TRIUMF

ANNUAL REPORT
SCIENTIFIC ACTIVITIES
1998

CANADA'S NATIONAL MESON FACILITY
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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

APRIL 1999

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.

EXPERIMENTAL FACILITIES

Proton Therapy Facility

(E.W. Blackmore, TRIUMF)

A total of 11 patients were treated during seven available treatment weeks in 1998, bringing the total number of patients treated with protons at TRIUMF to 47. Ten of the treatments were for ocular melanoma and one for an ocular hemangioma. As for previous years about half of the patients were from British Columbia and the remaining from Alberta, Saskatchewan and Manitoba.

Results to date indicate that about 60% of these tumours could not have been treated with radioactive plaque therapy – the usual alternative to protons. Those patients would have had to receive proton treatment outside of Canada or have the eye removed. The remaining 40% are considered to be better treated with protons based on location and size of the tumour. Control of tumours (at this relatively early stage) appears excellent. Factors pre-disposing to the development of significant treatment-related complications include large tumours, and those situated close to the anterior eye structures such as the ciliary body. Overall the clinical results appear to be in line with larger series from Europe and the United States.

It now appears that about 1/3 of the patients are being treated through the eyelid requiring slightly more range than originally planned for. We have remeasured beam data for a 74 MeV extracted beam, which gives 5 mm more range than the presently used 70 MeV, and will start to use this higher energy in 1999.

No significant changes were made to the hardware or software of the treatment control system. The dedicated computer PTCS0 which provides the operator interface was upgraded from a MicroVAX 3400 to a VAX 4100, resulting in faster response for displays, in particular during dose scanning measurements. The software code for homing the patient treatment chair at start up was modified. One motor on the chair failed and had to be replaced. The three-axis scanner which was developed in 1997 was commissioned and now lateral dose scans can be made in both the horizontal and vertical directions, as well as depth dose scans. At present the scanning program allows only two motions to be used at one time and needs to be re-written to provide the full three-axis capability.

The M.Sc. student project to measure proton dose profiles using a sensitive scintillation screen viewed by an integrating CCD camera was completed and a thesis written. Effort has now switched to using the same technique for imaging the x-rays taken for patient alignment, in order to speed up this process. Measurements show that the present camera is not quite sensitive enough and intensified cameras are being investigated, as well as the software for image processing.

During the August treatment week another set of cell irradiations was carried out by the biophysics group at the Cancer Research Centre to measure the relative biological effectiveness (RBE) of 70 MeV protons.

Proton Irradiation Facility

(E.W. Blackmore, TRIUMF)

The proton irradiation facility (PIF) is used to simulate the proton fluxes in space for testing and characterizing electronic components, materials or various types of radiation dosimeters intended for space applications. Typically a few minutes of testing in a few nanoampere proton beam from BL1B or BL2C corresponds to years of exposure in space. BL1B is used for energies from 500 MeV to 180 MeV and BL2C-1, the proton therapy line, for energies from 120 MeV down to about 20 MeV.

There was only limited PIF running during 1998 as beam time on both beam lines was difficult to schedule and a one week run at the end of October had to be cancelled due to serious problems with the cyclotron. In May a 40 MeV proton irradiation was carried out for the CAL Corporation in Ottawa on a CCD camera. A total dose of 10 kRad was used.

To make up for some of the beam time lost in October, two brief periods were scheduled at a later time. In November, a series of passive irradiations were carried out for DREO on three types of GaAs or AlGaAs devices: QWIPs (quantum well infrared photodetectors), LEDs and QWIP-LEDs. Proton energies of 30 and 63 MeV were used with fluences to 10^{12} protons/cm^2. In December, two days were used to test several devices for SPAR Space Systems. These included tests of proton upsets in two types of Pentium computers P-II and MMX under different operating conditions, and radiation damage studies of CCD and CMOS cameras. The computer tests were carried out at 200 MeV and 60 MeV with proton fluences to 10^{10} protons/cm^2. The radiation damage studies were carried out to total doses of 25 kRad.

μSR User Facility

(S. Kreitzman, TRIUMF)

This year saw a somewhat attenuated activity in the basic experimental science program at TRIUMF, due principally to long shutdown periods devoted to the installation of the ISAC beam line components. Also, the fall beam period was beset by substantial problems in the cyclotron operations further reducing (to ~13 weeks) the high intensity beam available from an already thinned schedule. Finally, 1998 was the last year (for the foreseeable future) in which μSR will have any access to M13, with only 4 weeks of effective beam time attained. Thus μSR usage in 1998, comprising approximately 30 experiments taking 37 beam weeks distributed on an average of three μSR channels, was considerably reduced from historical norms. 1999 sees a return to the historical allocation (~26 weeks) of high intensity beam delivered at TRIUMF and it is hoped that this will allow the μSR program to return to prior levels of activity.

More significantly in the longer term, the μSR user facility was required to reapply for its MFA (Major Facility Access) Grant from its funding body in 1998. This application was a request for the salary support of five individuals (two technicians, two liaison scientists and a new position) who maintain and facilitate μSR operations at TRIUMF. The grant application is for three years, and included the new position so that the facility could also support the condensed matter program taking shape in ISAC. The relative success of this application will determine the fundamental level of support the facility can provide its users.

On a more specific note, various initiatives that the facility undertook during 1998 are detailed in the sections below. The Infrastructure section discusses the basic changes in our standard data acquisition deployment encompassing both hardware and software issues. A section on spectrometers describes significant news regarding these experimental apparati. Finally, a brief section on documentation lists the location of relevant information which can be found on the facility's Web site.

Infrastructure

TDC clocks: The infrastructure development work centered mainly around testing and debugging the new BNC 980 VME based TDCs which the facility is about to adopt as its standard clock. We now have five of these instruments, all operating within the design parameters at high rates of data acquisition. It has been found that the key to stable timing within 100 ps/bin is careful calibration of each individual channel at the factory. These clocks along with their service modules (a dedicated VME PowerPC based processor board) can acquire data up to 100 K event/s, comfortably exceeding the requirements for μSR experiments. The clocks will run in all permanent μSR channels in the spring of 1999.

Cryogenic control: The long standing need of complete remote management of a sample's cryogenic environment has also been addressed. A VME base deployment of the hardware and software needed to remotely control needle valves (on both cryostats and transfer lines) and mass flow controllers has been integrated into the CAMP slow control system. With this new capability the need for the users to intervene in the beam area to facilitate cryogenic control will be much reduced.

Spectrometers

SFUMU: The SFUMU spectrometer rebuild has been completed. This newly versatile instrument is now capable of running either with its field along the beam momentum (the condensed matter set-up) or its field perpendicular to the beam (used in TF experiments for high momentum muons). Since SFUMU provides fields of up to 4 kG it extends the field range available from conventional spectrometers.

Belle: The 7.5 T Belle superconducting Helmholtz magnet, used in the high timing resolution spectrometer, has received a minor technical upgrade which will allow its field to be stabilized over a long period of time. This has proved necessary, since the supercurrent in persistence mode was found to degrade by 1 part in 10^5/hour, too high for precision experimental work. The method used was to rebuild the room temperature bore of the magnet and incorporate into it a correction coil whose flux lines are mostly well within the superconducting pancakes. Thus there is little net flux within the coil on the application of a small correction field, allowing one to correct the central field without having overall superconducting current change. In conjunction with this was the commissioning of a new type of cryogenic hall probe which could be located in the central field right beside the sample, thereby allowing for real-time field stabilization for experiments utilizing the high timing resolution spectrometer.

GEANT: A further issue which was confronted for this magnet/spectrometer surrounded the fact that creating a well focused beam in a sample regime that is closely bounded by counters on all sides is extremely non-trivial. The source of complication (and resolution) is the fact that at the high fields (>4 T, such as that found in our superconducting magnets) themselves focus and defocus the muon beam as it proceeds to the sample at the centre of the field. Controlling this action coupled with the beam scattering due to a somewhat remote muon counter and cryogenic windows is a great challenge. To help understand all the parameters involved the facility has developed an expertise in the use of GEANT to model such situations. It has allowed for the optimization of collimators, muon counter thickness and beam injection focusing in this apparatus, resulting in more muons landing in the central sample region, with the attendant reduction of correlated backgrounds.

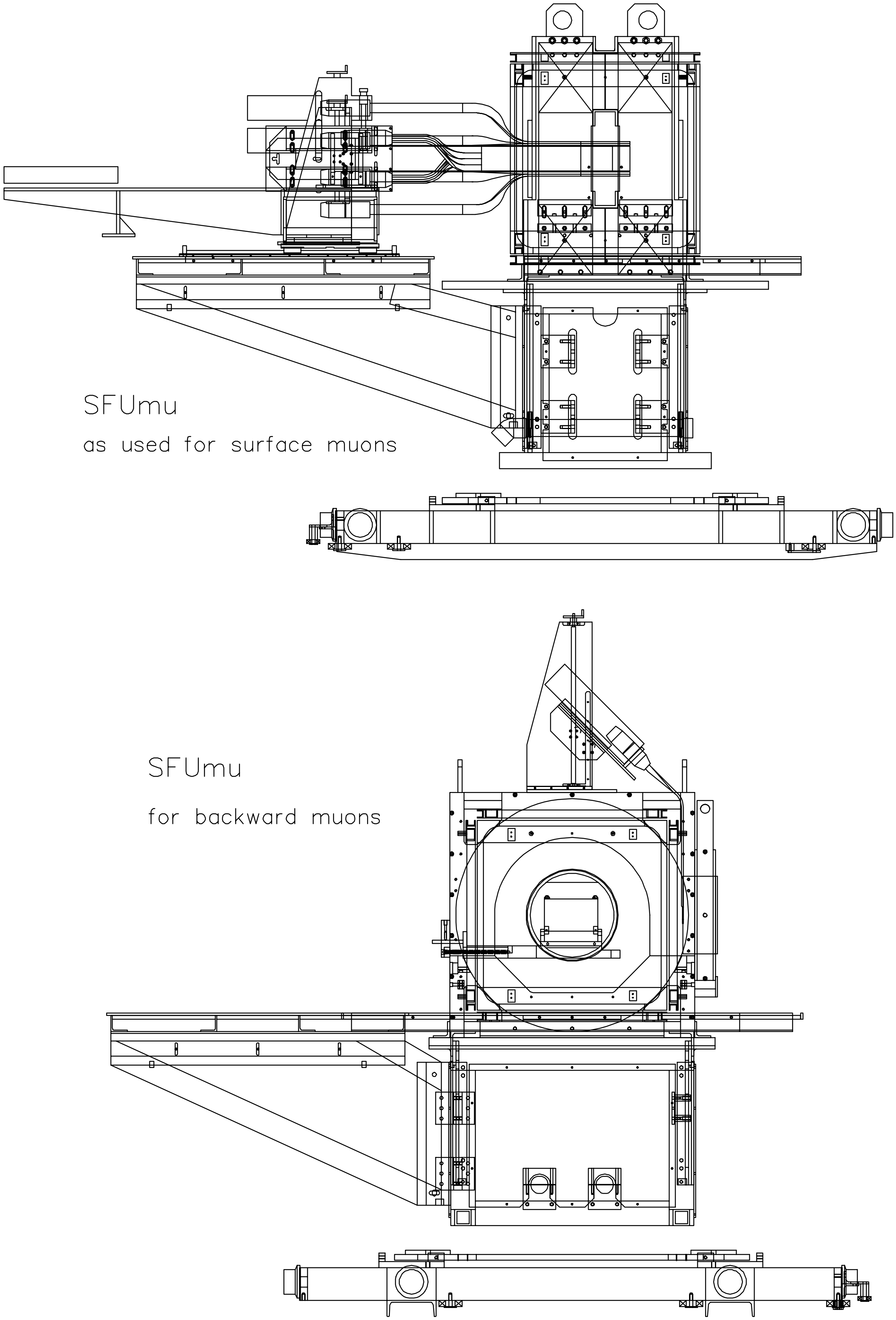

Fig. 97. The new SFUMU spectrometer.

