TRIUMF-ISAC GAMMA-RAY ESCAPE SUPPRESSED SPECTROMETER (TIGRESS)

TECHNICAL PROGRESS REPORT

August 31, 2006

TIGRESS COLLABORATION

P. Amaudruz[1], C. Andreoiu[2], A. Andreyev[3], R.A.E. Austin[4], G.C. Ball[1], D. Bandyopadhyay[2], C. Barton[5], J.A. Becker[6], L. Beaulieu[7], A.J. Boston[8], H.C. Boston[8], P. Bricault[1], W. Catford[9], A.A. Chen[10], J. Chen[10], R.S. Chakrawarthy[3], R. Churchman[1], F. Cifarelli[1], D. Cline[11], R.J. Cooper[8], D.S. Cross[3], D. Dashdorj[12], J.M. D'Auria[3], G.A. Demand[2], M.R. Dimmock[8], T.E. Drake[13], L. Erikson[14], P. Finlay[2], S. Fox[5], B. Fulton[5], A.T. Gallant[4], P.E. Garrett[2], K.L. Green[2], A.N. Grint[8], G.F. Grinyer[2], G. Hackman[1], L.J. Harkness[1], A.B. Hayes[11], R. Kanungo[1], W.D. Kulp[15], A. Laird[5], K.G. Leach[2], G. Lee[1], C. Leroy[16], R. Maharaj[1], J.-P. Martin[16], C. Mattoon[14], C. Mercier[16], D. Morris[1], A.C. Morton[1], L. Nelson[8], O. Newman[1], P.J. Nolan[8], E. Padilla-Rodal[1], E. Paul[8], C.J. Pearson[1], A.A. Phillips[2], M. Porter-Peden[14], J.J. Ressler[3], R. Roy[7], C. Ruiz[5], F. Sarazin[14], H. Savajols[17], M.A. Schumaker[2], D.P. Scraggs[8], N. Starinsky[16], M. Subramanian[1,3], C.E. Svensson[2], J.C. Waddington[10], R.W. Wadsworth[5], J.M. Wan[3], A. Whitbeck[11], S.J. Williams[1], J. Wong[2] and C.Y. Wu[6]

[1]TRIUMF, Canada
[2]Department of Physics, University of Guelph, Canada
[3]Department of Chemistry, Simon Fraser University, Canada
[4]Department of Astronomy & Physics, Saint Mary's University, Canada
[5]Department of Physics, University of York, United Kingdom
[6]Lawrence Livermore National Laboratory, United States
[7]Départment de Physique, Université Laval, Canada
[8]Department of Physics, University of Liverpool, United Kingdom
[9]Department of Physics, University of Surrey, United Kingdom
[10]Department of Physics & Astronomy, McMaster University, Canada
[11]Department of Physics, University of Rochester, United States
[12]Department of Physics, North Carolina State University, United States
[13]Department of Physics, University of Toronto, Canada
[14]Department of Physics, Colorado School of Mines, United States
[15]Department of Physics, Georgia Institute of Technology, United States
[16]Départment de Physique, Université de Montréal, Canada
[17]GANIL, France

Introduction

The TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer (TIGRESS) is a state-of-the-art new γ-ray spectrometer being developed for use at TRIUMF's Isotope Separator and Accelerator (ISAC) radioactive ion beam facility and, in particular, at its upgrade to higher-mass and higher-energy radioactive beams, ISAC-II. Construction of TIGRESS is being funded through an \$8.06 M NSERC Major Installation Grant over the six-year period FY 2003-08. The current document reports technical progress related to TIGRESS during the September 2005 – August 2006 period. The focus for developments of the past year has been to prepare two complete TIGRESS detector systems for a first physics experiment with accelerated radioactive ion beam from ISAC. This experiment was successfully conducted July 27 – August 15, 2006 at ISAC-I and represents the achievement of a major milestone in TIGRESS implementation.

