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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2006

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

The Accelerator Technology Division is responsible for most of the engineering, design and fabrication at TRIUMF. Other responsibilities include planning for projects and shutdowns, electronics development and services, the Building department, the Design Office and Machine Shop. New jobs requiring the resources of the division are submitted as a Request for Engineering Assistance (REA). In 2005 there were 82 REAs in mechanical/structural engineering and design and 21 in electronics development and services. This year saw further implementation of the Quality Assurance program which includes the TRIUMF Standard Operating Procedure TSOP-06, Design, Engineering and Manufacture. This process requires jobs to be assessed for risk and for design and safety reviews to be conducted if the graded risk is above low. This was being done at some level prior to the QA program so the main impact has been to produce better documentation of the process.

The site beam dynamics effort is also coordinated through the division. Some of the external projects are reported in this section and other reports are in the CERN, Cyclotron and ISAC sections. Further studies of non-scaling FFAGs are presented and the proposal to construct an electron model (EMMA) at Daresbury in collaboration with other accelerator laboratories is described.

Under magnets, the last of the superconducting solenoids being fabricated by Accel Instruments for the high-beta section of ISAC-II were delivered and the large toroid coils for the Q_{weak} experiment at Jefferson Lab finally passed acceptance tests after a difficult fabrication period. The Kicker group completed the design of a kicker for the Brookhaven AGS upgrade project and parts were ordered. However, the funding for the KOPIO experiment was terminated and this meant that the CFI funding for this work also stopped. A request was made to CFI to complete this innovative kicker, as most of the work has been done. Other kicker work is also described along with some ideas for developing a fast kicker (6 ns rise and fall time) for the ILC damping ring. For completeness, the development of the AGS microbunching cavity, and the other CFI support project, is also described.

ISAC-II cryomodules and the helium refrigeration and distribution systems were the large projects carried out by the Mechanical Engineering and Design groups. The assembly of five medium beta cryomodules was completed and installation started in the linac hall. The cryomodule service platform was fabricated and installed along with the cold piping for the helium distribution.

Engineering and design support was given to TITAN, TIGRESS and external projects, KOPIO at Brookhaven (project terminated in August) and T2K at J-PARC in Japan. A TRIUMF engineer provided the contract supervision for the fabrication of the Q_{weak} coil carrier plates by a Quebec company. TRIUMF is also committed to assisting KEK on some of the design work for the J-PARC neutrino hall. The first project being supported involves the TRIUMF Remote Handling group in providing a design for the final beam diagnostics station in front of the production target. This area is highly radioactive so remote handling techniques for the beam monitor and vacuum connections are required. The Victoria group developed the design of a manipulator arm for calibration of the near detector for the K2K experiment in Japan. A motor control system was developed at TRIUMF and the manipulator system was successfully installed, commissioned and run at KEK for the calibration.

The Planning group looked after the scheduling and coordinating of the many ISAC projects, the planning of the cyclotron shutdowns and the priority scheduling in the Machine Shop. The Machine Shop purchased a third, larger capacity, CNC vertical machining centre that is able to fabricate larger components. In the Design Office the use of Solidworks was expanded to 17 seats and the easy conversion of these files for CNC machining has proven to be very efficient. The Building department was involved in several structural projects for ISAC, including the cryomodule service platform and a nitrogen tank slab. The usual building and site maintenance and repair jobs were supervised and the Machine Shop was re-roofed.

In the Electronics Services group, hardware support was given to a large number of experimental groups including μSR, TWIST, LADD, TIGRESS and TITAN. Considerable assistance was given to the design and installation of the ISAC-II cryomodule tuners. Some data acquisition design help was made available to the T2K group for the optical transition radiation (OTR) beam profile detector for the proton beam at the production target.

The Electronics Development group continued to provide all of the hardware installation, maintenance and upgrades for the ISAC-I and ISAC-II control systems. Several types of VME, CANBus and other modules were designed and built for ISAC controls and experimenters. A PLC based control system for nuclear exhaust in the TR13 area was designed, built and installed in a very short period for the PET collaboration between TRIUMF and the BC Cancer Agency.

These are just some of the highlights of a busy year, with more details provided in the rest of this section.

BEAM DYNAMICS

Lepton and Hadron Acceleration in FFAGs

FFAGs are circular accelerators with fixed magnetic fields and strong focusing and pulse repetition rates extending to the kHz range. Linear-field FFAGs, which use constant gradient magnets, offer the promise of large dynamic aperture, and have been studied intensively since 2000. The initial muon study expanded in 2004 to include an electron model, and further widened in 2005 to include hadron machines. Whereas work in 2004 concentrated on 2.5–20 GeV FFAG accelerators for a muon collider or neutrino factory, and initial plans for an 10–20 MeV electron demonstration model of such machines, the focus of 2005 has been on the extrapolation of FFAG designs to medical applications using either 70 MeV protons or 400 MeV carbon ions, and the writing of funding proposals for the electron model. Theoretical accelerator research in support of all these activities continued throughout the year.

Funding proposals

The EMMA collaboration (Electron Model with Many Applications) formed in November, 2004. Led by Rutherford and Daresbury laboratories, and including collaborators from BNL, CEA, FNAL, KEK and TRIUMF, the group began the conceptual allocation of hardware to the electron model in January and in February a consortium of British universities applied for a Basic Technology (BT) grant on behalf of the collaboration.

Subsequently, the design matured and converged upon FNAL designs for the quadrupole and combined function magnets, and ELBE-style rf cavities, and the group accepted the FNAL-TRIUMF design for the 42-cell lattice. Following the presentation of this design at MUTAC in April and the FFAG05 meeting at FNAL, the EMMA collaboration submitted a proposal to the New and Emerging Science Technology (NEST) fund of the European Union. Further technical/hardware details of the electron model were presented at PAC05. The machine parameters (tunes, cells, gradients, etc.) and model objectives were frozen and presented at NuFact05 in June, on behalf of the EMMA collaboration, as a basis for hardware costing and 6D particle tracking of the machine acceptances.

After the BT and NEST grant proposals were refused, our British collaborators introduced the idea of a prototype medical machine, 20–70 MeV protons, to be funded by the UK Medical Research Council. This initiative seeks to demonstrate that the non-scaling concept can be applied to a machine with slow acceleration (hundreds of turns), with a view to a later 400 MeV carbon machine for cancer therapy and the eventual goal of commercialization. The resonance crossing problem is fierce in this application, and potential solutions are poorly understood. Nevertheless, a grant proposal is anticipated in spring, 2006.

Theoretical studies

Incremental improvements were made to the FFAG design macros, written in the scripting language Mathematica. Motivated by the electron model, the time of flight – rather than path length – has been symmetrized. Motivated by the muon application, and large emittances, the horizontal beam size has been introduced into the peak magnetic field computation.

Paramount is the effect of resonance crossing on the transverse emittances. Particle tracking results became available from August onwards (CEA and RAL). Until that time, the feasibility was based on approximate WKBJ formulae. However, it was uncertain whether the rapidity of parameter variation anticipated defeats the approximation. An analytic solution to the problem of a time-varying oscillator driven by a sinusoidal perturbation was obtained, leading to an exact calculation for the change of the adiabatic invariant. When scaled to the lepton FFAGs, the system was found to lie just within the domain of applicability for the WKBJ predictions of emittance growth.

The reference orbit is usually chosen with geometric simplicity in mind. An unusual feature of the FFAG designs is that the radio frequency is not necessarily isochronous with the reference momentum chosen for the lattice design. Particle-tracking programs such as MAD, though sophisticated in transverse optics, are crude in their longitudinal working and cannot cope with this case. In the context of a thin-element model, we have shown how to make the transverse reference momentum coincident with that of longitudinal rf.

There are two new features to the medical machines: there is no constraint to minimize the path length variation because the rf may be swept; and rapidity of crossing cannot be relied upon to avoid emittance growth from nonlinear resonances. These motivated two new investigations: re-optimization of the lattice for minimum cost, and flattening of the tune variation by the introduction of sextupole magnets.

The non-scaling FFAG is made from repeating cells containing D and F combined function magnets. Chromaticity is corrected by coupling focusing strength to dispersion, which is far stronger in the F magnet. We have demonstrated that a weak F sextupole can produce a substantial horizontal tune flattening, and has little impact on other optical properties, whereas placing the sextupole at the D element may destroy the dynamic aperture and/or vertical focusing.

The dipole field components are parametrized in terms of the positive bend in the D magnet and the reverse bend in the F element. The split between these bends sets the shape of the closed orbits. The cost function, based on stored magnetic energy, was explored in terms of the split. Two cost minima are found: (i) minimum peak magnet field in the F element, and (ii) minimum radial aperture in the D element. The former is similar to the lattices with minimum path length variation, but the latter presents a new direction for future detailed design studies.

EURISOL Beta Beam

The Beta Beam Study is part of the EU-funded EURISOL initiative which will develop a proposal for a new European ISOL-based radioactive ion beams facility. Beta Beam is a novel concept for a neutrino factory which utilizes radioactive light ions (^{6}He, ^{18}Ne) produced by the ISOL front end. The ions are collected, accelerated to highly relativistic energies in order to extend their lifetime, and then injected into a racetrack-shaped "decay ring" where copious neutrinos will be produced via the beta decay process. The Beta Beam Study commenced in January and will run for four years.

TRIUMF was invited to participate in Beta Beam in the area of multiparticle simulations of the operation of the decay ring, using our simulation code ACCSIM and other tools such as Geant4 and/or MARS. After reviewing requirements at the first Beta Beam task meeting in January, the first priority was to prototype the decay ring lattice in ACCSIM and implement new features for handling radioactive ions, including the decay process and the daughter secondary ions. These ions have a different charge/mass ratio and must be tracked accurately until they either exit the ring or are collected on a beam stop.

The injection of ions into the decay ring involves a novel bunch-rotation scheme for merging with the circulating beam, as well as an orbit bump system for reducing losses on the injection septum. These features were implemented in ACCSIM and demonstration runs of the bunch merging were performed. For the circulating beam, full-scale runs were done to predict the loss patterns of secondary ions in the arcs.

This work was presented at the second Beta Beam task meeting at Saclay – prior to collaboration with the decay ring lattice and injection system designers who have developed the interactive optics and design tool "BETA". Detailed comparisons of ACCSIM and BETA led to plans for putting new capabilities into both codes, including new ACCSIM methodology for secondary ions, and connections to allow the codes to work together efficiently.

Space-Charge Code Benchmarking

A collaboration has been formed to compare and validate several synchrotron space-charge simulation codes, including ACCSIM (TRIUMF), IMPACT (LBNL), MICROMAP (GSI), ORBIT (SNS), SIMBAD (BNL), SIMPSONS (KEK), and SYNERGIA (FNAL). The initiative is motivated by the need to raise confidence in predictions of beam loss and quality for mega-watt beam projects such as SNS and J-PARC, and to explain observations and possibly improve the performance of existing high-intensity machines.

The benchmark cases were based on actual beam and machine data obtained during experiments with the CERN Proton Synchrotron, with the machine tuned to the Montague (coupling) resonance driven by space charge. The simulations were specified to involve increasing complexity of the modelling, starting with a constant focusing approximation, then a linear version of the PS lattice, and then the fully non-linear lattice.

The agreement between codes was found to be very good at the coasting beam level, indicating that Poisson solvers in the various codes were sufficiently accurate to model the non-linear space charge features and resultant emittance transfer. However, differences in the damping of r.m.s emittance oscillations were observed, and these will be explored before proceeding to bunched-beam simulations planned for 2006.

MAGNETS

DC Magnets

Three high-beta superconducting solenoids for the ISAC-II Linac, that were ordered last year from Accel Instruments (Germany), were delivered.

Drawings of the ISAC pre-separator magnet were updated so the design could be used with ISAC's off-line ion source.

A contract was awarded to Advanced Engineering Systems (Pennsylvania) for five X-Y steering magnets for the beam line to the ISAC-II experimental hall. By year-end the magnets had arrived, been tested, and installation had started. To assist the Canadian contingent of the Q_{weak} experiment at Jefferson Lab, TRIUMF ordered nine coils for the QTOR spectrometer magnet from Sigmaphi in France in 2004. The coils passed the factory tests in December and have been shipped to MIT-Bates (see Fig. 322).

Preliminary work on designing a new dipole for the charge state booster (CSB) started. This work was put on hold to prepare for the installation of the M20 front-end.

Preparations to refurbish the M20 front-end continued. The plan is to replace Q1 and Q2, repair B1, install a new B1 vacuum chamber and stand, and replace the VA1 vacuum valve in the 2006 winter shutdown.

Fig. 322. Q_{weak} coils.

