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OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

JULY 2000

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 Irradiation Facility

(E.W. Blackmore, TRIUMF)

The proton irradiation facility (PIF) was used on five separate occasions during the year. There was a week long run from May 17–24, with the main users being the groups from NASA-GSFC, DREO, CresTech, BTI and MD Robotics. Both beam lines 2C and 1B were used, in some cases simultaneously. In June there was a short run for a University of Alberta group checking single event upset (SEU) rates in switched capacitor arrays intended for the readout of the ATLAS calorimeter.

The TNF failure in BL1A caused beam to be lost on the meson hall secondary channels in late summer. During August 16–20, the Expt. 614 group used a low intensity beam of about 10 MeV protons to simulate muons for testing the performance of their drift chambers. From October 31–November 6, there was another week long run using both beam lines. This time the main users were groups from NASA-GSFC, DREO, MD Robotics and ATLAS.

In December, the group from MD Robotics returned again and used three days of beam at 116 MeV for completing their work on testing the components of Pentium computers. Table XI is a listing of the PIF users since 1996 and the types of tests that have been carried out.

Several improvements to the facility were completed this year. A remotely controlled CCTV system was installed on BL1B to monitor the test area and to permit devices to be positioned in the beam remotely by viewing the horizontal and vertical alignment laser lines. This was especially useful for the MD Robotics work as many separate irradiations were carried out on specific chips on large circuit boards. Two additional alignment lasers were added to the BL2C test set-up for more rapid alignment than using the existing telescope. Further beam uniformity studies were carried out comparing beam profiles from Gafchromic film exposed to the beam with scanned diodes. The Gafchromic films were subsequently scanned using an HP 6300C flatbed scanner and the optical readings converted to dose. Figure 99 (top) shows a typical beam spot using film, and (bottom) the profiles from diode scans for the same spot.

Table XI. Space radiation effects testing program (1996–99).

Group	Devices Tested	Comments
DREO, Ottawa	Neutron detector	Sensitivity neutrons/protons
	QWIPs/LEDs	Passive irradiations
	HTS filters	Passive irradiations
	Memory devices	SEE (single event effects)
CAL Corporation, Ottawa	CCDs	Passive irradiations
Bubble Technology, Chalk River	Bubble detectors	High energy proton/neutron sensitivity
	Scintillating fibre detector	Sensitivity
Thomson and Nielson, Ottawa	SEU dosimeter	Full energy range calibration
Spar Aerospace, Brampton	Pentium computer chips	200 MeV protons
(MacDonald Dettwiler Robotics)	CMOS imagers	Total dose effect
	CCD cameras	Total dose effect
CressTech, Toronto	Electronics components	SEE
ATLAS Alberta Group	Gate array for DAQ	SEE
NASA/GSFC, Greenbelt, MD	Memory devices	SEE
	Optoelectronic devices	Displacement damage
	LEDs	Dose effects
	VICSELs	Dose effects
DERA Farnborough, UK	Particle detector	Neutrons and protons
	Memory devices	SEE

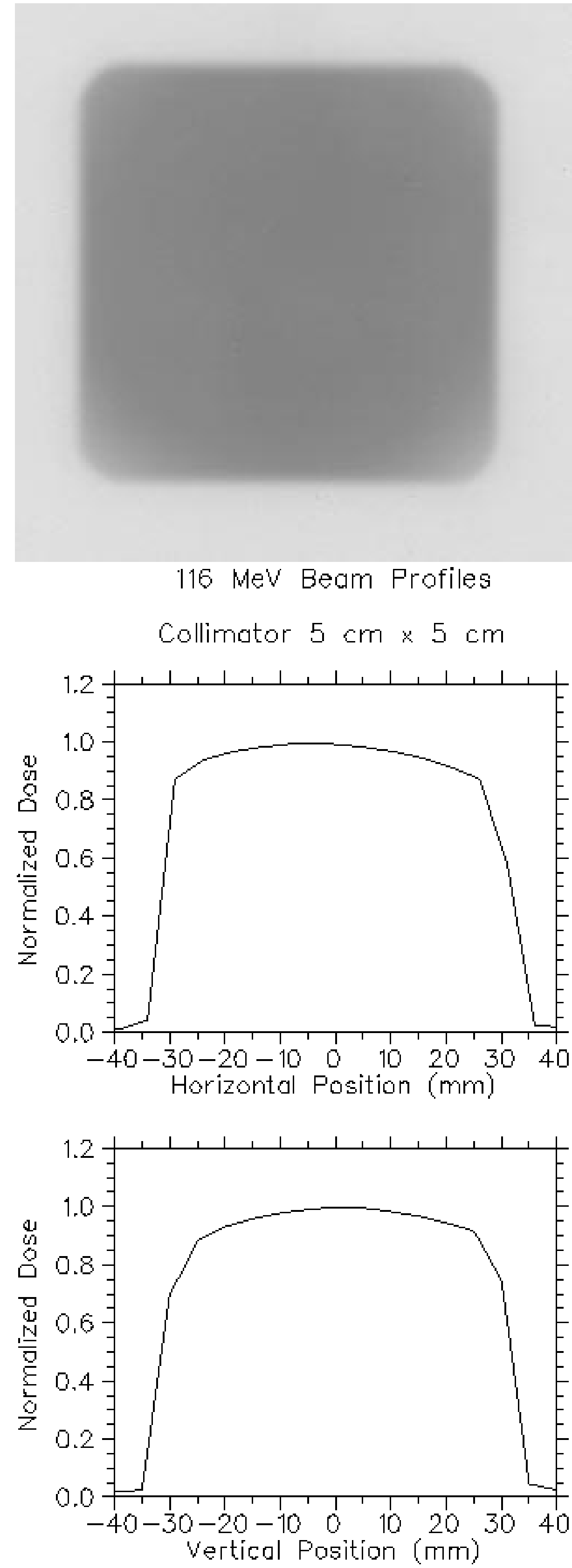


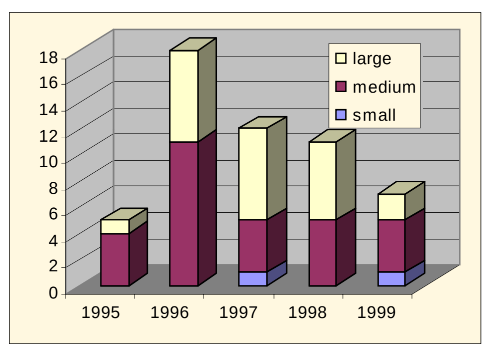
Fig. 99. (top) Gafchromic film showing collimated beam profile. (bottom) Beam profile from scanned diode.

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

Only 7 patients were treated during 1999, bringing the total number of patients treated with protons at TRIUMF to 54. The reduced number is a reflection of the reduced months of running and a decision to treat fewer of the larger tumours which have been shown to lead to more severe complications. Figure 100 shows the distribution of tumour sizes treated to date. Small refers to tumours less than 10 mm in diameter and 5 mm in height; medium to 10–15 mm diameter, 5–10 mm in height; and large is any tumour larger than medium.

The results continue to be encouraging with a 100% local control rate after 4 years of follow-up and a serious complication rate, leading to enucleation or neovascular glaucoma of 16% at 4 years. Patients this year were treated with 74 MeV incident protons instead of 70 MeV to get slightly more range for those patients treated through the eyelid. Detailed studies of eyelid thicknesses were carried out using MRI and this information is used in the treatment planning.

The controls software for scanning dose measuring probes in three dimensions was completed and tested. Previously only two directions could be scanned at one time.



Sizes	%
small	4
medium	53
large	43

Fig. 100. Distribution of tumour sizes treated to date.

μSR User Facility
(S. Kreitzman, TRIUMF)

From the μSR perspective this year at TRIUMF was one marked by two significant events, both of which should have a potential positive impact on the condensed matter/physical chemistry program. One was the commissioning of the first stage of the β-NMR spectrometer in ISAC, a project that is generating much anticipation and excitement. The second item, with potentially much broader consequences, arose from a significant failure in beam line 1A, necessitating the cancellation of a large fraction of the scheduled beam time during the summer. This failure, along with other significant secondary channel failures in the fall, is now rightly being viewed by the administration as a set of events which highlight the absolute criticality to engage in a very proactive maintenance and updating regime of the meson hall infrastructure in order to keep it operational. This new emphasis on maintaining the old, extremely productive infrastructure, in addition to building the new ISAC based program, should allow the μSR program to continue to flourish in the new decade. That being said, the consequences of these beam line related difficulties was a second consecutive year of reduced time to experiments. Approximately 20 conventional μSR experiments took 32 beam weeks distributed over an average of 2.5 beam lines, with β-NMR additionally utilizing a week in ISAC.

Also very significant to the long term future of μSR at TRIUMF is the state of its funding and support scenario by the broader scientific community. This is reflected in the Major Facility Access (MFA) grant on which the μSR program depends. The grant was reapplied for in the fall of 1998 to cover the three year period April 1999 – March 2002. A major theme of the MFA application was the proposal of a specific long term funding scenario based upon a model of shared financial responsibility among the various stakeholders of the μSR community. The results of the MFA competition were very positive in as much as the μSR User Facility was granted its full request. We see this as a strong vote of confidence in the μSR program and (by implication) of the funding scenario that was outlined in the MFA proposal. The grant renewal has allowed the facility to i) continue to support μSR activities at TRIUMF at current levels, ii) proceed (as outlined in the MFA application) with the addition of technical staff to support the β-NMR experiment in ISAC and, iii) continue with the project of upgrading the data support infrastructure which a modern user facility must embrace.