1. TIGRESS 32-Fold Segmented HPGe Clover Detectors

TIGRESS will be comprised of twelve 32-fold segmented clover-type HPGe detectors. Each TIGRESS detector consists of 4 individual germanium crystals, each of which is segmented 4 ways longitudinally and 2 ways transversely on its outer electrical contact, providing 8 outer contact signals plus the full-energy central core contact signal. The result is a total of 36 signals from each clover detector. A prototype of this new detector design, funded jointly by the Canada Foundation for Innovation, the Ontario Innovation Trust, TRIUMF, and the University of Guelph, was purchased from Canberra-Eurisys and underwent extensive performance testing in 2003 and 2004. Following this successful demonstration phase in which the prototype detector was demonstrated to meet all of the performance requirements of the TIGRESS project, a tendering process in the summer of 2004 culminated in the signing of a contract with Canberra-Eurisys for the manufacture and delivery of the 12 production TIGRESS detectors. During the past year, four of these production HPGe detectors (referred to as G.1, G.2, G.3, and G.4) were delivered to the TIGRESS collaboration. Upon delivery, each detector underwent an extensive 3-month acceptance testing process. During an initial 30 day acceptance testing phase, basic properties such as detector resolutions and efficiencies are measured. This is followed by a 60-day testing period on the TIGRESS precision scanning table in which a complete scan of the detector is performed with a collimated ^{137}Cs source to study position-dependent detector responses and crystal orientation effects, as well as time consuming coincidence scan measurements to obtain signal waveforms at three-dimensionally localized interaction points within the detector. The arrival of four production detectors at TRIUMF during the past year thus resulted in effectively continuous HPGe detector acceptance testing.

TIGRESS detectors G.1 and G.2 were originally delivered to TRIUMF in March and July of 2005, respectively. However, microphonics sensitivity for some of the contacts in these detectors, as well as transient crosstalk between the signals of various contacts led to these detectors being returned to the factory for modifications prior to the September 30, 2005 NSERC technical review of TIGRESS. Solutions to both of these issues were identified and implemented by the manufacturer shortly thereafter. Dr. G. Hackman of TRIUMF visited Lingolsheim, France on October 6-12, 2005 for a preliminary factory acceptance test prior to return shipment of the detectors, and detectors G.2 and G.3 (which was the first to be modified) were delivered to TRIUMF on November 12, 2005.

The initial 1-month acceptance tests for G.2 and G.3 were performed in parallel during November and December 2005. For G.2 all four crystal relative efficiencies exceeded the ≥ 38% specification (with the average efficiency 39.7% also above the ≥ 39% specification), all four core contact resolutions were significantly better than the ≤ 2.35 keV FWHM at 1.332 MeV specification (with the average 1.96 keV also well below the ≤ 2.30 keV specification), and all 32 outer contact resolutions were better than the ≤ 3.20 keV FWHM at 1.332 MeV specification (with the average 2.59 keV well below the ≤ 3.20 keV specification). Similarly for G.3, all four crystal relative efficiencies met or exceeded the ≥ 38% specification (with the average efficiency 39.4% also above the ≥ 39% specification), all four core contact resolutions were better than the ≤ 2.35 keV FWHM at 1.332 MeV specification (with the average 2.12 keV also well below the ≤ 2.30 keV specification), and 30 of 32 outer contact resolutions were significantly better than the ≤ 3.20 keV FWHM at 1.332 MeV specification. The average resolution of 2.58 keV over all 32 contacts was well below the ≤3.20 keV specification, and the 3.55 keV and 3.60 keV resolutions of the two contacts (Segments 8 of the Red and White crystals) outside specifications were deemed acceptable. Initial acceptance of both production detectors G.2 and G.3 was thus confirmed on December 12, 2005. Detector G.3 was then mounted on the TIGRESS scanning table and detailed singles and coincidence scans performed. The detector passed all performance tests, including greatly reduced crosstalk associated with the new cabling between the FETs and preamplifiers introduced to address this issue, and final acceptance of G.3 was confirmed on February 17, 2006. The following 2-months were devoted to the corresponding scanning measurements of G.2. Again all performance tests were passed, and final acceptance of G.2 was confirmed on April 18, 2006. Following dismounting from the scanning table, the G.2 and G.3 TIGRESS HPGe clover detectors were prepared for use in the first TIGRESS radioactive beam experiment in July-August 2006.