Magnet Measurements

In 2005, 14 magnets were set up and measured using the magnet survey equipment in the magnet measurement area in the proton hall extension. These magnets included:

1. M9BQ3 repaired and measured first as a symmetric quad and then rewired and measured as an asymmetric quad, with coils connected to two power supplies at different currents for steering.
2. 6 accelerator vault quads for ISAC-II (Danfysik L1 Quads)
3. 2 TIGRESS dump quads (8Q16/8 quads)
4. 5 SEBT double steering magnets for ISAC-II from Advanced Engineering.

Doug Evans was the only Canadian representative at the 14th International Magnet Measurement Workshop (IMMW14) that was held for a week in September at CERN. Approximately 65 magnet measurement experts from around the world gathered to exchange ideas and information. Doug presented a talk entitled "Hall probe measurements of S-bend magnets for ISAC-II at TRIUMF". Tours of the magnet measurement facilities at CERN and ATLAS target hall were included.

Experiment 614 – TWIST

TOSCA 3D simulations have previously been carried out for the TWIST magnet. These simulations provide important information because the measurements provide only one component (Bz) of the field at a limited number of space points. By contrast a good TOSCA computer model can provide the three field components at any point. A detailed comparison was made between field maps taken for the TWIST solenoid, at a field of approximately 2 T, and the TOSCA predictions. There is a small discrepancy between measured and predicted fields (up to 8 mT, in 2 T, in the Bz field). Simulations have been carried out to determine whether the discrepancy is caused by an inadequate mesh in the 3D TOSCA model or whether there is something missing from the model. This work has been carried out by various personnel under the general guidance of the Magnet group.

KICKERS

BNL AGS A10 kickers

The present AGS injection kickers at A5 location were designed for 1.5 GeV proton injection. Recent high intensity runs have pushed the transfer kinetic energy to 1.94 GeV, but with an imperfect matching in transverse phase space. Space charge forces result in both fast and slow beam size growth and beam loss as the size exceeds the AGS aperture. A proposed increase in the AGS injection energy to 2 GeV with adequate kick strength would greatly reduce the beam losses making it possible to increase the intensity from 70 TP (70×10^{12} protons/s) to 100 TP. R&D studies are being undertaken by TRIUMF, in collaboration with BNL, to design two new kicker magnets for the AGS A10 location which will provide an additional deflection of 1.5 mrad for 2 GeV protons. TRIUMF has proposed a design for a 12.5 Ω transmission line kicker magnet with rise and fall times of 100 ns, 3% to 97%, and kick strength uniformity for protons of ±3% over 90% of the aperture, powered by matched 12.5 Ω pulse-forming lines. A paper describing the prototype design concept including the results of detailed 2D and 3D electromagnetic modelling of a transmission line kicker magnet and PSpice time domain analysis of the magnetic kick strength was presented at the Particle Accelerator Conference in Knoxville, Tennessee, in May. The full results of electromagnetic modelling were presented at the Magnet Technology Conference in Genoa in September

The transmission line type kicker magnet consists of ferrite C-core sections sandwiched between high voltage (HV) capacitance plates. One C-core, together with its ground and HV capacitance plates, is termed a cell. This is a classic design concept that has been used extensively at CERN and elsewhere for decades. A kicker system is composed of a pulse forming line (PFL) and a multi-cell travelling wave kicker magnet, connected by a matched transmission line and terminated by a matched resistor. $Z = \sqrt{L/C}$, where L and C are the inductance and capacitance per cell of the kicker magnet, respectively. Impedance mismatches result in reflections which cause field ripple and potentially reduce the life of the thyratron switches. A carefully matched high bandwidth system is needed to obtain the stringent pulse response requirements. Modern kicker magnet systems are now designed to a precision of 0.5%. This requires the individual components to be designed to a precision of 0.1%. In order to achieve the required impedance of the kicker magnet the cell inductance and capacitance must be of the correct values to a high precision. A novel design approach was adopted at TRIUMF to predict the inductance and capacitance of the AGS kickers.

Unfortunately the funding for the AGS KOPIO experiment is not forthcoming and thus the AGS upgrade is cancelled. However, the kicker magnet design methods pioneered at TRIUMF for CERN were applied to the AGS design and the design methodology was further extended to include detailed 3D modelling for accurately predicting detailed inductance and capacitance of the kicker magnet. Hence the AGS work is a worthy research goal in its own right, since such modelling calculations have not been previously applied to such a complex magnet structure. The most complex components (machined ceramics and ferrites) have been obtained. Mirror finished stainless steel capacitor plates have been obtained and roughly cut to be ready for CNC machining. The final machining and testing are all that remain to be completed. The completion of the assembly and testing of the AGS A10 kicker will benefit the field of pulsed power and magnet technology: the measurements will determine the accuracy of the design method, pioneered at TRIUMF, for the kicker magnet. There is an application to the Canadian Foundation for Innovations (CFI) for funding to complete the assembly and testing of the prototype kicker.

Development of a 25 MHz micro-bunching cavity

Although this work was mainly carried out by the RF group in the Cyclotron Division, the project was supported along with the AGS kicker development by a common CFI grant. The development of the rf cavity up to the time that KOPIO was cancelled is described here.

Micro-bunching the proton beam extracted from the AGS is an essential part of the KOPIO experiment. The technique to produce micro-bunching, proposed at Brookhaven, is a clever way to manipulate the extraction parameters so that the extracted beam is bunched while the circulating beam is left unbunched to minimize potential instabilities. This is achieved by slowly extracting a coasting, debunched proton beam with a finite momentum spread by ramping the magnetic field through a transverse (betatron) resonance with a rf field on but asynchronous with the proton beam except for the fraction of beam at the maximum momentum just prior to extraction. As the magnetic field is slowly decreased, the resonant fraction of the beam briefly becomes synchronous with the rf frequency and is forced between the empty rf buckets as it is extracted leading to a narrow beam time width.

The rf field is provided by a special high voltage cavity that must be specially built for this purpose. A frequency of 25 MHz is chosen to balance the requirements of bunch spacing sufficient to prevent wrap-around, i.e. the fastest particles in the neutral beam produced by a primary proton bunch overtaking the slowest ones of the preceding bunch. The basic design parameters of the 25 MHz micro-bunching cavity are listed in Table LII.

The cavity parameters were calculated using the HFSS code and a full-scale copper-clad wooden model of the cavity was designed and constructed. The main steps in building the model cavity (see Fig. 323) involved laying copper foil on the inside of the outer wooden shell of the model and on the outer surface of the inner PVC tube. The cavity was supported on a support structure and the inner conductor alignment mechanism and gap adjustment mechanism were installed. Provisions were made to install a coupling loop and a coarse frequency tuner on top of the cavity and a fast frequency tuner at the bottom of the cavity.

Table LII. Design parameters of the 25 MHz cavity.

Parameter	Design value
Frequency	24.8694 MHz
Gap voltage	150 kV
Static tuning range	± kV
Quality factor	15100
Shunt impedance	1.0 MΩ
Cavity length	2.19 m
Cavity construction	Copper-plated steel

Fig. 323. Wooden model with two halves closed.

The resonant frequency and quality factor of the full scale prototype copper clad wooden model were measured and compared with computed values. The measured frequency was very close to the predicted value. Obtaining 83% of theoretical Q is an excellent achievement in this type of wooden model. The shunt impedance was also measured which came very close to the theoretical value.

The measured frequency was very close to the predicted value and between the HFSS and Superfish predictions. The quality factor was 83% of the theoretical Q, an excellent achievement in this type of wooden model. The shunt impedance was also measured which came very close to the theoretical value. A finite element study of the thermal effects due to the rf power dissipation in the prototype cavity was also made with the use of ANSYS software. This AGS work on the kickers and rf cavity provided Co-op projects for several students.

NLC collaboration

The Next Linear Collider (NLC) accelerator proposal at SLAC requires a highly efficient and reliable, low cost, pulsed-power modulator to drive the klystrons. A solid-state induction modulator has been developed at SLAC to power the klystrons; this modulator uses commercial high voltage and high current insulated gate bipolar transistor (IGBT) modules. Testing of these IGBT modules under pulsed conditions was very successful, however, the IGBTs failed when tests were performed into a low inductance short circuit. The internal electrical connections of a commercial IGBT module have been analyzed at TRIUMF to extract self and mutual partial inductances for the main current paths as well as for the gate structure. The IGBT module, together with the partial inductances, has been modelled using PSpice. Predictions for electrical paths that carry the highest current correlate with the sites of failed die under short circuit tests. A similar analysis has been carried out for a SLAC proposal for an IGBT module layout.

The research has identified inductive coupling from the power traces to both the gate traces and gate wire bonds as the primary cause of current imbalance between the die in the IGBT module from manufacturer "A". The coupling to the gate circuits can boost the Vge of die above the externally applied gate voltage, and therefore potentially increase the fault current. Hence IGBT module designs intended for high di/dt applications need to pay particular attention to the internal layout relative to the main power paths.

A value of gate resistance of less than 2 Ω per IGBT raft results in reduced fault currents, however, the absolute value of current imbalance between IGBT die is not significantly affected. A gate resistance of less than approximately 0.3 Ω per raft (of 4 IGBT die) is not recommended as it results in oscillatory gate current.

Preliminary simulations of the SLAC rectilinear IGBT module show that the current sharing between die, under soft short circuit conditions, is good.

The collaboration with SLAC, to analyze the failure mechanism of the IGBTs under fault conditions in the prototype NLC modulator, was successful. A paper was co-authored with SLAC and presented at the 2004 Power Modulator Conference. A more extensive version of the paper has been published in a Special Issue of the IEEE Transactions on Plasma Science [Barnes *et al.*, **33**, 1252 (2005)].

PSI MuLan collaboration

An international collaboration is measuring the lifetime of the muon to a precision of 1 ppm. The MuLan experiment is taking place at PSI in northern Switzerland. The central idea employed in MuLan invokes an artificial time structure on an otherwise dc beam. The MuLan method requires a fast beam line kicker, which can turn the beam on and off at a repetition rate of up to 40 kHz, and the 25 kV pulse, between a set of deflector plates, must have a flattop "droop" of less than 0.0001%: the TRIUMF Kicker group designed and built the kicker. The kicker runs with a standard "on-off time cycle", or in a Muons On Request mode. The MuLan kicker consists of 2 pairs of deflector plates mechanically in series, driven by 4 FET modulators. Each pair of plates is 0.75 m long. One plate of each pair is driven by a +12.5 kV FET based modulator and the other plate is driven by a –12.5 kV modulator. The potential difference between a pair of deflector plates is variable up to 25 kV. Each modulator consists of two stacks of FETs operating in push pull mode.

The kicker was successfully commissioned at PSI in July, 2003. However, tests at PSI showed that rf from the kicker interfered with experimental detectors. Also it was realized that the specification for the flattop of the voltage pulse was not adequate for this precision experiment. Significant reduction in the rf and improvement in the pulse flattop were required. The kicker was returned to TRIUMF and extensive changes were made, based on detailed measurements and PSpice simulations. After the changes the rf was reduced by a factor of more than 5000. The flattop variation, for a 22 μs pulse duration, was reduced from 0.18% to less than 0.001%. In addition the pulse overshoot was reduced from 10% to 2%. A gate resistance of 3.1 Ω was installed on each MOSFET card and calculations show that this is expected to result in another factor of between 2 or 3 reduction in the rf, although this was not measured. The results of this work were presented at the Pulsed Power Conference in Monterey in June, 2005.

During November and December, 2004 several stacks of MOSFETs were destroyed during a physics run. The cause of the failures is not completely understood but is believed to be due to several reasons including a short circuit on the output of a kicker and damaged fibre optic cables. The MOSFET cards were returned to TRIUMF in December, 2004 and January, 2005. Two parallel 6.2 Ω gate resistors have been incorporated on the PCB to make the MOSFETs less susceptible to failure resulting from timing mismatch (e.g. due to minor damage to the fibre optic cables). The timing of all the cards has been measured and adjusted, where necessary. In addition, fibre optic based overcurrent detection cards were designed, constructed and tested. An over-current card is connected on the dc end of each MOSFET stack. A TTL splitter box has been designed, built and tested at TRIUMF. This splitter box, which replaces one originally supplied by the MuLan collaboration, receives fibre optic feedback from each of the eight overcurrent cards and, under most operating conditions, prevents the stacks of MOSFETs turning off if a current of more than approximately 10 A occurs for a period of more than approximately 160 ns. The MuLan kicker was re-commissioned at PSI during August, 2005. By mid-November the MuLan collaboration had recorded 10^{11} good muon decays, which represents about 10% of their final statistics goal. David Hertzog reported that "The kicker worked flawlessly and was almost forgotten given other problems".

