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OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2002

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

ACCELERATOR TECHNOLOGY DIVISION

INTRODUCTION

This past year has seen a number of engineering and design projects come to fruition with successful commissioning and operation. One of these has been the DRAGON spectrometer where much of the installation was carried out in 2000, but commissioning of the electrostatic dipoles was delayed due to problems with ceramic feedthroughs. DRAGON was commissioned with stable beam in October and the first experiment with radioactive ion beams was carried out in November. Another significant milestone was reached with the commissioning of the 2 T solenoid magnet in its 60 ton iron return yoke for the TWIST experiment.

In terms of engineering and design effort, the largest project this past year has been the design of the east target station for ISAC. The switching magnet for beam line 2A, which permits the proton beam to be delivered to either of the two target stations, was completed and field mapped. Improved remote handling capability is being built into the target modules, as well as the services for running an ECR ion source. By the end of the year most of the modules were nearing completion and the entrance and dump modules were in fact installed before the Christmas break.

Some design work has started on the ISAC-II project related to the superconducting rf cavities. A 1200 sq ft test facility was constructed in the nearby BC Research complex for initial testing of the cavity and cryostat.

At Victoria the ATLAS engineering work is nearing completion. The large HEC assembly table was fabricated by a firm in Toronto and was nearing completion by the end of the year. The signal feedthrough project is in the final stages of manufacturing and testing. The engineering effort is now switching to supporting the design of the ISAC targets. At Carleton the TRIUMF engineer is involved in the tooling and assembly of the FCAL modules for ATLAS.

The Machine Shop was again heavily used for fabricating components for ISAC and supporting the experimental program. This year fabrication work valued at more than \$1.6 million was carried out in the TRIUMF shop and about \$0.5 million worth of work was sub-contracted to outside firms through the Machine Shop. In preparation for the ISAC-II and MDS Nordion building construction projects, a number of trailers were relocated and some were removed from the site. A contract for 29 new concrete shielding blocks was awarded and the blocks produced to replace some deteriorating blocks in the BL1A tunnel.

The Electronics Services group provided considerable support for the TWIST experiment this year, including the production of amplifier and other modules and large numbers of cables. PC support was increased with another full-time technician and an improved service for regularly scheduled backups. The Electronics Development group continued to put most effort on the ISAC control system and has started to take responsibility for the design and installation of safety related systems.

BEAM DYNAMICS

Three beam dynamics studies are reported this year, in addition to those for the CERN collaboration. The first is a continuation of the joint study with Brookhaven of the possibility of extracting very short proton bunches for the KOPIO experiment. The second, in support of a Fermilab study of muon acceleration in an FFAG ring, explored the best rf voltage and (fixed) frequency to use when the traversal time is too short to allow synchronization of the rf with the orbit frequency. The third investigated the effect of space-charge in destabilizing an intense circulating beam by moving it on to a betatron resonance.

Micro-Bunching at Brookhaven AGS

Particle beam simulations in support of the proposed rare kaon decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$ experiment have continued. The very short kaon bunches required are produced by extracting 0.15 ns rms long proton bunches with 40 ns separation with the aid of rf manipulations. Last year, the longitudinal dynamics of a variety of schemes were considered, resulting in the choice of fundamental and anti-phased fourth harmonic rf. This year, the simulations were elaborated to include the $\frac{1}{3}$-integer betatron resonance responsible for extraction in the horizontal plane. For this purpose, the SLEX computer program for the study of slow extraction schemes, written by Wienands for the KAON Factory proposed in the late 1980s, was simplified by eliminating the $\frac{1}{2}$-integer resonance dynamics and married with LONG1D which performs the longitudinal tracking. New graphical and analysis software was also written for displaying and processing the output.

Using the LONG1D-SLEX code a new effect was discovered that limits extraction efficiency. Because of the longitudinal motion, the betatron tune varies as particles are carried toward resonance. Figure 183 shows the circulating and extracted longitudinal phase spaces. The gap between neighbouring rf buckets acts as a venturi; and so the narrower the constriction in rf phase (i.e., the microbunch length), the faster is the motion in momentum. When it is fast enough, as occurs when the shortest bunches are demanded, some particles pass through the betatron resonance

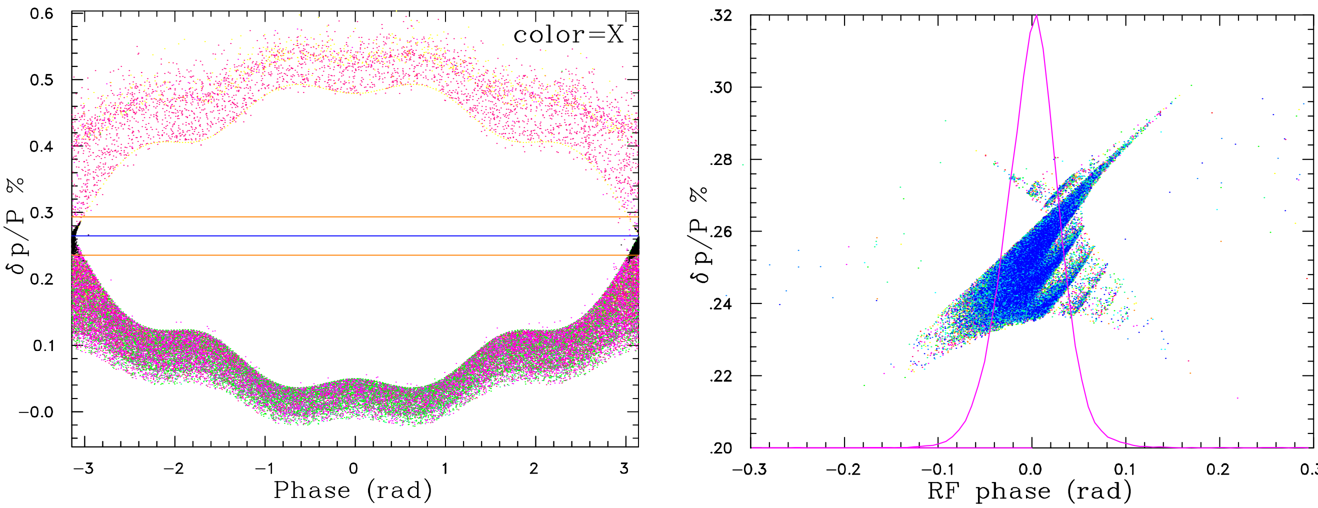

Fig. 183. Circulating longitudinal phase space and extracted microbunch shape.

without building up sufficient amplitude to be extracted. Parameters which promote this effect, in which some protons fail to be extracted, are increased machine chromaticity, slower magnetic field ramp, larger cavity voltages, etc. The presently favoured scheme uses a 3 s magnet cycle, the natural chromaticity, and 150 kV on each of the 25 and 100 MHz cavities. This yields 0.15 ns rms bunches, but leaves 7% of the beam circulating. Curative measures such as manipulation of the betatron tune will be studied.

Muon Acceleration in an FFAG

Muon accelerators have proved difficult to design because of potentially heavy losses from decay. Another concern is the cost of expensive rf cavities. The current baseline approach is a recirculating linac; but these have proved costly and present an acceptance bottleneck. Collaborators at FNAL have promoted the concept of a non-scaling FFAG (fixed field alternating gradient) accelerator. Such machines have exceptionally large acceptance both transversely and longitudinally; and superconducting rf and magnet technology could advance their reach into the multi-GeV regime. The proposed FFAG has a 2 km circumference, injection and extraction energy of 6 and 20 GeV, respectively, 300 equal cells each with up to 6 rf stations, and a train of up to 400 bunches; acceleration is completed in a few turns. A major drawback is the large change in pathlength as a function of energy. Thus traversal time, which must be synchronized with the rf waveforms, changes significantly from cell to cell of the lattice; and the rf adjustments would be impractically large to achieve in the microseconds circulation time.