Facility documentation and Web pages

For current or potential users of the facility, two guide documents are available. The TRIUMF μSR Facility Users Guide details general information about the nature of μSR experiments and how to go about preparing for them. The TRIUMF μSR Operations Guide is mostly for on site researchers who are involved in the actual running of an experiment. It is concerned with details of the data acquisition/analysis and experimental control. These documents can be obtained on request from msrorg.triumf.ca.

Further detailed information on many aspects of the the μSR facility is available through http://www.triumf.ca/musrfac. There one can find information about schedules, spectrometers, beam lines, safety, data acquisition, having an experiment approved and scheduled and other issues relevant to μSR users.

Detector Facility

(R. Henderson, TRIUMF)

This year has been a very active one for the detector facility. In particular, the large BaBar chamber was finished on time and delivered to SLAC. Since then, the facility has become strongly involved with two large projects, ATLAS and Expt. 614. In addition, we are contributing significantly to the ISAC facility.

In the Scintillator Shop a variety of scintillators have been built, the biggest customer being the μSR group. This year there were fewer scintillators required. This was fortunate since both the ATLAS and Expt. 614 projects are in pre-production stage, where the machining requirements are very significant. The Scintillator Shop is also starting work on prototype scintillators for the $G0$ project at CEBAF. After these are tested at CEBAF, the shop will start scintillator production for that project, which will involve about 1.5 man-years of shop time over the next two years.

The BaBar chamber was completed and shipped to SLAC at the beginning of March. This large cylindrical wire chamber was the first major sub-system to be delivered and was on schedule. Subsequently, the readout electronics have been fully installed and the chamber installed in the BaBar spectrometer. All tests indicate the chamber is working very well. This successfully concluded two years of work by the facility and the BaBar group.

The facility designed, fabricated and commissioned a large oven specifically for the ATLAS project. This oven contains the ALTAS pneumatic press for production of the many large foil laminates the project requires. This oven, and an electric winch system to lift the lid, has been installed in the upstairs clean room and the room exhaust system modified somewhat. This major production item for the project has been in use for several months, with excellent results.

The BaBar project required considerable modification of the large clean room and installation of large custom steelwork. Since the end of that project, the CR has been prepared for the ATLAS project. The BaBar steelwork has been removed and an extensive new crane system has just been installed for assembly of the calorimeter modules. These modules weigh 3.5 tons each. The facility organized all the changes to the clean room.

The ATLAS project also requires a ‘cleaning shed’ to the east of the large clean room. This steelwork will be covered with plastic. Copper plates will be cleaned in ultrasonic tanks, then rolled into the clean room on an overhead beam. This shed is now being fabricated. The granite table previously in this area had been relocated at the east end of the meson hall (beam floor level). This area of the Beam Lines group had been used mostly for storage. The facility had it cleaned, painted, an aluminum structure designed and built, then covered with plastic, making a production area for components of both the ATLAS and Expt. 614 projects. The granite table/foil stretching sysytem has been modified for the Expt. 614 requirements. The facility was responsible for all these changes.

With ATLAS expected to use most of both the facility clean rooms, another clean room was required for the Expt. 614 project. Fortunately, there was a suitable room. The Electronics Microstructure group has been considerably reduced and their clean room was available. The detector facility remodelled this room and dramatically improved its quality.

The facility is strongly involved with the Expt. 614 group. This sophisticated experiment aims to measure the Michel parameters to ten times the precision they are now known. R. Openshaw is designing the complex gas sytem. It will be built and tested in the facility. W. Faszer is also a member of the Expt. 614 experiment, adding his expertise. He will help oversee the chamber production. R. Henderson has joined the experiment and is doing a large part of the detector stack design and contributing to the overall experimental design.

W. Faszer has designed and tested circuits for the ISAC facility. These have ten times the sensitivity of those currently in use. This circuit has been tested very successfully. R. Henderson and R. Openshaw designed the prototype DRAGON ionization chamber. This has been successfully bench tested and will be tested in-beam. Since then, we designed a position sensitive PGAC (parallel grid avalanche chamber). If successful, this small chamber will be installed at the front end of the ionization chamber. The PGAC has been built and will be bench tested soon.

Cryogenic Targets
(W. Kellner, TRIUMF)

The demand for liquid hydrogen targets in experiments remained high in 1998. After the successful upgrade of cryogenic cooling on the parity (Expt. 497) target, described in the 1997 Annual Report, it ran successfully for three weeks in January and four weeks in July/August. The small LH_2 target of the CSB experiment (Expt. 704) on SASP was in operation for a total of ten weeks over the summer and autumn schedules. It too ran well, requiring only the replacement of one inner window and the addition of a small heater to prevent unwanted condensation of LH_2 in its cold gas volumes.

The protium target was re-activated in the RMC facility for use by Expt. 838. Although some parts of the mounting system had to be re-made and the control computer showed its age, the target was recommissioned and used successfully in a two-week run in December.

The new target for CHAOS was not a success – the resources allocated to this project proving insufficient to meet the challenges of this target. Those challenges included a need for an LH_2 cell with as large a diameter as possible, but inserted via a long, small-bore aperture in the CHAOS magnet. The cold-head and heat pipe used in a previous, smaller target of CHAOS did not have sufficient cooling power for the new cell. A revised version with more powerful cold-head and a new heat pipe is under construction.

Computing Services
(C. Kost, TRIUMF)

Overview

As predicted in the last Annual Report, the "third wave" (Pentium based machines, where the "first wave" constituted the VAX/VMS based machines of the 1980's and the "second wave" was based on the RISC architecture which started around 1990) has nearly matched the combined computing power of all other machines in a time spanning just 2 years. As was the case last year, the powers behind this wave were machines running LINUX. The problems of dealing with this wave largely remain:
- security concerns grow as LINUX becomes the favourite hacker environment
- decreased reliability of vendor software in a rush to market products
- lack of proper vendor support as we abandon major computer companies (or they abandon us) in an effort to reduce "costs"
- increased complexity of software management.

As a result, maintaining stability of a rapidly changing computing infrastructure continues to be a key challenge as we approach the millenium.

Hardware

Figure 98 shows the state of TRIUMF's computing facilities in December from Computing Services' point of view. After what must be the longest streak for an operating system, the campus MTS system was closed down early 1998. As well, many of TRIUMF's ULTRIX based DECstations were phased out. Support of this platform will dwindle over a number of years. The dual-4100 based VAX/VMS cluster remains a reliable, low maintenance work-horse for many users, although plans are to migrate the mail service from this cluster to a RAID based LINUX platform and reduce the hardware maintenance to a per-call basis.

The single ALPHA server, alph04 (an ALPHAstation 600 5/333), upgraded to 765 Mbytes of memory and having over 60 Gbytes of disk space, continues to provide the bulk of public UNIX support at TRIUMF. The public LINUX machine, a 200 MHz Dual Pentium Pro with 256 Mbytes of memory and 20 Gbytes of disk space, was replaced by a 450 MHz Dual Pentium II with 36 Gbytes of disk space. With increasing PC compatible software availability (e.g. from Corel and StarOffice) usage of LINUX should increase at an even faster pace in 1999. The Windows NT platform is still a minor, although possibly a significant, future factor.

Figure 99 shows our annual update for the growth of CPU power.

Since a cost-effective solution of an integrated X-support environment based on the Microsoft NT platform is not yet available, we continue to use the Windows-NT server, running the Wincenter product which allows up to 15 simultaneous users on Xwindow terminals to run PC software. Cost effective "thin-PCs" supporting Xwindows (so called NetPCs) did not materialize this year as expected. With the ever increasing power/lower cost of PC hardware, and despite their increased management costs, more Windows/98 based systems were purchased. Due to limited PC support that can be provided by Electronic Services and with our Computing Services group concentrating on a more "centralized" support model for PCs, much of the management of site PCs continues to be down-loaded to the end-user. This may well have a negative impact on some of our scientists and engineers.

LAN

The local area network, with its fibre-base FDDI backbone has proven to be quite stable, despite the fact that over 700 devices are connected to it. Plans are to migrate to a star-based topology at each of the 5 FDDI linked hubs using 10baseT/100BaseT. The first areas planned for rewiring are the Chemistry Annex and the

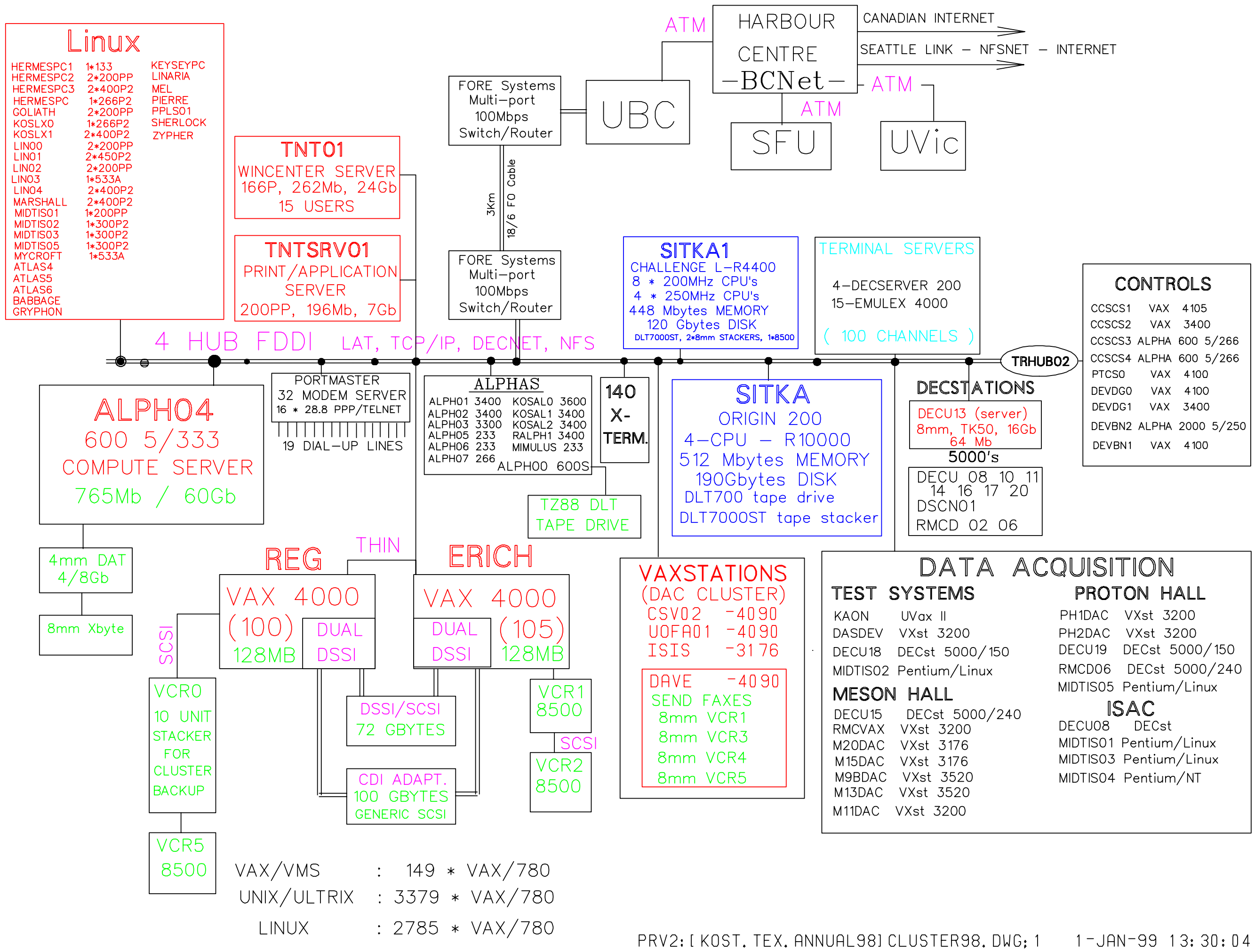

Fig. 98. TRIUMF computing facility.