Production HPGe detector G.1 was returned to TRIUMF on February 27, 2006, and initial acceptance testing proceeded in parallel with the scanning of G.2. Again all four crystal relative efficiencies exceeded the ≥ 38% specification (with the average efficiency 41.4% well above the ≥39% specification), all four core contact resolutions were significantly better than the ≤ 2.35 keV FWHM at 1.332 MeV specification (with the average 2.04 keV also well below the ≤ 2.30 keV specification), and all 32 outer contact resolutions were better than the ≤ 3.20 keV FWHM at 1.332 MeV specification (with the average 2.58 keV well below the ≤ 3.20 keV specification). Initial acceptance of detector G.1 was thus confirmed on March 27, 2006. Following completion of the G.2 scanning on April 18, detector G.1 was mounted on the scanning table and detailed singles and coincidence scans performed between April 19 and June 19, 2006. These measurements revealed 3 of the 32 outer contact signals for G.1 with anomalously slow risetimes, and anomalously large crosstalk signals associated with γ-ray interactions in these segments. Following discussions with the manufacturer, a systematic program of swapping preamplifiers between corresponding segments of the various crystals confirmed that the anomalously slow risetimes and large crosstalk signals were associated with particular preamplifiers and not intrinsic to the detector. Further measurements of the preamplifier responses with very fast (1 ns ristime) squarewaves injected into the test inputs of the core contacts also revealed oscillations in the preamplifier outputs for 3 of the 4 crystals of G.1. These oscillations were not observed in either the prototype TIGRESS detector or in the G.1 production detector when its preamplifier response was originally measured in the spring of 2005 prior to the cabling modifications to correct the large transient crosstalk signals. These oscillations are thus almost certainly associated with the change in FET-to-preamplifier cabling, and the decision was taken on August 18, 2006 to return G.1 to the factory to diagnosis and implement a solution to this oscillation issue at the same time as replacing the slow-risetime preamplifiers. When a solution is developed for G.1, it will be applied to G.2, G.3, G.4 and all subsequent TIGRESS detectors.

Shortly after the scanning of G.1 was complete, detector G.4 was delivered to the TIGRESS collaboration on June 26, 2006, approximately 3 weeks ahead of the original delivery timeline for this detector. Initial measurements performed in July 2006 again revealed excellent performance. The relative efficiency of one of the four crystals (Green) was measured to be 36.5(4)%, somewhat below the ≥ 38% specification. The average relative efficiency, 40.2%, over all four crystals was, however, well above the ≥ 39% specification and this was deemed acceptable. All four core contact resolutions were significantly better than the ≤ 2.35 keV FWHM at 1.332 MeV specification (with the average 2.02 keV also well below the ≤ 2.30 keV specification), and all 32 outer contact resolutions were better than the ≤ 3.20 keV FWHM at 1.332 MeV specification (with the average 2.49 keV well below the ≤ 3.20 keV specification). Detector G.4 is currently mounted on the TIGRESS scanning table for detailed singles and coincidence scans in August and September 2006.

While the major focus of TIGRESS HPGe development over the past year has been on hardware acceptance testing and preparation for the first accelerated radioactive beam experiment in summer 2006, the software program of signal simulation for the TIGRESS HPGe detectors has also continued in parallel. In particular, preamplifier response and delay-line cable distortion of the HPGe signals were further investigated. A schematic of the PSC823 fast preamplifiers was obtained from its designer, and a Pspice model generated. The results of this model were compared to the measured response of the core contacts to a 1 ns rise-time step function excitation on the test input. The shape was well reproduced by a simple RC response and the delay-line responses of the 25 ft RG-58 and RG-174 cables used in the tests were also measured. These rise times were <10 ns and, again, well represented by theory.

Looking forward, the next 3 TIGRESS production detectors G.5, G.6, and G.7 are scheduled for delivery in November 2006, March 2007, and July 2007, respectively. The continuous program of TIGRESS HPGe detector acceptance testing is thus expected to continue, and we anticipate 5 or 6 production HPGe detectors to be available for TIGRESS experiments at ISAC-II in the spring/summer of 2007.

