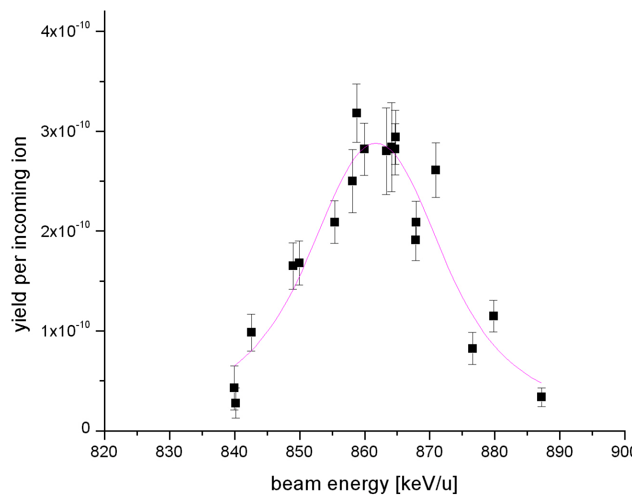

Fig. 172. Preliminary data for Expt. 824.

Science with DRAGON

Radioactive ^{21}Na beam was delivered to DRAGON for Expt. 824 for 2.5 weeks in April/May and about 3 weeks in November/December. Studies of resonances in the ^{21}Na$(p,\gamma)^{22}$Mg reaction at $E_{\mathrm{cm}} = 212$, 336, 461, 545, and 747 keV are discussed elsewhere in this Annual Report.

Outlook for 2003

Beam time (both stable and radioactive) will be requested for approved experiments 811 (U. Greife, spokesperson, the study of the ^{19}Ne$(p,\gamma)^{20}$Na reaction), and 805 (J. King / J. D'Auria, spokespersons, the ^{13}N$(p,\gamma)^{14}$O reaction). Both of these require the use of the ISAC ECR ion source, which is expected to be operational by April, 2003.

In addition, several new experiments were approved by the EEC and could run in 2003 with, at most, minor changes to the DRAGON facility. These include studies of the ^{17}F$(p,\gamma)^{18}$Ne, ^{12}C$(\alpha\ ,\gamma)^{16}$O, and ^{12}C(^{12}C, $\gamma)^{24}$Mg reactions. Some longer-term proposals, requiring more extensive changes to the BGO array or gas target include a revised ^{8}Li$(\alpha,n)^{11}$B study or phase II of ^{12}C$(\alpha,\gamma)^{16}$O. In addition, studies are in progress to explore the feasibility of producing a sufficient amount of ^{15}O (for Expt. 813) with the TR13 cyclotron using a (p,n) reaction, with an on-line gas transfer (of C^{15}O) to OLIS for the production of an accelerated beam.

Summary

The DRAGON facility is now operational with the completion of the first study, Expt. 824; a number of commissioning studies have also been performed. In addition to presentations at conferences and several manuscripts submitted or accepted for publication on DRAGON related studies, one M.Sc. thesis has been completed and four other thesis projects (two Ph.D., two M.Sc.) are essentially completed.

8π Spectrometer

(G.C. Ball, TRIUMF)

Since the 8π γ-ray spectrometer was moved to TRIUMF in 2000, it has undergone significant modifications to optimize its performance for β-decay studies with the non-accelerated radioactive beams available in the low energy area of ISAC (see 2000 and 2001 Annual Reports for details). The first radioactive beam, ^{26}Na, was delivered to the spectrometer in May, 2002. At that time all 20 Compton suppressed HPGe detectors were operational and the original signal-processing and acquisition system was used. This test run demonstrated that the LEBT was able to cleanly deliver a radioactive beam to the spectrometer without dumping radioactive beam on any slits in close proximity to the detector array. The experiment also demonstrated the proof-of-principle of the technique for measuring β-decay lifetimes using γ-rays.