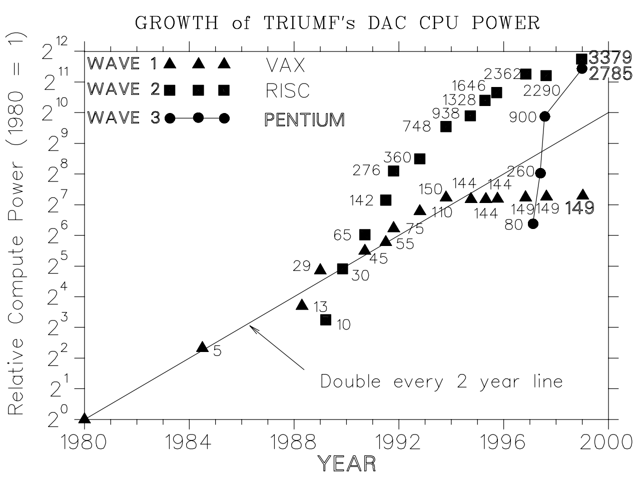

Fig. 99. DAC computing growth.

main office building. This should reduce a number of failures that have resulted when a break occurred in the currently used thin-wire loops.

Telecommuting

Offsite access to TRIUMF from home continues to grow at a modest pace as more staff acquire PCs at home. High speed network links to the home are still the exception since the costs are still high. Three 56 K modem lines will be added to the dial-up pool in early 1999.

ISAC and the Internet

The relocation of the FORE Powerhub 7000 from the main office to the ISAC building went very smoothly. The duplex 100baseT connection over the new 3 km optic fibre to UBC has proven to be very reliable.

The required cabling is now in place in the ISAC building to provide services to the ISAC controls and data acquisition areas.

Figure 100 shows the planned configuration, set for completion in the near future.

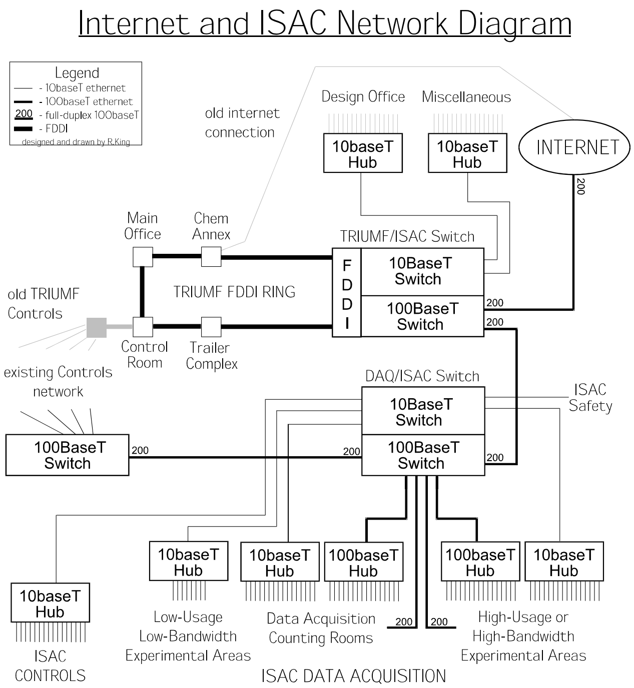

Fig. 100. Internet and ISAC network.

WAN

There were no significant changes in the performance of wide area networking over 1998 as seen from TRIUMF. The Internet is accessed via the fast Ethernet link to UBC, onto BCnet in downtown Vancouver. BCnet, as an integral part of the provincial information highway, provides direct links to the larger Canadian network, CA*net II and the BC GigaPOP, and the World Wide Internet.

Bandwidth and response time remains excellent to Canadian universities also connected to CA*net II and US institutions with a point of presence at the US STAR TAP in Chicago. For example, the University of Alberta, McGill and the University of Toronto are present on CAnet II. Carlton is still on the larger Canadian network. In the US, the ESnet supported labs, Brookhaven, SLAC, Fermilab and the major research universities connected via Internet 2, are all present at STAR TAP.

Unfortunately the European and Japanese networks are not connecting in Chicago. Part of a special transatlantic link to CERN is paid by NSERC via a grant to HEPCAN to ease traffic congestion over the Atlantic. Traffic to DESY is especially bad.

Image processing station

The 133 MHz Pentium with 128 Mbytes of memory was supplemented with a 350 MHz Pentium II with twice the memory. Added to the latter was a HP PhotoSmart scanner to handle high resolution scans of 35 mm slides, negatives, and regular photographs, and a Yamaha CRW-4260 CD-Rom burner to distribute and make legal copies in this format. A Kodak DC220 camera, taking digital images of resolution 1152*864, is now extensively used to document site projects during the assembly stage. Most of these images are subsequently catalogued in thumbnail format in pdf format and placed on a locally accessible Web page to allow users to browse and retrieve the relevant high resolution images.

This imaging station was also intensively used during the ICHEP'98 conference (URL ichep98.triumf.ca) held at TRIUMF July 23–29, to scan and place on the WWW some 7000 transparencies shown at this conference. Details on how this was done can be found via the URL www.triumf.ca/ichep_transparency_scanning.html All papers were on-line within minutes of the completion of the last conference presentation!

Software developments

GEANT4

Two members of our group continued to be very active participants in the GEANT4 international collaboration, aimed at creating a detector simulation tool kit for the next generation of HEP experiments. Their efforts were mainly directed to the development of low and medium energy hadron physics process and cross section classes. Detailed elsewhere in this Annual Report is TRIUMF's significant, and very visible contribution to this high profile, leading edge programming project. With the release of the first production version a new commitment has been recently undertaken with the signing of a 2-year Memorandum of Understanding to "define the distribution of the management, support, and future development of the GEANT4 software as from the release of the first production version".

ACCSIM

ACCSIM is a locally developed synchrotron multiparticle tracking and simulation code. This year the work was concentrated on implementing an improved model of transverse space charge, going beyond the existing "DQ" package which is able to give very efficient estimates (and simulations) of space-charge tune shifts but which is not fully self-consistent in its tracking of the macroparticle ensemble. In addition to CERN applications, the program was in active use at BNL and ORNL (for SNS accumulator ring design), KEK (JHF booster design) and LANL (PSR studies).

A survey was conducted of the common field-solution and tracking (integration) techniques. These come from the plasma physics realm and have been applied to linacs and beam lines but seldom to rings, where the ensemble must be tracked for many revolutions. Moreover, the popular FFT-based field solvers do not lend themselves well to beams with a large and growing halo, which is of concern for intense-beam multiturn injection schemes.

A field solver was developed which is a hybrid of fast-multipole (FMM) and particle-in-cell (PIC) techniques. It can accommodate charge distributions with any number of halo particles at arbitrarily large amplitudes, and at equivalent spatial resolutions it is competitive in speed with FFTs. ACCSIM tracking in test lattices with this method produced the expected fields, single-particle tunes, and envelope tunes for K-V beams. A paper on this work was presented at the Shelter Island Workshop on Space Charge Physics in High Intensity Hadron Rings.

Other additions to the code were: generalized rf cavity element allowing arbitrary (non-integer) harmonics and phases; rf voltage plotting; interactive injection steering; and import and export of particle ensembles, allowing generation and stacking of "beamlets" at arbitrary locations.

Potpourri

•To ease centralized printing support we are upgrading all public printers, and require any future networked printers, to be able to autosense and support Postscript.
•Mathematica is now licensed for up to 6 site users on any system running Digital UNIX, and up to 8 site users on systems running LINUX on Pentiums.
•The very large LANL supplied FORTRAN codes MCNP4B and LCS (Lahet Code System), both used for shielding calculations, were installed on the public LINUX system lin01.
•The locally developed and worldwide utilized data manipulation/display program Physica now has an upgraded reference manual as well as a new user's guide. Pdf and html versions can be accessed via WWW URL http://www.triumf.ca/physica/html/homepage.html. A large number of enhancements were added to Physica such as user functions implemented as a shared library for the Digital UNIX machines, MINUIT support similar to the existing FIT command, enhances to the scripting facility, and improved support for μSR data structures.
•The interactive beam transport code INTRAN was ported to the Intel/LINUX platform, while the beam scattering/transport code REVMOC was ported to the Windows/95 platform.

WWW

Our group continued to provide software management services for TRIUMF's main Web server, and to provide consultation and coordination with the many contributors providing content for our Web site. The growth in server content and usage continued unabated with improved optic-fibre links (running at 100 Mb/s) to UBC and the advent of Internet-2/Canet-2 that improved connectivity to other HEP sites.

Security

Daily attacks on machines at TRIUMF continue. Despite them we have been able to maintain the open computing environment that TRIUMF has been accustomed to and finds so beneficial to the user community. A number of additional security measures have been put in place as well as the provision of user tools such as the secure shell ssh, to prevent the clear transmission of passwords over the network, and mxconns, to control access to Xwindows. Policy measures are also being adopted to ensure that all computers connected to the TRIUMF site meet minimal security standards.

The single DLT drive continues to provide excellent reliability in the daily backup of many of the site's UNIX based machines. However, no such centralized service is as yet provided for the many PC/Windows systems.

Summary

So far the answer to last year's question: "Will these non-integrated vendors deliver reliable hardware and software" was a resounding "NO". Dealing with the highly fragmented software and hardware environment will prove to be the most challenging problem for the coming year.

Data Acquisition Systems

(R. Poutissou, TRIUMF)

Overview

During 1997, the migration from VAX host-based systems to Pentium host-based systems has accelerated.