2. TIGRESS Compton Suppression Shields

Each TIGRESS HPGe clover detector is surrounded by a Compton suppression shield designed to veto events in which a γ ray Compton scatters and escapes from the HPGe volume without depositing its full energy. These suppressors are formed by three components; the side shield, the back catcher, and the front shield which together comprise 20 optically isolated scintillator segments to provide position-dependent suppression capabilities.

Based on experience gained with a prototype TIGRESS suppression shield, specifications for the production suppression shields were put out for tender and a contract was signed with Scionix Co. on May 5, 2005 for the manufacture and delivery of the 12 production TIGRESS suppression shields. Since December 2005, the first four of these production suppression shields (referred to as

S.1, S.2, S.3, and S.4) have been delivered to the TIGRESS collaboration. Upon delivery, each suppressor undergoes an extensive 2-month acceptance testing protocol including noise thresholds, energy resolution, response uniformity, and rate stability tests for each of the 20 optically isolated suppressor segments (40 PMTs). The TIGRESS suppression shield testing program has thus also been operating effectively continuously, and in parallel with the HPGe acceptance testing program discussed in Section 1, since December 2005.

Suppression shield S.1 was delivered to TRIUMF on December 12, 2005. Testing of this detector was completed on February 12, 2006 and the detector was accepted at that time. During May 9-12, 2006 Dr. D. Quirion of the Canberra-Eurisys factory in Lingolsheim visited TRIUMF to provide training related to the mounting of the production TIGRESS suppression shields to the production TIGRESS HPGe detectors based on mounting hardware designed by Canberra-Eurisys. Suppression shield S.1 was mounted to HPGe detector G.3 in preparation for the July-August 2006 TIGRESS radioactive beam experiment. Technical drawings of the mounting hardware were also provided to the TIGRESS collaboration to allow simple coupling of any suppression shield unit with any HPGe detector, and all further BGO-HPGe mounting will be performed by the TIGRESS collaboration.

Suppression shield S.2 was delivered to TRIUMF on March 12, 2006 and testing of the detector was performed in March and April. While noise performance, energy resolution, and response uniformity were all acceptable, an unexpected rate sensitivity of the gain (changing by as much as 50% between 1 kHz and 20 kHz) was observed for 6 of the 16 PMTs of the S.2 side shield. The side shield component of the S.2 suppressor was returned to the factory on June 2, 2006 and the manufacturer confirmed the unusual rate instability for the PMTs in question. These PMTs were replaced by the manufacturer and the S.2 side shield was returned to TRIUMF on August 1, 2006. It is currently undergoing a full performance retest.

Suppression shield S.3 was delivered to TRIUMF on May 1, 2006. Testing of this detector was completed on June 28, 2006 and the detector was accepted at that time. The S.3 suppression shield was then mounted to the G.2 HPGe detector as the second complete TIGRESS HPGe plus suppression shield system for use in the July-August 2006 radioactive beam experiment at ISAC.

Suppression shield S.4 was delivered to TRIUMF on August 1, 2006 and is currently undergoing its 60-day acceptance testing.

The delivery of the TIGRESS production suppression shields has now caught up with the HPGe delivery and is currently well ahead of schedule (the delivery deadline for S.4 was Oct 15, 2006). Subsequent suppression shields S.5, S.6, S.7, and S.8 are now scheduled for delivery in October 2006, December 2006, February 2007, and May 2007. A full complemented of fully tested TIGRESS suppression shields is thus anticipated for the 5-6 production HPGe detectors expected to be used in spring/summer 2007 TIGRESS experiments at ISAC-II.

3. TIGRESS Digital Electronics

TIGRESS electronics are based on fast (100 MHz) waveform digitization of the HPGe, suppression shield scintillator, and auxiliary detectors signals using ten-channel TIG-10 modules read out by TIG-C collector modules which provide trigger decisions and control communication of the processed data between the TIG-10 modules and the DAQ computers. Both of these modules have been custom designed for TIGRESS and produced at Université de Montréal.