On a more specific note, various initiatives that the facility undertook during 1999 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 new high speed/high timing resolution VME based clocks with their associated hardware and software support are now in standard service. The systems have run problem free for the 1999 beam year and it is imagined that the clocks will be

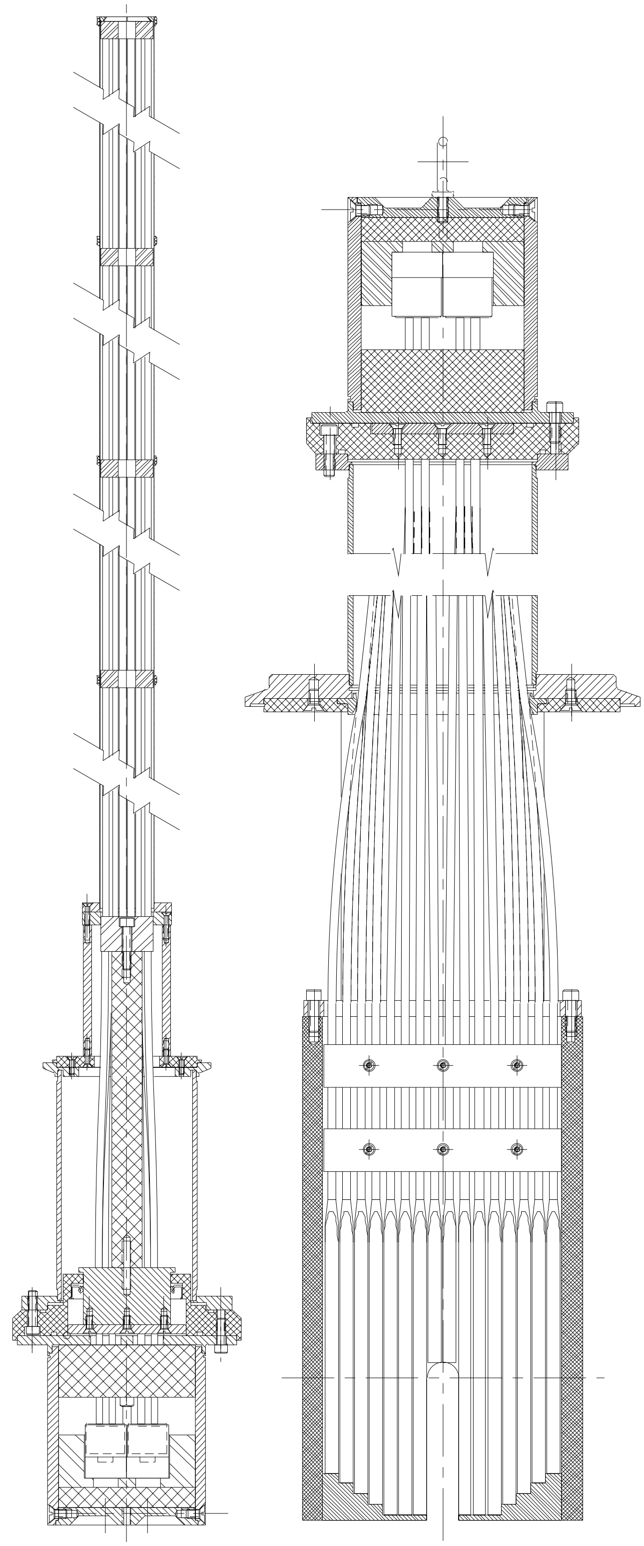


Fig. 101. Segmented counters used in the β-NMR spectrometer. The forward multi-counter (left) is part of the cryostat insert, with the square scintillator segments situated just past the sample. The backward counter, conversely, is a large paddle situated in the beam pipe well upstream of the sample, made from strips of scintillator with a slot to accommodate a narrow inner beam pipe.

supportable for approximately 10 years before the technology on which they are based is no longer used and maintainable.

Cryogenic control: The program of 100% remote cryogenic control is about 2/3 complete. Six remote flow control systems are now in place.

Spectrometers

Superconducting magnet field control: Older persistent current superconducting magnets (we have two such systems, one in the dilution refrigerator and the other in the high field/timing spectrometer) suffer field drifts due to decaying currents that are usually too large to tolerate during long μSR experiments. To counter this problem we have devised and implemented a control system based on shim coils internal to the superconducting windings coupled with cryogenic Hall sensors and a highly accurate and stable micro-ohm meter. The system had previously been installed in the HTR spectrometer and a completely cryogenic version of it is now also in the DR.

OMNI′: A redesign of the OMNI′ spectrometer is now under way, destined to become a modern versatile machine for use in the M9B secondary channel for longitudinal and low transverse field experiments. It has been specialized to easily accommodate vertical and axial cryogenic devices and also contains the necessary internal shielding required for effective use on the beam line.

Light guide design: The design of counters and light guides is often a very significant issue in the overall aspect of spectrometer design, particularly for very demanding applications like that found in the HTR spectrometer. We have now implemented the most recent version of CERN's Guide program (Guide-IT) and will be embarking on a program of developing improved counter design and fabrication techniques using its excellent analytical features.

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 μSR facility is available through http://www.triumf.ca/msrfac. 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.

Cryogenic Targets
(W. Kellner, TRIUMF)

A liquid hydrogen target was built, installed, and successfully run in the CHAOS spectrometer. A more powerful cold head and new heat pipe provided the cooling power needed to overcome the problems experienced in the previous year. The target was completely rebuilt, except for the outer vacuum jacket. A new control system provided more versatile and reliable operation of the target as well as improved communication of target parameters to the experimenters' data acquisition system. The target was operated for 18 weeks during the summer and 6 weeks of the fall/winter schedule for CHAOS Expt. 778.

Other cryogenic hydrogen targets which saw renewed use in 1999 included:

- Protium target for Expt. 766 in channel M9B (30 shifts)
- LH_2 target for Expt. 704 in beam line 4B (160 shifts)
- LH_2 target for Expt. 497 in beam line 4A2 (60 shifts)

Computing Services
(C. Kost, TRIUMF)

Overview

The impact of Y2K has been surprisingly minimal. Steady growth in the number of Linux systems took place. "Farming" has not yet taken hold but one group has set up a small Beowulf cluster and a number of others see the need for more. The rapid increase in the pieces of PC based hardware has exacerbated the following:

- security concerns,
- hardware maintenance,
- software management,
- overloading the backup facility,
- and network congestion.

The most significant events of the year were:

- Moving primary mail service from VMS to Linux.
- Moving our site Web server from ULTRIX to Linux.
- Upgrading from 10BaseT to 10/100BaseT.

The latter was completed for the Chemistry Annex and ISAC with the Main Office building scheduled for early 2000. Plans were also put in place in late 1999 to upgrade from FDDI to gigabit Ethernet.

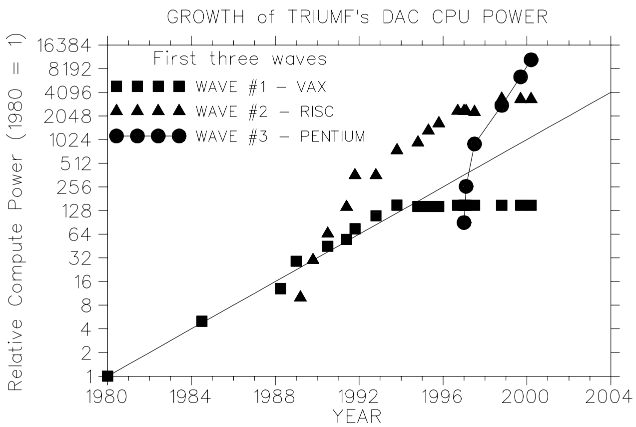


Fig. 102. DAC computing growth.

Hardware

Figure 102 shows our annual update for the growth of CPU power.

A new central mail facility, based on an identical pair of Pentium II-350 machines, with 128 Mb of ECC memory, and connected to an Omega 2400 Raid Subsystem with two hot-swappable 18 Gb Seagate UW-SCSI disks and hot-swappable power supplies/fans and including a 5 year 7 × 24 service contract, was put into service. Tools were provided to allow a smooth migration from VAX/VMS mail to this Linux based system. This sets the stage for the eventual phase-out of the dual-4100 based VAX/VMS cluster, despite the fact that it continues to be a home-base for a number of users. The new mail service also provides for a directory service (LDAP) to allow easy access to mail addresses of TRIUMF staff.

The Dual PII-450 public Linux facility is showing signs of strain and will need to be upgraded or supplemented with like machines in a clustered configuration.

Software developments

A new ftp site (ftp://csftp.triumf.ca) was set up for the distribution of our software and documentation for the following programs: ACCSIM, DIMAD, EDGR, GPLOT, INTRAN, PHYSICA, RELAX3D, and REVMOC.

GEANT4

As a member of the GEANT4 Documentation Subgroup (http://wwwinfo.cern.ch/asd/geant4/geant4.html), a large portion of the GEANT4 documentation was edited, correcting English usage and modifying the "look and feel" of the documents, the goal being to make the documentation more readable, homogeneous and concise.

In conjunction with colleagues at CERN, the HETC particle tracking codes were implemented into the GEANT4 framework, including translating FORTRAN legacy code into C++ and reorganizing it into a more object oriented style. Development plans were presented at the GEANT4 workshop held September 20–24 at ESTEC, Noordwijk, The Netherlands.

After the release of the first production version of GEANT4 at the end of 1998, the Collaboration has reformed under a new Memorandum of Understanding (http://wwwinfo.cern.ch/asd/geant4/organization/MOU.html) in which our group continues its manpower contribution and retains membership in the Low Energy Physics, Testing and Quality Assurance, and Documentation working groups. Our T & QA member was involved in system-testing and diagnostic activities, including a visit to CERN to assist with a major release milestone and the planning and initial prototyping of WWW-based software management and testing tools. Details are reported elsewhere in this Annual Report.