The VAX based systems run under VMS with VDACS event by event software or μSR MODAS software. VMS and VDACS are frozen at the present versions except for fixes of serious bugs. There are 9 active VAX legacy systems:

- 3 VMS/QBUS/CAMAC legacy systems – ph1dac, ph2dac, m11dac
- 1 VMS/CFI/FASTBUS RMC system – rmcvax
- 2 VMS/QBUS/CAMAC μSR systems – m9bdac, m13dac
- 2 VMS/Ethernet/VME/CAMAC μSR systems – m15dac, m20dac
- 1 test system VMS/Ethernet/VME/CAMAC or QBUS/CAMAC – dasdev

The Pentium based systems run mostly under LINUX with MIDAS software. This is the platform where software developments and improvements are active. Efforts on incorporating slow controls to the main data stream are ongoing. There are 6 new Pentium based systems:

- 2 active LINUX/Ethernet/VME-VxWorks – CHAOS, TRINAT
- 3 active LINUX/CAMAC – TISOL, GPS, DRAGON test stand
- 1 active Windows NT – LTNO

The VME front-end MVME162 68040 CPU running at 32 MHz has been replaced by a 300 MHz PowerPC CPU, MVME 2305. The VxWorks software license has been upgraded to include the PowerPC family. By changing CPU family, there is a factor 10 improvement in clock speed as well as in Ethernet with support for 100BaseT. The cost of memory is also much lower with a PowerPC than with a 68040 CPU. The new front-end systems have 16 MBytes or 32 MBytes while the older ones had only 4 MBytes.

MIDAS software

Throughout the year, the MIDAS system was used by several experiments (CHAOS, TRINAT, TISOL, DRAGON test stand). Some experiments required new acquisition hardware, which consisted of a PC running a LINUX OS with a dedicated CAMAC interface connected directly to the acquisition computer. These new systems phased out the previous acquisition system "VDACS" and users provided us feedback on how MIDAS behaved. In general the capabilities of MIDAS exceed what the users are currently requiring which makes future implementation of MIDAS in more demanding experiments possible. Programming specific to the experiment was implemented with our help and a substantial amount of our time was devoted to support and training of new users. Continuous development and improvement of the MIDAS system were the main topics of the year. Previous goals were mostly achieved and new features were implemented. The overall status of the MIDAS system can be summarized as follows: Support for direct CAMAC access through several manufacturers' brands of CAMAC interfaces was implemented. Slow control structure has been cleaned up and EPICS device support for NT tested. Solaris OS support was added. A new MIDAS run control interface was developed for Web browser. Revision of YBOS and MIDAS utility tools was completed. Code management for MIDAS using the CVS package has been implemented and is accessible through the Web. A TRIUMF Web site for MIDAS is currently under construction (http://www.triumf.ca/midas) which includes a first round of documentation in URL format and link to other MIDAS related Web pages. The current MIDAS version released is 1.6.1.

μSR systems

The μSR data acquisition package (MODAS running on a VAX/VMS) has been extensively modified to support a new TDC in VME (Highland V680). A customized program developed at TRIUMF was loaded into the microEngine chip to enable data rejection to be performed within the TDC module itself. The TDC is set up and read out by a MVME 162-23 PowerPC module running software under VxWorks. Valid TDC data are histogrammed in an area of memory known as the "histogram memory". The histogram memory is read out periodically and stored by the VAX. Communication between the PowerPC and the μSR data acquisition program is by RPC over Ethernet.

One of these new VME systems was installed in M15, and was successfully used to take data during the fall.

A driver in TCL was written to support a flux magnetometer in the CAMP slow controls system for μSR.

Custom hardware

A. Daviel implemented a system to improve the signal/noise of UTC data for the rare kaon decay experiment E787 at BNL. The system consists of a number of complex programmable logic elements implemented in Altera FPGAs and designed to interface with commercial FASTBUS TDC units. It was deployed at BNL during the summer.

After being idle for several years, the RMC DAQ system was required again for a new experiment. The RMC DAQ computer had to be replaced, and other problems with the FASTBUS hardware had to be diagnosed and fixed.

Future development

In the coming year, development will continue to add features needed at ISAC and integration with EPICS control system elements. Special systems for the Expt. 614 FASTBUS based system and for a segmented μSR detection system will be developed. All μSR systems will see their dependency on the QBUS removed.

Scientific Services

(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Information Office, Publications Office, Library and Conferences. Its activities during 1998 were mainly focused on supporting eleven past, present and future conferences and workshops.

Conferences

During 1998 support was provided for the following conferences and workshops.

- HERMES collaboration meeting, TRIUMF, February 9–13.
- 35th Western Regional Nuclear and Particle Physics Conference (WRNPPC'98), Chateau Lake Louise, Alberta, February 13–15.
- Workshop on Accelerator Operations (WAO'98), TRIUMF, May 18–22.
- XXIX International Conference on High Energy Physics (ICHEP'98), UBC, July 23–29.

  This conference, with some 882 delegates from 43 countries together with 251 accompanying persons, constituted the major workload for the Scientific Services group.
- International Union of Pure and Applied Physics (IUPAP) Council meeting, TRIUMF, September 25–27.

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

- 1999 Particle Accelerator Conference (PAC'99), New York, March 29 – April 2, 1999.
- KEK/TRIUMF Workshop, Victoria, September 1999.
- Third International Conference on Isotopes (3ICI), Vancouver, September 6–10, 1999.
- 14th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications (EMIS-14), Victoria, September, 2001.

Publications Office

This TRIUMF Annual Report Scientific Activities has been produced totally electronically, as was the 1997 report. It is available on the WWW 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. During 1998, over 600 people accessed the 1997 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.

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

Producing the PAC'97 conference proceedings constituted the major workload for the Publications Office in 1998. The 1,261 papers resulted in 4,030 pages of proceedings which were published in three formats: three paper volumes, one CD-ROM (which also included the PAC'95 proceedings), and a WWW site with mirror sites around the world.

Assistance was provided at all stages of producing the WAO'98 workshop proceedings.

Work began on producing the final camera-ready versions of the manuscripts for the ICHEP'98 proceedings.

Information Office

The TRIUMF Welcome Page, which is accessible directly at http://www.triumf.ca/welcome or via the TRIUMF WWW Home Page, received over 5,000 visits in each of its first two years of operation. The series of WWW pages were developed by two co-op students. They are intended to provide an overview of TRIUMF in a format understandable to the general public. The virtual tour of TRIUMF allows people to "visit" from anywhere in the world via the WWW, or to gain a good introduction before coming to TRIUMF for a real tour. The latter is particularly intended for students using TRIUMF and its science as part of school projects. The Information Office responds to any questions posed by visitors to the site.

The Information Office coordinated tours for over 1,500 people during 1998. The majority of public tours were conducted by a summer student during the May–August period when tours were offered twice a day.

The front lobby was redecorated and reconfigured during the summer months. Plans for replacing the display material and building a new ISAC model commenced during the year.

The group has operated without an Information Officer since July.

Library

Faced with declining budgets and increasing journal subscription costs, the Library had to cancel ten journal subscriptions and curtail all book purchases in 1998. The Library was fortunate to receive several book donations during the year, which ameliorated the situation a little.

The Library was able to renew all of the 1998 journal subscriptions for 1999. However, the journal subscription budget and electronic access alternatives are constantly under review.

New shelving was acquired during the year and a new plan for the layout of the stacks was finalized. The new layout meets floor loading limitations and allocates empty shelf space for the active journals that will accommodate the anticipated growth of the collection over the next five years. A relatively minor addition of shelf space will allow an extension to seven years. After that, the Library will have outgrown its present location due to floor space and floor loading considerations.

Relocation of the Library collection into the new, optimized shelving layout began at the end of the year and should be completed early in 1999.

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

GEANT4

(P. Gumplinger, TRIUMF)

The original GEANT4 was a large distributed software project, involving a world wide collaboration of about 100 scientists and software engineers from over 40 institutions and laboratories, participating in more than 10 experiments in Europe, North America, and Japan. Its objective was the production of a detector simulation program which has the functionality and flexibility necessary to meet the requirements of the next generation of subatomic physics experiments. The GEANT4 strategy was proposed to and approved by the CERN Detector Research Development Committee at the end of 1994 as the R&D project RD44. TRIUMF joined RD44 in September, 1995 with the decision to set up a three year program at the laboratory. Our efforts centered around the upgrade and porting of FORTAN code in the low energy electromagnetic and hadronic physics sector of the venerable GEANT3 package.

From 1995 to its completion in 1998, the RD44 project represented a pioneering effort in redesigning a major CERN software package for a modern object oriented (OO) environment based on C++. RD44 exploited advanced software engineering techniques and OO technology to improve the validation of physics results and to facilitate distributed software design and development, in order to profit from the expertise and contributions of scientists regardless of their geographical locations. Thirteen specialized working groups were responsible for fields as diverse as physics, geometrical modelling, visualization, event generation and user interfaces. Collaborators from TRIUMF made extensive contributions to RD44 and TRIUMF associates became prominent contributors in discussions concerning the overall architecture of the program.

RD44 has met all the required milestones. A first prototype was delivered at the end of 1995, the first alpha version was released in spring 1997, and the first beta version in mid-1998. At the end of 1998, with the release of the first full production version, which included detailed documentations, examples, and tutorials, the RD44 project had achieved its goals and ended. A Memorandum of Understanding was subsequently signed by many of the same laboratories and experiments who participated in RD44, including TRIUMF. It set up a new GEANT4 collaboration to address the management, support, and future development of the software during the production phase. TRIUMF has a seat in both the Collaboration Board and the Technical Steering Board of the new collaboration. We also have representatives in the following GEANT4 domains: Hadronic Physics, Electromagnetic Physics, Testing and Quality Assurance, Software Management, and Documentation Management.

The RD44 collaboration was unprecedented in high energy physics (HEP), both for its size and its geographical extension, and in many ways will provide a benchmark for future large-scale scientific software development. The GEANT4 (G4) detector simulation toolkit has already been selected as the main simulation platform for several major particle physics experiments in the next decade (ATLAS, BaBar, CMS, ALICE etc.) Although G4 has now gone beyond the initial R&D phase, new physics algorithms are being introduced on an ongoing basis. Many collateral benefits are anticipated from applications in a number of fields other than particle physics detectors.

During the past three years TRIUMF had a key role in RD44. Canadians were involved in low energy hadronic interactions (parameterization and cross section generalization), stopping kaons and muon physics, intra-nuclear cascade models at <20 GeV, and optical photon physics. The latter involvement consisted of code development for Čerenkov and scintillation photon generators, and the propagation of optical photons, which includes absorption, wavelength shifting, Rayleigh scattering and refraction and reflection at media boundaries.

The OO design and coding of the low and medium energy hadron physics models in G4 involved, firstly, the conversion to C++ of the well-known hadronic shower package GHEISHA. This had the obvious benefit that algorithms and physics insight contained in the original code were re-utilized. Secondly, the code was redesigned in order to better match the OO paradigm. This facilitates the ease of program maintenance, as well as provided a framework for refining and expanding the physics models, and for including new data and improved parameterization. The bulk of hadronic processes were amalgamated into a single structure that allows for flexibility in process type, particle type and energy range. The work is now in the final phase of stepwise improving the essential hadronic physics.

This year we also implemented the hadronics portions of the test and example suites that are part of the G4 distribution. In addition to extensive testing and debugging of our own code, we appointed a member to the G4 system testing team which carried out the same activities for the entire code and established testing and problem-reporting procedures that carried us forward from beta releases to the first production version. In July we sent a representative to the Fourth Annual G4 Workshop in Niigata, Japan.

The TRIUMF GEANT4 team has started to support the construction of end-user applications by TRIUMF and affiliate-university physicists. In December one of us undertook a week long work-trip to the University of Montreal to help a graduate student launch a G4 based simulation of the ATLAS hadronic endcap calorimeter (HEC). Following the first G4 production release, we have begun to inform researchers about the use of and capabilities of G4, and provide assistance in evaluating G4 for specific user applications. We act as a resource to those who want to create the next generation analysis software, for skills in OO analysis and design, C++ programming, simulation techniques, OO data management, and other technologies required to support the GEANT4 project. Such technologies include, the concurrent version system (CVS) and various GNU code management tools, 3D graphics and visualization, and graphical user interfaces (GUI).