In the past year, the TIG-10 electronics has been upgraded to revision 2.1 and 24 of the new TIG-10-rev2.1 units have been produced. These modules are sufficient to instrument 4 complete TIGRESS HPGe and suppressor systems, or 2 complete HPGe+BGO systems and 120 channels of auxiliary detector. The V2.1 revision was minor and does not change the basic functionality of the TIG-10, but adds new features or improvements: a) common mode chokes on the signal inputs to improve the ground loop immunity; b) 3 software controlled levels of DC baseline to optimise the dynamic range according to the polarity and nature of the detector signal; c) the programmed controlled relays for the dual gain feature have been replaced by two separate ultra low noise front end amplifiers with tri-state enable capability; d) new model of FADC driver chips with lower noise.

The communication architecture was also brought to its full functionality in summer 2006 by implementing the multi-level data collection/trigger scheme required when the number of TIG-10 cards exceeds twelve units. At the same time, a new trigger concept was implemented, replacing the previous lookup table based version. The new trigger uses virtual "logic units" similar to the familiar analogue NIM logic boxes. The virtual units are completely imbedded in the TIG-Cs FPGAs and the "cabling" is, of course, also virtual. All the parameters of these virtual "logic units" (delay, pulse width, masks, enable bits, multiplicity) can be controlled from the run software. This trigger system is still in a preliminary stage but satisfied the requirements for the first run of physics data taking. Extensive effort was devoted to interfacing the complete multi-level TIG-C readout with the TRIUMF MIDAS DAQ standard. All of these developments converged for the first TIGRESS radioactive beam experiment in July-August 2006. In this experiment, 160 channels of TIG-10 digitizer were used to read out both processed data and raw signal waveforms from 2 complete TIGRESS HPGe+BGO systems as well as 40 channels of Si auxiliary detector via 2 slave-level TIG-C cards and 1 master TIG-C module controlling trigger decisions. The system functioned smoothly throughout the 3 week experiment, representing the achievement of a major milestone in the TIGRESS electronics development program.

The complete TIG-10/TIG-C system has now proven to be reliable in actual data taking conditions. Most of the improvements envisioned for the future will be associated with the firmware, rather than hardware. Some new features will be added, the trigger flexibility will be increased, the readout speed optimised, and the ease of interaction with the experimenter will be improved. The TIG-10s are now machine assembled and can be produced rapidly in large quantities and new TIG-10 and TIG-C modules will be fabricated to match the arrival rate of the HPGe and BGO detectors.

4. Mechanical Support Structure

A one-detector prototype of the TIGRESS mechanical support structure was manufactured and tested in 2004. Experience with this prototype structure led to a number of design modifications which were implemented both in the original one-detector structure and in a second one-detector structure that was machined in parallel at the University of Guelph and TRIUMF shops during the past year. These two one-detector support structures served both as prototypes for the full TIGRESS mechanical support structure and to mount the two complete TIGRESS HPGe and suppressor systems for the July-August 2006 radioactive beam experiment at ISAC-I.

The full TIGRESS mechanical support structure can be broken into three distinct components: i) a superstructure (inner coronas and lampshades, spokes, rims and legs) that supports the detector units as two halves of the overall rhombicubocatahedral configuration and facilitates rapid reconfiguration and access to the target location, ii) a substructure (base and rails) that couples the device to the appropriate beamline position, and iii) detector mounting hardware.

Over the course of the past year, the Algor finite element analysis calculations for the support superstructure were completed to include buckling modes, and were repeated with an alternative stress analysis package. All calculations confirmed that load-induced deformation of the support structure would result in deflections of detector head positions of less than 0.25 mm, well within the design spacing of the detector units themselves (2 mm). Furthermore, the superstructure exhibits a safety factor of 10 against failure and more than 1000 against buckling. The results of these calculations are summarized in a TRIUMF design note (TRI-DN-06-02), dated February 2006.

Based on these calculations, procurement and fabrication of the longest lead-time items – the coronas and lampshades – was initiated. The large 6061-T6 Al stock was procured in November 2005 for shipment directly to the appropriate machine shop. A call for tenders was released in March 2006 and the fabrication contract was awarded to Canadian CNC of Richmond, British Columbia in April 2006. Delivery of the coronas is anticipated in September 2006 and the lampshades in October 2006.