We have developed a strategy to optimize acceleration of a bunch train. Initially, the ideal phases and gap-crossing times, cavity-by-cavity and turn-by-turn, are recorded for a single synchronous particle. To select the optimal frequency and actual phases, one guesses a frequency and then calculates the phases at the gap-crossing times of the ideal particle. The mean-square deviation of the fixed-phases from the ideal values is summed over all rf stations and turns. A search is then made to find the "best frequency" which minimizes this sum. As for other synchronous machines, it is found to be necessary to use a modest over-voltage and to run off the crest of the rf wave to accelerate a finite emittance. The voltage is optimized numerically so as to minimize the bunch-to-bunch variation of the extraction energy. Next, the longitudinal phase plane is flooded with trial particles; those which survive the complete acceleration to 20 GeV are recorded and used to map out both the input admittance and the output emittance. The main conclusion is that useful admittances (≃1 eV s) can be achieved with acceleration at 200 MHz in 5 or 6 turns using best phases and voltage up to 14 MV/cell (over voltage ≃30%). The transport is non-linear and the useful phase space is compromised. Acceleration over more turns may allow a reduction of costs associated with rf systems. If 100 MHz rf, with 6.5 MV/cell, is used the admittance rises to 2 eV s and acceleration can be extended to 10 turns. In all cases, addition of a second harmonic roughly doubles the admittance but the non-linear effect is augmented.

Multi-Turn Simulation of Coherent Betatron Resonance with Space-Charge

The space-charge envelope code, TRANSOPTR, has been paired with the tracking and simulation code, ACCSIM, to study the half-integer betatron resonances in a high intensity proton ring and, in particular, the relationship of coherent-mode frequencies with the incoherent (Laslett) tune as a function of beam intensity, and the existence of space-charge intensity limits due to detuning of the coherent modes on to a resonance.

The TRANSOPTR code was used to solve the envelope equations to establish a stable set of initial conditions in a given intensity range. The matched solutions for the beam have been used to generate initial distributions of macro-particles which were run through the modified ACCSIM multi-particle tracking code. This approach allowed us to validate the space-charge simulation and to provide a clear benchmark against which to measure resonant growth.

This technique has been used to investigate the $\frac{1}{2}$-integer stopband at $\nu_x = 13/2$ in the FNAL booster lattice, when space-charge depresses the envelope eigentune to 13. We have demonstrated that the resonance occurs not when the incoherent tune is near 13/2, but when half the envelope tune is (see Fig. 184). The two-tune shifts differ by a factor of 0.68.

An interesting finding of these studies was that, while matched solutions exist for intensities which are beyond the limit imposed by the envelope instability, these solutions cannot be accessed by increasing intensity slowly. Moreover, single-turn injection of a beam that is matched, but beyond the envelope instability, is only stationary for the artificial Kapchinsky-Vladimirsky (KV) distribution; when the distributions are different from KV, the rms beam sizes grow until the beam is large enough that the tune shift has fallen below threshold.

This has practical implications for multi-turn injection in storage rings. As well, for a bunched beam, where particles with large synchrotron amplitude

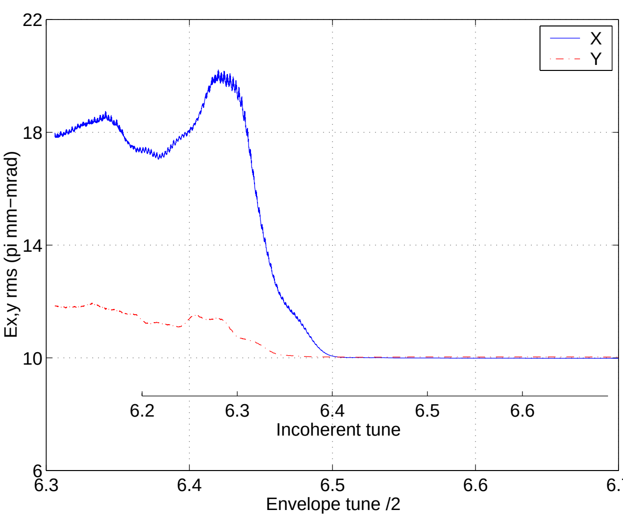

Fig. 184. Emittance growth as the intensity is swept from 0–2.5 A. This is plotted as a function of tune, so the curve proceeds from right to left. Resonance occurs at $I = 1.3$ A, corresponding closely to when the envelope tune is 13. The simulation used 10^4 macro-particles.

circulate between regions of high and low local charge density, the space-charge limit is likely imposed by the envelope instability. Even if the $\frac{1}{2}$-integer stopband is very narrow, for intensity beyond the limit, there will be some part of the bunch always on the envelope resonance, and this will cause emittance growth.

MAGNETS

In addition to contract supervision on the fabrication of the CERN twin aperture quadrupoles described in the CERN collaboration section, work was carried out on a number of other magnets during this year.

In order to permit the proton beam in beam line 2A to be switched between the west target station and the new east target station, a new dipole magnet with two output legs is required. The design of the 2A switching magnet was completed and the order for manufacture placed in March. Sunrise Engineering (Surrey, BC) delivered the magnet in October. The coils were fabricated by Sigma Phi (France). The magnet was field mapped and ready for installation by the end of the year (see Fig. 185).

The conceptual design of a Wien filter to spin precess radioactive ions (sodium, potassium, nitrogen, lithium, and fluorine) for the β-NMR experiment was completed. This was reported in "A Wien filter for TRIUMF's β-NMR experiment" [TRI-DN-01-5].

A pair of Helmholtz coils was designed and fabricated at TRIUMF for the ISAC polarimeter station.

Fig. 185. The BL2A switching magnet in location.

This was reported in "Concept design of a Helmholtz coil pair for the ISAC polarimeter station" [TRI-DN-01-11].

Sicom Industries (BC) manufactured quadrupole steel assemblies for the spare DTL quadrupole triplet, and Danfysik (Denmark) fabricated coil assemblies.

The concept design of a 60 Hz steering magnet to paint the high intensity proton beam on to the ISAC targets is nearing completion.

Experiment 614 – TWIST

In preparation for mapping of the TWIST solenoid at fields up to 2.2 T, an existing "Bonnie dipole" was modified to achieve a flux density of 2 T. This dipole was used to calibrate 14 Bell BHT-910 Hall probes from −2 T to +2 T. Calibration coefficients were calculated and entered into new software for collecting the field data. The Hall probes were mounted on the initial 6-way probe apparatus. Initial field profiling showed a gradient in the B_Z field with Z. A detailed comparison of measurements and predictions at approximately half-current showed that the field asymmetry was probably due to coils that were shifted in Z by approximately 30 mm; the resulting coil forces at full field (2.2 T) would be well outside the manufacturer's specified limit of 1 tonne.

The superconducting solenoid was removed from the yoke. An internal support strut was found not to be connected; this was rectified and the solenoid repositioned in the yoke. The TWIST solenoid was remapped at several currents. Measurements were carefully assessed, in light of the predictions, to determine the position of the coils and therefore the resultant forces on the coil assembly. The analysis showed that, at a current of 144 A, the coils are within 1.1 mm, 1.3 mm and 1.9 mm of the centre of the yoke in X, Y and Z, respectively. Simulations at full current ($\approx$245 A) show that the resultant coil forces are well within the manufacturer's specifications.