In summary, the GEANT4 project has brought a new level of computing expertise to our laboratory. We most recently advanced the intention of the TRIUMF/ATLAS group to reap the benefits of its significant investment in the detector, by initiating a G4 application to simulate the ATLAS HEC, so that TRIUMF can evolve into a regional ATLAS analysis centre.

The GEANT4 collaborators are: D.A. Axen, University of British Columbia; J. Chuma, L. Felawka, P. Gumplinger, F.W. Jones, C.J. Kost, A. Olin, D.H. Wright, TRIUMF; L.G. Greeniaus, University of Alberta.

Sudbury Neutrino Observatory

(R. Helmer, TRIUMF)

Most of the equipment built and/or designed at TRIUMF is now in use in the SNO detector. All of it has performed flawlessly. The whiffletrees on which the acrylic vessel is hung have been in use since early 1997. The storage device for the source umbilicals and the glove box were installed during 1998 and have been used extensively. The cards, cables and backplanes supplied by the Electronics Shop are connected into the electronics systems and are in continuous use. The high voltage cards and front end card motherboards tested at TRIUMF last year are also now in continuous use.

The components of the device used for spooling the water sampling tube have been manufactured, and the unit will be assembled in the near future. It will not be needed in the detector for some time.

Infrastructure support for SNO was provided during the past year with a TRIUMF physicist acting as the commissioning manager for scientific components in the detector. Most of this effort was related to overseeing commissioning of the electronics and DAQ systems.

The BaBar Experiment

(C. Hearty, UBC)

Physics of BaBar

BaBar will study the violation of charge/parity (CP) symmetry in the decay of B-mesons at the PEP-II, the "B-Factory" currently being commissioned at the Stanford Linear Accelerator Center.

The origin of CP violation is one of the most important unresolved issues in particle physics, as it is an essential ingredient to our understanding of the baryon-antibaryon asymmetry in the universe. The only experimental observation of CP violation is in K_L^0 decays. The standard model describes these observations using an imaginary phase in the CKM matrix, but it is not known whether this explanation is correct.

The study of B^0 decays to CP eigenstates promises a definitive test of the standard model explanation. More generally, it will provide us with a series of unique consistency tests of the quark sector of the standard model and the best opportunity for precision determination of CKM parameters.

The large sample of identified B decays will be cleanly obtained at PEP-II, a high-luminosity asymmetric energy e^+e^- storage ring running at the $\Upsilon(4S)$. The $\Upsilon(4S)$ decays roughly 50% to B^+B^- and 50% to $B^0\overline{B^0}$. The two B mesons are almost at rest in their centre of mass with no additional particles, making this an ideal situation for complete reconstruction of rare decay modes. In addition, the B^0 and $\overline{B^0}$ are produced in a coherent state which remains coherent until one of the particles decays. Events in which one B^0 decays to a flavour-tagging mode and the other to a CP eigenstate can be used to reconstruct the time dependence of the CP asymmetry.

PEP-II collides 9 GeV electrons on 3.1 GeV positrons in order to produce an $\Upsilon(4S)$ system with sufficient boost that the measured separation between the two B decay vertices can be used to determine the relative time of the two decays. PEP-II is designed to operate with a luminosity of 3×10^{33} cm^{-2}s^{-1}, producing 3×10^7 pairs per year.

PEP-II will also provide the ability to make precise measurements of many interesting B decay channels, perform measurements of rare B decays, search for rare effects in the charm sector and make precision measurements in the tau lepton sector. Studies of charmless B decays, for example, produce additional constraints on the CKM matrix elements V_{ub} and V_{cb} that help to over-constrain the CKM unitary triangle and thereby probe new physics.

The construction of the BaBar drift chamber

The drift chamber is one of the central components of the BaBar detector, providing the first level trigger, momentum measurement of charged tracks and particle identification at low momentum. The Canadian hardware contribution to BaBar has been the construction of the drift chamber at TRIUMF, which was undertaken with substantial infrastructure support from TRIUMF.

Following the completion of stringing in November, 1997, the chamber was made gas tight and tested using a gaseous ^{133}Xe source. None of the 7,104 channels were found to be dead or noisy. The detector was shipped to SLAC, on time, in early March (Fig. 101).

The chamber has subsequently undergone cosmic ray tests by itself and integrated into the complete BaBar detector, including the superconducting solenoid. The tests indicate that the cell resolution and efficiency already meet the requirements and are likely to improve with more sophisticated calibration techniques.

BaBar will move onto the PEP-II beam line in early 1999 in preparation for the start of data-taking in May, 1999. This engineering run will last several months.

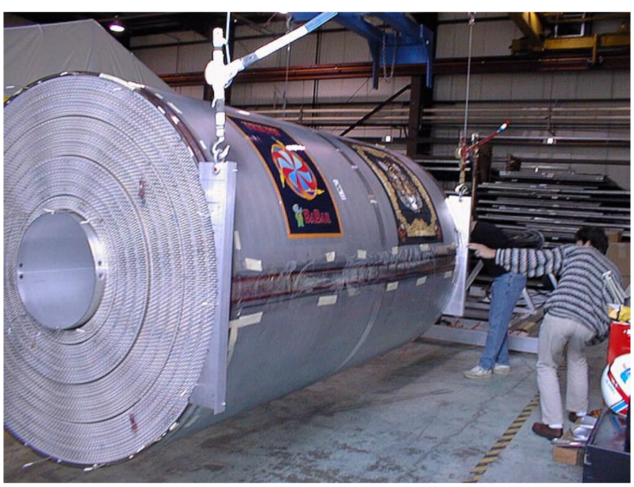

Fig. 101. The BaBar drift chamber being inspected upon delivery to SLAC in March.

Scientific personnel involved with the construction of the BaBar drift chamber at TRIUMF: C. Hearty, M. Kelsey, J. McKenna (UBC); P. Bloom, P.M. Patel, J. Trischuk (McGill); A. Hasan, J.-P. Martin, R. Seitz, P. Taras, V. Zacek (Montreal); R. Henderson (TRIUMF); A. DeSilva, R. Kowalewski, M. Roney (Victoria).

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

In the past year negotiations with DOE led in May to the transfer of the Low Temperature Nuclear Orientation facility from the Oak Ridge National Lab to TRIUMF-ISAC. The dilution refrigerator cryostat provides vertical access for the radioactive ion beams. The implanted nuclei can be subjected to a horizontal magnetic field of 1.5 T. An advantage of this configuration is identical detector geometries for the directions at 0 degree and at 90 degree with respect to the magnetic field. A drawback is the extensive height of the set-up which is indicated in Fig. 102. In the past this system has reached temperatures below 10 mK during on-line experiments.

After inspection of the components a service structure was designed and installed at the end of the year to provide safe access for operation of the set-up as

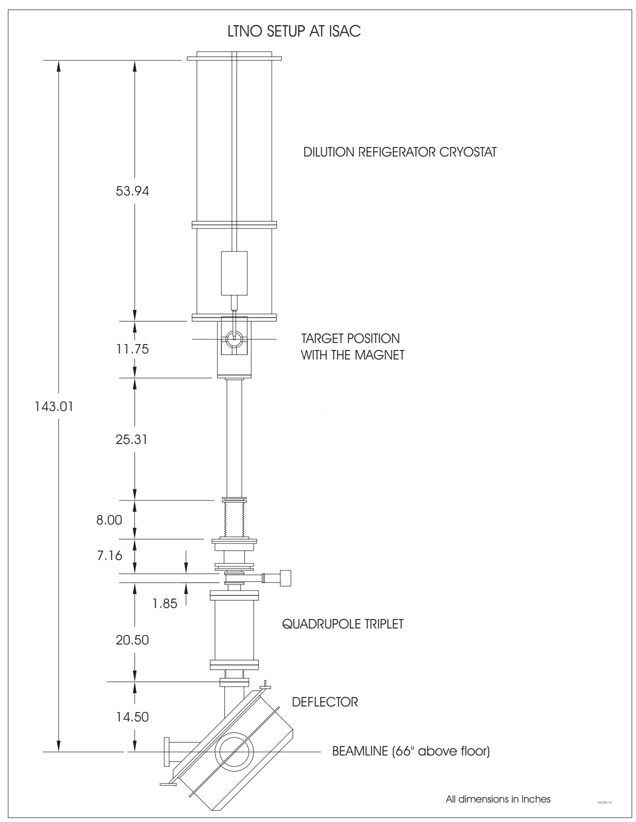

Fig. 102. Elevation view of the LTNO cryostat and vertical beam line section.

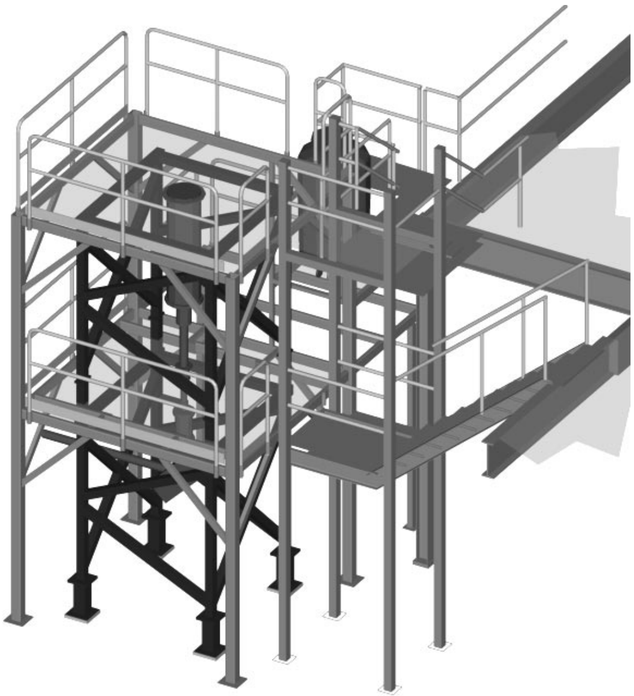

Fig. 103. The LTNO set-up integrated in the ISAC hall.

shown in Fig. 103. It was found that vibrations were transmitted through the floor at a level that is considered unacceptable. Therefore, a support system with self-leveling air pads is installed for the cryostat and all vacuum lines have been fitted with force-compensated bellows arrangements.

For experiments in the low energy area of ISAC, the PC based version of the MIDAS software was selected for data acquisition. Several germanium detectors were tested with evaluation models of the D(igital) S(ignal) P(rocessor) based integrated multichannel units from ORTEC and Canberra. A substantially improved stability was observed compared to conventional shaping amplifier-adc combinations. After these preparations the goals in the first half of 1999 are evaluation of the cryogenic performance and installation of the beam transport. In the second half of the year are planned the start of magnetic moment measurements (Expt. 828, K.S. Krane, Oregon State Univ. and P. Mantica, Michigan State Univ.) and the investigation of thin magnetic layers (Expt. 826, B. Turrell, Univ. of British Columbia).

DRAGON at ISAC: A Status Report

(J.M. D'Auria, SFU)

Overview

The TRIUMF-ISAC facility will produce and accelerate high-intensity radioactive beams of A<31 to energies from 0.15 to 1.5 MeV/u. An essential part of the experimental program with such beams is to make a ∼20% measurement of the absolute rates of radiative capture reactions in which one of the reactants is unstable. The DRAGON facility uses inverse kinematics to measure capture rates, in which the beam is the heavy, unstable nuclide and the target is hydrogen or helium gas. Table XVI indicates some of the initial reactions that are planned for study.