In mid-November the beam line at PSI was reconfigured for the MuCap experiment and the kicker was successfully used in a Muons On Request mode. During a run a collimator in the beam line fell, short circuiting one of the deflector plates to ground. The presence of the gate resistors, the overcurrent cards and the TRIUMF TTL splitter box probably prevented the destruction of a stack of MOSFETs when the fault occurred. Once the cause of the short circuit was understood and rectified the kicker operated correctly.

IGBT

In 2005, efforts to design a solid-state replacement for thyratrons for use in kicker applications at TRIUMF continued to be focused on IGBTs. In particular, research continued on the anticipated performance of press pack (otherwise known as "hockey puck") style modules under the switching conditions required of a thyratron replacement.

The main focus of this research continues to be the Westcode 5.2 kV IGBT module. This module consists of 14 individual IGBT die in parallel (Fig. 324). For a

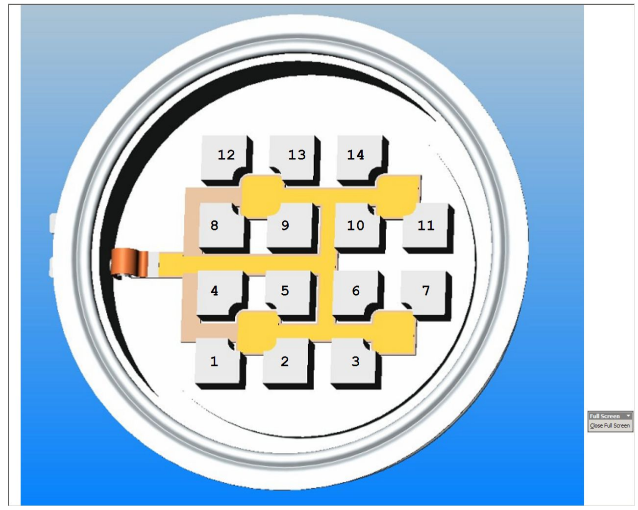

Fig. 324. Westcode module, internal layout.

thyratron replacement, such modules would be stacked in series to obtain a sufficiently high blocking voltage (e.g. 60 kV), and each module would be subjected to the total switch current (e.g. 6 kA peak).

Some high power thyratrons used for kicker applications can switch several thousand amperes in several tens of nanoseconds. However, semi-conductor technology is not yet capable of such high di/dt. Hence an initial goal of the IGBT research project is to determine how rapidly the semiconductor can go from blocking state to full current, with a goal significantly less than 1 μs. This corresponds to a goal di/dt in excess of 10 kA/μs.

Much of the research from the last year has been concerned with how the current will distribute itself within a hockey puck module under the switching conditions outlined above; it was anticipated that the geometry of the module could result in the inner-most die experiencing significantly higher impedance (and therefore a lower die current) under switching conditions. If this current imbalance were large enough, it could result in the destruction of the module, or at least raise its switching impedance to a degree that would make it unusable for the intended application.

To predict this current distribution, several commercial software packages were used, and multiple models of the IGBT module geometry were created and analyzed. The packages used were: Opera2D, Opera3D, IES Oersted, and FastHenry. Between these packages, the module was modelled by means of: finite element, boundary element, and magnetoquasistatic multipole analyses, in both two and three dimensions.

These models were then either used to provide coupled PSpice circuit parameters (which electrically represented the geometry of the device) or solved to directly obtain the current distribution. When the latter method was employed, the current distribution was obtained either for a single frequency at steady-state, or at specific times during a transient analysis. Generating circuit parameters allowed the versatility of using PSpice as a simulation engine, which, in turn, facilitated a wide variety of possible simulation scenarios, including the insertion of non-linear elements to represent the individual IGBT die. Producing the current distribution from within the modelling software packages, while not as versatile or time effective as the PSpice method, provided us with the ability to cross-check results between software packages, as well as the results from (linear) PSpice analyses.

Simulations of the model geometry showed very good corroboration between the various modelling and simulation techniques. For both steady-state and transient analyses, there was little deviation between the current distributions predicted by each solution method. Further confirmation of these results may come as a result of physical measurements of the IGBT internal current distribution, which are scheduled for 2006.

The results from simulations showed that current sharing could be a significant issue with the Westcode IGBT module, and that the determining factor appears to be the conductivity of the actual silicon IGBT die. As this parameter varies considerably during the switching process and is dependent upon the gate-emitter voltage, work is under way in association with Dr. Patrick Palmer of UBC to create a non-linear PSpice model that is tuned to reflect the characteristics of the Westcode IGBT die. This model may be inserted, along with our extracted parameters, into a solvable PSpice schematic. Preliminary results utilizing an International Rectifier PSpice IGBT model to represent the IGBT die tentatively showed the current distribution to be sufficiently uniform. However, more analysis is required before a mock-up can be constructed.

The CERN kicker group have recently commenced "life-testing" a Westcode IGBT, similar to the one modelled in the above simulations. The severity of the test conditions will be gradually increased until the IGBT fails. Measurements taken at CERN can be run through the TRIUMF model of the IGBT to determine current distribution: this may be a very interesting means of understanding the final mode of failure of the IGBT.

ILC damping ring kickers

During a visit to TRIUMF on November 1, 2005, Gerald Dugan, the Americas Region Director for the International Linear Collider (ILC), provided some parameters for a very challenging damping ring kicker. The rise and fall times of the injection kickers have an influence on the minimum circumference of the ILC damping rings. The baseline conceptual design features 6 km rings that will require pulsers to feed a 50 Ω stripline with a 5 kV pulse, with 6 ns rise and fall times, and a total duration of 14 ns. The kicker will operate in burst mode with a 3 MHz burst, for 1 ms, once every 5 s. Thus the average rate is less than 1 kHz. The beam bursts will be deflected by the combination of the electric component from the 5 kV voltage pulse and the magnetic component from the 100 A current pulse. The magnetic and electric components add when the beam burst travels in the opposite direction to the current pulse.

The TRIUMF Kicker group has designed and built a kicker for the MuLan experiment at PSI, with deflection voltages up to 25 kV at 75 kHz continuous with 40 ns rise and fall times. The PSI kicker consists of stacks of 17 series 1 kV FETs, from DEI, which have been individually tested at 3 MHz continuous. The present design of the MOSFET cards allows a FET to collapse almost 1 kV in approximately 3 ns, but this does not translate to a sufficiently fast switching time, for the ILC kicker, for a stack of FETs when constructed in the conventional manner. The maximum pulse current for these DEI FETs is 72 A, whereas 100 A is required. In addition PSpice simulations show that two parallel 100 Ω stacks result in better rise and fall time than a single 50 Ω stack of FETs.

The TRIUMF Kicker group has developed a new modulator circuit concept for an ILC kicker. Proof of principal tests were performed using the PSI kicker prototype as a test bed and a set-up using components on hand (Fig. 325). The final design will consist of two parallel 100 Ω drivers combined to provide a 50 Ω driver. The test circuit, which is a single 100 Ω driver, has been used to generate 5 kV pulses, with 6 ns rise and fall times (10% to 90%), into a 100 Ω load at 1 kHz. The post pulse noise in Fig. 326 is attributable to impedance mis-matches. The total width of the pulse at the base was 20 ns compared with 14 ns required.

As a result of these encouraging tests the TRIUMF Kicker group plans to make a series of improvements in the design to meet the ILC kicker specifications. The 3 MHz burst mode requires fast charging circuits, and the impedance matching needs to be more precise than in the prototype. Reduced inductance will lead to shorter pulse lengths and shorter rise and fall times. New lower inductance FET cards have been designed, and the stack configuration is also being modified with the goal of reducing the inductance to approximately 620 nH or less. In addition it is planned to eliminate the fibre optic triggering used on the present FET cards.

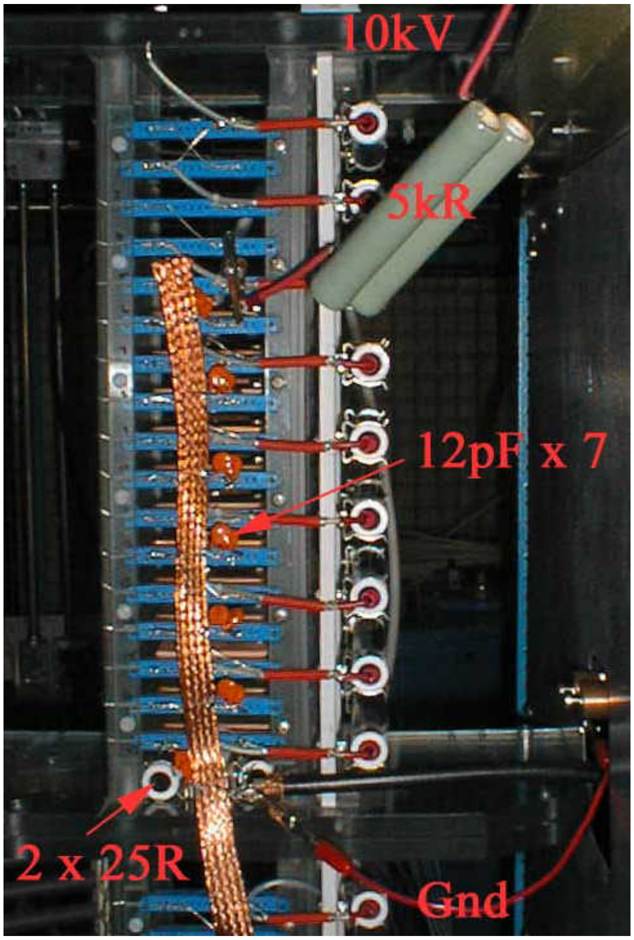

Fig. 325. Prototype PSI kicker stack adapted for ILC kicker "proof of principle" test bed.

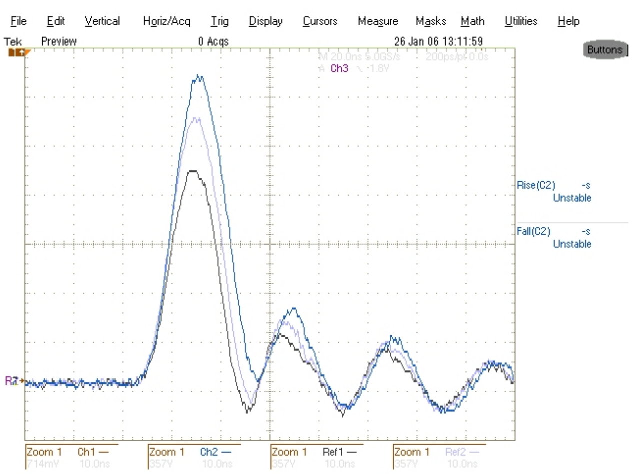

Fig. 326. Output voltage pulses, into 100 Ω load, of 3 kV, 3.9 kV and 4.6 kV (10 ns/div, 714 V/div).

TITAN

TRIUMF's ion trap for atomic and nuclear science (TITAN) radio frequency quadrupole (RFQ) beam cooler is a device that cools and collects short-lived isotopes, with half-lives as short as 10 ms, created by an isotope separator and accelerator (ISAC). An rf square wave driver (RFSWD), that must have rise and fall times of less than 125 ns (10% to 90%), performs 2 dimensional focusing of the ion beam within the RFQ, along planes normal to the beam's intended trajectory, to confine ion motion along a stable path; hence the ions can be trapped and collected for extraction. The RFSWD, which is based on previous kicker designs developed at TRIUMF, employs stacks of MOSFETs, operating in push-pull, to generate high voltage (HV) rectangular waveforms at a prescribed frequency and duty cycle. Currently a 500 V, 2 MHz drive system is undergoing tests, however, the system configuration allows for operation with higher voltage amplitudes and a repetition rate from 300 kHz up to 3 MHz, continuous.

The Kicker group has provided significant design support for the TITAN RFQ driver, providing advice and carrying out simulations. Simulations include analyses of the capacitance of the RFQ using Coulomb 3D modelling software from Integrated Engineering Software (Canada), and modelling of the equivalent circuit using PSpice. A paper was presented at the Pulsed Power Conference in Monterey in June.

MECHANICAL ENGINEERING

Mechanical engineering, mechanical design and engineering analysis work is initiated by the submission of a Request for Engineering Assistance (REA) form. These are assessed on a weekly basis and assigned according to size, complexity and schedule. Large tasks such as KOPIO and the ISAC-II linac system require a team approach guided by a project engineer.

During 2005 there were 82 REAs submitted. There are also lengthy projects that are carried over from the previous year such as the two already mentioned plus projects such as target/ion source development, TIGRESS, TITAN, etc. Engineering personnel also participate in activities such as specification writing, budget and schedule creation, safety issues related to structural integrity, quality control, sub-contractor management, design reviews, etc.