The predicted field at the centre of the solenoid has an absolute value of approximately 3% more than the measured field at a coil current of 228 A. Figure 186 shows the measured field at a current of 228 A and the predicted field at a current of 221 A (i.e., 228 A less 3%). There is excellent agreement between the shapes of the measurements and predictions. The measured field has a slope upon it, which is thought to be due to the coils being slightly (1.9 mm) off-centre of the yoke in the Z-direction. The magnitude of the field "lobes" decreases as the current is increased.

A talk detailing the first results and problems of the TWIST magnet mapping was presented at the 12th International Magnet Measurement Workshop, Grenoble, France, October 1–4.

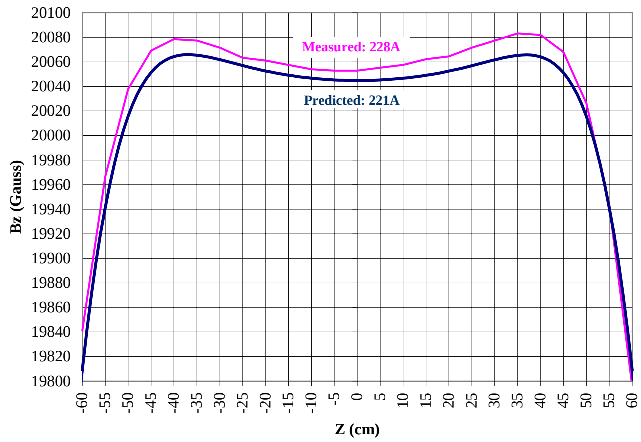

Fig. 186. Measured field at 228 A and predicted field at 221 A, along X=0, Y=0.

Magnet Measurements

Other magnets surveyed this year included a spectrometer magnet, a β-NMR superconducting solenoid, a water cooled 2C steering magnet, and a 2A switching dipole.

Kickers

As mentioned in the 2000 Annual Report, the Kicker group designed a fast kicker (see Fig. 187) to study the characteristics of an existing charge booster designed by ISN (Grenoble, France), to assess the suitability of using this charge booster at TRIUMF. This

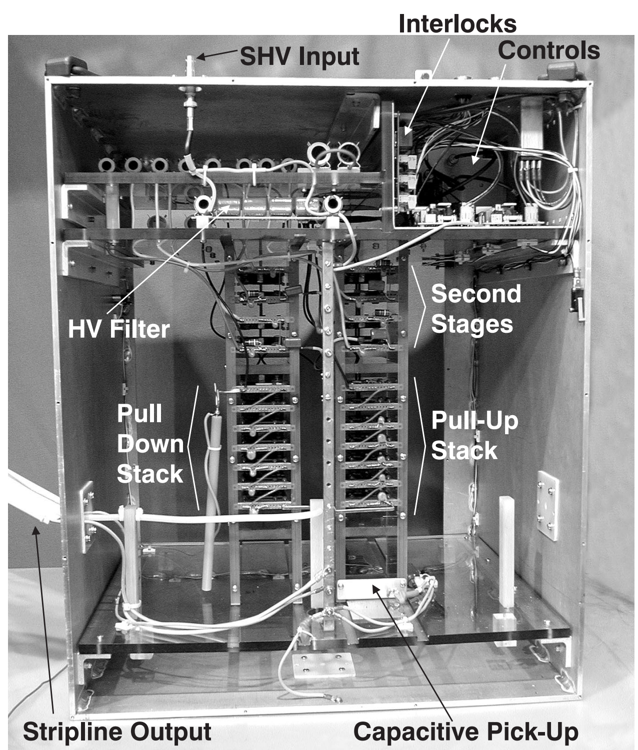

Fig. 187. Rear view of charge booster kicker.

fast kicker will subsequently be used in the TRIUMF-ISAC facility for time-of-flight separation of the chosen charge and to recycle the higher and lower charges back to the charge booster. This will increase the efficiency from 10–60%. ISAC is presently capable of accelerating only isotopes with atomic mass up to 30. The charge booster will allow ISAC to accelerate all masses in the periodic table. The kicker is unique because of its ability to produce variable output voltages up to –3.5 kV, and variable pulse widths and repetition rates from dc to greater than 50 kHz, with rise and fall times of better than 65 ns. The kicker was successfully commissioned in Grenoble in February, 2000, and is now back at TRIUMF waiting to be installed in ISAC. The FET stack can produce –6 kV pulses at repetition rates of up to 15 kHz.

A paper regarding design of the kicker was presented at the 13th IEEE International Pulsed Power Conference, Las Vegas, June 17–22.

MECHANICAL ENGINEERING

Mechanical engineering work at TRIUMF is initiated by the submission of a Request for Engineering Assistance (REA) form which is assessed and assigned according to the size and schedule of the task. Large, complex projects may require a team approach guided by the assigned engineer. Many of the ISAC REAs fall into this category (i.e., east target station modules, and DRAGON). Some requests were submitted prior to this report period, the work being extensive enough to require several years for completion, i.e., DRAGON, Expt. 614.

There were 29 ISAC REAs submitted during the year. However there were, as well, about 8 REAs carried over from the previous year of which perhaps 3 are long term projects. In non-ISAC engineering, there were 19 REAs submitted plus about 4 carried over from the previous year.

As in the past, in this report period there was continuous participation of engineering personnel in performing engineering analyses, consideration of safety related issues, design reviews and other ad hoc engineering related small jobs.

ISAC East Target Station

The major work load was again in support of ISAC. In January it was decided that completion of the east target station would be the first priority for the ISAC project. The goal was to have an operational east target station in early 2002, and the Engineering group was asked to coordinate the overall project.

In order to achieve this objective the project was broken down into 9 work packages and schedules, which are detailed packages supporting the following major activities as listed and briefly described below.

Modules

Prior to this report period, 2 target modules had been built (TM2 and TM3), but were incomplete insofar as services (H_2O, high voltage, high current and signals) and service connections at the bottom of the service duct were concerned. The requirement is to be able to remove not only the containment box tray (i.e., ion source extraction column), but also the service tray in case of HV problems. This means disconnecting the services in such a way as to allow both trays to be removed in the hot cell when necessary. The problem is making a connection which allows the transmission of H_2O, in and out, as well as being able to transmit up to 1000 A across the interface. For a surface source the problem is simpler and the H_2O block connection could be avoided. An ECR source (TM3) does not allow this option due to the increased number of services. This problem was dealt with during this report period and has resulted in a solution requiring a set of fixtures such that all subsequent target modules are built to be identical (i.e., any tray will fit any target module). TM2 and TM3 will be completed with this new set-up early in 2002. The assembly fixtures are necessary to ensure that each half of the H_2O connection block is accurately placed so that they will mate with any tray combination.

At the same time, design commenced on the rest of the east station modules (i.e., entrance, dump and exit). The entrance and dump modules are identical to the west station modules except they are mirror images, and hence required a new drawing package for the east station.

The exit modules for the east station use the same module design as used for TM2 and TM3. However, the contents of the exit modules differ from that of the west station due to a new optics design and also improvements required in the service ducts. The new optics design also required considerable alteration to diagnostics (and actuation) in both exit modules.

All the above design work was accomplished, as well as manufacture of the major module components. Assembly of all modules was well under way by the fall of 2001, and entrance and dump modules were installed just prior to the Christmas break. Figure 188 shows a view of the module assembly area.

Components to be installed in the target and exit modules (i.e., extraction column, all services, optics and diagnostics) were released to the shop starting mid-year and all packages released for manufacture by the end of the year.

Installation of the target module TM2 and both exit modules is scheduled for completion by April 10, 2002.