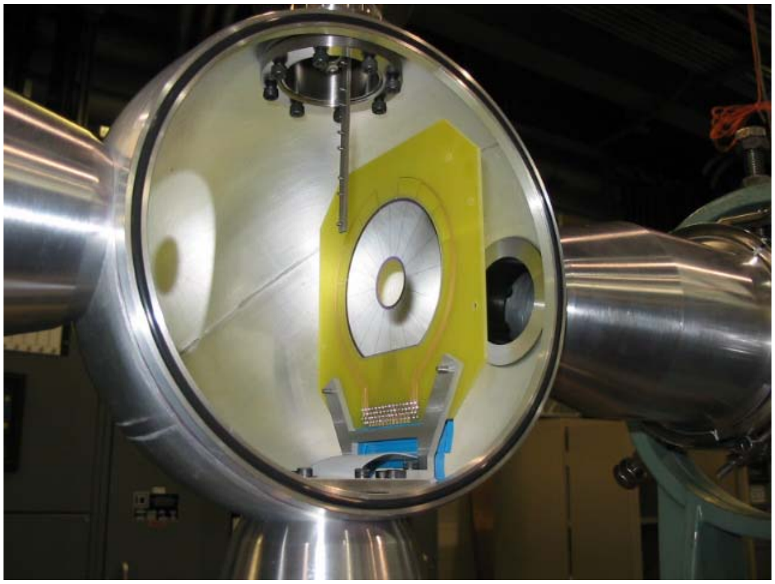
In December 2005, the beam optics for the ISAC-II experimental hall were re-evaluated by TRIUMF Accelerator Division staff. This investigation revealed that the original reference beamline design would result in unacceptably large beam halos and related higher-order effects that would compromise a radioactive in-beam γ-ray spectroscopy experiment. In response to the redesign of the ISAC-II experimental hall beamline optics, the TIGRESS substructure was redesigned to avoid any dependence on the final details of the beamline layout. The TIGRESS substructure now consists of two I-beam frames that are positioned on the floor by 3 mounting pads and pins. High-precision rails couple the substructure and superstructure. Each frame includes jacks and wheels; to move the array from one target location to another, the wheels are engaged and each half of the array is manually moved across the floor. The TIGRESS detector mounting hardware required some re-design to accommodate this new substructure design. This modified TIGRESS mechanical support design was approved in April 2006. Drawings for the substructure are currently in the final “check” stage and procurement and fabrication of the substructure, remaining superstructure, and carriage components is expected to commence in autumn 2006.

5. Bambino: A Segmented Silicon Detector System for TIGRESS

Every planned experiment with TIGRESS will require the use of one or more auxiliary detection systems to record beam particles and/or light ejectiles (p, d, t, ^{3}He, α, n, …) in coincidence with the γ rays. The first of these, the Bambino array, has been developed at Lawrence Livermore National Laboratory (LLNL). Bambino is a charged-particle detector system with sufficient energy and position resolutions for the differentiation between projectile-like and target-like particles in Coulomb excitation experiments with TIGRESS. Such a system is essential in order to define the velocity vector of the γ-ray emitting nucleus and Doppler-correct the γ rays detected in TIGRESS. Bambino consists of two annular silicon detectors having an active inner diameter of 22 mm and outer diameter of 70 mm and a thickness of ~150 μm. They are placed 3.0 cm from the target and provide solid-angle coverage of 1.15π sr. Each has 24 rings in θ for the angle coverage between 20.1^{o} and 49.4^{o} and between 130.6^{o} to 159.9^{o} and has 16 sectors in ϕ for 2π coverage. Three of these detectors and the matching preamplifiers, cables, and associated hardware were ordered and received by LLNL in 2005 at a cost of approximately \$50k funded by the U.S. D.O.E. Bambino is housed in a side-accessible spherical vacuum chamber designed and built at the University of Rochester in the second quarter of 2006 at a cost of approximately \$28k funded by the U.S. NSF and AFOSR. The Bambino system underwent extensive tests at both LLNL and TRIUMF in the second quarter of 2006 and, together with the Rochester target chamber, was successfully integrated into TIGRESS for the first radioactive beam experiment in July/August 2006.