ISAC-I

Febiad ion source development was delayed in 2005 due to test stand problems. As a result target module 4, which was scheduled for completion in order to do on-line tests of the Febiad ion source, was also delayed. By December, target module 4 was 90% mechanically complete awaiting electrical wiring and then final installation of the service cap lid, source tray, Penning gauge and finally the target. Currently the source tray is assembled and awaiting the installation of the water blocks. The schedule requires that target module 3 be available in April, 2006.

ISAC-II

TRIUMF is currently constructing a 43 MV superconducting heavy ion linear accelerator (linac) to accelerate radioactive ion beams from the current ISAC-I level of 1.5 MeV/u to 6.5 MeV/u. Phase 1, currently under way, involves the installation and commissioning of a 500 W (at 4.5 K) liquid helium refrigeration system, a liquid helium distribution system transporting liquid helium from the refrigeration system collection dewar to the linac, and the linac, comprising 5 medium-beta cryomodules located in the accelerator vault (see Fig. 327). The medium-beta section of the linac will produce 20 MV of accelerating voltage for initial experiments. It was scheduled that all of the above would be available for some initial tests by the end of 2005. However, refrigeration and distribution system commissioning took longer than expected plus cryomodule delivery for installation in the vault was delayed due to a recurring helium leak in the helium reservoir that required development time to solve. Medium-beta cryomodule installation will be completed in February, 2006, and cold tests will commence thereafter. Accelerator beam tests to an experiment in the experimental hall were scheduled to occur about August, 2006. Phase 2 will add 3 high-beta cryomodules, an extension to the helium distribution system and doubling of the refrigeration capacity. This is scheduled to commence in 2007.

Cryomodules

Medium-beta cryomodule engineering has been reported extensively in previous Annual Reports as well as technical conference reports [Stanford *et al.*, "Design of the medium-beta cryomodule for the ISAC-II superconducting heavy ion accelerator", CEC/CEMC-2003, Anchorage, AK] over the past several years and the details will not be repeated in this report. The first cryomodule which was designated SCB3 (location designation) was treated as a prototype and the assembly was completed in April, 2004 in the SCRF clean room. It was subjected to a series of cold tests to investigate alignment repeatability, thermal efficiency, cooldown procedure, and rf operation. In addition, alpha particles from a radioactive source were accelerated to an energy of 9.4 MeV with an average cavity gradient of 5.6 MV/m which is within 7% of the design goal of 6 MV/m for each cavity. See "ISAC-II Accelerator Development" in the ISAC chapter of this Annual Report for more information on the cryomodule test program. As mentioned, of concern was the repeatability of the alignments of the cryo elements over repeated cooldown cycles. This was carefully examined by employing a wire position monitor as well as optical targets in the rf cavity and solenoid beam ports. Tolerances of ±200 μm for the solenoid and ±400 μm for the cavities were met in all cases.

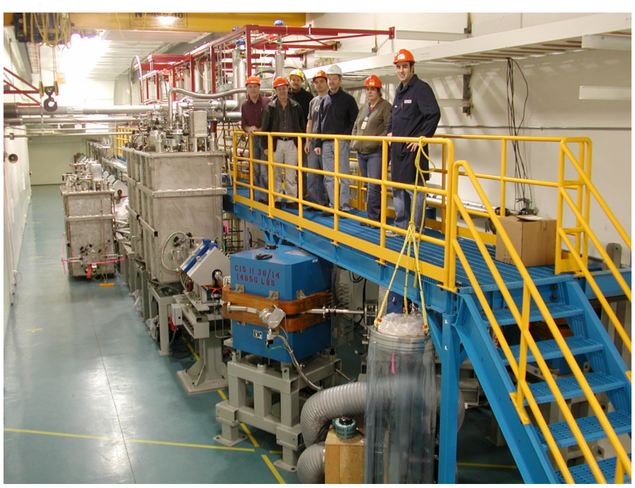

Fig. 327. Service platform for the ISAC-II cryomodules.

Several deficiencies were discovered during the assembly of SCB3 that were corrected and some improvements made and incorporated in the design of subsequent cryomodules. SCB1 assembly was completed in July, and similar tests conducted with satisfactory results. This was followed by SCB4 and SCB5, which were completed and ready for testing by the end of 2005. SCB2 was partially assembled by this time. During tests of SCB4 a helium leak at cryogenic temperature appeared and was traced to the helium reservoir end cap indium seal. This problem also occurred on SCB5 and was thought to be manufacturing related. Several machining iterations did not improve the problem. Finally Argonne Laboratory was contacted and an indium seal design that they have been using for many years was adopted along with a thicker end cap. SCB2 was available to test the design since it was not far enough along to require component disassembly. Repeated cryogenic tests were successful and this design was incorporated on SCB4, SCB5, and SCB2. SCB3 and SCB1 have not experienced this problem to date.

High-beta cryomodules

The original schedule had intended that the phase 2 high-beta cryomodule engineering commence in 2005, such that manufacturing could commence in 2006 and cryomodule assembly in early 2007. This has been delayed by approximately one year due to budgetary restraints. In the interest of moving the high-beta forward within the budgetary restraints, several steps commenced in 2005.

1. The quarter-wave medium-beta rf cavities have been re-engineered to reflect the dimensional requirement necessary to accommodate the higher frequency of 141.44 MHz from the medium-beta frequency of 106.08 MHz. There were also

some detailed design improvements included. The drawing package was released in July.

2. A local company called Pavac Industries (electron beam welding specialists) has been engaged as a potential manufacturer of the high-beta rf niobium cavities and has been commissioned to manufacture a prototype stainless steel cavity based on the aforementioned drawing package to investigate and display their manufacturing capabilities, especially related to electron beam welding. Upon completion and acceptance by TRIUMF they will continue on and build a niobium cavity. The availability of a local manufacturer for niobium cavities would be advantageous to TRIUMF.
3. In support of the above, TRIUMF requires a facility to chemically etch niobium accelerator parts before and after welding, preferably located at TRIUMF. TRIUMF is currently in the early stages of investigating what is required to accomplish this and has commissioned a chemical engineering consultant for assistance. Engineering of such a facility will occur in the near future.

ISAC-II helium refrigeration system

As outlined in the 2004 Annual Report, the phase 1 refrigeration system was broken down into 5 subsystems and basically all were separate sub-contracts managed by TRIUMF. They are as follows:

1. Refrigeration system major components, i.e. compressors, cold box, gas management system, oil removal system, and control system.
2. Warm piping sub-system – all the stainless steel pipe work necessary to connect the refrigeration components.
3. Buffer storage tanks – utilized for the storage of gaseous helium.
4. Liquid helium dewar – utilized for the storage of liquid helium produced by the cold box and to be distributed to the linac by the CPS/s.
5. Cold piping sub-system (CPS/s) – utilized to transport liquid helium from the dewar to the linac and clean room.

Item 1 A contract was signed in 2003 with Linde Kryotechnik AG (Switzerland) to provide a 500 W helium refrigerator. All the components were delivered and installed in 2004. After completion of the warm piping sub-system and installation of the dewar, the refrigeration was initially commissioned in March, 2005. A final operational commissioning will be required once the CPS/s and medium-beta cryomodules are in place in early 2006. In the meantime a special circuit has been installed from the dewar in the cryo room to the clean room and back to the refrigerator to allow for clean room cold testing, thus eliminating the purchase of liquid helium and exhausting to the atmosphere.

Item 2 The contract for the refrigerator also included process and instrumentation diagrams. From this, TRIUMF created a drawing set defining the entire warm piping sub-system and its installation in order to create a specification and tender package and engage a contractor. Lockerbie and Hole won this contract, began work in September, 2004, and completed the work in February, 2005 in time for the refrigeration system commissioning. This work, although late to the defined schedule, was well executed.

Item 3 The single 30,000 USG horizontal tank was installed on the mounting pad in October, 2004. No further activity occurred in 2005 other than to connect the pipe work between it and the refrigerator. Future plans include the installation of a framework straddling the existing tank and emanating from the mounting pad allowing the installation of two more 30,000 USG tanks above the first. The framework and second tank will be installed in 2006. The third will not be required until phase 2 of the program.

Item 4 This is a 1000 l dewar that was acquired from the Chalk River inventory. It was inspected and refurbished and then installed next to the cold box in February (see Fig. 328). It has been operating satisfactorily since that time.

Item 5 The CPS/s was conceptually designed by TRIUMF after consultation with a number of other laboratories. The conceptual design resulted in a set of drawings depicting what was deemed to be the best solution from the point of view of distribution and thermal losses as well as cost. A specification for phase 1 was created and went out for tender in December, 2004. The contract was signed with DeMaCo (Holland b.v.) in March, 2005, and has proven to be one of the more

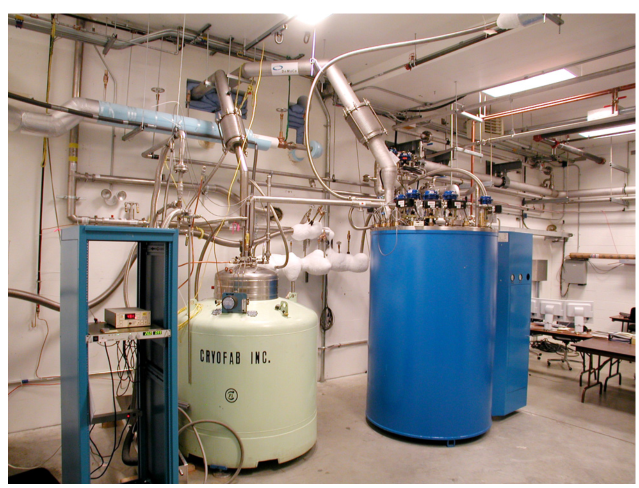

Fig. 328. Cold box and dewar for ISAC-II liquid helium system.

complex tasks for TRIUMF to manage. The CPS/s is a complex sub-system that transports LHe from the collection dewar in the accelerator vault and returns the gaseous He to the cold box/compressor. All the pipe work is vacuum-jacketed and liquid N2 shielded, and all valves, joints and interfaces are custom made for the application. TRIUMF elected to use field joints rather than valve boxes at the cryomodules and at strategic locations when the CPS/s may have to come apart. This allowed a compact, simpler system minimizing vertical excursions of the main trunk lines and transfer lines. The CPS/s has liquid nitrogen (LN_2) distribution and return lines running parallel to it supplying LN_2 to the CPS/s as well as to the cryomodules. This was done outside of the DeMaCo contract. There is also a separate warm return manifold which is used during cooldown of the cryomodules. This allows the return of gaseous helium which is still above 20 K, and not usable by the cold box, to be returned to vaporizers and then to the compressor. This also was done outside of the DeMaCo contract.

DeMaCo delivered the CPS/s in October and their mechanics, along with TRIUMF personnel, installed it onto the support frame in November. Some acceptance tests were performed at that time but full acceptance tests cannot be conducted until all the cryomodules are installed in the vault in early 2006.

Engineering – Other

ISAC-II SCB medium-beta cavity

The SCRF cavity tuner system that was developed in the previous year was upgraded and modified to suit a permanent installation for amplifiers controlling tuner motors for 20 cavities in 5 separate cryomodule cabinets. All five SCB cryomodule rf cavity tuner control systems were fabricated and installed into the SCB/SCC linac rf power supply room and tested/commissioned. Necessarily concurrent with the latter effort, 20 rf cavity tuner motors with the accompanying control linkages from the niobium tuner plates to the vacuum feedthroughs were fabricated, installed and tested. Each cavity tuner plate mechanism is preadjusted in the class 3 clean room area such that the cold temperature (at $\sim$7 °K inside the cryostat) frequency of the cavity ends up within $\pm$5 kHz of the target linac frequency. This is well within the drive range of the tuner motors. All rf cavities in each of the 5 cryomodules were cold tested in the class 2 clean room pit and all the tuners maintained the required frequency phase lock regardless of induced cavity frequency changes such as those produced by pressure disturbances due to helium boiling.

FEA analysis

A new ultra high pressure (2.5–3.5 GPa) cell was designed for the μSR group to be tested and further developed in 2006 with the intention of manufacturing variants to this design for other labs internationally. Analytic equations were developed for predicting stress and deflections for this particular type of thick walled cylinder. These were then extended to double prestressed interference fit cylinders. This allows the pressure inside the target volume to be increased dramatically. Other design variations are planned that don't lend themselves too well to analytic formulations and so they will be optimized using FEA methods.

As well, a hydraulic 25 ton jack system has been designed to pressurize the cells to the required specifications. The HP cells are instrumented on all sides in order to monitor the distortions of the cell on the outside as the load is increased. Forces are monitored via a load cell attached to the jack. Instrument signals are collected by a multi-port ADC then via RS232 link transferred to a PC running a LabView program which acquires the data, interprets it then stores it. This system will be used to test and develop high pressure cells as well as to accurately pressurize the cells before delivering them to other labs or to various experiments at TRIUMF.