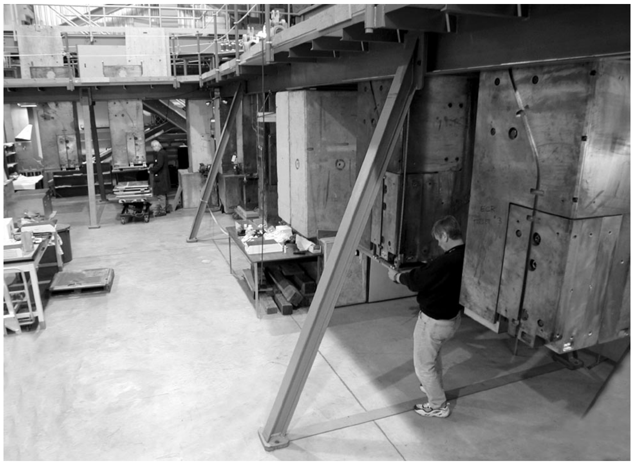

Fig. 188. View of module assembly area.

2A3 beam line

This task mainly involved design and manufacture of the 2A switching magnet (2AB3). This work commenced early in 2000 and the magnet is ready for installation during the shutdown in early 2002 along with the rest of BL2A3.

Electrical room and east Faraday cage

Nothing had been done up to this report period to provide HV services to the east station and work could only proceed during maintenance days and target change intervals. This was done and the Faraday cage constructed, services run, racks and cell trays installed, and power supplies, transformers and controllers were ordered. Work is progressing well and will be completed by April 10, 2002 when the west target station is next scheduled to operate and access to the electrical room will be limited to maintenance days.

Target hall service systems

All service systems (i.e., H_2O, vacuum, electrical, ventilation, compressed air, etc.) have been installed and are operational for the west target station but have not been completed for the east station. The H_2O system distribution manifold and some pipe runs were completed in this report period. However, the bulk of the work on all systems could not commence until the shutdown in mid-December. The H_2O and vacuum systems will require revision due to the requirement of running the off-line station as a conditioning station which requires all services simultaneously. HV chase work will mimic that of the west HV chase, except that 4 gas lines will be required to provide target gases from the Faraday cage.

Controls and safety interlocks

This work requires that a control and interlock system be provided allowing operation of both stations independently. Details of these systems can be found in the ISAC section of this report under Safety and Radiation Control.

East station module access area (EMAA)

This is the volume below the shield plugs and above the top of the east vacuum tank. Apart from placing and aligning the east vacuum tank, nothing had been done at the start of this report period to complete this work package. Therefore the following work was necessary: completion of the 5b shielding package between the east tank and the preseparator magnet; installation of the east tank top plate, seal and leak checking; installation of the proton beam entrance window; installation of the 3 intermodular connectors in the east vacuum tank; completion of the nuclear ventilation system sealing; and layout of the EMAA for all services such that adequate access is assured.

DRAGON

Electrostatic dipole vacuum tanks

Both the ED1 and ED2 stainless steel vacuum tanks were clad with $\frac{1}{4}$ in. thick lead sheets all around them for X-ray shielding. All lead sheets were pre-cut: pie shaped for the top and bottom spherical heads, and straight panels for the tank's vertical sides. Most of the lead cutting was done off-site, but some trimming was done at TRIUMF for custom fitting. The top and side panels were glued to the tanks using 5 minute epoxy #1130K06 (made locally by Industrial Formulators, Burnaby, BC) and the bottom lead sheets were glued using 3M Scotch Grip #1357 contact cement. This type of lead work was done at TRIUMF for the first time. It was a very labour intensive task and was very well executed by the TRIUMF personnel involved.

Figure 189 shows lead sheets being installed on the bottom of the ED1 tank at TRIUMF.

Fig. 189. Lead sheets being installed on the bottom of the ED1 tank.

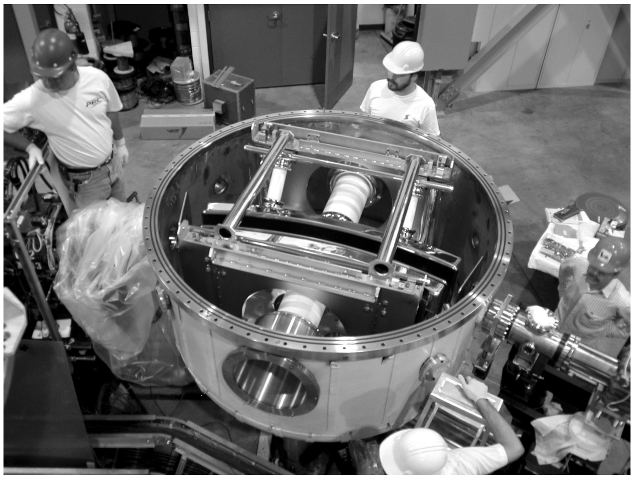

Fig. 190. ED2 installed in its vacuum tank.

Electrostatic dipoles (ED1 and ED2)

The electrostatic dipole (ED1) was reinstalled in the lead clad ED1 vacuum tank and aligned to the beam line using alignment jigs. Field clamps were installed and aligned to ED2 electrodes using precision machined jigs. The ED2 assembly was then installed in the lead clad ED2 vacuum tank and aligned to the beam line using its alignment jigs and looking along the beam centre. After alignment, the position of the dipole assemblies was recorded using TRIUMF's new Leica Total Station system. If the dipole assemblies have to be removed for any reason, they can be reinstalled without using the beam port centres for alignment.

Figure 190 shows ED2 installed in its vacuum tank.

High voltage power supplies for EDs

The manufacturer of the ceramic feedthroughs for the high voltage stack could only produce two feedthroughs successfully and submitted regrets for the remaining order. These two feedthroughs were used in the ED2 vacuum tank. A nylon feedthrough assembly was designed and manufactured as an alternative. Two of these assemblies were used in the ED1 vacuum tank. Both the ceramic and nylon feedthroughs were filled with two atmospheres (absolute) of SF_6. A residual gas analyzer (RGA) was installed on the ED1 vacuum tank. The ED1 and ED2 vacuum tanks were evacuated and the RGA scan revealed there was a large water content present in the ED1 tank. The tank was mildly baked to about 60°C using heating tapes. The nylon feedthroughs were also heated to about 60°C using heating guns. After pumping for a few weeks, vacuum in the ED1 tank was in the order of 2.8×10^{-8} torr, and 1.8×10^{-8} torr in ED2. The high voltage stacks were installed and the high voltage power supplies turned on. Conditioning of the electrodes began. By year-end both electrostatic dipoles had been conditioned to 140 kV.

Beam line components

In 2001 most of the installation of the DRAGON beam line was completed.

Highlights of DRAGON construction included:

- Design, fabrication and installation of a new gas target box and positioning tables complete with gamma array detectors.
- Installation and alignment of all diagnostic boxes, diagnostic devices, e.g. slits (vertical/horizontal, Fig. 191), Faraday cups and beam position monitors. Profile monitors are partially assembled.
- Completion of the vacuum system.