ACCSIM

A member of the group contributed to the CERN/TRIUMF LHC collaboration (Beam Dynamics Task No. 4, reported in the CERN Collaboration chapter of this Annual Report) in the development of the ACCSIM multi-particle tracking and simulation code. With the major milestone of a self-consistent treatment of space charge in place, a new public release of the code was made and a new Reference Guide was written. In addition to CERN applications, the program continues in active use at BNL and ORNL (for SNS accumulator ring studies), KEK (JHF booster design) and LANL (PSR studies).

RELAX3D

RELAX3D, a locally developed 3-dimensional Laplace/Poisson solver, continues to be used for electrostatic design studies at TRIUMF and many other sites. This year, the program was ported to the Linux platform and CVS source code management was put in place. In support of TRINAT studies, the code was upgraded to allow dielectric materials in 3D problems solved on a Cartesian grid. The treatment of curved dielectric boundary surfaces on this grid at first presented some concerns about accuracy and the combinatorial blow-up of boundary-point configurations, each requiring a special finite-difference template. After some study and comparison with analytically-solvable textbook cases, a new "cumulative" finite-difference algorithm was determined which greatly reduced the code complexity and provided accurate and unbiased solution values near boundary surfaces.

PHYSICA

This general purpose data analysis/display program (somewhat resembling PAW from CERN) continues to evolve from its original inception in 1974 (then called OPDATA, then PLOTDATA, and finally PHYSICA after undergoing several complete re-writes). New features include:

- enhanced restore of Hbook structures,
- more flexible graphics commands,
- user (re)definable special delimiters and file extensions,
- improved debugging for macro scripts,
- expressions can now be up to 3000 characters, with up to 2200 tokens.

A number of bugs were fixed, including a small number resulting from Y2K due to system routines of some platforms – although VMS will still have a problem in the year 3000! Efforts continue to port PHYSICA to Windows9x.

Telecommuting

After adding 3 more dial-in modems early in 1999, it is expected that modem capacity will no longer expand as a number of regular users of that facility have begun accessing TRIUMF using alternative ADSL or video cable services. This raised a number of security concerns as these are considered as accesses from "off-site".

WAN

The 100 Mbit fast Ethernet link to UBC was extremely reliable/stable. The same could not be said for the UBC to BCNet link to downtown Vancouver. CAnet2 is shortly being upgraded to CAnet3, the world's first all optical national IP network, which will connect all provinces in Canada initially at 1 gigabit/second, about 7 times the speed of Canet2, and further doubling in speed in the "near term", and in the "mid-term" to at least 10 Gigabits/second. Traffic throughput to key collaborative laboratories, CERN and DESY, has also improved significantly over the past year.

WWW

Our group continued to provide software management services for TRIUMF's main WWW server, and to provide consultation and coordination with the many authors and groups providing content for our Web site. Just prior to the end of the year we moved to a new server platform, a dual-processor Pentium Pro-200 Linux system running Redhat 6.0, replacing the extremely reliable but aging DEC ULTRIX platform that had served us so well for many years. The move was completed without serious interruption or incident and the new platform will provide us with clear software and hardware maintenance and upgrade paths for the future. Currently this Web server doubles as our group's software server, although there are plans to separate this critical function to a raid-based Linux system (much like our current site mail server) in the next budget year. Netscape continues to be the current Web browser and mail client standard at TRIUMF due to its price (free) and availability on many platforms. However, maintaining upgrades, plug-ins, and mail service related issues is having an impact on our work load.

Linux

Linux has become a central element in computing at TRIUMF, as it has at every high energy physics laboratory. The summary trip report (http://www.triumf.ca/hepix99/trip_report.html), which resulted from attending the HEPNT/HEPIX Workshop held at SLAC on October 4–9, yielded a number of valuable lessons which were immediately applicable to TRIUMF.

- Due to its many problems, and improved prospects for the soon to be released Windows-2000, it was recommended that we hold off (using) Windows-NT as long as possible.
- One must take a leading role on Windows-2000 to avoid future user conflicts.
- Laptops, networks, and Windows-2000 should work much better together than with Windows-NT.
- Security must be taken more seriously **before** there is a serious incident.
- Perl was highly recommended as the language of choice for system administrators.
- Phase out X-terminals, move from network hubs to (gigabit) switches.
- Redhat Linux is a good choice.

Redhat Linux is the recommended standard at TRIUMF and the CERN Library has been made available for both V5.1 and V6.0 on our central application server lin00. A large number of free/shareware tools are now available, such as StarOffice and Qcad, to support those familiar with the Windows environment. We have yet to come to terms with specifying and supporting the distribution of a standard set of these utilities.

Thin clients

Due to time and financial constraints, little progress was made on implementing thin clients. With the release of Windows-2000, early next year, we may see improved prospects of an integrated X-support environment. In the meantime we continue to use the Windows-NT-3.51 based server, running Wincenter, to allow up to 15 users on X Window terminals to run PC software. In addition, it was demonstrated that a diskless PC, with 128 Mb of memory, running FreeBSD from a CD-ROM, can provide a stable environment (typically 1–2 months between reboots) as an

X-terminal. Diskless Linux or Free-BSD systems are recommended over purchasing more NCD-terminals, since the latter lack 24 bit colour support and security elements.

Security

Daily attacks on machines at TRIUMF continue. Fortunately, to date, they have not been serious. Several attacks have resulted in TRIUMF machines being used as mail relay points. The security weaknesses on these (largely older) machines were subsequently addressed. In general, we have become more pro-active towards security. Tools such as ssh, scp, sftp are now in regular (albeit not universal) use at TRIUMF. As well, we now monitor traffic coming into the site and have applied a number of input/output filters as well as installed an intrusion detection system which triggers alarms, mails notifications and allows for log analysis after the "event". Unfortunately, clear passwords can still be sniffed on our network and much more needs to be done in the near future. Maintaining the accustomed open computing environment at TRIUMF will be a real challenge – especially in light of the urgent need to make the site more secure.

Due to limited network bandwidth and tape capacity, the single-drive DLT tape backup system can no longer maintain service standards of the past (e.g. daily site incremental backup of UNIX based platforms). Moving to gigabit Ethernet for the site and improving tape backup hardware in the coming year will address this. A centralized backup service for PC/Windows is expected to be in operation by the second quarter of 2000.

Potpourri

- The annual computer account renewal process was automated, using perl scripts and html, so that the users could renew/delete their accounts from a Web page.
- From the TRIUMF dial-in Web page, it is now possible to see who is logged in at the current time, and to check on your current dial-in statistics, i.e., how much dial-in time you have accumulated for the current reporting period.
- Canada pays about 10% of the cost of the CERN-US link. All the traffic details can be seen on URL http://sunstats.cern.ch/mrtg/.

Data Acquisition Systems

(R. Poutissou, TRIUMF)

Overview

The growth of Intel PCs as hosts of DAQ systems continued in 1999. ISAC experimental set-ups are all different in nature requiring customization of the software components. MIDAS remains the main software package for acquisition and control. NOVA is supported for analysis, as well as HBOOK/PAW. PHYSICA is also available for data manipulation.

MIDAS software

New hardware support has been added to the MIDAS software package in order to permit the use of state-of-the-art hardware modules. An EPICS to MIDAS interface has been written in order to guarantee proper communication between these two systems, especially for the ISAC hall where all the beam controls are performed by the EPICS package.

Continuous development and improvement of the MIDAS system includes:

a) Integrated alarm system based on events, task status, database values state.
b) Electronic logbook and runlog capability accessible from the MIDAS run control Web page.
c) PowerPC support for the VME modules.
d) Dual buffer capability for the VxWorks front-end code.

Additional applications are now available such as:

a) Lazylogger: multiple background data logging facility including FTP transfer.
b) Elog: electronic log message writer.
c) Odbhist: odb variable retriever from odb save-set.

NOVA

The NOVA data analysis system has been integrated with the latest version of MIDAS (1.7), and has been installed on all data acquisition Linux PCs, as well as several analysis machines at TRIUMF and other labs. Several minor modifications to the system were implemented to better meet the needs of ISAC experimenters. NOVA is currently used by all, except one, ISAC experiments for both on-line data monitoring and off-line analysis.

The next major version of NOVA (2.1) has been released and is in limited use for off-line analysis. Major enhancements include the ability to transport dump files/analysis code seamlessly among different computer architectures, and support for the Bank structure (both YBOS and MIDAS) generated by the on-line acquisition system. User feedback will be evaluated before this version is released in an on-line environment.

ISAC systems

The latest ISAC experiments, i.e. Lifetime, LTNO and β-NMR, have been set up using various components of the MIDAS DAQ package. Each experiment required customized software to fit the particular hardware configuration. This software development involved people with minimum knowledge of the MIDAS system. In a few sessions, each group was able to create/implement specific program tools in order to ease both the run control part as well as the off-line analysis of the data. In particular, LTNO "slow control" drivers were written for controlling and monitoring the LTNO target. In this case the development and the running code have been done on a Windows-NT system.

Design of a video multiplexer system for the ISAC hall was done. Proof-of-principle software has been written as well as tests of video capture software. A simple monochrome video monitoring system for TRINAT and GPS was installed in the ISAC counting room.