NPDGamma CSI detector stand and control system at LANL

The NPDGamma CSI detector stand motion control system at Los Alamos National Lab (LANL) had maintenance issues. This was chiefly due to an intermittent but obstinately persistent ground noise problem which caused interference with the controllability of the servo-motors. This required a tear down and rebuild of a great portion of the electrical wiring. An engineer was sent to LANL to debug and rectify these problems. Also some PC controller component failures were fixed and upgrades were performed on the hardware as well as the software. Further development on the supervisory LabView GUI control software will be done to add data acquisition upload/download and safety monitoring features. This can be done from TRIUMF via a fully secure VPN connection to the LANL yellow network to which the stand PC is attached. Then, via a VNC connection to the PC, work can be done on it remotely as though the operator was there in person.

Design evaluations and FEA

The Engineering group has negotiated a new software upgrade and services package with Algor Incorporated. The original FEA package, which was a limited commercial package with basic multiphysics capabilities, was replaced with the full blown professional multiphysics version which contains all of the features that are available to that version. Also, we acquired this at university/educational prices so that the yearly support charge is 30% less than before, and we are now licensed for unlimited seat usage. The overall cost for this is 6 times less than the actual commercial package for only one seat.

The following mechanical designs were evaluated, analyzed and approved for manufacture:

- The TIGRESS detector frame super-structure design specifications were verified using FEA to determine the maximum stresses, deflections and buckling loads and were approved for formalized design.
- The TITAN lid mounted RFQ removal frame design was checked for function and structural integrity. It was upgraded, then approved for manufacture.
- The CSB lead target shield lifting frame structural integrity was checked via FEA, then upgraded and approved for manufacture.
- The ISAC emergency target module frame for remote handling was checked for design function and strength. Again, after upgrades, the design was approved for manufacture.

The remote handleable 4 in. beam line clamp, that has been used so successfully by the Remote Handling group at TRIUMF, is being up-scaled for use on the T2K 8 in. beam line flanges as a remotely handleable clamping device. FEA software is being used to minimize the weight and to optimize the strength so that it can be remotely installed without the use of a crane.

KOPIO

Scintillator extrusion A mini production run to produce 8 mm × 7.2 cm × 1.7 m long scintillator planks enough for one module was held in October. This was a continuous 52 hour run and produced about 370 good planks. About 30 of these planks were machined tongue and groove at Multicam (Langley, BC). The gluing jig has been finished. It was cleaned and several of these machined planks were glued together to develop the gluing technique. Unfortunately, KOPIO was cancelled at this point. The remaining planks were stored in light-tight boxes for some possible future use. It is still intended to glue one full sheet of scintillator to demonstrate the procedures.

Pre-radiator fibreglass panels Several fibreglass sheets varying in thickness from 0.011 in. to 0.25 in. were successfully produced in 6 ft × 6 ft sizes at Profile Composites (Sydney, BC). These sheets were within the specified tolerances and had the required quasi-isotropic mechanical properties. Again, the contract with this company was terminated due to cancellation of the KOPIO project.

Cathode strips A flexible circuit of polyamide based Nova clad (Kapton based) material with 1/2 oz glueless copper deposit was received from Sheldahl. This was to be used as cathode plane for the wire chambers of the KOPIO pre-radiator. Upon inspection, it was discovered that the copper strips had anomalies at repeatable intervals where there was an arrowhead like protrusion between the strips, hence narrowing the gap between the conductors. No further effort was vested in the project to remedy this situation and this contract was also terminated due to cancellation of the KOPIO project.

Q_{weak}

Contract management services were provided to supply eight 5 in. thick coil carrier and sixteen 1.25 in. coil carrier stiffener plates for the QTOR spectrometer for the Q_{weak} experiment at Jefferson Lab. A machining contract was awarded to GL&V Fabrication (Trois-Rivieres, PQ). Figure 329 shows four finished coil carrier plates.

Contract management services were also provided to supply some smaller parts for assembling the coils to the coil carrier plates for the QTOR spectrometer mentioned above. A local company, Modern Engineering, was awarded the contract to machine these parts on their fully automated CNC machining centre.

These plates and smaller parts have been delivered to MIT-Bates for assembly with the coils and then subsequent shipment to Jefferson Lab.

T2K

The T2K fine grain calorimeter needs about 15000 pieces of 2.0 m scintillator bars having a cross section of 1 cm × 1 cm with a 0.3 mm coating containing 15% of TiO_2. Celco Plastics has been chosen again to produce

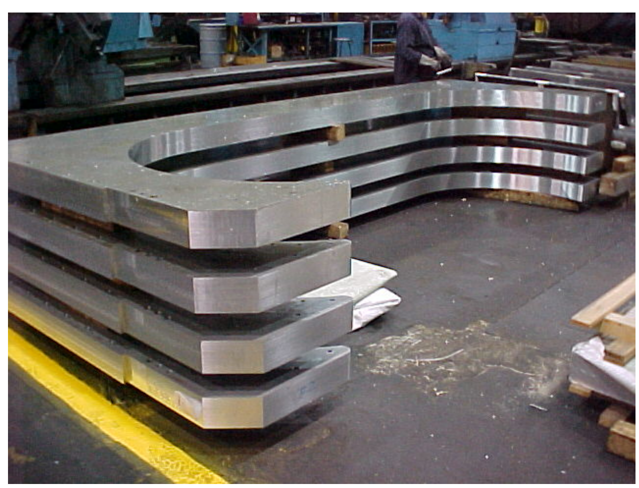

Fig. 329. Four finished coil carrier plates.

these bars. New tooling has been developed and a test run using a co-extruder was conducted at the end of the year. Co-extrusion proved to be successful and gave a consistent coating of TiO2 without any pinholes. Much more refinement is needed to produce the bars with geometry in acceptable tolerances. Another test run is planned in the first week of 2006.

Safety

Quality Assessment Program As part of a continued commitment to the Quality Assessment Program at TRIUMF, assessments were conducted of some groups at TRIUMF during 2005.

Engineering – Victoria

Manipulator arm

In 2004, a multi degree of freedom manipulator arm was designed to provide off axis calibration for the K2K neutrino detector at KEK, Japan. The improved calibration capability was needed to replace the existing system, which consisted of hanging a wire dropped through a tube into the water filled detector. In 2005, the components of the manipulator were machined at the University of Victoria, then delivered to TRIUMF for assembly, calibration and testing. Upon successful operation of the manipulator, it was shipped to Japan for installation and commissioning and, after some troubleshooting, was used for successful calibration of the K2K neutrino detector. More information on the manipulator arm and measurements is included in the Science section.

ISAC-I Febiad ion source

The development for both a single walled and double walled tubular filament design was continued for the ISAC Febiad ion source. The purpose of these filaments was to find a replacement for traditional wound wire filament, which began sagging and causing electrical shorts. A magnetic loop was also added to create a field around the filament. Continued success from testing the tubular filaments in the high temperature vacuum system at the University of Victoria demonstrated that both designs would be an improvement over the wound wire design and either system could reach temperatures nearing 2200°C from power supply heating. However, the double walled system increased the length of the filament allowing twice the thickness of tantalum foil to be used without an increase in current, which extends the lifespan of the filament. Testing of these filaments continued in the test stand at TRIUMF.

CNC router

An old XYZ positioning table was salvaged from TRIUMF and converted into a working 3 axis CNC router table. This involved reverse engineering the connections to the power amplifiers to allow communication and control by a PC without using an obsolete unsupported proprietary controller. A work table with accurate reference points was attached, a router head on the vertical axis was fastened, and a remote controlled fan and router control were added. The integration of this machine and appropriate software has produced a system capable of performing repeatable light prototype production work, which has been used for the TPC project at the University of Victoria. Companion software for translating AutoCAD DXF files to industrial CNC G-code was used to control the CNC router, but there are plans to add a new operating system to upgrade the conversion process.

T2K time projection chamber (TPC)

The conceptual design, detailing and manufacturing of the GEM modules and readout boards for the TPC prototype detector were completed at the University of Victoria. This required precise manufacture and assembly techniques using available resources, including the modified 3 axis CNC router table, during the prototype development process. This included the machining of GEM frames and high voltage connections, GEM foil stretching and frame gluing jigs, the construction of testing equipment, and the development of instrumentation systems for data acquisition. The combined efforts from TRIUMF and the University of Victoria engineering group produced a working prototype that underwent successful testing in late 2005. The success of the prototype detector was crucial to gain support for the use of GEM modules in the full scale TPC.

The University of Victoria engineering group will be leading the development and construction of GEM modules for the full scale TPC, which will begin in 2006. Work has begun to produce the initial 3-D design concepts for the outer containment box of the full scale TPC.

The University of Victoria engineering group has also been involved in addressing the misunderstandings over anticipated versus actual space allocations for the various sub-detector components, including 3 TPC detectors within the ND280 basket. Using the measured UA1 magnet and coil data at CERN, which will be transferred to Japan for the T2K project, a preliminary basket design was undertaken to ensure sufficient space was allotted when considering the ECAL detector envelope. This drawing was adopted by the ND280 conveners as the baseline solution for detector space.

A technical board meeting was held at CERN to discuss CERN's involvement in providing logistical support for the refurbishment of the UA1 magnet components prior to shipment to Japan. It was the first meeting between major groups, including TRIUMF and the University of Victoria, to discuss the implications of the ECAL detector envelope and the proposed basket design.

TITAN

The TITAN experiment includes a Penning trap mass spectrometer capable of measuring ion masses with high precision of $\delta m/m \leq 10^{-8}$. In the centre of the spectrometer is a set of hyperbolic electrodes placed in the strong magnetic field, which are held within a vacuum tube secured by an alignment jig on each end. Since the accuracy of the mass measurement is dependent on the precision of the alignment between the superconducting magnet field and the field of the Penning trap electrodes, the alignment jig was designed and analyzed to ensure external loads would not affect the stability of the critical components during operation. The expected heat loads while the system is being operated were also considered for the analysis. Engineering support throughout the development and analysis of the components of the Penning trap mass spectrometer will continue in 2006.

The engineering analysis for the RFQ vertical ion source of the TITAN project was also completed, and the components are now being manufactured at TRIUMF.

ISAC-I

ISAC actinide target evaporator Extensive analysis was completed for the vacuum chamber of the actinide target evaporator to confirm the integrity of the apparatus when thermal and pressure induced stresses are applied during operation. These calculations and the supporting COSMOS analysis confirmed the chamber was sound when subjected to 25 kW of radiant power while under vacuum pressure.

ISAC entrance module collimator A similar analysis to what was completed for the ISAC actinide target evaporator was done for the entrance module collimator. This supported the suggestion that the thermocouple embedded in the collimator plate was failing and providing readings much higher than the actual plate temperatures, which were setting off the temperature limit alarms. Based on the conclusions from the analysis, it was agreed that the acceptable temperature limit could be raised so long as the cooling water temperatures from other parts of the module were monitored accordingly.

University of Victoria lab renovations

Due to increasing office space limitations, renovations were required to add two rooms for office and meeting space at the back of the TRIUMF laboratory at the University of Victoria. The University of Victoria engineering group was involved in all aspects of the renovations including the proposal and initial sketches for office design, dismantling complicated research apparatus and fragile instrumentation systems, reviewing the renovation documents and liaising with the University of Victoria facilities management architect as construction progressed, and finding new storage solutions for all equipment in the now reduced lab space. Construction and electrical work was completed towards the end of 2005, and an improved storage system is under way for better representation and easier access to the equipment and other resources available. All members of the University of Victoria engineering group now work from the same office space.

General

The University of Victoria engineering group continues to offer engineering support and technical expertise for various projects at TRIUMF and to the particle physics group and their associates at the University of Victoria. This has included, but is not limited to the following: contributing to safety protocols for quality assurance, calculations and analysis for ISAC-I high powered target and graphite target development, detector support stand design and discussion for TIGRESS, continued support for the ATLAS project at CERN, and expertise for any vacuum, thermal and mechanical project needs. The TRIUMF facilities at University of Victoria allow the engineering group to provide autonomous design, analysis, technical and manufacturing capabilities for any assignment.

Engineering – Carleton

Enriched xenon observatory (EXO)

This year saw the completion of the design and the start of the manufacture of the approximately 54 tonne lead shielding for the experiment. The shield consists of about 130 interlocking blocks and arches. These pieces assemble to form the 12 sided cylinder that encloses the experiment's copper cryostat, which in turn contains the TPC vessel holding 200 kg of liquid xenon. Also, the overhead crane for assembling the shield and the experiment was installed in the portable clean room designated module 1. The experiment support equipment includes 6 portable clean room modules, self contained air-handling system, cryogenic refrigerators, chillers and dedicated UPS (Fig. 330).