Table XVI. Reactions to be studied using inverse kinematics at the DRAGON facility.

Reaction	Proposal	Interest
^{13}N$(p,\gamma)^{14}$O	E805	Hot CNO Cycle
^{15}O$(\alpha,\gamma)^{19}$Ne	E813	Hot CNO Cyc/Breakout
^{19}Ne$(p,\gamma)^{20}$Na	E813	Hot CNO Cycle/Out
^{20}Na$(p,\gamma)^{21}$Mg	-	Hot NeNa Cycle
^{21}Na$(p,\gamma)^{22}$Mg	E824	Hot NeNa Cycle
^{22}Mg$(p,\gamma)^{23}$Al	LOI	^{22}Na Production
^{23}Mg$(p,\gamma)^{24}$Al	E810	rp process
^{23}Al$(p,\gamma)^{24}$Si	LOI	^{22}Na Production

The main components of the DRAGON system are a windowless gas target; a two-stage electromagnetic mass separator, detectors of the heavy reaction products and detectors of the capture gamma rays. The expected radiative capture rates are typically of the order of 1 event/sec or lower for a beam intensity of 10^{10} sec^{-1}. The role of the DRAGON is to provide clean separation of the recoiling reaction product from the incident beam and to allow for the measurement of the rates of these essential reactions as a function of the incident beam energy.

Funding over a three-year period for the building of DRAGON and its initial operation was received from NSERC (and TRIUMF) in April, while funding for the gas target was received in 1997. A detailed conceptual design of DRAGON is displayed in Fig. 104. The location of the DRAGON in the ISAC hall is shown in the ISAC experimental hall figure that appears elsewhere in this Annual Report. A summary of the status of the various components is provided below.

The DRAGON

The gas target

All of the components of the gas target system are now available and are being assembled at the University of Alberta. Following initial testing and modifications, the system will then be moved to the ISAC hall in the summer of 1999, where a systematic testing of the completed system will be performed. Figure 105 displays a schematic oblique view of the gas target. In addition, a system is being developed to clean and recirculate hydrogen or helium target gas while the experiment is in progress.

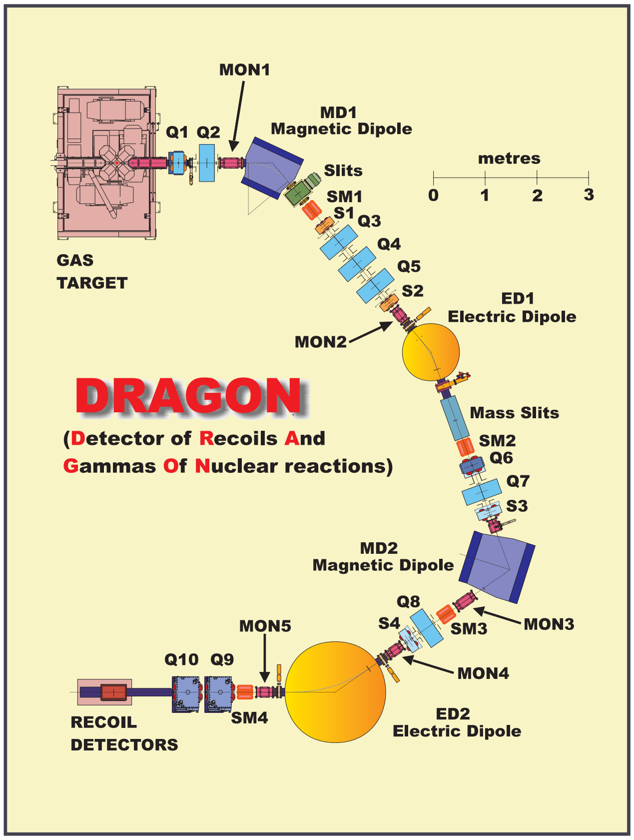

Fig. 104. Top view of the DRAGON layout showing components of interest.

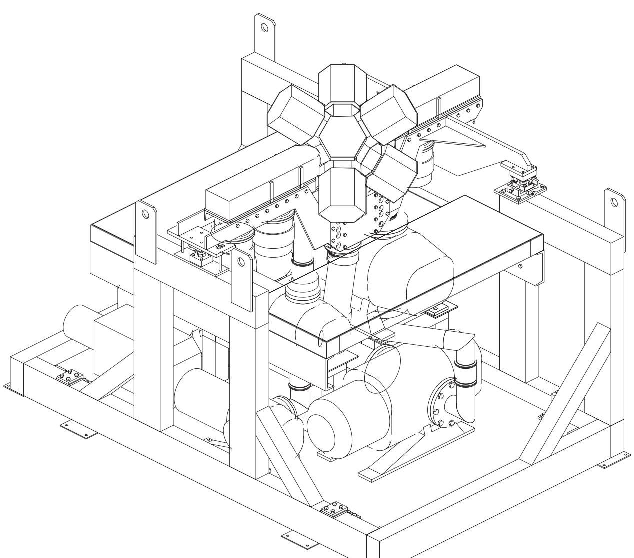

Fig. 105. Oblique view of gas target.

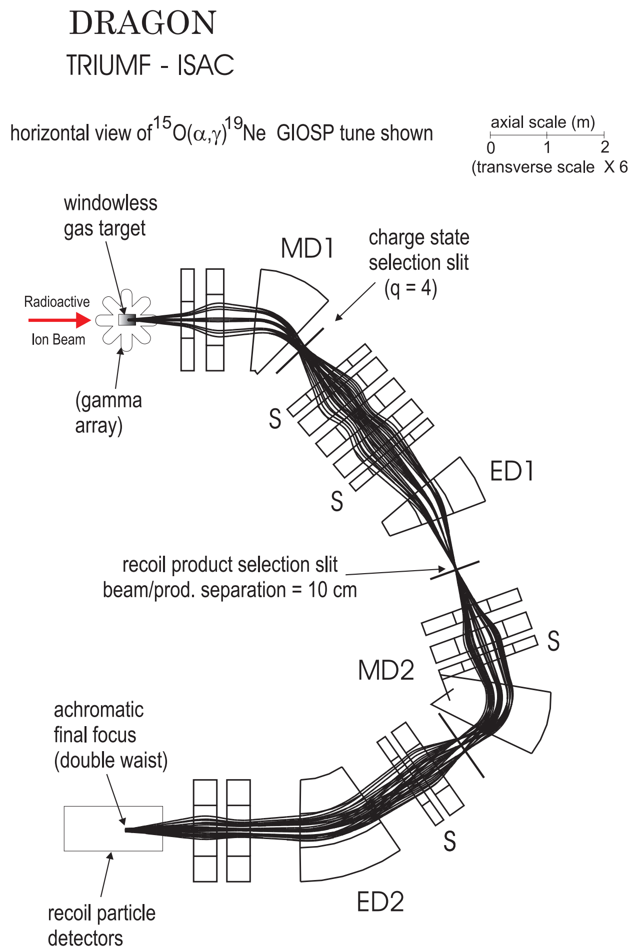

Fig. 106. DRAGON layout showing projection of ^{19}Ne trajectories onto the horizontal plane. The scale transverse to the beam axis has been expanded 6 times for clarity.

Recoil separator

The recoil separator uses both magnetic and electrostatic dipoles to separate recoil product from the up to 10^{16} times more intense beam of the same average momentum. In Fig. 106 a top view of the separator illustrates its mode of operation for ^{19}Ne recoils. It is a two stage device, each stage ending in an energy-achromatic, mass-dispersive focus. After selecting a single charge state of beam and product following the magnetic dipole (MD1), the electric dipole (ED1) directs the lower energy recoil product towards the mass selection slits. Mass dispersions after the first and second stages are 0.47 cm% and 1.85 cm% respectively. Each stage has 5 quadrupoles (Q) for focusing, 2 sextupoles (S) to correct aberrations, and 2 steering magnets (SM) (see Figs. 104 and 106).

Initial design and optimization was done to third order using the matrix-based program GIOS (Fig. 106 shows GIOS ^{19}Ne trajectories). Separator performance was simulated using the ion optic code RAYTRACE. A Monte Carlo simulation that included the beam emittance, the capture reaction and scattering of beam and product within the gas target was made for each reaction using GEANT. In addition, a number of simulations of different types of background to be expected from beam scattered off residual gas and surfaces were made. None of these simulations resulted in more beam than product passing through the final slits of the DRAGON.

The last significant change in ion optics of the DRAGON separator, in the sequence of magnetic (M) and electrostatic (E) dipoles, was made early in the year. The original design had dipoles in the sequence M-E-E-M. Simulation of background due to beam collisions with residual gas molecules revealed a susceptibility to successive charge-changing collisions in the E dipoles. The revised design with sequence M-E-M-E avoids this potential problem. While the shape of the separator changed from 'S' to 'C' (see Figs. 104 and 106), the basic ion optics design is not much different from the original M-E-E-M version.

Once the optics design was frozen, a number of tests of sensitivity were undertaken. The method used was to simulate the transmission of recoil ions of the important $^{15}O(p,\gamma)^{19}Ne$ reaction to find the conditions leading to an additional 2% reduction in transmission for canonical slit settings.

- Field strengths: amongst the quadrupoles, transmission was most sensitive to the field in Q2 – 2% loss in transmission was experienced for an increase of 0.25% in the nominal field.
- Misalignments: an extensive study of possible translational or rotational misalignments was undertaken. Two aspects of the problem were studied: the extent of losses if no corrective action was taken, and the extent to which losses could be reduced with correction by steering magnets. The conclusion was that with re-steering the transmission criterion could be met for any reasonable values of errors in position or orientation of the quads.

Component design status

Detailed design has been completed for the magnetic dipoles and bid tendering has been initiated [Clark, TRIUMF Design Notes TRI-DN-98-10, TRI-DN-98-12 (1998)]. Two pairs of sextupole magnets presently installed in TRIUMF channels M13 and M15 will be available to DRAGON. Two 'SMIT' quadrupoles from CERN are being refurbished for use as Q9 and Q10. Conceptual design of the remaining eight quads is nearly complete, after considerable design effort to determine a pole shape which extends the region of uniform field gradient and to understand the contribution of end effects to aberrations.

The electrostatic dipole fields in the region of the electrode ends have been studied with both 2-D and 3-D models, determining the location of the effective field boundary for the design location of field clamps, and variation of effective length with height above the median plane. A concept of the electrode mounting system has been worked out, including detailed design of the backing structure. Detailed designing of the Ti electrodes for the electric dipoles is completed and two concepts for their support structure are under consideration. A drawing showing some details of the electrostatic dipoles can be found in the engineering section of this Annual Report (see work of N. Khan, project engineer for the DRAGON project).

A conceptual design for the four steering magnets (labelled SM in Fig. 104) has been completed [Stinson, TRIUMF Design Note TRI-DN-98-7 (1998)].

Recoil detection systems

The prototype ionization chamber, used to $\Delta E - E$ discriminate between beam and recoil product ions (see drawing and photo in Figs. 107 and 108), has been designed, built, assembled and tested successfully with alpha sources. As part of a local time-of-flight system, a PGAC (parallel-grid avalanche chamber), which will be mounted on the front of the chamber, has been built and is ready for testing.