μSR systems

Both M20 and M9B μSR set-ups were upgraded following the successful upgrade of M15 in 1998. All three μSR systems now have the same hardware: VME crate containing a CAMP slow control MVME 162 CPU, a new Highland V680 TDC, and a MVME 2603 PowerPC CPU for fast histogramming. Communications between the two VME CPUs and the host computer is done via Ethernet. The scaler module remains in CAMAC. There are plans to change to a VME SIS 3803 16 ch, 200 MHz module during 2000. The host machines remain VAX Workstations. Further improvements to the software for the VME TDC and HM were also made.

A special set-up was developed for Expt. 777. In this case, the standard μSR scintillators were segmented to permit use of a more intense beam. To make use of the segmentation required a pipelined TDC. The DAQ in M20 was extensively modified for a test run last June. The VME TDC/HM system of the standard μSR DAQ was replaced by a FASTBUS system, comprising a LRS 1877 TDC, and a STR 340 SFI (both in FASTBUS) with a VME MVME 2305 PowerPC driving the system. Data from the LRS 1877 was saved as histograms in the MVME 2305 memory in the same format as for the standard μSR system, so that it could be read out by the standard μSR DAQ software on the VAX.

β-NMR at ISAC

A DAQ system for the β-NMR experiment running on ISAC was required that had similar functionality to that of the standard μSR system. Since the standard μSR system is based on obsolete hardware (and software) it was decided to use the standard TRIUMF DAQ system of MIDAS running under Linux. The standard μSR front-end hardware for slow controls (comprising an MVME 162 running CAMP) was used, but the β-NMR experiment required a VME SIS 3801 multichannel scaler accessed by a MVME 2305 PowerPC, that processed the data into histograms. The histogram data had to be saved in a custom format for μSR, readable by the off-line μSR data analysis programs. Therefore the μSR data archiving program was ported to Linux and required extensive modification to run with MIDAS. The CAMP software also had to be ported to Linux.

Expt. 614 slow controls

A slow controls/monitoring system, with a user interface based on Tcl/Tk, has been developed for Expt. 614. A single Tcl window (the Status Bar) presents the global status of the complete experiment to the operator, with warning/error conditions being presented as different colours for buttons on the bar. A single mouse click provides access to a hierarchical system which allows the operator to pinpoint the exact cause of the alarm more precisely. In addition, easy access is provided to the history of any slow control variable monitored by the system.

Scientific Services
(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 1999 included: producing the 1998 Annual Report, a TRIUMF Brown Report, the TRIUMF preprints, and two conference proceedings; reorganizing the Library shelving and journal collection; updating the display material in the front lobby; and supporting nine past, present and future conferences and workshops.

Publications Office

The TRIUMF Annual Report Scientific Activities 1998 was the first truly electronic report published by TRIUMF. From initial contributor submission, through editing, transmission via ZIP disk to the printer, and subsequent direct printing on a Xerox Docutech system, electronic files were used throughout. The same files were used for the WWW version of the report which is 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 was available to readers five weeks before the printed version. During 1999, over 650 people accessed the 1998 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.

A similar procedure was followed to produce the TRIUMF Brown Report TRI–99–1, ISAC-II A Project for Higher Energies at ISAC. Despite the scientific and technical editor and several of the contributors being off-site, all document preparation was performed on a computer at TRIUMF and the latest version was immediately made available to all contributors via the WWW.

During the production of these two documents, many new techniques were devised to ensure optimum display of figures, no matter what software package was used to produce them. In order to incorporate the new techniques in this report, and to encourage the submission of legitimate Encapsulated PostScript figure files, a post mortem of the 170 figures in the 1998 Annual Report was produced and included on the website with the instructions to contributors. The instructions were also updated to include hints on producing more legible figures, especially for the monochrome printed version. This 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. These techniques were presented as part of an invited talk at the First Joint Accelerator Conference Website (JACoW) Workshop on Electronic Publication of Proceedings of Particle Accelerator Conferences at Brookhaven National Lab in December.

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.

Numerous shipping problems encountered with the PAC'97 Particle Accelerator Conference proceedings, which were published in 1998 in both hardcopy and CD-ROM versions, began to be reported in March. They were due to both inadequate and incorrect packaging by the printer of the hardcopy version, and erroneous returns of legitimately addressed packages by the US Postal Service. All problems had to be resolved by TRIUMF, as the publisher had no spare copies. The last replacement shipment was sent in September.

The final camera-ready versions of the manuscripts for the XXIX International Conference on High Energy Physics (ICHEP'98) proceedings were produced, contract liaison with World Scientific, the publisher, maintained, and shipping details arranged. Secure packaging ensured safe and prompt delivery to the delegates less than a year after the conference.

Contributions to the proceedings of the Third International Conference on Isotopes (3ICI) were accepted at the conference in September, mainly electronically, and by the end of the year almost all of the camera-ready manuscripts were ready to be sent to the publisher.

Library

Despite increasing journal costs, the Library was able to renew all of the 1998 journal subscriptions for 1999 and 2000. However, the journal subscription budget and electronic access alternatives are constantly under review.

The Library had to curtail all book purchases in 1999 and continues to rely on donations.

Relocation of the current journal collection into the new, optimized shelving layout was completed in April when the 1998 journals returned from the bookbinders. Several older journals were also bound and damaged volumes rebound.

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. After that, the Library will have outgrown its present location due to floor space and floor loading considerations.

Further rearrangement of the discontinued journal collection and of the book collection will proceed as manpower permits.

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

Information Office

Both Information Office and Conference personnel now reside in the Information Office located adjacent to the lobby. This has allowed optimum utilization of staff during vacation periods, and starting in September the functions were temporarily combined to cover for a longer leave of absence.

The new ISAC model was completed and installed in the lobby in February. During the year several new display panels were produced as part of an effort to gradually redesign the layout of the lobby and replace the existing PR materials.

The Information Office coordinated tours for over 1,000 people during 1999. The majority of tours were conducted by a summer student during the May–August period when public tours were offered twice a day and many pre-arranged tours were given to high school students.

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

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

Conferences

During 1999 support was provided for the following conferences and workshops.

- 1999 Particle Accelerator Conference (PAC'99), New York, March 29 – April 2.
- First Meeting of the American Physical Society, Northwest Section, UBC, May 21–22 (189 delegates).
- Third International Conference on Isotopes (3ICI), Vancouver, September 6–10 (300 delegates).
- TRIUMF–ISAC Scientific Symposium (TISS'99), TRIUMF, December 12 (130 delegates).

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

- Astbury Symposium, TRIUMF, April 15–16, 2000.
- Fourth International Symposium on Radiohalogens (4ISR), Whistler, September 9–14, 2000.
- 14^{th} International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications (EMIS XIV), Victoria, May 6–10, 2002.

GEANT4

(P. Gumplinger, TRIUMF)

GEANT4 is a collection of software, arranged like a toolkit, and designed to accurately simulate the passage of particles through matter. Its capabilities include a very powerful kernel, extensive physics models, the ability to visualize the detector, particle trajectories and hits, and the creation of a persistent detector description and persistent events. GEANT4 is a next generation simulation program. It replaces the successful and venerable GEANT3 package, but with some important added functionality. Representative are the following four examples:

- Tracks created in an event can be handled in a user-defined priority, thanks to a new stacking mechanism. For example, particles forming an event trigger may be tracked first, and only if they in fact trigger the detector will the detailed simulation of the remaining tracks proceed.
- The tracking code is completely general and common for all particle types, but the order in which processes (energy loss, multiple scattering, etc.) are invoked, is user-prescribed. As a matter of fact, anyone can create a new physics process and register it for a particle type. Even the stepping of a particle through the geometry has become, by design, a transportation process.
- GEANT4 does not apply tracking cuts but only production cuts. Those are specified in terms of a particle's range and not its energy. Consequently, the energy below which particles are not created in a process depends on the density of the material. Nonetheless, should the minimum range exceed the distance to the nearest volume perimeter, particles are created below the cutoff range down to the reach of the boundary.
- A set of physics processes has been developed to describe the electromagnetic interactions of photons and electrons with matter down to 250 eV. In addition, algorithms based on parameterization methods of evaluated experimental data are in place to simulate the energy losses of hadrons and heavy ions with kinetic energies down to a few eV.

GEANT4 is also the name of a large international collaboration of scientists and software engineers, whose mandate it is to perform production service, oversee the ongoing further development of the program, and provide user support. This collaboration superseded the R&D project, RD44, which produced the first public production version at the end of 1998. TRIUMF has a seat on both the Collaboration Board, which manages the resources and responsibilities of the new collaboration, and the Technical Steering Board, which decides technical matters regarding service, development and support, and assigns priorities to user requests.

A clean overall problem decomposition has led to a clear hierarchical structure of domains, linked by a unidirectional flow of dependencies. Each area is individually managed by a working group of experts, in fields as diverse as physics, geometrical modelling, visualization, event generation and user interfaces. TRIUMF collaborators are involved in the sectors: Hadronic Physics, Electromagnetic Physics, Testing and Quality Assurance, Software Management, and Documentation Management.

GEANT4 is written in C++ and exploits advanced software engineering techniques and object oriented technology to achieve transparency of a multitude of physics implementations. For example, the way cross sections are input or computed is split from the way they are used or accessed. Similarly, the way the final state is computed can be divided into alternative or complementary models, according to the energy range, the particle type, and the material. To build a specific application the user-programmer chooses between these options and implements code in user action classes foreseen by the toolkit.

GEANT4 is available for a variety of operating systems: flavours of UNIX, Linux, and Windows NT. In order to link and build the program, only two underlying software packages are mandatory: CLHEP (Class Library for High Energy Physics) and STL (Standard Template Library for fundamental classes like C++ containers and strings). GEANT4 has already been selected as the main simulation platform for several major particle physics experiments (ATLAS, BaBar, CMS, ALICE, etc.). Likewise, the quality of the program is expected to benefit from applications in a number of other fields such as: medical physics, nuclear physics, heavy ion physics, accelerator physics and space science.