With the move to the final experiment location 640 m below New Mexico at the Waste Isolation Pilot Plant (WIPP), set for late 2006, the engineering design work was begun on experiment infrastructure items. These include a jig to install the 6 tonne cryostat in the clean room through an end wall, a custom xenon bellows pump, and refrigeration feedthroughs that will

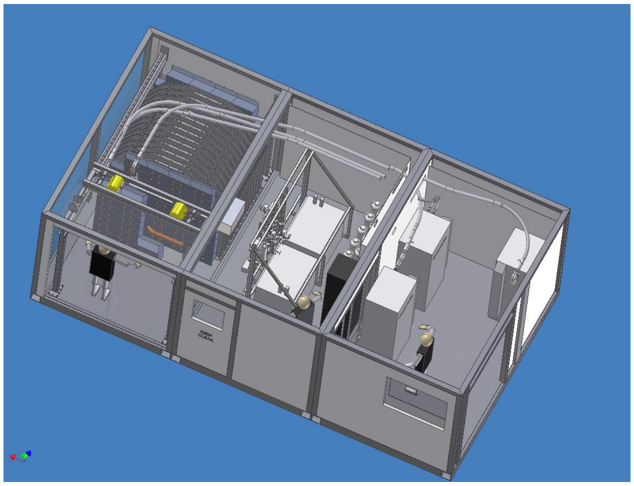

Fig. 330. Model of three of the six clean room modules with experiment equipment.

operate as low as 135 K. As the experiment is assembled and tested at Stanford University, engineering at Carleton will finish designing equipment to move and support the experiment's clean room modules, each weighing between 15 and 30 tonnes, and other equipment underground at WIPP.

PLANNING

This year the Planning group was involved in planning, scheduling, coordinating and expediting several sub-projects for ISAC-II (medium-beta cavities, cryogenics system, ISAC vault installation, high-beta cavities, S-bend transfer line, SEBT, charge state booster); planning and coordinating activities for two shutdowns (December, 2004–April, 2005 and September 21–October 5, 2005); ISAC experimental facilities (TIGRESS, TITAN); and M20Q1Q2 refurbishing.

The Planning group was also extensively involved in preparing manpower and cash flow estimates for the Five-Year plan (2005–2010), annual cost centre analysis for TRIUMF NRC accounts, manpower analysis of overall TRIUMF projects, with detailed manpower histogram for Design Office effort to help allocate the priorities, and help in estimating TRIUMF efforts for the DTL project in India. Extensive effort was spent on a regular basis to plan and schedule the workload in the TRIUMF Machine Shop to meet various TRIUMF priorities and deadlines.

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.

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 where necessary to optimize the scientific output and meet overall milestones.

ISAC-II

Medium-beta cavities All cavities were chemically treated at Jefferson Lab and two cavities were further sent to Argonne for electropolishing, and were received back at TRIUMF in October.

All the tuners and coupling loops were received, fabricated, assembled and tested. All components for the 5 tanks were fabricated and 3 tanks were assembled and tested by the end of the year. The first tank was installed in the beam line in June as an intermediate milestone to test SCB1 rf system, controls, S-bend and other related systems. A detailed PERT was developed for the assembly and installation of various components for rf, controls, diagnostics, power supplies and safety systems in the electrical room. These activities were monitored and coordinated on a regular basis. The test required significant coordination of all groups and was successfully accomplished in July. Problems with vacuum leaks in tanks #4 and #5 were encountered which caused some delay in installing all 5 cryo modules by December.

Now it is planned to have all 5 tanks installed and rf tested by early March, 2006, with an aim to commission with stable beam before April, 2006.

Cryogenics Lockerbie and Hole installed the associated valves and piping from late 2004 to early 2005. Refrigeration and distribution systems were installed in early 2005 and Linde commissioned the overall system in April, 2005.

The helium and LN_2 systems have been fabricated and most of the piping has been installed and should be completed by the end of January, 2006. Temporary lines were installed to the clean room to save on helium costs for rf testing of cryo modules in the clean room.

HEBT S-bend The DB0 dipole was installed in the January, 2005 shutdown as a high priority so that beam could be turned on in ISAC-I while continuing the installation of the S-bend. The remaining beam line components were installed and commissioned by June. Beam commissioning was done with a stable beam through the S-bend and through the first cryo module (SCB1).

SEBT The SEBT beam line PERT was divided into two parts: vault installation and up to first experiment in the ISAC-II experimental hall.

Vault installation The specs, layout and design were completed during the first part of 2005. Stands and other components were fabricated and installation started in September. A conflict was addressed and resolved between the route of the DeMaCo support trolley for the helium piping installation, and the installation of SEBT components. All beam line components were installed and connected by December, except for the diagnostic boxes, which will be installed by the end of January, 2006. Necessary modifications were designed and installed for the vault shielding door to meet functional and safety specifications. Safety had a concern about the shielding, so additional shielding was designed as five packages – for the dipole in S-bend, the beam line window into the vault, the cored holes for the helium piping from the cryogenics room to the vault and to the clean room, and for the holes from the cryogenics room to the vault for the warm LN_2 return line. These will be installed in March, 2006.

ISAC-II experimental hall A detailed schedule was done for all components required for the first experiment in the ISAC experimental hall. The aim is to have all beam line components installed and commissioned by the end of July, 2006 and beam to the experiment in August.

ISAC-II safety system expansion A schedule was done and regularly updated to identify and track the progress of the systems required to complete this project. It required extensive effort from the Electrical Services group to install conduit and cabling for the radiation monitoring system and area lockup system. A test is planned for January, 2006 that will require extensive coordination between the Safety group and various other TRIUMF groups.

High-beta cavities A feasibility study is being done to see if we should build a facility at TRIUMF to chemically treat the cavities on site rather than sending them out to Jefferson Lab. If approved, the facility could be ready for operation in the beginning of 2007.

Two stainless steel and two Nb prototype cavities are being fabricated by a BC company and will be tested and evaluated in May, 2006. When this is completed specifications can be finalized and an order for all 20 cavities will be placed. The plan is to test all three cryo modules for the high-beta system and prepare to install in early 2009.

Charge state booster Tests and optimization on the test stand continued through 2005. After reviewing various options, it was decided to install the CSB system in the mass separator room, implying that beam will have to be off due to restricted access to the electrical room. Therefore, to optimize the installation schedule, it was decided to install CSB in the mass separator room in 2 phases. The first phase starts in January, 2006 with the installation of electrical and mechanical services and other infrastructure. Some stands may be installed if possible. The installation will be completed in the second phase in the January, 2007 shutdown.

TIGRESS

Design of the overall superstructure, stands and components for the remaining 4 detectors has been ongoing throughout the year. The beam line components will be designed and fabricated with an aim to be ready for the first experiment with 2 detectors by the end of 2006, and preparation to install more components in January, 2007 ready for experiments with more detectors in the fall, 2007.

TITAN

The TITAN platform was installed in place during the January, 2005 shutdown and basic services have been installed during the year. Tests on the rf cooler in the proton hall continued and the RFQ support structure was fabricated and installed on the platform. It is planned to install the cooler on the platform in April, 2006. The EBIT is being fabricated, assembled and tested in Heidelberg, Germany, with the plan to be ready to ship to TRIUMF in the spring, 2006. The Wien filter will also be shipped to TRIUMF in the spring, 2006 from McGill. Optics for the transfer beam line have yet to be finalized, at which time design of the beam line components and support structure will continue. The Penning trap superconducting magnet was delayed to 2006. The overall plan is to be able to install all the components on the platform as they arrive and be ready for the first experiments by the end of 2006.

Actinide target tests

A task force was formed to define the overall project scope with an aim to do preliminary tests and prepare a safety report for CNSC to get a licence to do tests with RIB. A work breakdown structure was developed and the major sub-projects included: alpha monitoring system, hot lab and target preparations, and hot cell modifications. Project progress was very slow in 2005 due to the longer time required to answer many outstanding questions in order to start proper engineering conceptual design. Various concepts were developed and will need detailed reviews and analysis. The aim is to organize a workshop in the spring, 2006 to develop the specifications and a realistic plan by summer, 2006.

Febiad

Higher priority was assigned to this project towards developing new targets and ion sources. Extensive work was done in the Design Office and Machine Shop on the target assembly jigs, Febiad source and target assembly, services tray, TM4 modification and other associated components. The aim was to carry out the development work and test the Febiad source by the end of 2005. However, due to technical problems in testing the source successfully to meet specifications, modifications were made and tests will continue in January. The plan is to install the Febiad source on TM4 and commission it by March, 2006 with an aim to be ready for experiments before summer, 2006.

T2K

A detailed work breakdown structure (WBS) has been drawn up for this project to identify all the subprojects and work packages to be done to complete this project. The main components are: accelerator, OTR and T2K tracker. TRIUMF will be actively involved in the T2K tracker, which includes: basket, fine grain detector (FGD), TPC (3 modules), and the water cooling system. The concept design for TPC is in progress at the University of Victoria by Dean Karlen, and the TRIUMF Detector group was actively involved in the conceptual design of the FGD.

KOPIO

Among external projects at TRIUMF, KOPIO started with a high demand for TRIUMF resources in the Design Office and detector facilities. A detailed WBS was prepared to design and build the KOPIO prototype 4 and vacuum chamber. Extensive effort in the Design Office was spent on the conceptual designs. However, due to funding problems, this project was cancelled and the Design Office efforts were diverted to other high priority projects.

2C

Due to several water leaks and other operational problems with the 2C solid target facility system in 2004, it was decided to upgrade this system. The project included: target, mechanical system, cooling package, controls, diagnostics, double window, and hot cell modifications. This project was handled in collaboration with the Applied Technology group. Extensive design work was done in the Design Office and components were fabricated in the TRIUMF Machine Shop, with an aim to install the upgraded system in the January, 2006 shutdown. However, due to delays in testing the critical components in the mock-up, it was decided to make the necessary modifications with an aim to do full functionality tests in the mock-up by April, 2006 and prepare the system for installation in the cyclotron vault in January, 2007, or earlier if possible.

M20

Due to high dose, the aim was to test all critical components by December, 2004 to be ready for installation in the January, 2005 shutdown. However, due to delays in assembling the mock-up, it was decided to postpone the installation of M20 front end improvements to the January, 2006 shutdown. All components were fabricated to expedite the work flow and minimize the radiation dose required for this installation.

Shutdown Activities

There were two shutdowns during the year: the winter shutdown (December, 2004–March 31 for ISAC beam production, beam to proton therapy and PIF, and to May 4 for BL1A), and a fall mini-shutdown (September 21–October 5 for ISAC and to October 12 for BL1A).

Winter shutdown

Shielding blocks were removed from BL1A on January 3–4. Major jobs completed by the Remote Handling, Beam Lines, Vacuum and Diagnostics groups in the meson hall included: 1AQ9 repair, 1AQ10-11 (repaired thermal switch and water leak), 1AQ12-13 (inspected and repaired radiation damaged dc cables and control cables), 1AVA8 (installed new seals, spring eye replaced), M15VA1-VA4 (found leaking ferro fluidic on slits box #3 and #4), M9BQ3,4,5 (removed and Q3 mapped), M9 beam blocker (seal fixed), T1-2 water package and target MRO, M13B1 NMR probe work, 1AQ15 back flush, BL1A exhaust work, and 1AM10 (repaired vacuum leak).

In the vault, the cyclotron lid was not raised until January 17, to allow sufficient cool down. During this time, work was done on the elevating jacks maintenance (station #7 and #8). The lid was then up for over five weeks until February 22. Some of the major jobs completed in the cyclotron tank include: HE3 (new head and track), periscopes work, extraction probe work (new foils on 1A, 2A, 2C4), MRO on LE2 and 2C extraction probe, LQ2,3,4 (replace chore pads), resonator adjustments (4U10, 2U10, 2L10), correction plates and thermocouples MRO, rf coupling loop leak repair, cryo pump #2 (fix leaky valve and cryoline), repair tank south turbo leak and leak check cryo #5.

In addition to the jacks maintenance work, some of the other major jobs in the vault included: inflector MRO, correction plates cabling replacement, rf transmission line (replaced matching section from station 1 to cyclotron), installed safety rails for 1A, 2C and cyclotron stairs, and vault crane inspection and MRO.

The major jobs completed for ISAC included: ITW module access area MRO, install TM2 in ITW (to check for future operations), ITW (install TM1 with Ta target), repair and test water leak in TM3, ITE (install TM2 with SiC high power target), and OLIS MRO work. Several maintenance jobs related to ISAC-I rf systems included: DTL5 amplifier was upgraded to increase output power from 24 to 30 kW, modifications were done to improve DTL cage safety interlock, eight DTL amplifiers were upgraded to incorporate remote amplifier controls, RFQ ancillary cooling circuits were refurbished to incorporate water flow controls. The dipole DB0 was installed for the HEBT S-bend beam line. The TITAN platform was designed, fabricated and installed along with the basic services by March.