The gamma ray detector array

Detection of the reaction gamma rays in coincidence with the recoil ions could add orders of magnitude to the beam suppression capability of DRAGON. An array of scintillators is seen as the optimal approach but the device must deal with potentially high singles counting rates from the radioactive beam itself. A new scintillator material, LSO, has light output close to that of NaI and is relatively fast in comparison. Studies of its properties revealed new features previously unknown which are described elsewhere in this Annual Report.

Conceptual design of the gamma array has been continued using GEANT Monte Carlo simulations. The design of the pixelated detector module, including a method for 3-dimensional gamma position determination, is nearing completion. A preliminary report will appear in the proceedings of the 1997 IEEE Nuclear Science Symposium, held in Toronto [Rogers and Gumplinger, *A pixelated 3D Anger camera with light-loss compensation*, oral presentation NM1-7, IEEE Trans Nucl. Sci. (in press)]. In addition, experiments with the new LSO crystals have further elucidated the advantages and limitations of LSO as a gamma detector material. One limitation we discovered is the presence of a substantial afterglow component to the scintillation light emitted following gamma irradiation [Rogers and Batty, *Afterglow in LSO* (submitted to IEEE Trans. Nucl. Sci.)]. Although the afterglow will require pulser gain stabilization in the electronics, LSO is still considered the best scintillator choice for the DRAGON gamma array.

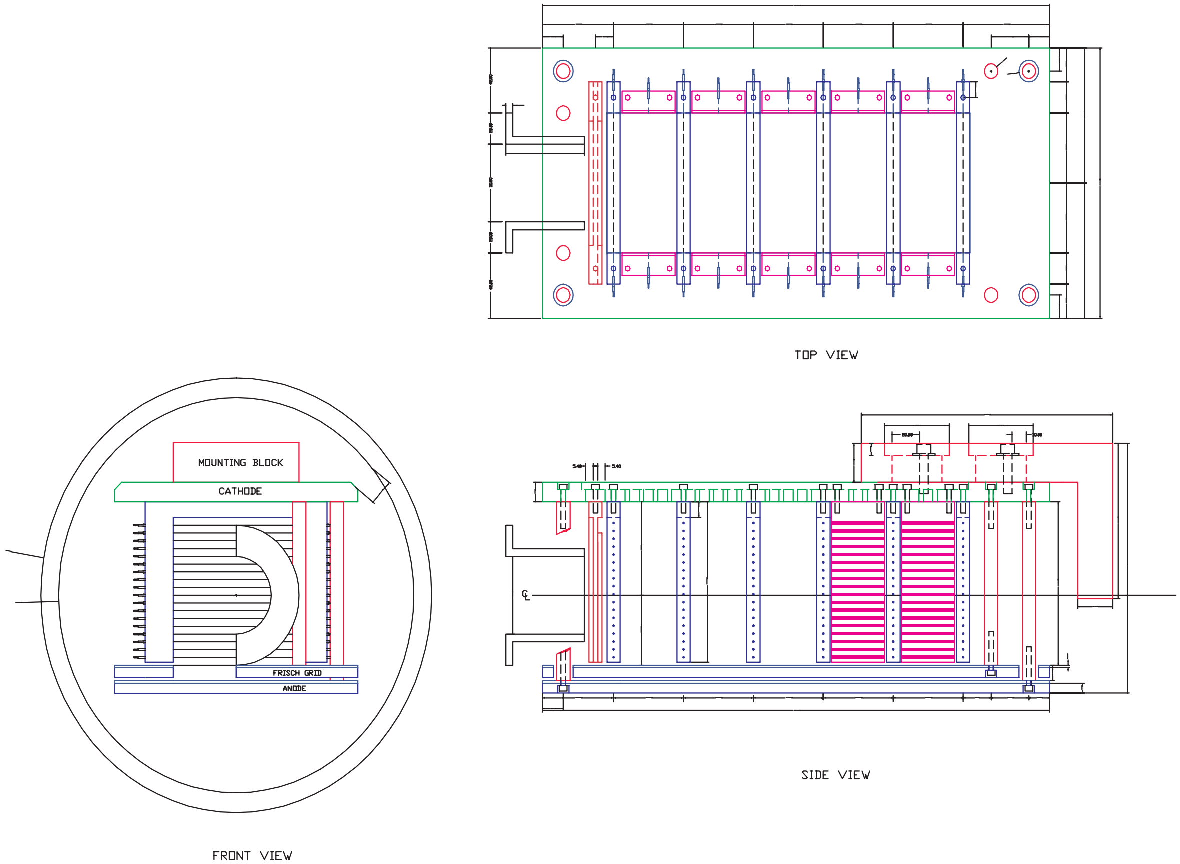

Fig. 107. Schematic representation of ionization chamber.

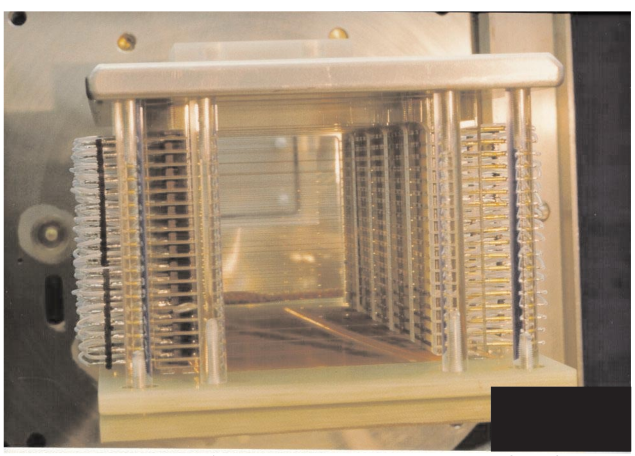
Fig. 108. Beam's eye view into ionization chamber.

The Science

Experiment 824

The first experiment planned for the ISAC-DRAGON facility is a measurement of the rate of the ^{21}Na$(p,\gamma)^{22}$Mg reaction. The rate of this reaction is influential in the production of ^{22}Na during explosive hydrogen burning in novae. The isotope ^{22}Na is interesting because its decay can be detected by gamma ray telescopes and because it is present in pre-solar meteorites. Unfortunately the resonance energies are not well known for this reaction, so we have initiated a study to accurately measure them in Japan, using the ^{24}Mg$(p,t)^{22}$Mg reaction. Further details of this study can be found under Expt. 824 of this Annual Report.

Network calculations

In order to test theoretical models of the dynamics of novae and supernovae, network calculations can be performed which simulate the chains of nuclear reactions occurring in such explosive events. Final isotopic abundances can then be calculated which are compared with observed abundances. These network calculations require computer codes containing the experimentally-determined rates of all relevant reactions which may occur, as well as an approximation of the physical processes involved.

Such a code is being implemented at TRIUMF to explore further the key reactions important for heavy element production and pinpointing to what precision such rates must be measured for an accurate nucleosynthetic mode. The code is presently being validated and will be modified to allow simulations using temperature and density profiles as a function of time to better simulate the nova process.

Gamma-ray Detectors for DRAGON and Industrial Applications

(J.G. Rogers, TRIUMF)

As reported last year, a gamma-ray detector array is being developed for use in the ISAC-DRAGON facility. This year, the detector development has concentrated on the use of the new scintillator lutetium oxyorthosilicate (LSO) in position-sensitive detectors, both for the ISAC application and others. Several small LSO crystals were obtained from CTI, Knoxville, TN, and used in experiments to validate the ongoing GEANT computer simulations. In the simulations, the gamma-ray energy range usable in the detector was extended from the ISAC energies (i.e. 1–5 MeV) to span a wider range, 100 keV to 100 MeV, for new applications in industry, medicine, and physics.

To validate the GEANT simulations, certain basic properties of LSO, and for comparison NaI, were measured using small crystals and gamma-ray sources over the energies 16 keV to 6 MeV. The recently reported non-proportional response was confirmed at TRIUMF for energies below 100 keV, in the vicinity of the L-absorption edges. In LSO, significant afterglow was discovered to be induced by high energy gamma activation. The presence of this afterglow will require pulser stabilization for high-rate applications of LSO, such as DRAGON. Our findings were submitted to IEEE Trans. Nucl. Sci. for publication [Rogers and Batty, *Afterglow in LSO and its effect on energy resolution*, TRI-PP-98-30].

GEANT simulations were extended to a segmented-detector design which accomplishes three-dimensional gamma-ray position encoding. As reported last year, the DRAGON detector incorporates an array of long narrow LSO fingers, of length appropriate to the gamma-ray energy of interest. To this basic design was added a new feature which induces a small shift in the apparent transverse position of the gamma detection, the amount of the shift being proportional to the depth-of-interaction of the gamma ray along the length of the finger. This provides a vernier encoding the depth coordinate (Z) of the scintillation point in the array. When added to the usual transverse (X and Y) finger coordinates, this Z-encoding completes the three-dimensional read-out of each gamma-ray's position. A key feature of the detector design is its scalability with gamma-ray energy. Detection of higher energy gamma rays, useful in resonant-gamma contraband detection, and lower energies, useful in nuclear medicine cameras, are optimized by simply scaling of the dimensions of the fingers and photomultiplier tubes incorporated in the detector module. These simulation results were reported in an oral presentation at the 1997 IEEE Nuclear Science Symposium in Toronto and will soon appear in the conference proceedings [Rogers and Gumplinger, *A pixelated 3D Anger camera with light-loss compensation* (in press)]. The same paper has also been submitted to IEEE Trans. Nucl. Sci. for publication.

Experiment 715 Off-line Laser Development Lab: Optical Pumping of ^{41}K

(P. Dubé, SFU; J.A. Behr, K.P. Jackson, TRIUMF)

Experiments with ^{37}K require that nuclear polarization of a small, confined sample of atoms, such as that produced by a magneto-optical trap (MOT), be known to an accuracy of about 0.1% [Häusser, EEC report, Dec. 1997]. Such an accuracy in the measurement of the nuclear spin of a small ensemble of atoms is not readily obtained, and we make use of the similarity between the atomic energy levels of ^{41}K with that of ^{37}K to carry out the developmental stage of this experiment with the convenience of stable isotopes.

Off-line trapping of ^{41}K

We have set up a magneto-optical trap in an off-line lab for the cooling and trapping of ^{41}K, and obtained our first trap with that system in the spring. Our all solid-state laser system consists of a 10 mW external-cavity diode laser seeding a semiconductor power amplifier that is capable of producing a 500 mW laser beam. The combination of the seed laser with the power amplifier is often referred to as a MOPA, which stands for master oscillator power amplifier. The output from the power amplifier has the same frequency properties as that of the seed laser, which in the present case is a laser linewidth estimated at $<$500 kHz when locked to a Doppler-free potassium line obtained by saturated absorption spectroscopy.

In a first stage we have measured various characteristics of our system as a function of parameters such as laser frequency detunings, laser power, magnetic field gradient, and background density of potassium atoms. Typical values were 2×10^7 for the maximum number of trapped ^{41}K atoms, and 2×10^9/cm^3 for the maximum density observed with a field gradient of 14 g/cm.