6. E1058: First TIGRESS Experiment with Accelerated Radioactive Ion Beam

The E1058 Experiment to study the Coulomb excitation of the radioactive isotope ^{21}Na and its stable isobar ^{21}Ne represented the first TIGRESS experiment with accelerated radioactive ion beam from ISAC and has been the focus of developments for all of the TIGRESS sub-systems over the past year. This experiment was carried out at the ISAC-I zero-degree beamline from July 27 to August 15, 2006 and involved 2 TIGRESS production HPGe detectors (G.2 and G.3) with full Compton suppression shields (S.1 and S.3) mounted on the 2 TIGRESS one-detector support structures, a Ti target mounted inside the Rochester target chamber in front of the forward Si CD detector of the Livermore Bambino array, with the full system read out by 160 channels of TIG-10 electronics interfaced via 3 TIG-C cards with a MIDAS DAQ system. Figure 1 shows photographs of Bambino inside the target chamber and of the complete experimental setup, which functioned flawlessly throughout the 3 week experiment. The first week of the experiment was devoted to setup, tuning, and measurement of the Coulomb excitation of the stable ^{21}Ne beam (Figure 2 a). In the second week of the experiment, a 1.7 MeV/u beam of radioactive ^{21}Na at intensities of 2-5 × 10^6 ions/s was delivered by ISAC-I. A major question entering this experiment was whether the γ rays emitted following Coulomb excitation reactions in the target could be detected over the intense background of 511 keV photons arising from the β^+ decay of the beam. This question was answered in the affirmative within the first hours of the experiment and, as shown in the online spectrum of Fig. 2b), the combination of the excellent ISAC beam quality and the active collimation of the TIGRESS HPGe detectors by their front suppression shields resulted in almost negligible contamination of the



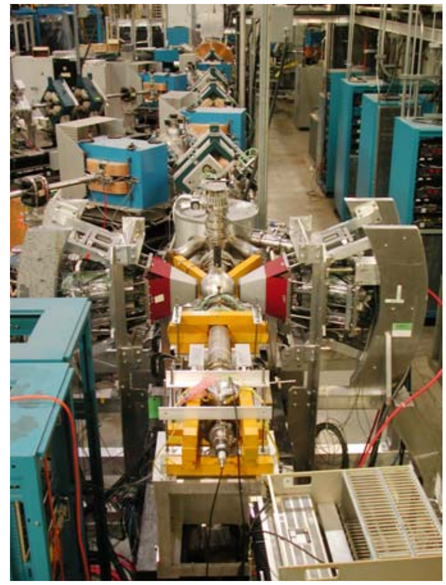


Figure 1: The Bambino Si CD detector inside the Rochester target chamber (left), and the setup for the 2-detector TIGRESS experiment on the ISAC-I zero-degree line in July/August 2006 (right).