During the next three months a major upgrade of the 8π spectrometer data acquisition system was carried out. This upgrade was needed to meet the requirements of the superallowed β-decay program for precision branching ratio and lifetime measurements (see C. Svensson, Expt. 909). The cost of this upgrade was shared with LLNL. The original system which was based on the LeCroy CAMAC booster (CAB) was replaced with one utilizing FERA readout. The new system uses Ortec ADCs for digitizing pulse heights, LeCroy multihit TDCs for the Ge times and pile-up markers and a LeCroy universal logic module acting as a latching scaler to give an absolute event tag, time stamp and dead time on an event by event basis. The data is streamed into a 64 kword VME triple port memory unit and readout with standard TRIUMF supported data acqusition hardware/MIDAS software. This upgrade has resulted in a factor ten increase in through-put from under 4000 Hz to a theoretical maximum rate of 50000 Hz. In addition, at instantaneous rates of 30000 triggers/s, less than 1 in 10000 events is lost between the FERA and the on-line analyzer.

A new on-line spectrum viewer was also developed by the 8π collaboration based on ROOT, the object-oriented data analysis framework developed at CERN to replace PAW.

ROOT is a very powerful and versatile tool but also requires a knowledge of C++, therefore it was decided to provide a user-friendly viewer. Following recent developments at GSI, a graphical user interface, GUI, was produced by linking ROOT with QT, a commercial software specialized for designing GUIs. The project was completed over a six month period by F. Sarazin and B. Eshpeter, a summer student, with the support of the TRIUMF DAQ group who converted MIDAS data to ROOT formatted data. The spectrum viewer provides a wide range of display options and specialized features including: one and two dimensional spectra, isometric projections, simultaneous display of multiple spectra, peak fitting etc. Following the early success of the implementation of the new 8π GUI, TRIUMF has decided to develop and support ROOT based graphical software for on-line monitoring of ISAC experiments.

The first 8π development run using the upgraded data acquisition and on-line monitoring system was carried out in August, 2002. With a beam of 10^{4--6}/s ^{26}Na the system was operated at various rates in several different modes to thoroughly understand all possible sources of systematic error for precision lifetime measurements. Approximately 100 GB of data were obtained; the analysis is in progress (see C. Svensson, Expt. 909 for more details). A study of the β-decay of ^{11}Li was also carried out this time (see page 65, β-decay of ^{11}Li). In addition, three experiments were done with the 8π spectrometer using long-lived radioactive sources, namely ^{176}Lu, ^{178}Hf and ^{150}Eu (see page 64, Other studies with the 8π spectrometer).

There are currently seven approved ISAC experiments that will use the 8π spectrometer (Expts. 909, 921, 929, 954, 955, 957 and 961) including four which were approved by the TRIUMF EEC in December, 2002. Several of these experiments are β-γ coincidence studies requiring the scintillating electron positron tagging array (SCEPTAR) that is currently under development. The design goals of SCEPTAR are to provide high β detection efficiency, a low energy threshold, minimum sensitivity to γ-rays, high count rate capability and a detector granularity comparable to the HPGe array. An integral part of SCEPTAR is a fast tape transport system being designed by E. Zganjar (LSU) to remove long-lived daughter activities from the focus of the array. During the past year the development of prototype detectors was completed. A detailed design of the array, the associated vacuum chamber and moveable support stand was also carried out and machining of the components is in progress. Fabrication and assembly of the complex detector array is scheduled for completion in February, 2003 with installation and initial beam tests in April, 2003.

Finally, during the past year a total of 40 collaborators from 12 institutions actively participated in the development and or/use of the 8π spectrometer, including: 10 undergraduate students, 4 graduate students and 7 post-doctoral fellows.

Towards TIGRESS

(G. Hackman, TRIUMF)

To take full advantage of the physics opportunities presented by ISAC-II beams, a state-of-the-art γ-ray detector array with high efficiency and high resolution is needed. In 2002 the TIGRESS (TRIUMF-ISAC gamma-ray escape suppressed spectrometer) team was pro-active in its goals of building the detector in stages for early implementation in 2005 and full implementation in 2009. The full array will have 16 elements, the active detector elements of each being a high-purity germanium (HPGe) multi-crystal high-resolution spectrometer of the "clover" variety with eight-fold segmented outer contacts, each clover surrounded by reconfigurable bismuth germanate (BGO) and CsI(Tl) suppression shields. Progress involving major contributions from TRIUMF staff in 2002 includes: a) optimization of the suppressor shield design; b) conceptual design of the support structure; c) procurement of a prototype HPGe detector; d) design, construction, and testing of a reliable LN_2 control system for maintaining the HPGe detectors at cryogenic operating temperatures; and e) submission of a Major Installation Grant RTI-3 to NSERC for funding of the full array.