Collaboration highlights during the past year were the July release of GEANT4.0.1 and the December release of GEANT4.1.0. The target in July was a consolidation of outstanding issues from the first ever production release the previous December, bug fixes, time performance improvements, as well as the inception of granular libraries for each program sub-domain. By December, the migration away from Rogue Wave Tools.h++ was accomplished and G4.1.0 became the first entirely STL based production version. This also ended our dependency on a commercial product, which had been a major criticism from potential users. The developer's version of G4.1.0 has since also undergone a complete migration to the ISO C++ standard.

The Technical Steering Board met five times during the course of 1999. A TRIUMF representative was present for the inaugural meeting at CERN in February and participated by video conference in all subsequent meetings. During the February trip, work done with a CERN colleague added the tracking of a particle's spin in electromagnetic fields to GEANT4's functionality.

Throughout the year, a TRIUMF associate participated as a member of the STT (System Testing Team) in performance testing, problem diagnosis and debugging. In March an automated, internet based, bug report system, called Bugzilla, was put in place to facilitate and structure the work of the STT. The Canadian collaborator visited CERN to participate in the prerelease testing phase running up to the July release, and in discussions about automated testing procedures and associated tools from the Open-Source project. He helped formulate a draft proposal to develop prototypes of such tools. He later realized a working prototype of LXR, a WWW-based source code browser with cross-reference and full-text indexing. This work led to the formulation of a detailed proposal, with background and explanatory material, for the implementation of an integrated set of WWW-based tools: LXR, Bonsai (a visual interface to a source code and version management tool), and Tinderbox (an automated multi-platform system testing and reporting tool). These ideas were subsequently presented at the annual GEANT4 workshop at ESA (European Space Agency) in Noordwijk, The Netherlands, in September.

TRIUMF is also helping to improve the standard of GEANT4 documentation by making the HTML format consistent all through various documents, and by assisting in the English representation. A Canadian is presently involved in the conversion to C++ of the high energy transport code (HETC). This code was developed by researchers in the Nuclear Analysis and Shielding Section of Oak Ridge National Laboratory's Computational Physics and Engineering Division. HETC simulates hadronic transport and particle production in nuclear collisions of charged hadrons and neutrons. It performs this in a three-fold manner: (1) for energies less than 3 GeV, particles are generated by means of an intermediate energy intranuclear cascade and evaporation model, (2) for 3 GeV to approximately 10 GeV, particle generation is done by means of a scaling model, and (3) above 10 GeV, particle generation is done by means of a multi-chain fragmentation model. HETC has been benchmarked against numerous experiments with excellent success. It was incorporated into the CALOR95 calorimeter analysis system and also into the GCALOR99 simulation suite.

In April, the TRIUMF/G4 team purchased a computer with dual Pentium III processors. It is intended to be the nucleus of a dedicated GEANT4 visualization station for the development of end-user applications by TRIUMF and affiliated university physicists. We installed Linux, GEANT4 software and associated packages before a visitor from ATLAS-Canada arrived. With our support, the student from the Université de Montréal commissioned his ground breaking HEC (hadronic end cap) G4 simulation, with visualization and histogram capabilities, on the TRIUMF platform.

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).

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

Sudbury Neutrino Observatory
(R. Helmer, TRIUMF)

A major difficulty with the underwater connection between the signal cables and the photomultiplier tube bases was uncovered last year. The cables also carry high voltage to the tubes. It was noted that as each connector was submerged during the cavity water fill, it became subject to high voltage breakdown. The consequences of the breakdown were, first, that a back termination resistor located in the base became an open circuit after some number of breakdown events and, second, that eventually a resistor in series with the dynode chain resistors also became an open circuit. There was little consequence from the first of these resistors blowing—the signal from the tube was doubled at the expense of a slightly increased chance of a pulse reflection—but destruction of the series resistor rendered the PMT inoperable. A great deal of effort was expended in trying to understand the phenomenon, and it was finally hypothesized that air inside the connector was being pumped out by diffusion across the seals into the degassed water in which the connectors were immersed. The problem was greatly ameliorated by adding nitrogen gas back into the water.

Nevertheless, the connector was not in fact designed to carry a high voltage and breakdown continues to be observed, although at a much reduced level. It is unknown whether regassing the water will hold the breakdown in check over the lifetime of the experiment, or indeed whether the gas is causing some other, unexpected, long term difficulty. As a result, TRIUMF has taken on the responsibility of designing a new connector which could be used in place of the present one in the event a replacement becomes necessary. A prototype of a new design has been constructed and a system has been set up to test it under the original specifications of satisfactory performance in ultra pure, degassed water.

Some difficulties have also been encountered with the optical calibrations in that the laser ball has an unknown anisotropy and the small phototube built into it to monitor the light output does not receive sufficient numbers of photons to be useful at low light intensities. In order to check some of the measurements made with the ball, a source consisting of an alpha emitter embedded at the centre of a four inch diameter sphere of scintillator is being fabricated in the TRIUMF scintillator shop. It is anticipated this source will be isotropic to a high degree and the constant rate of decay of the alpha emitter renders unnecessary inclusion of a separate monitor.

The TRIUMF scientist involved in SNO is the convener of the Energy Calibrations Working Group, and as such is responsible for overseeing the analysis of energy calibration data.

Low Temperature Nuclear Orientation
(P.P.J. Delheij, TRIUMF)

The low temperature nuclear orientation set-up at ISAC is operated in a collaborative effort of Oregon State University, University of British Columbia, Michigan State University, Georgia Institute of Technology and TRIUMF. During 1999, all activities were directed towards the installation and commissioning of the set-up. At the beginning of the year the support structure had just been completed. The first goal was to test the cryogenic systems and demonstrate that a temperature of 10 mK could be reached. With two germanium detectors the gamma ray anisotropy of a ^{60}Co<u>Fe</u> source was measured to determine the temperature unambiguously. After this milestone was reached in March, the construction of the beam line and the connection to the cryostat could proceed. In August the first 3 days of radioactive beam were delivered to the complete set-up. From the radioactive isotopes that could be produced, ^{79}Rb was chosen because it has a number of favourable properties. The analyzing powers for the 688 keV and 505 keV pure E1 gamma-ray transitions are large and have opposite signs, 0.94 and –0.75 respectively (see Fig. 103). The 350 keV transition that originates from a spin 1/2 level shows no anisotropy. These features provide internal consistency checks to study systematic errors. A drawback is that the hyperfine field for Rb, as usual for alkali elements, is fairly small at 5.5 T. The result for the alignment parameter $f_2 = 0.085 \pm 0.015$ showed a significant orientation. Errors for the results of the preliminary analysis are statistical only. Next the beam control was improved by installing a wire scanner in the vertical beam line section of LTNO, by isolating the iris in this section to serve as a Faraday cup, and by segmenting the Faraday cup closest to the target into 5 components, 4 equal sectors and a backing plate covering the gaps. With four germanium detectors, two located in a parallel and two in a perpendicular direction with respect to the magnetic field, a value of $f_2 = 0.114 \pm 0.002$ was obtained, indicating a temperature of $T = 5.6$ mK for a magnetic field $H = 5.5$ T. It should be noted that the uncertainty in this value is 1 T. Since the parameter f_2 is a function of the ratio H/T a shift in the value of the field H causes a proportional change in the temperature T.

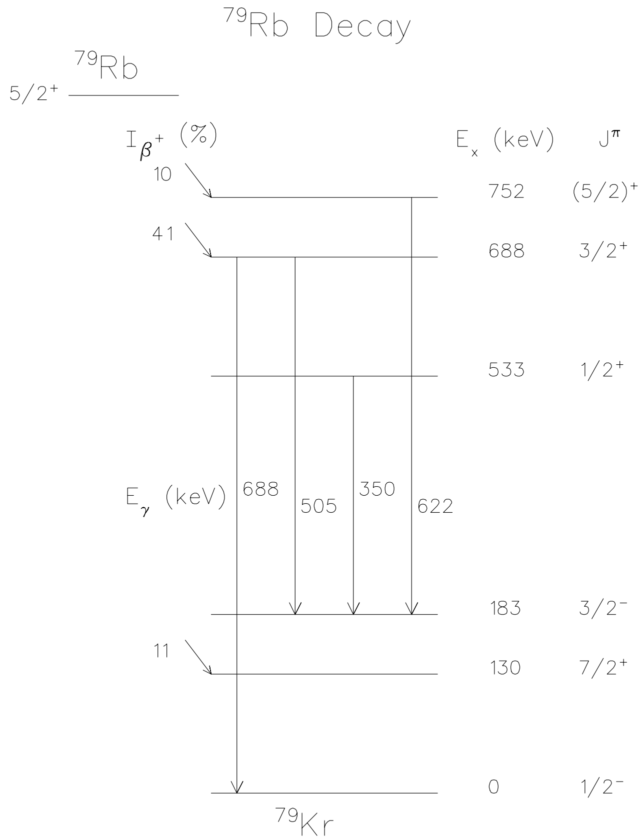


Fig. 103. Partial level scheme of ^{79}Kr following the decay of ^{79}Rb.

Nuclear Astrophysics Studies Using 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 $\leq$ 30 to energies from 0.15 to 1.5 MeV/u. An essential program with such beams is to measure with a precision of about 20%, the absolute rates of radiative proton or alpha capture reactions in which one of the reactants is radioactive. Such reactions are believed to play an important role in the synthesis of elements during stellar explosive phenomena such as nova, supernova, and X-ray bursters. Such measurements will be performed at ISAC using inverse kinematics (heavy projectile intercepting a hydrogen or helium gas target) in the DRAGON facility.