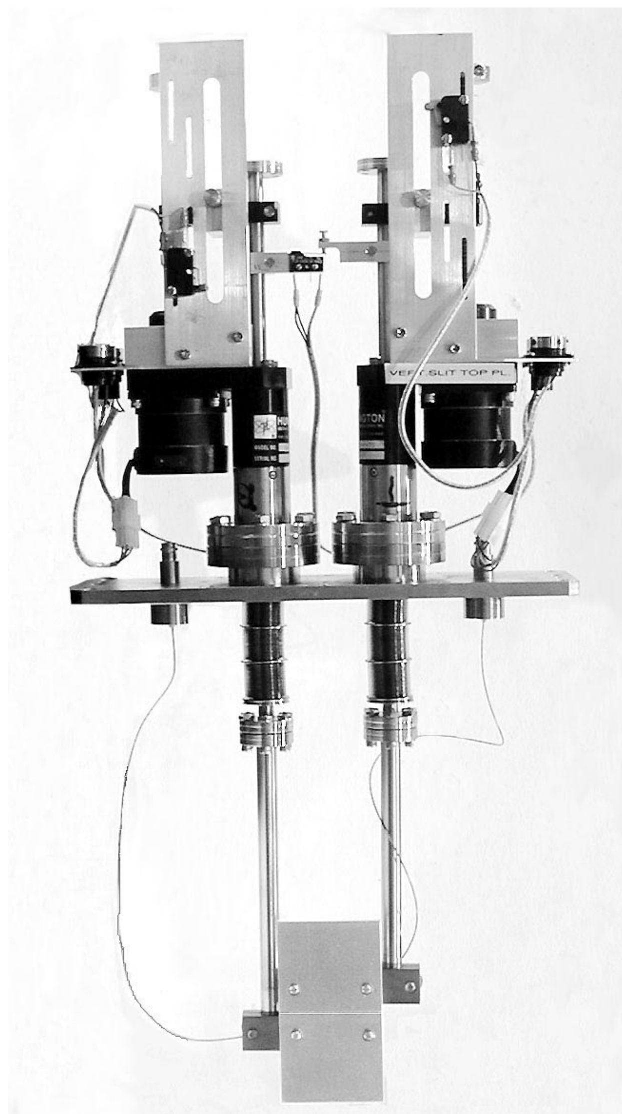

Fig. 191. Vertical/horizontal slits.

For alignment of the diagnostic boxes, special alignment jigs were used that mount to the ports of the diagnostic devices. Jigs (dummy devices) are also used to pre-align the diagnostic devices, therefore eliminating alignment of a device in the beam line after repair or when installing a new device.

Work is continuing on the lead shields and supports for the charge/mass slits boxes, the security fence, and the working platform on one side of the beam line. Most of the fabrication is complete and installation is planned for spring, 2002.

Engineering – Other

Experiment 614 (TWIST)

With the successful completion of the assembly of the Expt. 614 magnet steel yoke in the M13 experimental area at the end of 2000, continued engineering support was provided during installation, alignment and testing of the Oxford Instruments superconducting solenoid magnet in the steel yoke early in 2001. The solenoid magnet was cooled over several weeks from room temperature to liquid helium temperature and energized to a fraction of the rated maximum current. At this relatively low current the uniformity of the magnetic field in the bore of the magnet was measured. During field measurements it was discovered that the internal support structure of the solenoid magnet was not properly restraining solenoid coils from movement. The solenoid was accidentally quenched during a low-power ramp-down while this movement was being investigated. It was decided to warm the solenoid back to room temperature to allow for disassembly and inspection, and eventual repair of the solenoid support structure. When the solenoid was disassembled it was discovered that some of the components comprising the support structure were not properly fastened, and in one case was actually missing. Once the support components were eventually replaced, Engineering recommended that load cells be installed on the support structure to allow the forces experienced by the internal supports to be measured. The solenoid was reassembled with load cells installed, the assembly leak checked, then cooled to liquid helium temperatures, and field uniformity tests resumed. Load cells proved useful in providing an indication of the correct centring of the solenoid magnet within the steel yoke, by minimizing the forces experienced by the solenoid support structure.

In the fall, a uniform field of 2 T was achieved in the bore of the Expt. 614 solenoid.

Other support

Ongoing engineering support was also provided throughout the year for the operation and maintenance of the M9B superconducting solenoid and helium refrigerator.

G∅ experiment

The *G*∅ superconducting magnet mapper project was completed with a final visit to the Nuclear Physics Laboratory (NPL) in Champaign, Illinois. Several laboratories in the US expressed interest in using this to map their own magnets because of its high accuracy and easy to program features implemented via the TRIUMF developed graphical user interface (GUI). It is also portable. For example, a group from Indiana University visited NPL to get a close look and demonstration of the gantry in action.

Numerous phases of the gantry system development have been reported and documented on the Web.

The gantry has been used successfully throughout the year at NPL with no electro/mechanical or software incidents. With special tuning and data averaging, the gantry's repeatability has been verified at $\pm 25\ \mu$m using laser alignment techniques. Note that the 3D Hall probe head can cover a 4 m $\times$ 4 m $\times$ 2 m spatial volume. What makes this unit so useful is its portability and the GUI software. Very simple point-to-point position data text files need to be written and the machine takes care of the rest after a few simple mouse clicks.

Other projects

Numerous analysis/design projects performed included the following:

- BL1 T2 target cassette development – Thermal analysis of the BL1 T2 target cassette, to investigate internal temperatures of the beryllium target rod. It was discovered that nucleate boil cooling is very likely occurring at the coolant surface given the incident beam currents presently used (and is necessary for the target to cool sufficiently).
- ISAC-II superconducting rf cavity development – A new design for the tuner diaphragm of the ISAC-II superconducting rf cavity was investigated via finite element analysis (FEA) software and a prototype built from niobium for development because it met the stiffness/stress requirements well.
- A proposal was written in the form of a design report for a new servo controlled electro/mechanical system to operate the tuner diaphragm of the ISAC-II superconducting rf cavity, with a high Q, to an accuracy of 1 μm with a bandwidth of 100 Hz. It uses state-of-the-art direct drive linear motor motion technology.

- Finite element analysis of the ISAC-II superconducting rf cavity was performed to determine deflections, stresses, natural frequencies and mode shares. RF FEA will be done using deflection data to determine the frequency shift of the cavity due to liquid nitrogen pressure fluctuations.
- TPC detector – Analytical and FEA calculations were done of thin foil vacuum windows to investigate very thin foil support design technology for the solar axion search project (CAST) being built at CERN. Various combinations of submicron thickness foils backed by fine wire mesh and/or very thin honeycomb structures were investigated. Spherical and flat configurations were looked at. The latter proved simpler and cheaper to make, although the spherical shape is much stronger and can be made to provide higher radiation transmission values. However, it does not sufficiently offset the cost of producing it. A small 8 mm diameter kapton window (400 nm), which is supported by a Ti strongback, has been purchased and works well. The next step is to develop a 50 mm diameter self-supporting beryllium window.
- Other analysis – Many structural analyses were performed for various groups at TRIUMF, and fabrication approvals given.

Engineering – Victoria

The organization and housekeeping practices for the TRIUMF labs and Machine Shop at the University of Victoria were reviewed to ensure the work and research being performed is carried out safely. A complete overhaul of the entire lab and storage space was performed, which involved disposing of and recycling many unused chemicals and obsolete equipment. Proper storage for flammable and hazardous materials has now been provided and all work is being performed in a safe and orderly manner.

ISAC target stations

The targets designed for the ISAC target stations are being modified to handle the increased heat dissipation required when they are operated with the increasing proton beam currents. Annular fins along the length of the target have been considered with various mounting patterns, sizes and shapes. For each case, a thermal analysis is being studied to determine if sufficient heat dissipation will occur.

Contributions were made to the design and detail of the beam dump modules for the west target station. Similar contributions have been made for the east target station. Drawings of all the dump module components have been provided and the dump element for the east target station was successfully produced, assembled and delivered to TRIUMF.

Signal feedthrough project

There is continuing support for the ATLAS feedthrough project, which is entering the final stages of manufacturing and testing. To date, half of the required fifty feedthroughs have been made, and several have already been sent to CERN. Acceptance tests were successfully carried out at the CERN site on all the shipped feedthroughs. There are some thermal analyses which are ongoing to determine if sufficient heat is being provided by an external heater plate to avoid condensation developing on the feedthrough cables.