Suppressor design evaluation

GEANT-4 simulations were performed to decide between two possible suppressor designs, one with a monolithic suppressor shield and one with multi-component shields as shown in Fig. 173, comprising a "back-catcher" of CsI(Tl) fixed directly to the HPGe cryostat, a "back-side" shield of BGO also fixed to the cryostat, and side BGO shields that could move independently of the HPGe. In the simulations, the latter design exhibited far superior performance while providing the ability to reconfigure the components to maximize either photopeak efficiency ϵ or photopeak-to-total ratio P/T, whichever is apropos for a given experiment. In the close-packed configuration, with the BGO retracted and the HPGe inserted to a radius of

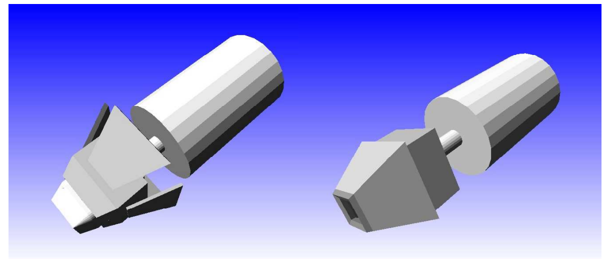

Fig. 173. Schematic of TIGRESS module configured for maximum efficiency (left) or maximum peak-to-total (right).

11 cm, $\epsilon = 27\%$ and P/T $= 64\%$ for 1 MeV γ-rays. In the pulled-back configuration the HPGe are withdrawn to 14 cm and the side suppressor shields are inserted between, $\epsilon = 14\%$ and P/T $= 73\%$.

Mechanical design

The mechanical support structure for the array required a detailed conceptual design study. Figure 174 shows the overall support superstructure while Fig. 175 shows the mechanism for insertion and

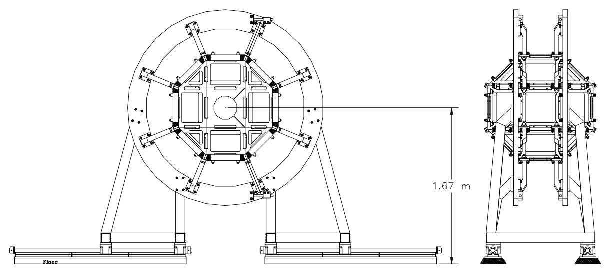

Fig. 174. Mechanical superstructure design.

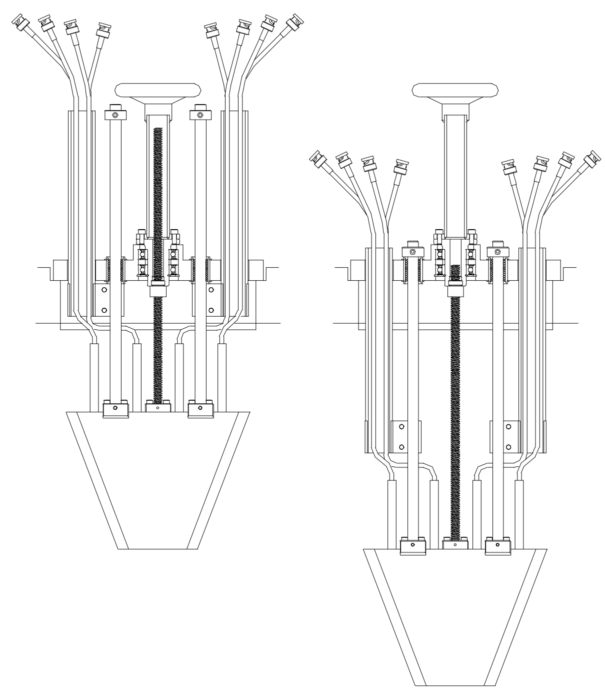

Fig. 175. Side BGO retraction mechanism.

withdrawal of the BGO side shields. This design provides the ability to adapt the array to, for example, a large downstream recoil spectrometer. In addition, this design permits manual reconfiguration from close-packed to maximum-peak-to-total in an afternoon. Cost estimates for final design and component fabrication were also determined.