Trap lifetimes

We have also measured trap lifetimes of (100 ± 20) seconds for the low density regime, limited by the residual gas pressure in our vacuum system. At high trap densities, collisions between the trapped atoms accelerate the decay rate. Collisions between ground state atoms have little effect since their energies can only change by the hyperfine structure energy of 254 MHz which is insufficient to kick the atoms out of the trap. However, the internal energy available in collisions between an atom in its excited state and an atom in its ground state, or between two atoms in their excited states, can lead to an energy transfer which releases enough kinetic energy to expel the atoms from the trap. We have modeled the decay of the atomic number density as follows:

$$\frac{dn}{dt} = -\alpha n - \beta n n^*$$

where n and n^* represent the atomic number densities of ground and excited state atoms, respectively. α is the decay rate at low density of (0.010 ± 0.002)/s mentioned above, and β is the non-linear decay rate that we found to be $(5.0 \pm 2.5) \times 10^{-10}\text{cm}^3/\text{s}$ for ^{41}K. The main contribution to the error quoted is from the estimate of the density of excited state atoms. The Gaussian number density distribution was taken into account in the present analysis. The equation above leads to a rate β that is insensitive to intensity to within 10% for intensities between 40 and 160 mW/cm^2.

In the literature, β is rather defined by the following equation, where n^* is replaced by n in our equation above:

$$\frac{dn}{dt} = -\alpha n - \beta' n^2$$

This definition gives a value β' that depends on laser intensity. An upper limit for β' in ^{41}K is given in Williamson *et al.* [J. Opt. Soc. Am. **B12**, 1393 (1995)]: $\beta' < 9 \times 10^{-11}\text{cm}^3/\text{s}$. This value must be multiplied by the ratio n/n^*, which typically ranges from 2 to 20, before it can be compared with our result. This correction depends on the fine details of laser detunings and intensities, and a good model to extract the correction factor. Our data are thus in reasonable agreement with that upper limit. Our analysis does not rely on a model to estimate the total population, but rather on the trap fluorescence for a measurement of the excited state population.

For the β-decay experiments, using a total number of trapped atoms of 10000, and a fraction of excited atoms of 0.20, in a 0.001 cm^3 trap volume, we find that this decay mechanism alone would give a trap lifetime of 1000 seconds, which far exceeds the ≈1 second half-life of $^{37,38\text{m}}$K.

Trap temperatures

Our present scheme for polarizing the atomic nuclei is based on optical pumping of the atoms into a single Zeeman sublevel, a 'stretched' state, that defines the nuclear spin as being directed along a known magnetic field axis provided externally. In order to achieve this, the atoms must first be trapped in a MOT and then released, because the unwanted magnetic fields from the coils and the random optical pumping from the trapping laser beams must be turned off. The release from the MOT allows the atoms to spread according to their temperature, and this happens at a rate of 64 cm/s for a temperature of 1.0 mK, causing the diameter of the sample to expand at twice that rate. This expansion limits the time that we can usefully carry out the measurement without deteriorating the quality of the recoils data, and thus the temperatures must be kept as low as possible.

We have carried out temperature measurements of the MOT sample with a CCD camera. The diameter of the trap was measured by recording an image of the cloud at different time intervals after release, with short laser exposures of 2–3 ms. The rate of expansion of the diameter was readily converted into a temperature by assuming a Maxwell-Boltzmann velocity distribution of the atoms. Temperatures along one axis as a function of the total laser intensity at the centre of the trap are shown in Fig. 109. As expected from the Doppler cooling theory, the temperature decreases with lower intensities. The lowest temperature we have measured so far is about 1 mK. According to the Doppler cooling limit for a two-level atom, we should be able to reach a temperature of 148 μK. The values of frequency detunings and laser powers required for optimum capture efficiency and for lowest temperatures are substantially different; this has been a limitation for the signal-to-noise ratio of measurements in low temperature regimes with the present set-up. With additional acousto-optic modulators for the rapid control of those parameters we should be able to obtain and measure temperatures close to the Doppler limit. The ^{37,41}K isotopes have a small hyperfine splitting in the $4P_{3/2}$ excited state manifold which prevents the usual methods of sub-Doppler cooling, routinely used for most other alkali, to be easily implemented here. However, it is believed that sub-Doppler temperatures are possible in potassium although this hasn't been demonstrated yet [Fort *et al.*, Eur. Phys. J. **D3**, 113 (1998)].

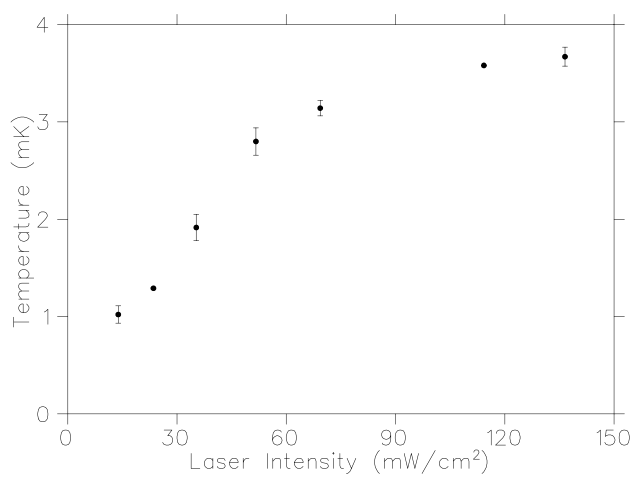

Fig. 109. MOT temperature for ^{41}K atoms as a function of total laser intensity at centre of trap, for a detuning of 1 MHz below lowest level in the $4P_{3/2}$ excited state manifold.

An Ultra-sensitive Radioactivity Monitoring Station on UBC Campus and its Relation to TRIUMF

(T.J. Stocki, D.F. Measday, UBC)

On the University of British Columbia campus, there is an atmospheric radiation monitoring station of very high sensitivity. It is one of 20 stations around the world that are prototypes for enforcement of the Comprehensive Test Ban Treaty. Along with atmospheric monitoring, there are three other methods of detecting nuclear explosions, which are also used to enforce the treaty. These other methods are seismic monitoring, infrasonic monitoring, and hydroacoustic monitoring. These three methods will not be discussed here, but details can be found at the Web site http://www.pidc.org.

The station monitors airborne radioactivity by blowing approximately 24000 m^3 of air through a 60×60 cm filter paper over a 24 hour period. This is two orders of magnitude more air than previous monitors and is similar to the amount of air a human lung receives in 30 months. The purpose of the glass fibre filter is to trap radioactive aerosols. To reduce the amount of natural radioactivity from radon, the filter is changed in the late afternoon. The filter is then folded and compressed under a pressure of 11 metric tonnes, after which it is a 6 cm diameter disk. Then it is allowed to cool down for 24 hours, to reduce the background. After 24 hours, the filter is placed in front of 2 high purity germanium detectors which are 40% of the efficiency of a 3×3 in. NaI crystal. Thus the efficiency of each of these detectors at a γ-ray energy of 1 MeV is approximately 2×10^{-2} for the full energy peak.

One advantage of this method is that the large airflow through the filter concentrates the activity. Another advantage is that the γ-rays retain origin information by not losing energy before detection. The high purity germanium detectors also have high resolution (approximately 2 keV) in the energy region of interest, so there are very few misidentifications. The disadvantages of the system are that gases, pure α emitters, and pure β emitters do not get detected. Gases go right through the filter paper, so the germanium detector will not see them. The filter paper can trap pure α emitters, and pure β emitters, but the germanium detector does not detect α or β particles, because of the thickness of the paper disk.

The station detection goal is to pick up γ-rays from the following isotopes: ^{140}Ba, ^{134,136,137}Cs, ^{95,97}Zr, ^{131,133}I, ^{95}Nb, ^{103}Ru, or ^{132}Te (to detect atmospheric nuclear tests or to detect reactor accidents like Chernobyl); and ^{137}Cs, ^{95}Zr (to detect nuclear weapons fabrication). There have been a few sightings of ^{137}Cs, but these are presumed to be false or accidental readings. So, there has been no verified detection of atmospheric weapons tests, reactor accidents, or nuclear weapon fabrication.

The Vancouver station has seen a few anthropogenic isotopes in small amounts. These small amounts are several orders of magnitude below permissible limits. These isotopes have originated from controlled releases, from the TRIUMF site, which is approximately 1.7 km away in the southeast direction. Figure 110 shows the locations of the lab with respect to the monitoring station. The rosette on the figure also shows the annual average wind speed and the direction. The length of each arm on the rosette is proportional to the frequency of winds from each direction in percent. As one can see, SE winds are common, about 20% of the time. These winds could then bring man-made isotopes to the station from the laboratory.

One of the isotopes seen at the station is ^{123}I, which has a half-life of 13.3 hours, so it lives long enough to

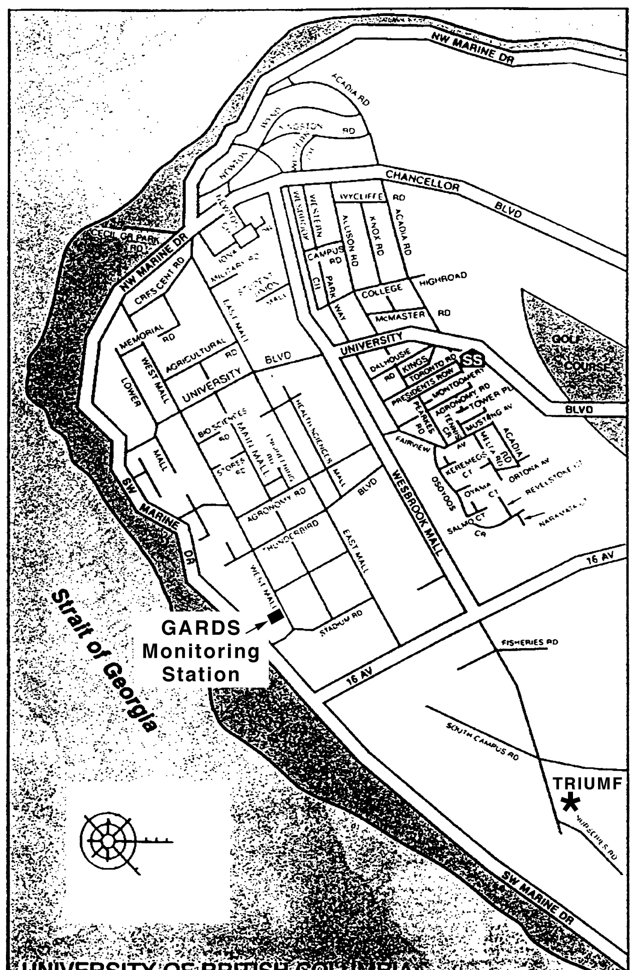

Fig. 110. The relative location of the monitoring station and subatomic physics lab (TRIUMF). The rosette shows the frequency of the wind direction, in percent, for this area.

survive the cool down period and its 159 keV γ-ray is detected. ^{123}I is produced at the medical radioisotope facility, MDS Nordion.

Another man-made isotope that has been seen at the station is ^{24}Na, by detection of its 1369 keV and 2759 keV γ-rays. ^{24}Na is a product of ^{24}Ne, which is also a noble gas. This isotope is produced whenever the laboratory's cyclotron is producing a 500 MeV, 150μA proton beam. The beam interacts with the argon in the atmosphere producing ^{24}Na directly or Ne which decays into ^{24}Na with a 3.38 minute half-life. This activity is only just above detection threshold even for this very sensitive monitor.

In conclusion, a very sensitive air monitoring station has picked up radioactive emissions from TRIUMF, at the limit of detectability.

This paper was the winning student paper presented at the Canadian Radiation Protection Association conference in Ottawa in May and was published in the Bulletin of C.R.P.A [**19**, 8 (1998)].