The original beam production to ISAC was scheduled for March 16, but was delayed to early April due to vacuum leaks in the cyclotron, which required raising the lid. At first the leak was suspected in LQ3, but was eventually traced to UQ3. It took a long time to confirm the exact location. On March 18, the leak was found to be in 3U6. The upper trolley had to be retro fitted, mock-up trials done and the resonator removed over the weekend. The lid was lowered by March 24, and it was baked and pumped over the Easter weekend. Beam injection occurred on March 31. The total dose incurred in this shutdown was 168 mSV distributed over 112 workers. Five people went over 4.0 mSV.

Fall mini-shutdown

1A was shut down from September 13–October 12. The major job completed in the meson hall was back flushing and checking the 1AQ15 triplet. Other jobs completed in the meson hall included: changing 1A triplet flow meters, drain and refill T1 and T2 cooling packages, and repair M20Q1 water leak (Hanson coupling).

The cyclotron lid was not raised this shutdown so there was no work in the tank. In the vault the major jobs were: rebuild CuALCW pump, B20 MRO work, replace 2A turbo pump, probes MRO (O-rings near 2AVM1, Ex1 foils, check WCP water flow, install 2C4 harp monitor), test UPS system, and rf MRO. The total dose incurred was minor in this shutdown because the lid was not raised and 1A triplet back flushing did not require uncovering the area and the work was done from outside the high radiation field area.

2A was shut down from September 21–October 5. The major jobs completed include: laser alignment tests (required installation of laser power meter at TM2 in ITW), install SiC target on TM2, 19F tests to polarizer, reconfigure OLIS for Mg beam, and install RFQ turbo shields. There was also MRO work done in the target hall, ITW, LEBT and MEBT.

DESIGN OFFICE

The ISAC division received the majority of billable hours during 2005, ISAC-II leading the way with the component details of the SCB2 (production) medium-beta cryomodule, the cryogenic system to deliver LHe (from refrigerator to cryomodules), and LN_2 distribution sub-systems. The SEBT beam line in the accelerator hall which will deliver beam to ISAC-II experiments was designed and manufactured and is currently being installed, as are the services for this beam line. Safety requirements including the redesign of the 30 ton shielding door mechanism were concluded. Preliminary design commenced on the high-beta cavities and cryomodules, projected to replace the temporary SEBT section in 2008. Design is proceeding on the TIGRESS 12 detector array after design of the second prototype was concluded. Target development continued in several areas including actinide target fabrication, surface source modifications, the Febiad target assembly and MYSTIC on-line ECR. ISAC-I MRO continued with upgrades to OLIS, LEBT, RFQ, diagnostics and tuners. DRAGON and TUDA experiments received small upgrades and proposals were developed for the installation of TITAN vertical LEBT and RFQ, the charge state booster in the mass separator area and for beta NQR above the polarimeter station. Development of CSB extraction continues. (Total ISAC division = 57% or approximately 8714 hours.)

TRIUMF's main program continued with a proposal to upgrade the 2C solid target facility. This was designed and built and is currently undergoing pre-installation tests in the proton hall. The cyclotron HE probe redesign is undergoing tests in the probe area, the LE probe head underwent a mass reduction exercise and designs were approved for a 300 keV emittance scanner and wide band extraction head. Cyclotron rf upgrades for the PA hairpin inductor, transmission line and rf power distribution were completed. Beam line upgrades were designed for M20 Q1/Q2 and the 1A triplet. (Total main program = 28% or approximately 4272 hours.)

External projects continued with the AGS Brookhaven upgrade and kicker design; KOPIO prototype4 and vacuum chamber; the J-PARC beam monitoring station and a collaboration with Arup Bandyopadhyay on DTL design. (External projects down slightly from last year = 12% or approximately 1906 hours.)

Photographic and visual art services continue in support of seminars, conferences, and publications, such as the Annual Financial and Administrative Report and material for TRIUMF's corporate presentation and Outreach Program.

SolidWorks 3D modelling software has been adopted as the platform of choice for all TRIUMF users and was expanded to 17 seats during 2005, including one seat of COSMOS PRO. The close relationship between software for engineering analysis (COSMOS), CNC machining (MasterCam) and SolidWorks is proving to be both powerful and efficient. Network 2D AutoCAD is available through PC Support.

MACHINE SHOP

Over the past year the Machine Shop continued to go through a re-structuring process that entailed the following:

1. The replacement of retirees.
2. Restructure the shifts in order to maximize efficiency.
3. Purchase a third larger capacity CNC vertical machining centre. All three CNC machines have already had a major impact on the quality, quantity and versatility of work produced in the shop.
4. The recruitment of another highly skilled technician who is an experienced programmer/machinist using software such as MasterCam and SolidWorks.
5. Continue to support local industries by contracting out work that is beyond the capacity of the TRIUMF Machine Shop.

Major projects worked on included the ongoing Febiad development, surface ion source development, 2C solid target facility, 25 MHz rf cavity and cryomodules #4 and #5. The Machine Shop kept pace despite a heavy workload and the continual shortage of manpower due to retirements and lag time as a result of the recruitment process.

The Machine Shop continues to support local industries by sub-contracting out work that is beyond the capacity of the shop or large volume components that are extremely time sensitive in nature. Specialty companies such as anodizing, electro-polishing and copper plating amongst others are also supported.

Table LIII demonstrates the utilization of the Machine Shop by TRIUMF divisions and other user groups.

The goal for 2006 is to continually fine-tune the Machine Shop's efficiency. As designs are becoming more complex it is becoming increasingly difficult to machine these components on manual machines and, consequently, CNC machining is the only option (Fig. 331).

Table LIII. Machine Shop utilization.

CERN	0.04%
Cyclotron operations	8.74%
Cyclotron refurbishing	2.32%
Science	15.61%
ISAC development	13.90%
ISAC operations	7.27%
ISAC-II	39.18%
NSERC	1.11%
Affiliated institutions	9.88%
Miscellaneous (CFI)	0.30%
Site infrastructure	0.20%
Accelerator Technology and Administration	0.02%
AGSUPER and Royalty	1.20%

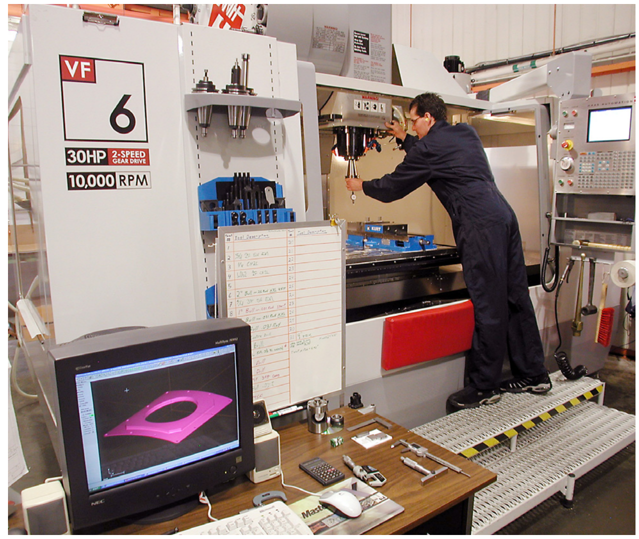

Fig. 331. VF-6 CNC machine.

BUILDING PROGRAM

During the year the building department was involved in the following activities:

- Design and management of minor construction projects
- Structural design and engineering review
- Construction review
- Architectural design
- Management of maintenance and repair work
- Management of landscaping work
- Drawing library maintenance and services

Design and management of minor construction projects

The department was involved in a number of various construction projects around the site. Projects like TITAN installation platform, cryomodule service platform, and Machine Shop re-roofing were some of the bigger ones.

Structural design and engineering review

Structural design was done for a variety of structures including the cryomodule service platform and the nitrogen tank slab, and the seismic restraints were also designed for a number of small structures. Engineering review was performed for the various small structures like steel frames, concrete foundation slabs, cranes, etc.

Construction review

Besides the reviews of minor construction projects managed by the department, the construction reviews of TITAN RFQ mounting fixture in the ISAC-I building and installation of router room roof top units were also done.

Architectural design

Architectural design was done for a few renovation projects and new small buildings. Trailer A renovation, and MESA basement modifications were just some of them. The building department also worked on the architectural re-design of the lobby and café areas in the main office building.

Management of maintenance and repair work

During the course of the year, there was the usual amount of maintenance and repair work at various TRIUMF buildings and around the site including interior and exterior painting. The parking lot was upgraded and some roads were repaired.

Management of landscaping work

The Building department continued with the management of the landscaped areas on site. There is an annual contract for landscape maintenance and related landscape projects.

Drawing library maintenance and services

The department continued with organizing and updating the site and buildings drawing library, and provided services for creating new and issuing existing drawings to many in-house clients. ISAC-II control room 3D drawings and printer location plans were some of the projects from this group.

ELECTRONICS SERVICES

General

Electronics Services continued the tradition of assisting virtually all groups and experimenters on the site as well as our international collaborators during 2005. The diverse and experienced staff of Electronics Services was able to supply solutions to virtually all requests presented to the department, from complex data acquisition systems and precision equipment required by TITAN, specialized wiring harnesses for SCRF, all manner of support for PCs to repairs of undocumented foreign equipment. Electronics Services personnel also assisted in the site reorganization task force, actively participated in recycling, assisted TRIUMF Stores in many technical and supply issues and wrote a report detailing problems with the aging cables in the cyclotron vault that has initiated a major cable replacement program.

Electronics Shop

ISAC-II required major support this year from the shop. Hundreds of cables were requested, sometimes with very little notice and all were delivered on time. These cables included rf, HV, vacuum and SCRF tuner cables as well as many specialized internal cables for the cryo modules. Numerous interface modules were also built up for equipment in the ISAC-II power supply room. Work in the vault this year included replacement of rf phase probe cabling as well as replacement of a group of correction plate cables. A number of emergency repairs in active areas were carried out during maintenance days. Support for CERN as well as the MuLan Kicker project was ongoing for about 10 months of the year. Other customers in the shop included 8π, RF, Diagnostics and Controls groups, μSR, TWIST, LADD, TIGRESS and TITAN. All of these groups had special requests ranging from special high temperature ion gauge wiring to polished fibre optic cables. More than 100 site standard delay lines were manufactured for TRIUMF Stores. The Electronics Shop continues to assist the library and this year gave ongoing support to reorganize the library space with new shelves and re-populating all existing books and journals.

Electronics Repair Shop

For the Electronics Repair Shop, equipment in the Machine Shop was a significant area of repair effort, including overhauling the cooling pump for the Mazak lathe, repairing the readout for another lathe, replacing the motor driver unit for the sharp milling machine, repairing their leak detector as well as the Hobart welding machine. Other repair and calibration work involved a total of 165 electronic devices, including: 10 monitors and terminals (6 monochrome and 4 colour types), 48 power supplies (13 NIM units, 16 CAMAC units, 9 high-voltage units, and 10 various other units), 51 nucleonics modules (48 NIM and 3 CAMAC modules), 11 test and measurement instruments, and 45 other miscellaneous items of electronic equipment (mostly various controllers and experimental support devices). Also a large amount of obsolete electro-mechanical devices were processed through the recycling program, and some site cabling was installed.

Technical Support

Technical Support spent a large fraction of time this year in the design and installation of five servo systems for the ISAC-II cryo module tuners. This project included planning the packaging of the supplied servo amplifiers in equipment racks, and designing a control panel and interface board between the servo amplifiers and the controlling computer. All the cabling was specified, ordered, manufactured, installed and tested with direction from this department. For the μSR group, PC boards for the standard photomultiplier tube base were both reverse and re-engineered and properly documented. Sixty fully assembled and tested units were supplied. As these units are moderately complicated to test, a special test jig was proposed to the μSR group to allow them to test PMT bases easily. Work was started on this test fixture based upon a stand alone computer integrated with a compact HV module. An SWR trip circuit for a rf amplifier was also designed and built for the μSR group. Some circuit design work to support the TITAN experiment was started late in the year. The first project was a high performance multi-channel summing amplifier to mix various groups of signals to drive the MPET trap electrodes. Work also started on some precision 200 V amplifiers that will be used to drive other Penning trap electrodes. There are always a number of small jobs being worked on such as the development of a VSWR monitor unit for the RF group. Support was given to the Electronics Shop, TRIUMF stores, other members in our group, as well as numerous experimenters.