Prototype HPGe

The TIGRESS team has procured a prototype HPGe detector of the "clover" configuration, with four HPGe crystals in a single cryostat. The outer contacts are electrically split into 8 segments arranged in two layers of four quadrants per crystal, with the lateral segmentation 20 mm from the front of the crystal. With this segmentation it is possible to localize γ-ray interactions within a quadrant and also obtain some indication of the depth within the crystal. Furthermore, such an outer-contact configuration, in conjunction with advanced digital-signal processing techniques, can allow for determination of the first-interaction location to within a few millimeters. This feature will be needed for the full TIGRESS array for Doppler-shift correction of γ-rays emitted from the products of reactions involving high-energy radioactive beams from ISAC-II. A prototype design study carried out by Aptec was funded by TRIUMF and the detector was ordered in April, funded by a CFI-OIT grant obtained by C. Svensson (Guelph). The detector arrived at the end of 2002 (see Fig. 176). Initial tests showed that all 36 contacts functioned; in particular, the 32 outer contacts were operating well within specified resolution for a ^{60}Co source. An extensive testing and characterization program to measure the position sensitivity of the detector will commence in 2003.

LN_2 system

A prototype, compact, portable, and reliable LN_2 distribution control system was developed to maintain the prototype HPGe at operating temperature (Fig. 177). The system is based on Modicon PLCs, and all process control is self-contained. A graphical interface is provided through the ISAC standard EPICS system.

Submission of NSERC grant request

The R&D developments described herein were included in an NSERC grant request with C.E. Svensson (University of Guelph) as lead spokesman, and J.C. Waddington and Alan Chen (McMaster University), J.P. Martin and C. LeRoy (Université de Montréal), R. Roy and L. Beaulieu (Université Laval), T. Drake (University of Toronto), J.M. D'Auria (Simon Fraser University), and G.C. Ball and G. Hackman (TRIUMF) as grant-elligible collaborators.

Finally, the team held a mini-workshop at the UBC campus following the Big DRAGON workshop in July. The mini-workshop was attended by A. Boston (Liverpool), C. Gross and D. Bardayan (Oak Ridge), C. Beausang (Yale), J.M Casandjian (GANIL), A. Shotter, J.-M. Poutissou and R. Poutissou (TRIUMF). The mini-workshop provided an opportunity for team members to share their progress and also to obtain expert input and feedback.

The TIGRESS team is large and growing. From TRIUMF, the core group in 2002 was G.C. Ball, J. Braun, K. Cheung, R. Churchman, F. Cifarelli, G. Hackman, F. Sarazin, H. Scraggs and M.B. Smith. We also received valuable technical assistance and support from P. Gumplinger (GEANT4), R. Roper (cost estimates), D. Bishop, D. Dale, R. Keitel and D. Morris (LN_2). The performance simulations were performed in collaboration with P. Finlay, M. Schumaker and C.E. Svensson (University of Guelph).

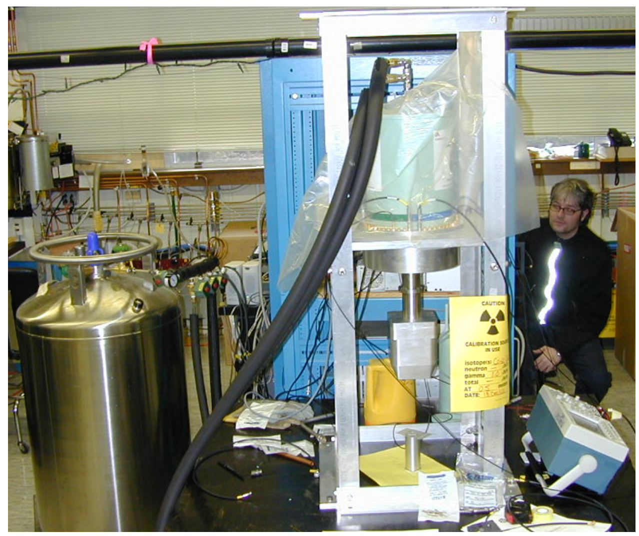

Fig. 176. The prototype clover detector, with its pale green LN_2 holding dewar and with the HPGe in the tapered-rectangular vacuum cryostat, is shown mounted on an aluminum testing frame and connected to the LN_2 distribution manifold to the left.