The first reaction that will be pursued is ^{21}Na$(p,\gamma)^{22}$Mg (Expt. 824) in the energy range from 0.2 to 0.8 MeV/u. Aside from the availability of an intense ^{21}Na beam from ISAC, the choice of this reaction is based upon its importance in the NeNa cycle, leading to the rp process in a nova or in an X-ray burster. This cycle is especially important to the possible production of the long-lived radioisotope ^{22}Na, whose presence is predicted to be detectable in novae through the observation of its gamma ray at 1.28 MeV. Although the rate of this reaction has never been measured, based upon estimates made of resonance strengths from the analogue nuclide, ^{22}Ne, a counting rate of about 155 events/h is expected for radiative proton capture to the most important resonance at 5714 MeV (in ^{22}Mg). This assumes a radioactive beam intensity of 10^{10} per second and an overall transmission for DRAGON of 40% (without the gamma array mentioned below).

The main components of the DRAGON system presently under production are a windowless gas target, a two-stage electromagnetic mass separator to separate the rare reaction products from the more intense beam, and at the end, several detection systems for the recoiling, heavy ion reaction products. A beam suppression figure of at least 10^{-12} is expected. A conceptual layout of DRAGON can be found in Fig. 104.

In addition, a funding proposal was submitted this year to NSERC for the installation of a BGO based gamma array system to be positioned around the target chamber for the detection of the emitted prompt reaction gammas. This will further help reduce the effects of beam related background, of particular importance for reactions involving very weak resonance strengths.

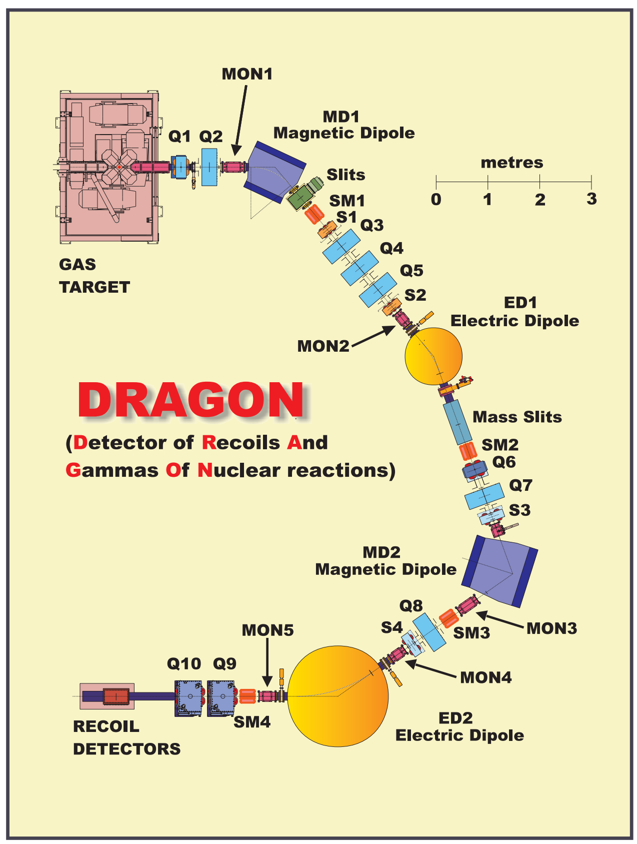


Fig. 104. Conceptual layout of DRAGON.

It is expected that the DRAGON facility will be ready for operation using an intense alpha emitting source during the latter half of 2000 and commissioned with heavy ion stable beams from the ISAC accelerator when they are available, probably not before December, 2000. A summary of the present status of the various components is provided below.

The DRAGON facility

Layout

Prior to proceeding with actual construction of the components of the DRAGON, intensive reviews by the TRIUMF-ISAC group were conducted. Figure 105 presents a detailed layout in a plan view of all components of the facility. The service platform shown was installed in December. An external safety fence will be used to restrict entry especially while radioactive beam is being used.

Gas target

The main frame and most of the components of the windowless gas target were constructed at the University of Alberta and then moved to TRIUMF in September (see Fig. 106). The target consists of 4 large Roots

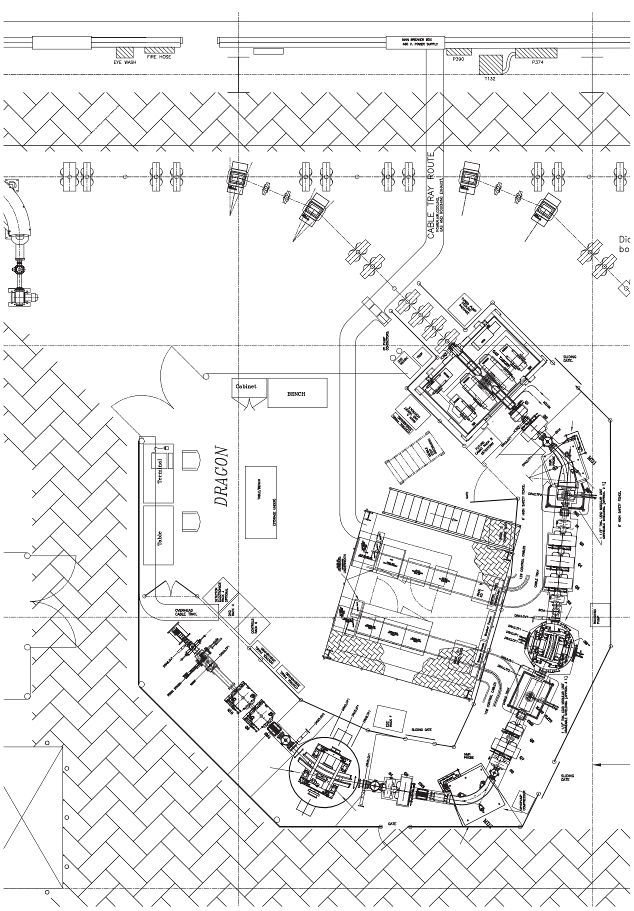


Fig. 105. Projected detailed layout of DRAGON.

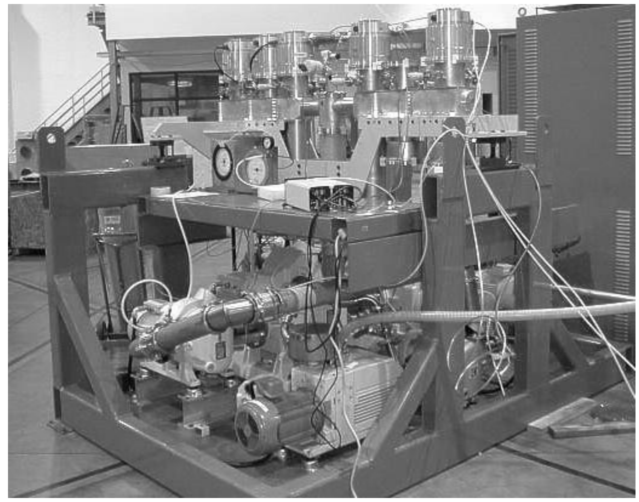


Fig. 106. The DRAGON windowless gas target.

Blower pumps and 5 1000 l/s turbo pumps positioned above and below the beam line. The performance of the target for He and N_2 gas met desired specifications, namely, for an inner cell target pressure of 5 torr, the pressure in final chambers just prior to the start of the separator was of the order of 2×10^{-6} torr. Tests with hydrogen gas are now in progress to be followed by installation of the gas recirculation system and remotely operable control system.

The electromagnetic separator (EMS)

The EMS is designed to transmit the desired recoil product ions with good efficiency, while providing beam suppression of at least 10^{-12}. The momenta of the recoil ions bracket the momenta of the beam particles, both in magnitude and direction. Therefore, it is necessary to have both magnetic and electrostatic dipoles to accomplish the separation.

The two new magnetic dipoles are essentially now ready for installation as are the sextupole units (from TRIUMF) and the new steering magnets. There are three different types of quadrupoles needed, 2 with 4 in. diameter and 6 with 6 in. These are still being manufactured but their coils have been completed. Two additional quadrupoles were obtained from TRIUMF. Assembly should be completed early in 2000.

A design review was held for the electrostatic dipoles ED1 and ED2 and orders placed for the manufacture of the Ti electrodes. These were completed and a contract for the final machining of the electrodes using wire EDM will be awarded early in 2000. Design of the support and alignment system for the electrodes was completed while detailed designing is almost completed. The design of the special high voltage multiplier stacks was completed and a prototype assembled. It was tested successfully to 200 kV in a pressure vessel at 30 psig of SF_6 gas. More details of these specially

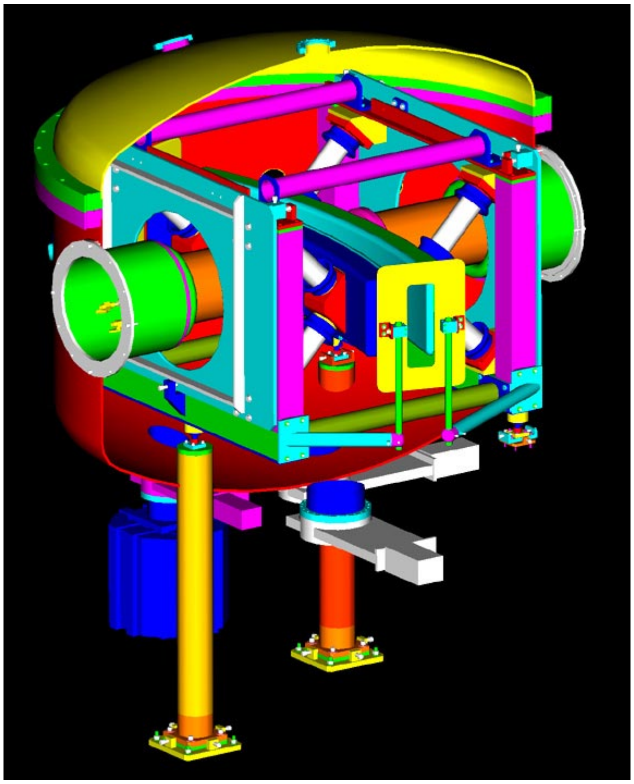


Fig. 107. A 3D CAD rendition of the electric dipole unit.

designed electrostatic dipoles can be found elsewhere in this Annual Report. A 3-D, CAD rendition of this dipole unit is shown in Fig. 107.