PC Support/Desktop Services

This department continues to provide service for most of the PC hardware at TRIUMF along with Windows operating systems and Windows applications. General responsibilities include: recommending PC hardware as well as notebooks and servers, diagnosing and correcting faults in hardware and applications, maintaining Windows servers for multiple purposes, providing backup services for PCs and the Windows servers, controlling the centralized virus and spyware service, stocking spare parts, assisting with network, e-mail and printer connection issues, and contributing to the computing security initiative. The migration from the Novell servers to the Windows 2003 server structure was completed this year. With four servers within the domain, a high level of redundancy and reliability has been achieved. Approximately 165 user accounts were transferred over and another 20 added. Sixteen TRIUMF departments now rely on these Windows servers for their data storage and networked application needs. Much attention is still given to the virus and spyware threats. About 400 threats were detected and blocked at the desktop level. The TRIUMF e-mail scanner caught many thousands. The number of Windows PCs that became infected has dropped from the previous year. There has been considerable review of products and procedures to improve the security of Windows PCs at TRIUMF. This department is extensively involved with the TRIUMF computing security committee which strives to improve security yet maintain the flexibility that so many TRIUMF users demand of their PCs. The PC hardware standards that have been defined by this department are being adhered to and thus purchasing problems, hardware service calls, and compatibility issues have been reduced. The recommended PCs are sufficient for most uses at TRIUMF for office applications and 3D modelling. Help desk activities have shifted from the 2004 levels. PC hardware tasks have decreased by 5% to 350. Software related tasks decreased 28% to 366 and network related tasks have increased by 151% to 269. The number of users on this department's servers has increased 13% to 184. The PC backup service is utilized by 54 PCs which is down from 60 last year. The full backup load has increased by 24% for the PCs to 240 GB and the server backup is 222 GB, which is a 124% increase. The networked AutoCAD pool is now accessed by 87 users, which is up from 76 users last year.

Experimental and Target Technical Support

A large fraction of this year's effort was in the design, assembly, wiring and installation of five ISAC cryo module tuner cabinets. In the ISAC experimental area, the 8π safety interlock system was completed and commissioned. International support went to the on going testing and modifying of a variety of components related to the MuLan Kicker project. General help was given to various groups and individuals including assistance in a number of cabling installations.

High Level Software Support

A manipulator arm for calibrating the front Ĉerenkov detector for the long baseline neutrino oscillation experiment was completed and installed at KEK. The arm worked much as expected, although some position sensors failed due to water ingress in the sensor encapsulation. A poster was submitted to the IEEE-NPSS Real Time Conference describing the manipulator arm and the control system. The associated paper was submitted to Transactions on Nuclear Science and was accepted for publication. Two other papers submitted to TNS for review were edited.

A number of multi-month projects were completed including: a new version of the TIGRESS liquid nitrogen fill system, controls for positioning the new high energy probe in the cyclotron tank, several motor channels were installed in ISAC (OLIS) and ISAC-II (DSB, SCB) for beam diagnostics and the first of two new 400 kV supplies was modified to integrate into the existing M15 separators high voltage power supplies.

Joint coordination with DAQ personnel started on the development of the TITAN data acquisition system. The system was blocked out, several drawings created, much research was made on suitable components, and some stability tests on power supply control were completed. Support was provided to PIF/NIF/PT for positioning monitors in the beam area, and for assisting visiting experimenters. A new cryostat positioning system was assembled and tested for M9B.

An initial design was completed for the optical transition radiation beam profile monitor data acquisition system for the T2K neutrino beam line at J-PARC. Cost and time estimates were made to include in the grant request submitted to NSERC. An initial proposal was submitted for testing the properties of foil samples for the OTR beam profile monitor using the TRIUMF 500 MeV facility. An initial design for a motorized system to position parts of the T2K TPC chamber in the M11 beam line for testing and calibration was submitted.

A measurement system was developed using image analysis to measure wire positions on wire planes for the TWIST detector. The magnet survey system was re-designed to replace the existing system running on aging computer equipment. These were both developed with a student during the summer. In addition to all the major projects carried out this year, there is constant assistance given to site personnel, visitors and students. The incumbent in this area also acts as a site First Aid Attendant as well as a tour guide.

Site Communications

Site communications worked in a wide variety of areas this year. Early in the year, many people were reporting problems in maintaining reliable high-speed connections in a number of areas on the site. This was traced to cables that had been supplied to TRIUMF from an outside vendor. The repair required the replacement of 450 cat6 patch cables while minimizing the disturbance to the site. A major task this year was the assistance given in helping with the conversion of TRIUMF House to a VOIP phone system. This task involved cable installation at TRIUMF as well as complex changes to third party patch panels for the 46 phones at TRIUMF House. Other communication work this year included the installation of 25 cat6 cables and 6 Ethernet switches in the ISAC power supply room as well as 16 more Ethernet cables to the ISAC-II control room. Assistance was given to the PC support group in migrating servers from Novell to Windows. Help was also given to the Electronics Shop in preparing drawings for the Machine Shop and assembling a number of power supplies.

ELECTRONICS DEVELOPMENT

ISAC-II control system design and installation as well as support for ISAC-I accounted for the majority of the group's effort this year. Several modules were constructed for ISAC and development continues on the data acquisition board (DAB) for CERN. One member of the group, as part of the quality assurance task force, continued to expand the TRIUMF QA program. Two members served on two separate task forces examining a reorganization of TRIUMF. Three members of the group attended the International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS) in Geneva, Switzerland. The group received 12 Requests for Engineering Assistance (REA), 3 of which were for major projects: S-bend controls, cryomodule controls, and SEBT controls. In addition 30 Engineering Change Requests (ECR) were received.

ISAC Support

The group continued to maintain and upgrade the ISAC-I control system, as well as perform all the hardware installation for the ISAC-II control system. Included in that are the helium refrigeration and distribution systems. This work, with emphasis on the software and system aspects, is described in detail in the ISAC Controls section of this Annual Report.

As part of the ISAC-II expansion, 81 CANBus controllers were built and installed in the S-bend and SEBT beam lines. Five of the new RS232 serial CANBus controllers were installed for the solenoid power supplies in the cryomodules. Four hall-probe modules were built and installed for the ISAC HEBT S-bend magnets.

Continuous modifications occurred in the ICB target conditioning station for the testing and development of the Febiad ion source.

A controller to provide fast beam switching between the β-NMR and β-NQR experiments was designed and installed. This controller module also allows control of the IMS kicker via fibre from anywhere in the ISAC-I experimental hall.

Support for TITAN continued. The development of a beam integrator module synchronized to the pulsed beam was required for emittance scans. In addition, the group provided engineering support for the design of the TITAN facility.

CERN Collaboration: LHC Orbit System

Firmware development for the DAB-64x Rev0 VME module continued throughout the beginning of 2005. CERN provided the latest version of the CES RIO3 8064VME crate controller, which was remotely configured from CERN to run in the TRIUMF environment. A VME access problem reported by CERN staff was reproduced and a solution was forwarded to CERN.

In April, two members of the Electronics Development group travelled to CERN to test the DAB-64x firmware functions and check for hardware compatibility with the new VME-64x acquisition system. DAB-64x hardware tests were completed successfully for the wide band time normalizer (WBTN) mezzanine, the individual bunch measurement system (IBMS) mezzanine, and the beam loss monitor (BLM) mezzanine. A further revision of the DAB-64x module was required to provide additional hardware support for the IBMS and BLM mezzanines. Ten DAB-64x Rev1 modules were manufactured and assembled at CERN; two modules were sent to TRIUMF for firmware development. Minor additional printed circuit board modifications were requested by CERN to improve test coverage of the JTAG test jig during module manufacture. Two DAB-64x Rev2 modules will be delivered to TRIUMF in January, 2006. Production of 1850 DAB Rev2 modules is scheduled for completion by December, 2006 (see Fig. 332).

Engineering Support

The group provided engineering support as members of technical committees, design review panels, QA task force and as members of the task forces for the reorganization of TRIUMF. The group continues to provide electronics engineering assistance to other groups at TRIUMF.

As part of a TRIUMF agreement to provide ^{18}F to the BC Cancer Agency, a hot cell and associated exhaust system was installed in the TR13 area. The group committed to providing a control system to meet the requirements of a nuclear exhaust system within a short time frame. A PLC based system was designed, built and installed in less than two months. This project required significant organization and task flexibility in order to cope with pre-approved vacations and associated transfer of responsibility between personnel.

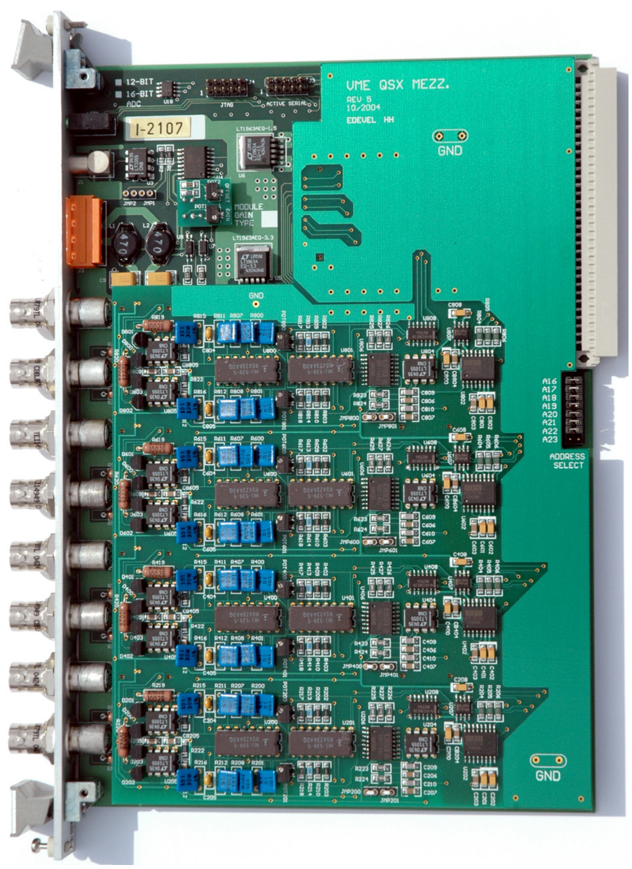

Fig. 332. VME module for beam current measurement at ISAC.

Assistance for the Magnet/Kickers group continued with engineering and prototyping work for the International Linear Collider kicker project, as well as modifications to the overcurrent interlock board for the PSI Kicker.

A PID controller module was designed and built for laser stabilization control of the laser ion source, as well as an rf driver module for the laser RFQ ion source.

Experimental Support

Six high speed fan-in/fan-out amplifiers were delivered to μSR. These sum 4 input signals, bandwidth limit the sum to 200 or 800 MHz and provide 2 output signals.

A “Pol Synth” module was constructed with modified firmware to provide phase aligned rf outputs up to 70 MHz for the μSR group. Design of a Pol Synth II module was started, as the direct digital synthesizer (DDS) chip in the original design cannot provide the required phase stability between channels during frequency sweeping. The possibility of performing all the digital functions of the DDS chip in a Stratix FPGA is being explored.

A low noise 60 V bias supply for the T2K avalanche photo detectors was designed and prototyped.

For TUDA, a high voltage interlock box was built.

A prototype 1 kHz – 1 MHz power amplifier was built for the β-NQR facility. A higher current version with control and protection functions is in the design stage.

A current to voltage pre-amplifier with selectable gain was delivered to Jefferson Lab as part of the Q_{weak} experiment collaboration. An initial production run of 10 units is under way. Work has started on an 8 channel, 18 bit, 500 kSample/sec VME ADC/summation module for the same collaboration.

Beam Lines Support

Paddle wheel flow sensors for magnets Q14, 15, 16 on beam line 1A were integrated into the T1 control system using the CANBus flow monitoring module.

New Hardware Designs

Several new modules were designed and built during this year:

- Firmware was written for our CANBus serial controller to support a FUG HV power supply in OLIS and an AMI power supply for the superconducting solenoid in the ISAC-II cryomodules. No modification of the supervisory EPICS interface is necessary since the firmware is written to emulate the standard CANBus power supply controller.

- A single channel CANBus stepper motor controller was developed. This controller will allow single motor installations without the high cost of the existing VME-based stepping motor control system. The controller supports position readback using either an analogue potentiometer or an optical encoder. Two-phase motors with currents up to 5 A are supported.
- A 32-channel VME output module was designed to replace the combined input/output VME modules used in output mode in the ISAC control system. This module provides better fault tolerance than the original. The installed VME I/O modules were recovered for use as input modules in ISAC-II.
- The radiation fields in the IMS area require a move of the VME processor out of the VME crate on the HV platform. A search for a VME-VME interface failed to locate a suitable commercial unit and an in-house design was started. The specifications are currently being drafted.