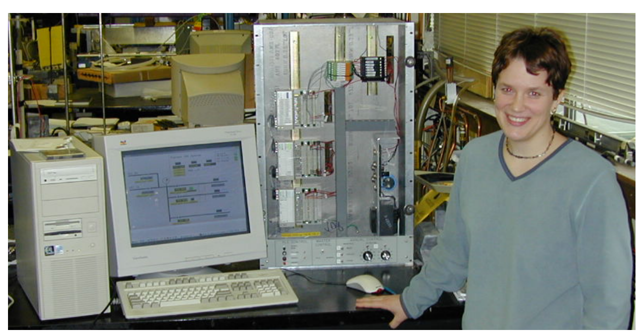

Fig. 177. PLC-based LN_2 control system in the centre, with interface computer displaying EPICS monitoring page on the left.

RFQ Cooler and Buncher Developments for TITAN

(J. Dilling, TRIUMF)

RFQs filled with buffer gas, operating as coolers and bunchers, are widely used or under construction at almost all radioactive nuclear beam facilities, for example at ISOLDE/CERN, GSI, Argonne and MSU. This is due to their proven ability to provide a 10–50-fold improvement in beam quality and their capability to convert a dc beam into well defined bunches with an overall efficiency of up to 60%.

The basic principle is the following: the incoming ion beam is electrostatically retarded and guided into a segmented four rod structure where alternating potentials generate a quadrupole field. Interactions with the buffer gas cool the ion beam and applied potentials allow for both an accumulation of the ions and an extraction as a bunch with well-defined transverse and longitudinal properties.

The developments at TRIUMF include two significant changes over existing devices:

1. The RFQ can be installed both horizontally and vertically, allowing one to extract the beam both at the entrance side and the top side in the latter orientation.
2. Employ very high rf amplitudes (we intend to go to 10 kV) instead of the typical 100–500 V peak-to-peak voltage.

The modification for a vertical set-up will allow other experiments at the ISAC beam line level to make use of a cooled and bunched beam, for example for co-linear laser spectroscopy in the polarized beam line. This will be possible with the new concept of a square support structure to hold the segmented rods on insulator bars (see Figs. 178 and 179). The system will be mounted to the lid of the vacuum-housing box, allowing one to lift out the structure for easy access. Moreover, the vacuum vessel and alignment system provides for set up in both orientations.

The advantage of going to higher rf amplitudes is to raise the space charge limit. The pseudo-potential, and hence the number of charges that can be stored until the outer trapping force and the repelling Coulomb force are in equilibrium, is proportional to the rf amplitude. At present, our collaboration partner at McGill University has reached amplitudes of 6 kV, employing new coupling techniques. The high fields are required in order to provide large samples of cooled bunched ions, needed for example for β-NMR experiments.

Intensive calculations and simulations have been carried out which show that a 100% acceptance of the ISAC beam (emittance of $\epsilon_{\rm trans} = 40\,\pi$ mm mrad at 60 keV) can be reached. For the extracted beam an emittance of $\epsilon_{\rm trans} = 1\,\pi$ mm mrad at 2 keV can be expected, corresponding to an improvement by a factor of over 50. The longitudinal energy spread is $\epsilon_{\rm long} < 5\,{\rm eV}\,\mu{\rm s}$. The kinetic energy of the extracted beam can be adjusted using a drift tube, where the potential can be rapidly ramped to ground.

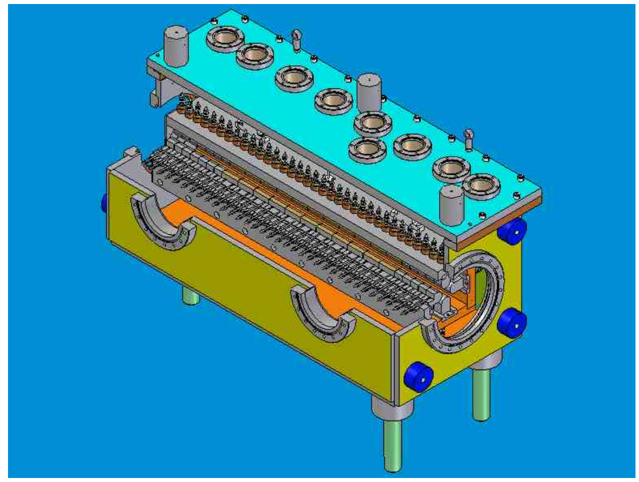

Fig. 178. The RFQ rods are supported by a squared structure, which allows for a vertical and horizontal orientation of the system.