The present plan calls for installation of the various electromagnetic elements to begin early in 2000.

Diagnostic elements

Specifications of diagnostic elements and slits have been provided and conceptual designs have been completed. Detailed designing was delayed until 2000 for lack of available draftspersons.

A new concept for a beam profile monitor which could be used for providing spatial information for both low and high intensity heavy ion beams was developed and a prototype (see Fig. 108) tested successfully using the OLIS system. Further details of OLIS can be found elsewhere in this Annual Report.

Recoil detection systems

Two options are being considered to provide the necessary signals of the separated, recoiling reaction products. In both cases the intention is to measure the time of flight of the heavy ions over a local 50 cm flight path, and also their total energy to determine their mass.

In the first approach a start signal is to be obtained from a micro-channel plate (MCP) located at the focus of the EMS. The stop signal will come either from a second MCP or a parallel grid avalanche counter (PGAC) located at the front of a multistage ionization chamber (IC). The IC will also provide a total energy signal and in some instances information on the Z of the recoil. In the second approach a Si surface barrier detector will be used to provide the total energy.

The IC has been built and has exhibited energy resolution of $< 2\%$ (for ^{241}Am alpha). Both the IC and Si system will be tested with the required low energy heavy ions early in 2000 at some off-site laboratory.

Gamma array

A proposal was submitted to NSERC for a gamma array which is intended to detect the coincident prompt gamma rays for the radiative capture reaction in the gas target. This system would provide additional factors of beam suppression, definitely required to perform some of the very weak capture reactions. The system is composed of about 30 individual BGO crystal modules arranged around the gas target to achieve high geometric efficiency (80%).

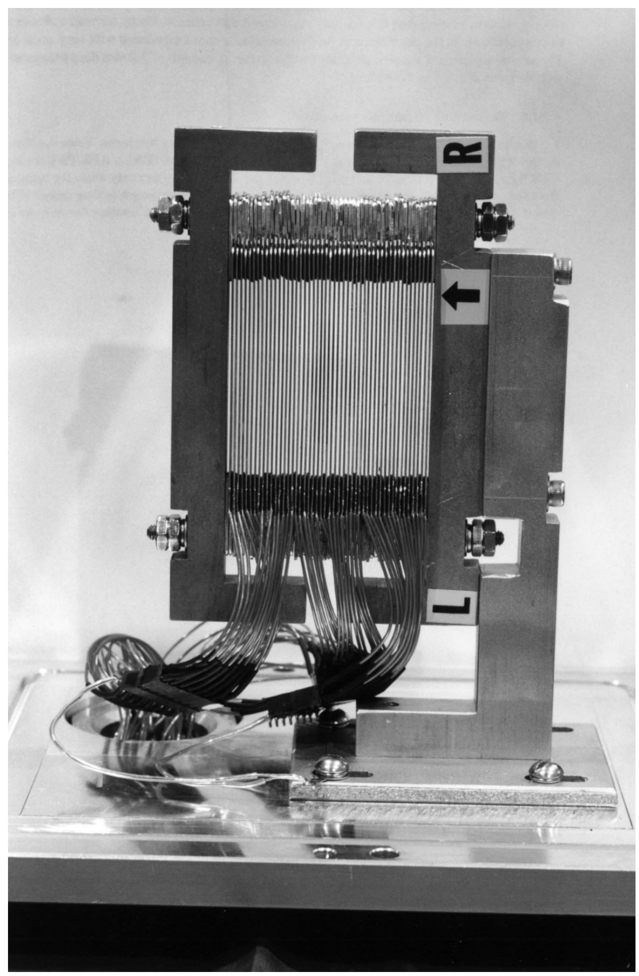


Fig. 108. The prototype beam centring device developed at TRIUMF.

β-Detected Nuclear Magnetic Resonance at ISAC

(G.D. Morris, R.F. Kiefl, UBC/CIAR/TRIUMF)

We are developing a beta-decay nuclear magnetic resonance spectrometer which will accept an intense beam of low energy, highly polarized radioactive ions produced by the ISAC facility. Although the main application is condensed matter physics, the polarizer itself may also have applications in nuclear physics. What follows is an introduction into the scientific motivation, a description of the polarizer and spectrometer, and first test results from the spectrometer.

Introduction

Nuclear magnetic resonance (NMR) and related nuclear methods such as muon spin rotation are important probes of local electronic and magnetic properties of solids. A common feature in all forms of magnetic resonance is that one first creates nuclear polarization and then measures how that polarization evolves in time. The spin precession rate or Larmor frequency is a measure of the local magnetic field at the nucleus, whereas the spin relaxation rate senses the low energy dynamics. However, there are significant differences between methods which may influence particular applications. For example, in conventional magnetic resonance a small nuclear polarization is generated in thermal equilibrium by applying a large magnetic field, and a pickup coil is used to detect the precession of the nuclear magnetization. Typically one needs about 10^{17} nuclear spins to generate a good NMR signal. On the other hand, in related nuclear methods such as muon spin rotation (μSR) or β-detected NMR (β-NMR) a beam of highly polarized radioactive nuclei (or muons) is implanted into the material. The time evolution of the spin polarization is picked up through anisotropy in the distribution of particles from the decay of a radioactive nucleus or muon. The much larger initial polarization and nuclear method of detection result in a factor of about 10^{10} fewer spins being required to obtain a signal from nuclear methods such as μSR or β-NMR. This enhanced sensitivity means that nuclear methods are well suited to studies of dilute impurities or small structures with few host spins. Areas of application include many of the most interesting problems in condensed matter physics, e.g. high-T_c superconductors, magnetic multilayers, and semiconductor quantum wells.

The principles for β-NMR and μSR are almost identical. In fact the two methods became possible at almost the same time when it was demonstrated in 1957 that parity is violated in weak interactions. In a decay mediated by the weak interaction, the direction of the outgoing charged particle is correlated with the nuclear (or muon) spin at the instant of decay.

Muon spin rotation is now widely used as a sensitive probe of internal magnetic fields, to simulate the behaviour of hydrogen in semiconductors, and in studies of hydrogen chemistry and organic free radicals. The most important contributions from μSR in chemistry and physics came after the building of the meson factories in the late 1970's and a period of development in the technique. β-NMR has been used by nuclear physicists studying properties of unstable nuclei. Although elegant experiments have been performed on a variety of materials such as simple metals [Jäger *et al.*, Phys. Lett. **123**, 39 (1987)], surfaces [Jänisch *et al.*, Phys. Rev. Lett. **75**, 120 (1995)], disordered solids [Heitjans *et al.*, J. Non-Crystalline Solids **131-133**, 1053 (1991)], and semiconductors [Ittermann *et al.*, Phys. Rev. **B59**, 2700 (1999)], the method has not been developed as a probe of condensed matter to the same extent as μSR. One reason for this is condensed matter studies typically require a high signal-to-noise ratio which is not as easy to achieve as in the case of muons. This situation is now changing since at facilities such as ISAC it should be possible to generate intense ($>10^8$/s) and highly polarized (80%) beams of various radioactive nuclei [Keim *et al.*, Hyp. Int. **97/98**, 543 (1995)]. Under these circumstances one can expect large enhancements in the signal to noise with β-NMR. Furthermore such beams can be implanted at very shallow depths (1–1000 nm) whereas conventional muon beams are used primarily as a bulk probe of matter.

Most elements have at least one isotope that can be studied with β-NMR. Naturally the number of isotopes suitable for use as a probe in condensed matter is considerably smaller. The most essential requirements are: (1) a high production efficiency, (2) a method to efficiently polarize the nuclear spins, and (3) a high beta decay asymmetry. Other desirable features are: (4) small Z to reduce radiation damage on implantation, (5) a small value of spin so that the β-NMR spectra are relatively simple, and (6) a radioactive lifetime that is not much longer than a few seconds. Table XII gives a short list of the isotopes we have identified as suitable for development at ISAC. Production rates of 10^6/s are easily obtainable and in some cases, such as ^{8}Li, we anticipate rates as high as 10^8/s.

Table XII. Examples of isotopes suitable for β-NMR.

Isotope	I	$T_{1/2}$ (s)	γ (MHz/T)	β-decay Asy (A)	Flux (s^{-1})
^{8}Li	2	0.8	6.2	0.33	10^8
^{11}Be	1/2	13.8	22	0.33	10^7
^{15}O	1/2	122	10.8	0.7	10^8
^{19}O	5/2	26.7	4.7	0.7	10^8
^{17}Ne	1/2	0.1		0.33	10^6

One of our objectives will be to develop new probes tailored for specific applications in condensed matter. For example, the spin-$\frac{1}{2}$ ^{17}Ne isotope should act as a pure magnetic sensor since it has no quadrupole interaction and is chemically inert. Oxygen is also interesting since oxides are playing a major role in research on superconductivity and magnetism. Furthermore, in the case of oxygen it will be possible to switch from an isotope with a nuclear quadrupole moment to one without a quadrupole moment (see Table XII). Although the quadrupole interaction can be very useful in distinguishing sites, it is also desirable in some circumstances to eliminate the quadrupole interaction.