Hadronic endcap (HEC)

Contributions to the design and manufacture of the HEC assembly table are ongoing. The critical components being constructed in Canada were closely supervised and the control actuators for the project were carefully researched.

Engineering – Carleton

ATLAS forward calorimeters (FCAL)

This year the final assembly of FCAL module 3C began. This involved setting up and aligning two end plates on the assembly stand and then "stacking" the module. This was the process of inserting 8224 copper tubes and approximately 641,000 tungsten spacer slugs. Each slug is approximately 2.6 g in weight and 9.89 mm long. Once this was complete the tubes were "swaged" into place. This was accomplished with custom tooling, developed and built at Carleton, which expanded the tube ends into small grooves in the endplates. The swaging gives the module its structural strength. The outer absorbers were then installed to protect the outermost tubes from damage. The last steps to be completed, before shipping the module to CERN in July, 2002, are the installation of approximately 14,300 ground pins and the inserting of the 8224 tungsten anode rods. Final assembly of FCAL 3A is to begin in February, 2002, for shipment in January, 2003.

A module cradle, to support the module's final mass of 4000 kg, was also designed and built this year. The cradle will be used for shipping, for module handling at CERN, and for final assembly of the module into the liquid argon support tube. The design of the packing and container for shipment by aircraft was also started.

Figure 192 shows the completely stacked module awaiting ground pins and anode rods.

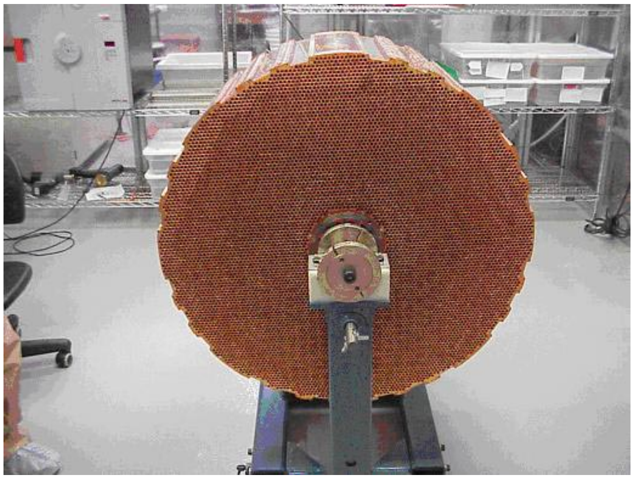

Fig. 192. Completely stacked FCAL module awaiting ground pins and anode rods.

PLANNING

This year the Planning group was involved in planning, scheduling, coordinating and expediting several sub-projects for ISAC; planning and coordinating activities for two scheduled shutdowns (December 22, 2000 – April 25, 2001 and September 19–26); prototype chambers for KOPIO, M8 decommissioning, and 1A triplet repairs and replacement.

ISAC

Various plans and PERTs were prepared and updated regularly with manpower estimates and analysis to identify critical areas and resolve any problems. ISAC priorities were evaluated and higher priority was assigned to: the east target station with an aim to install in the winter, 2002 shutdown; expedite the low energy experimental program that included the first data run at β-NMR, move GPS1, install the Osaka beam line; and commission TUDA and DRAGON with stable beams and RIB.

On the accelerator side, major milestones (after beam to 1.5 MeV/u in December 2000) included: install and commission the 11 MHz buncher by September to facilitate commissioning of high energy experiments (TOJA, TUDA and DRAGON) by November. Manpower planning was done, activities were coordinated and expedited, and the above goals were achieved on schedule.

Technical details and progress on PERTed activities are described elsewhere in this report under the respective principal group. However, following is a summary of the main projects along with the major milestones achieved.

East target station

This project received high priority and had to be fast-tracked for installation in the January, 2002 shutdown. This project was broken down into 9 work packages and the major highlights of these work packages included: 2A beam line (switching dipole received in September, monitors, and associated beam line hardware received in December), Faraday cage (constructed by July and isolation transformer, high voltage and other power supplies procured by October), target hall (included modification and commissioning of south hot cell and storage silos in July, alignment components and water package shielding in November), controls (included 2A controls, target protect interlocks and RIB controls for vacuum system, beam optics and beam diagnostic systems).

The work on the target modules required extensive Design Office and Machine Shop effort. Several design modifications were made for better manufacturability and handleability. Shield plugs were ordered in April, with a staged delivery for most modules in July.

Target conditioning box

An alternative conditioning system was designed and fabricated by December to expedite the process of changing and conditioning ISAC targets. Assembly was delayed to January, 2002, due to lack of manpower.

HEBT

After completing HEBT1 to the benders for the DRAGON and TUDA beam lines and delivering beam to 1.5 MeV/u in December, 2000, resources were focused to complete the chopper and bunch rotator (July), and 11 MHz buncher (September).

Low energy experiments

This work included moving GPS1 to a new location, modifications to LTNO and yield station, and β-NMR. Extensive work was done on planning, coordinating and expediting activities and critical components from the Machine Shop and outside suppliers for β-NMR, laser polarization systems, spectrometer, and associated LEBT components. Among other low energy experiments, the Osaka beam line was installed and tested in October/November with a new chamber and associated services, and the 8π beam line with a simple chamber was installed and commissioned with a test beam in December.

High energy experiments

Installation of HEBT components up to the TUDA experimental station, with associated services, was finished in March. A special room was designed and constructed for the TUDA detector system electronics, with all services and a special grounding system. The first stable beam to TUDA was delivered in March. First RIB was delivered to TOJA in June, and to TUDA in September, after commissioning the 11 MHz buncher.

DRAGON

After completing installation of most components up to MD2 in December, 2000, the overall progress on DRAGON installation was relatively slow due to lack of technical resources and ceramic feedthrough problems. Several initial tests were done to commission the gas target with its control system. Alpha particle tests up to the charge slits were done in January, and continued down the line as services were completed. DRAGON was commissioned with stable beam in October, followed by RIB in November.

ISAC-II

PERTs were prepared that included work on specifications and design of a superconducting rf test facility and dummy cavity. A construction contract was awarded in October, and a test facility at BC Research was constructed at the end of November. A dummy cavity was tested in a cryostat (without rf) in October, and (with rf) in December, with a plan to repeat these tests at BC Research in early February, 2002 followed by cold tests on a niobium cavity with rf controls in March, 2002. Detailed schedules of ISAC-II projects were prepared that included: medium beta cavities (with cryostats, refrigeration system and solenoid, with an aim to test the first cryo module by summer, 2003); high beta cavities system; charge state booster system which included tests on the test stand with an aim to order the CSB by December; and test the whole system on the test stand by October, 2003; HEBT transfer system; and H^- HEBT to experimental stations.

Shutdown Activities

There were two shutdowns during the year: the winter shutdown (December 22, 2000 – April 25, 2001), and a short maintenance shutdown (September 16–26). Major jobs completed in the winter shutdown included: electrical and cooling services; upgrade to the front-end of BL1; and replace target position limit switches for the solid target facility in BL2C4. Most of the vault services upgrade work was done with the lid down to minimize dose levels, and service modifications for the quads were done one at a time in the bunker constructed in the vault basement. A 2 mm horizontal displacement of the quads with respect to their initially measured position was discovered and led to some delay in completing final beam pipe and vacuum connections. Lid up jobs included: probes MRO on 2C, EX1, EX2A; measure probe positions in the tank to verify proper indexing; remove and service inflector; rf surface cleaning; and inspection of correction plates. The lid had to be raised a second time on April 6 to upgrade the HE1 upright and replace vertical drive ferro fluidic feedthroughs for HE1 and HE2, which delayed the beam operation by one week. Meson hall jobs included: MRO work on water packages for 1AT1, 1AT2; rebuild M9T2 beam blocker; rebuild 1AM8, MRO on 1AM9 (leaking gas package); repair vacuum leak on 1AQ11; repair M11B2 leak; and install rebuilt M9A rf separator.