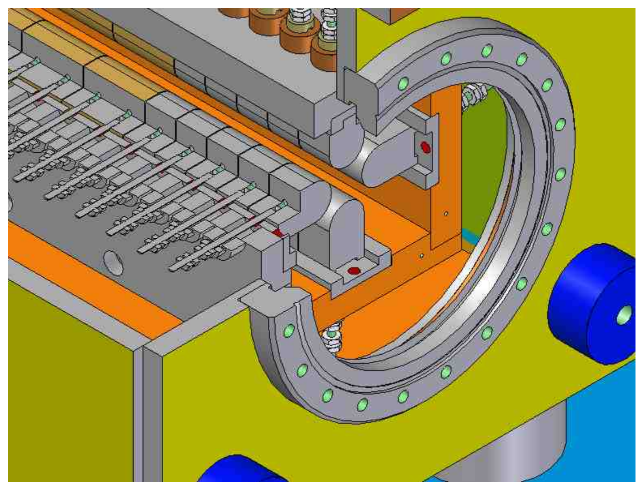

Fig. 179. Design drawing detail of the RFQ structure including the vacuum housing (small inlet).

These features are ideally suited for further beam manipulation of the ISAC beam in, for example, charge-breeding devices, like the EBIT system in the case of the TITAN facility or the ECR charge breeder. For the latter one the improvement in emittance should make a significant difference in the overall performance, leading to increased breeding efficiencies.

The entire system has been designed and is partially in the fabrication stage awaiting assembly in the TITAN test area being set up in the proton hall extension.

The rf driver for the RFQ has been designed and is being built in conjunction with the TRIUMF Control group and will be finished in September, 2003. Plans are initially to carry out tests to characterize the performance of the RFQ system. Later, a coupling to the ECR charge breeder in horizontal orientation will allow for tests to determine the effect of the beam quality improvement (spring/summer 2004). Finally, this RFQ system will be installed in a vertical configuration at the ISAC beam line as part of the TITAN system and for use as cooler and buncher for the polarized beam line employed for β-NMR or laser spectroscopy experiments.

TRINAT Off-line Laser Lab
Progress in precision optical pumping
(S. Gu, TRIUMF)

When polarizing nuclei using optical pumping, there are quantum field effects of laser-atom interactions that must be considered. Complete polarization of alkali atoms like ^{41}K and ^{37}K requires two frequencies of circularly polarized laser light, one for each hyperfine-split ground state. When the difference between the two frequencies matches the ground state splitting, there can be coherent transfer of population between the states, and the states are mixed by the interaction. The new eigenstates of the full Hamiltonian are linear combinations of the bare atom eigenstates, with phase determined by the laser light phase. The result is one eigenstate that does not absorb laser light, and that eigenstate is not optically pumped so that atoms remain unpolarized. We have found that such states are very fragile and easily destroyed, so they are not a practical impedance to achieving high polarization. The following is a more detailed characterization of similar phenomena explored as part of our group's participation in the Canadian Institute for Photonics Innovations.

Coherent population trapping refers to the process described above. In constrast with coupled atoms ($|C>$) which interact with the laser, atoms that are coherent population trapped don't interact with the laser and are hence denoted as un-coupled atoms ($|UC>$) [Arimomdo, Progress in Optics **XXXV**, 257 (1996)].

We have experimentally studied hyperfine $|UC>$ with cold ^{41}K atoms in a magneto-optical trap. The results are compared and agree with our numerical solutions of the optical Bloch equations for the time evolution of the density matrix. We have also proposed a "pseudo 3-level" theoretical model which explains hyperfine $|UC>$ behaviour well.