Polarizer

Ions emerging from an ISOL target are unpolarized. A fast collinear polarization technique can be used to generate high nuclear polarization in all the alkali metal atoms such as Li. This is possible since the ground state of a neutral alkali atom can be excited with visible or near visible lasers. The method has been used extensively by Neugart *et al.* at ISOLDE to measure magnetic and electric quadrupole moments of unstable nuclei [Keim *et al., op. cit.*].

Our first set of experiments will be on ^{8}Li (nuclear spin I=2) which is the lightest isotope suitable for β-NMR (see Table XII). The Li$^+$ ion beam is first neutralized by passing it through a Na vapour cell. Li$^+$ has a large cross section for charge exchange with Na (>10^{-15} cm^2) and is neutralized efficiently with little or no change in the beam emittance. The neutral Li beam drifts 1.7 m in a small longitudinal magnetic holding field of 1 mT while being pumped with circularly polarized laser light brought in along the beam axis. The D1 atomic transition of neutral Li $2s^2S_{1/2} \rightarrow 2p^2P_{1/2}$ occurs at about 671 nm. Doppler broadening of the resonance is dramatically suppressed by accelerating the beam up to 30 keV and this reduces the required laser power. Tuning of the resonance is done by making fine adjustments to the beam energy (Doppler shift) while stabilizing the laser frequency externally. Both the ground and first excited atomic levels are split by the hyperfine coupling between total spin states $F = 5/2$ and $F = 3/2$, and both of these hyperfine states must be pumped in order to maximize the polarization. The object is to pump all the atoms into the $F = 5/2, M_F = 5/2$ spin state which is fully nuclear polarized.

The final step is to ionize the neutral beam by passing it through a He gas cell. Results from the test stand (see elsewhere in this Annual Report) show that this can be done with high efficiency and only a nominal increase in the emittance. The beam line after this point has been designed to accept a large emittance beam (200 mm mrad). After reionization, the polarized Li$^+$ ion beam passes through two 45° electrostatic bends which preserve the longitudinal polarization. The final section before the magnet has three Einzel lenses, two pairs of steering plates and three adjustable collimators which control the beam spot on the sample. This eliminates the need for collimation downstream of the back counter since all the ions passing through the back detector stop in the sample. Only betas originating from the sample reach the detectors. This final leg in the beam line is ultra-high vacuum (UHV) compatible in order to reduce the pressure from 10^{-7} torr upstream of the spectrometer to 10^{-10} torr in the main chamber. This is necessary to avoid accumulating residual gases which would otherwise be condensed onto the surface of the sample at low temperatures.

Spectrometer

Figure 109 shows a schematic of the high field β-NMR spectrometer which will be complete in a few months when a new 9 T magnet arrives. The main function of the spectrometer is to record the beta-decay anisotropy from spin polarized ions implanted into the sample, either as a function of rf frequency or time after implantation. The nuclear polarization is longitudinal with respect to both the beam and the axis of the high homogeneity 9 T solenoid. This geometry is required for measurements in high magnetic fields where both the incoming ions and outgoing betas are strongly influenced by the magnetic field. All elements of the spectrometer are UHV compatible and a base pressure of 10^{-10} torr has been reached. Two large cryopumps are used to achieve the desired UHV vacuum condition. The cryostat is mounted on a large bellows so that it can be removed from the magnet bore in order to change the sample through a load lock on top of the main vacuum

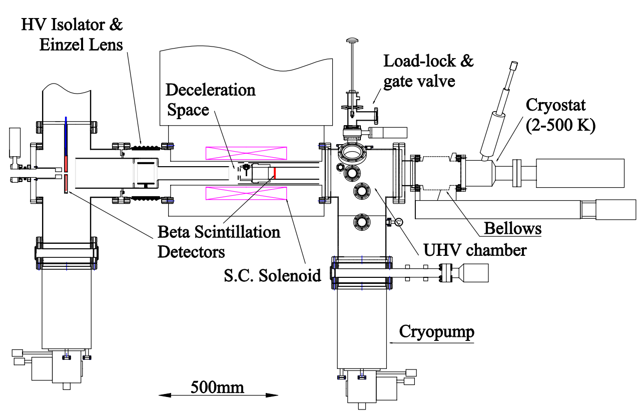


Fig. 109. High field β-NMR spectrometer at ISAC. The beam enters from the left, passes through a small hole in the backward scintillation detector and is focused onto the sample with the Einzel lens. Betas are detected with two segmented scintillation counters centred on the axis of the superconducting solenoid.

chamber. Fast plastic scintillators are used to detect the betas from ^{8}Li $\rightarrow$ ^{8}Be + ν_e + e$^-$ for which the end point energy is 13 MeV. This is enough to easily penetrate thin stainless steel windows. Since we anticipate that the counting rates may reach 10^8/s, the detectors are segmented into 16 elements each to reduce distortions in the time histograms due to detector deadtime. The plastic scintillators and light guides are held in reentrant stainless steel housings with thin stainless steel windows which isolate the detectors from the UHV vacuum chamber but allow transmission of the low energy betas. In order to detect betas in the backward direction (opposite to the beam) it is necessary to place the detector outside the magnet since the betas are confined to the beam axis while inside the bore of the magnet. Simulations and now experiment show that as the betas emerge from the magnet bore in high field the angular cone of emission collapses. Consequently the two detectors shown in Fig. 109 intercept betas over very similar solid angles even though they appear very asymmetric.

In December we had our first test run to commission the beam line and spectrometer. Both parts were very successful. Figure 110 shows our first lifetime spectrum for ^{8}Li measured with unpolarized beam. The ^{8}Li rate at the spectrometer is estimated to be 10^7/s with a Ta target confirming that we should easily reach 10^8/s with 100 μA on a carbon target. This lifetime spectrum, uncorrected for background or deadtime, is undistorted indicating that the detector segments can easily operate at 1 MHz.

One of the most important features of the spectrometer is that the ions can be implanted over a wide range of energies (1–90 keV) with the same high efficiency. This will be tested in July, 2000 by floating the spectrometer and all ancillary equipment (magnet, power supplies, cryostat, thermometry, etc.) on a high voltage platform. For example by applying a bias voltage to the platform between +29 keV and –60 keV one can adjust the energy of implantation in the range (1–90 keV). For ^{8}Li this corresponds to an average implantation depth of between 6 nm and 300 nm respectively.

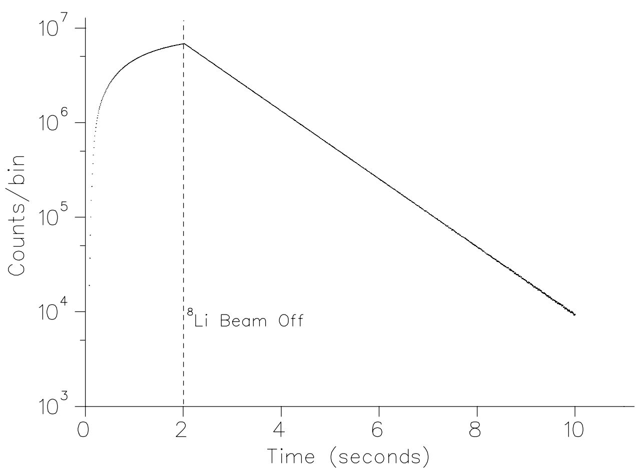


Fig. 110. First ^{8}Li decays at the spectrometer in December. During this run the beam was turned on for the first 2 s of each 10 s cycle. Note the single exponential decay with the characteristic lifetime of ^{8}Li. The data accumulation rate is about 3.2×10^9 per hour or about 100 times that in a typical μSR measurement.

Detector Facility
(R. Henderson, TRIUMF)

This year has been a very active one for the detector facility. In particular, the large clean room was modified by the addition of an internal crane system suitable for ATLAS module production. After an initial problem with the first modules, ATLAS modules are now in full production. A large part of the facility is now strongly involved with the Expt. 614 project. In addition, we are contributing significantly to the ISAC facility.

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. TRIUMF members are playing a central role in this collaboration. R. Henderson has designed the detector modules and is playing a large part in the overall experimental design. R. Openshaw has designed the complex gas sytem. W. Faszer has designed and built the high precision wire surveyer, and he will help oversee the wire-plane production and OC.

In the Scintillator Shop a variety of scintillators have been built, the biggest customer being the μSR group. This year fewer scintillators were required at TRIUMF and the shop committed to making a large number of scintillators for the G0 experiment at TJNAF. This involves about 0.9 man-years of shop time over the next 18 months. In addition, the larger mill in the shop will be refitted as a 4-axis NC mill. This will facilitate the large amount of G10 machining required by the Expt. 614 experiment and the curved scintillators for G0.

The DRAGON ionization chamber was designed in the facility by R. Henderson and R. Openshaw. This was successfully bench tested and will soon be tested in-beam. We also designed and built a position sensitive PGAC for ISAC and it is being bench tested. R. Henderson and D. Hutcheon designed a prototype ISAC beam monitor. A prototype of this monitor has been built by M. Goyette in the facility. It uses 48 brass blades on a 1 mm pitch and has been successfully tested in a low energy beam. Based on what we learned from making this prototype, the design has been improved and a second prototype will be built.