Fall mini shutdown

Premature finishing of the PIF run gave a headstart by two days. There was no plan to raise the lid in this shutdown. The only major jobs included the installation of the water-cooled steering magnet (2C4) and repair of the M13 beam blocker. Measurements of Cu ALCW system loss rates confirmed increased water leaks in the 1A triplet and M20Q1, which were deferred to the winter, 2002 shutdown.

TWIST

The Planning group was actively involved in planning and monitoring TWIST activities. In spite of a few technical difficulties, half of the detector stack was powered up in the detector facility in July and moved and tested upstairs in November, along with the commissioning of the 2 T solenoid in the 60 ton iron return yoke. More commissioning continued in the November/December beam run.

KOPIO Preradiator

A PERT was prepared for prototype chambers at level 2, 3A, 3B and 4 with associated electronics R&D, scintillators R&D, and simulations.

DESIGN OFFICE

The ISAC project received 10,967 hours of Design Office time, which was 70.3% of available hours. The office prepared conceptual and detailed designs for many different aspects of the project. Specifically, and in order of magnitude, they were: (a) east target and exit modules, including ECR target; (b) LEBT beam diagnostics, polarimeter and 8π beam line components, and upgrades for LTNO and OLIS; (c) DRAGON electrostatic dipoles and beam diagnostics; (d) HEBT1 and 2 beam line components for service to DRAGON and TUDA; (e) ISAC-II cavity development; and (f) components for the installation of the 2A3 beam line and upgrades to the mass separator.

The CERN contribution received 11.6% of Design Office time, with most effort concentrated on the pulse forming network and HV switches.

TRIUMF projects received 15.2% of Design Office time, for a magnetic field mapper and front-end diagnostics for Expt. 614 (TWIST), μSR solenoid support stand and sample mounting system, cyclotron HE probe redesign, and BL1A MRO.

Photographic and visual art services continue in support of seminars, conferences and publications.

MACHINE SHOP

The TRIUMF Machine Shop, with 22 technicians, produced approximately $139,000 worth of fabricated and machined components for various on-site groups each month. The shop charge out rate is $66.50/hour. The distribution by TRIUMF divisions and other groups is shown in Table XXXIII. In addition, 277 separate work packages worth more than $536,000 were sub-contracted through the Machine Shop to local industrial companies.

Table XXXIII. Machine Shop utilization.

ISAC Development	50.8%
Science	32.4%
Cyclotron	5.0%
Cyclotron Refurbishing	3.4%
ISAC Operations	2.4%
NSERC	1.5%
ISAC-II	1.5%
MDS Nordion	1.4%
CERN	1.1%
Affiliated Institutions	0.5%
Accelerator	0.1%
Administration	0.1%

BUILDING PROGRAM

Funding approval for the new ISAC-II experimental hall set the year 2001 apart from other years. The Building department was called upon to assist outside consultants in the development of the conceptual and final design for this new facility.

Clearing and preparing the construction site for ISAC-II became a priority involving disposal of several office trailer units and trailer complex S, the former Design Office for 21 years. Other office trailer units A, Ll, Mm, P, Pp, Aa, and the two-storey MDS Nordion complex Ss, were moved to other locations on the TRIUMF site and reconnected to their respective services.

The Building department designed and contracted construction of a cryostat test facility for ISAC-II in rented space at the neighbouring BC Research complex. The approximate 1200 sq ft partitioned space comprises a test area, docking space, boot-up room, assembly area and rinse room, together with all required services including HEPA filters and exhauster.

Several smaller finishing projects had to be carried out in the ISAC-I complex:

- Design and construction of the DTL exclusion area, consisting of steel framework and plywood-lead-plywood removable shielding panels;
- Contracting construction of three additional 6 ft × 6 ft × 10 ft high reinforced concrete target storage vessels for the target hall;
- Design and construction of the 9 ft-6 in. × 9 ft-6 in. × 9 ft-0 in. high electrically shielded room for the high voltage source to the east target station.

The annual contract for maintenance and repair work to various TRIUMF buildings consumed $34,000. A further $13,500 was spent on interior repainting, much of it in the TRIUMF main office building.

The roof of the now 30-year-old accelerator building has deteriorated to a point where only a complete replacement of the same will offer a satisfactory remedy. A start was made in 2001 with replacement of the section over the proton area at a cost of $92,000.

Decommissioning and removal of beam line M8 in the meson hall resulted in the need for reconfiguration of the shielding blocks in this area. The Building department designed and contracted construction for a total of 29 new reinforced concrete shielding blocks, mainly of the 2 ft × 3 ft × 6 ft category, to replace specially shaped and also deteriorated blocks in the beam line 1 tunnel.

Parallel in timing with the ISAC-II project, MDS Nordion began their northward extension of the radiochemistry annex and construction of a new TR30 cyclotron. The Building department liaised with MDS Nordion and its consultants on the conceptual building design, particularly concerning matters of underground services relocation, general access and spacial separation of ISAC-II and MDS Nordion interests.

ELECTRONICS SERVICES

Overview

TWIST was the operative word for a majority of the group this year. A concerted effort involving six members of Electronics Services ensured that all components and services requested by the TWIST group were delivered on time. Site communications managed to upgrade the majority of the remaining antiquated network cabling, as well as dealing with the major trailer move for ISAC-II. PC support saw a personnel change and instigated new procedures for tracking equipment. CERN support was another major component for the department.

Technical Support

Support of the TWIST experiment was one of the top priority jobs for Technical Support this year. Jobs for TWIST included: coordinating final assembly and testing of 300 TWIST postamp/discriminator modules including a dozen control boards; PC layout and coordinating assembly of a new PACT module; design and assembly of a number of low voltage power systems; a CAMAC based 64-channel HV control and monitoring system; as well as design of cables for the above systems. The prototyping and initial testing of a new 32-channel 16-bit ADC CAMAC board was started for the Controls group. Small jobs included a special serial interface built for the PET group, chamber PC boards for the DRAGON experiment, ISAC target protect thermocouple modifications, and modifications to a very complicated rf control box for β-NMR.

PC Support

There have been several changes in this department throughout 2001. Keith Ng was hired as a full-time technician in May and our communications technician has been providing some part-time assistance. New helpdesk software was purchased to track hardware, log service calls, and organize tasks. It was implemented in early July, and has greatly assisted us in staying organized. We have developed an asset tracking system such that incoming hardware is tagged at receiving, and existing equipment is tagged when serviced, so that histories are now being created to aid with servicing. Due to the introduction of the helpdesk software in the middle of the year, the number of specific tasks performed, as shown in the last Annual Report, is not available. However, a general review of the year indicates that the volume of service calls is somewhat higher compared to 2000, with the exception of e-mail and network related support calls being noticeably higher. More time was dedicated to developing the department services such as licence management, Web site revisions, and improved access to data. The results of this effort will be seen in 2002.

The Novell server was upgraded to NetWare 5.1 on new hardware and about 15 new users have been added, for a total of 74 users. The PC backup service has been improved by standardizing the schedules and tape rotation periods. Several data recoveries were successfully completed. A 100-user site wide licence for Winzip was purchased to bring the site into compliance with licensing. A significant effort was put forth to identify AutoCAD usage on site by preparing a survey and tallying responses. The results were forwarded to Purchasing.