In the experiment we used a right-circularly polarized bichromatic D_1 laser beam to optically pump atoms in a magnetic field ($\mathbf{B}$) to the fully polarized $F=2$ $m=2$ sub-state. When the two laser frequencies ν_1 and ν_2 satisfy the Raman resonance $h(\nu_1-\nu_2)=W_m$ condition, certain atoms will be trapped in that pair of m sub-states, i.e. in $|UC>$ (where $W_m (m=-1,0,1)$ is the ground state hyperfine level splitting of the m sub-state in the given $\mathbf{B}$ field). Unlike most experiments in which $|UC>$ are mixed with $|C>$, in our experiment we have successfully realized pure $|UC>$. Our study shows that $|UC>$ is physically characterized by the off-diagonal "hyperfine coherence" terms of the density matrix, rather than the on-diagonal populations. This is made manifest by off-Raman resonance oscillations (ORRO), an experimental technique we developed for studying the hyperfine coherence.

In realizing the ORRO experiment, we first feed rf into two acousto-optic modulators to shift the diode laser frequency into two frequencies satisfying the Raman resonance condition. After $|UC>$ has been prepared with this bichromatic laser light, we then change the rf so that the laser frequencies are switched off the Raman resonance, that is, $h(\nu_1-\nu_2)-W_m=h\Delta\nu$. Under this condition the atomic system won't be in pure $|UC>$ anymore and will oscillate between $|UC>$ and $|C>$ at the frequency $\Delta\nu$, that is ORRO. We experimentally study the ORRO process by observing the fluorescence from those original $|UC>$ atoms. We can see from Fig. 180 that the initial phase of the recorded oscillation curves is different. We have realized that it

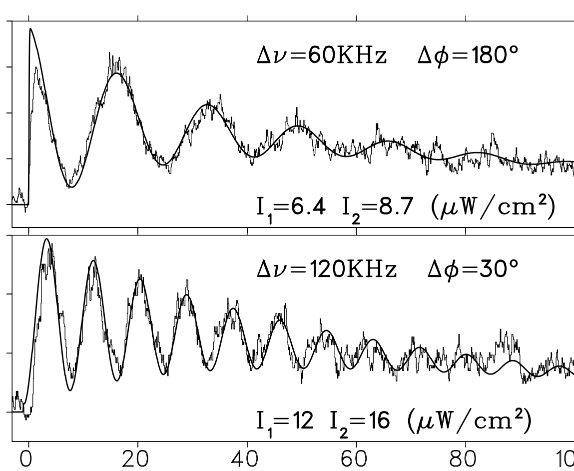

Fig. 180. Experimental measurements of off-Raman resonance oscillations compared to full optical Bloch equation calculations. With lasers on the Raman resonance, $h(\nu_1-\nu_2)=W_0$, atoms were pumped for 900 μs to prepare $|UC>$ with $m=0$ hyperfine states. Then (at $t=0$) ν_1 and ν_2 were switched off-resonance, $\nu_1 \to \nu_1+\Delta\nu/2$, $\nu_2 \to \nu_2-\Delta\nu/2$ for the ORRO process. In the calculation $\Delta\phi$ was fit to the corresponding ORRO curve, and laser intensity was calibrated by fitting incoherent fluorescence data during the optical pumping process. $B=1.74$ G was measured from the Zeeman shift of the rf frequency of the $\Delta m=1$ Raman resonance.

is from "phase jumping". Note the change in phase between the two lasers before and after the rf is switched to be $\Delta\phi$. Including $\Delta\phi$ into the optical Bloch equations, it can be seen in Fig. 180 that the experimental function can be reproduced.

We have experimentally realized ORRO with uncertainty of $\Delta\nu$ less than 600 Hz, but have not been able to experimentally control the switching time precisely enough to control the phase jumping. We fit the theoretical calculations to the experimental curves by varying $\Delta\phi$. From Fig. 180 it is seen that the first oscillation peak of the $\Delta\nu = 60$ kHz curve is cut by about half a period. By comparing to the calculated curve we concluded that in the switching process corresponding to this curve the phase jumping $\Delta\phi$ is about $(2n+1)\pi$, while the other data in Fig. 180 correspond to $\approx (2n+1/6)\pi$.

Since the oscillations occur at a rate equal to the detuning of the laser frequency difference from the hyperfine ground state splitting, this technique could be used to determine the hyperfine splitting of radioactive isotopes, as the lasers do not need to be scanned over the resonance.

The ORRO provide a way to study $|UC>$ with which we have proven $|UC>$ is characterized by hyperfine coherences. Because the frequency can be precisely controlled by tuning rf, and the oscillation curve can be manipulated by $\Delta\phi$, with better control of $\Delta\phi$, ORRO could have applications in quantum information.