Electronics Repair Shop – Nucleonics

As in recent years, much of the effort in the Electronics Repair Shop has gone into repairing increasingly ancient equipment, often requiring rebuilding of decrepit assemblies and re-engineering them to make modern components replace ones that are obsolete and unavailable. In total, 238 pieces of electronic equipment were repaired and/or recalibrated. This included: 13 terminals, 48 monitors, 7 SCSI devices, 73 power supplies (which included 25 NIM devices, 21 CAMAC devices, 20 high voltage units, and 7 generic types), 46 nucleonics modules (of which 38 were NIM and 8 were CAMAC), 7 test equipment devices, and 44 miscellaneous electronic devices. Some of this specialized equipment included cryogenic controllers, turbo pump controllers, vacuum leak detectors, and milling machine readouts for the Machine Shop. This department successfully refurbished 14 CAMAC crates from the Chalk River surplus pool, saving the TWIST experiment tens of thousands of dollars.

High Level Software Support

High level software support had a very diverse year. Work included the entire gambit from using new software applications and programming techniques to supporting systems that are 20 years old. Some of the new work included using a Java data acquisition system for charge booster studies at ISN (Grenoble, France), β-NMR solenoid measurements, as well as TWIST magnet measurements. For the LTNO slow control system (MIDAS), a new DVM and network analyzer were installed. For ISAC, there was assembly and installation of DRAGON and 8π stepping motor drives as well as modifications of the ISAC DB0 diagnostics motor drives. For the main site, support was given to BL2C probe TRIMAC upgrades for activity logging, and completion of the new thermocouple measurement program (TRIMAC-C) for controls. For M15, there was the repair of M15 separator high voltage supplies as well as the slit controls. Dave Morris continues to be an active First Aid attendant as well as a TRIUMF tour guide. Dave made the Dean's list graduating from the PCST program at Langara College this year.

Site Communications

It has been a rather busy year with the extra role in PC support, the re-location of trailers to make way for ISAC-II and MDS Nordion expansion, and major upgrades for both meson and proton hall buildings. There was an acceleration in the installation of the newer 100 base-T wiring to replace the older troublesome Thinet cables. Areas with new cabling included the meson extension service annex, proton hall extension and mezzanine, ISIS and level 264. New cables were installed for TUDA and DRAGON as well as ISAC and Stores. In total, over 200 cables were installed. The trailer move this year was another major job. This included preparation of the trailers to minimize downtime for communications. Five trailers were involved with over 60 communication drops. Other work included assisting in the estimate for a security camera system for the site, documentation for the Ethernet system, and assisting PC support one or two days each week.

Electronics Shop

The Electronics Shop was very busy producing what seemed like "a million and one" cables for TWIST during the first nine months of the year. Many more cables were in production for ISAC, DRAGON diagnostics, 8π spectrometer, DAQ, BCP07 experiment, detector facility, magnet, Osaka, β-NMR and TUDA, as well as many more delay cables for TRIUMF Stores. Again we had many orders for flow-switch interlock boxes, IGOR CAMAC modules, bias supplies, and QSX modules for BL2A and ISAC. Waltraud Dilling gives ongoing daily support to the TRIUMF library.

Experimental and Target Support

The majority of work was supporting CERN projects, the TWIST experiment, as well as some ISAC work. For CERN, there was assembly and testing of pulse forming networks (PFNs) as well as bias supply PCBs for the switch tanks. Work was also done on the 3 kV and 66 kV switching supplies. Efforts for TWIST included assisting in setting up racks and cabling, along with testing and debugging various systems. In ISAC, work was started for the east target protect system due for installation in early February, 2002. Target support included maintenance for 1AT1 and 1AT2.

ELECTRONICS DEVELOPMENT

This year again, a large fraction of the group's effort went into support of the ISAC control system design and installation, and the CERN collaboration. Klara Pelzer joined the group as junior technician.

ISAC Support

The group provides all hardware installation support for the ISAC control system. As part of this function, the production of 100 CAN-bus modules for power supply control, and 33 VME modules of various types was organized. The modules were tested after delivery.

Testing and calibration of the Gauss-meter module was completed and a resolution of better than 1 part in 10^4 was achieved. 18 modules were built and installed on the OLIS and HEBT dipole magnets and the DRAGON beam line quadrupoles.

The four high voltage power supplies for the DRAGON electrostatic dipoles were successfully commissioned.

Design and construction of a chopper for the charge state booster was completed and used successfully in tests at Grenoble.

A gas valve controller for the ISAC west target station was installed and integrated into the ISAC control system.

CERN

Substantial changes to the digital acquisition board (DAB) functional specification Rev5 by CERN required a complete redesign of the DAB VME module. The horizontal and vertical wide-band time normalizer (WTBN) digitizers now connect directly to the DAB as mezzanine cards. These cards receive an analogue signal from the front-end WTBN via fibre optic cables. The DAB II supports two additional operating modes: (i) Global Orbit Histogramming – to obtain distribution of data during an acquisition; and (ii) Post-mortem – which is used to diagnose and understand beam loss or sudden beam dumps in the LHC. The calibration mode has changed so that beam position data can be acquired with no beam synchronous timing signals present. Two DAB II prototype modules were shipped to CERN in October for preliminary tests. Two members of the group went to Geneva in November to test the integration of the WBTN with the DAB II. The primary functions of the module were tested successfully, however, modifications and additional features will be required for the next beam test in June, 2002. A substantial amount of time was spent on the design of PLL and DSP circuits, which were later removed from the revised DAB specs.

Two members of the group spent a month each in Geneva to help with the testing and integration of the TRIUMF designed hardware and software into the CERN systems.

Safety Systems

A first attempt was made at improving QA for the TRIUMF safety systems by dividing the responsibility between the TRIUMF Safety group and the Electronics Development group. Safety will be responsible for the requirements specification and testing. The Electronics Development group will be responsible for the design and installation of the systems. A Modicon Momentum series PLC system was designed and installed to enforce the DTL exclusion area. A similar system was designed for the mass separator HV lock-up area.

Miscellaneous

A Web-based information system was developed using Perl cgi-scripts for use by both Electronics Development and ISAC Controls groups. It keeps track of Requests for Engineering Assistance (REA), Engineering Change Requests, and other project related information. Any group member can add comments via a Web browser. Group members on a project's notification list are notified of any additions by e-mail.

Design work was completed on an NMR readout module, which can replace the existing NIM modules. Board layout for a prototype module has started.

The M9 vacuum system was fully supported with an EPICS system. This system will later be integrated with the new EPICS based secondary channel control system.

For the ISAC β-NMR experiment, two VME modules were developed on fairly short notice. They interface to a commercial rf synthesizer and allow fast steerage of the β-NMR rf program. Another module was constructed for the Data Acquisition group.

A generic VME module tester was designed and constructed, and final application software is being written.

A new NIM fibre optic transceiver was designed and 6 modules built. NIM pulses less than 10 ns in width can be transmitted across the light link. Each card consists of two transmitters or receivers. Up to four cards of mixed types are fitted into a standard NIM housing.

Four VME multipurpose I/O modules were constructed for the Data Acquisition group.

For the TRIUMF Diagnostics group, five VICA VME harp readout modules were produced.

A system for applying a bipolar voltage of 1 kV across a test sample was constructed and tested for the μSR group.

A four-channel remote integrator low current module was designed. The module communicates over the standard CAN-bus link. Initial results have demonstrated a resolution of better than 50 fA.

The VQSX beam current readout module underwent a redesign, and current ranges were adjusted to better match the requirements for ISAC.