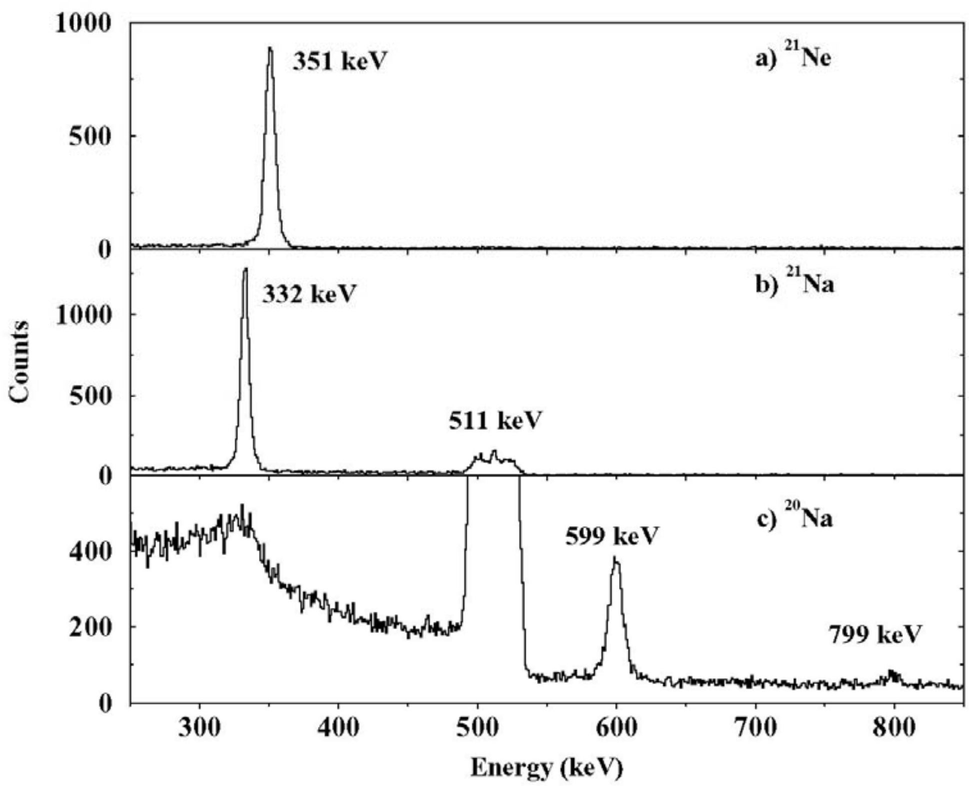


Figure 2: Online γ-ray spectra from the Coulomb excitation of a) stable ^{21}Ne beam, and radioactive beams of b) ^{21}Na and c) ^{20}Na. In each case a basic Doppler correction based only on the TIGRESS HPGe crystal hit patterns has been applied.

^{21}Na Coulomb excitation spectrum by 511 keV photons from the decay of the beam. After one week of ^{21}Na Coulomb excitation it was concluded that the extraction of the B(E2) matrix elements from this experiment were no longer statistics limited, and the decision was taken to utilize the final week of the experiment to attempt the more challenging measurement of the Coulomb excitation of the odd-odd proton-dripline nucleus ^{20}Na. Furthermore, one of the TIGRESS HPGe detectors was moved into the high-efficiency configuration with the front suppression shields withdrawn and the HPGe pushed forward to 11.0 cm from the target to explore the balance between increased efficiency and increased exposure to 511 keV photons from the decay of the beam in this configuration. A 1.7 MeV/u beam of approximately 2×10^6 ^{20}Na ions/s was delivered by ISAC and, as shown in Fig. 2c), a simple online Doppler correction was sufficient to cleanly identify the 599 keV and 799 keV transitions from ^{20}Na Coulomb excitation with sufficient statistics to extract the first B(E2) measurements for this dripline nucleus. While further analysis is clearly required to extract precise transition matrix elements, these successful Coulomb excitations of accelerated radioactive beams of ^{21}Na and ^{20}Na during the first TIGRESS experiment represent a major milestone for the project and the official launch of the TIGRESS physics program at ISAC.

7. ISAC-II Development

The first stage of the ISAC-II superconducting linac was completed in early 2006. It consists of five medium-beta cryomodules each with four quarter wave superconducting cavities. The linac is capable of producing continuously variable energy beams up to a maximum of 5MeV/u for A/q = 6. Higher beam energies can be obtained up to ~ 10 MeV/u for A/q =2. Until the charge state booster is installed in January 2008, only radioactive beams with A ≤ 30 will be accelerated. The linac was commissioned with stable beams in May 2006. The performance of the superconducting cavities exceeded specifications and the beam quality was excellent. Neutron, gamma and x-ray radiation field measurements confirmed that the accelerator vault shielding was adequate. An application to operate the accelerator for experiments has been prepared and the license is expected to be approved in the fall of 2006. During the first year of operation in the experimental hall the beam energy will be limited to 5 MeV/u and the stable beam intensity limited to 5 pnA. Once the proposed beam intensity control monitors are built and tested a request for full operation of the facility will be made.

Two experimental beamlines are presently under construction at ISAC-II. A general purpose beamline scheduled for completion in Oct 2006 and a dedicated experimental beamline for the full TIGRESS array, scheduled for completion in April 2007.

8. Associated Detectors

Experience with previous γ-ray arrays has repeatedly demonstrated the enormous gains in sensitivity that are achieved by coupling large γ-ray spectrometers with auxiliary detection systems. This will also be true for TIGRESS at ISAC, and compatibility with a variety of auxiliary devices was an important design criterion for TIGRESS. Extensive progress has been made on many auxiliary detector systems associated with TIGRESS during the past year. Each of these devices will provide unique capabilities that will enhance the sensitivity of TIGRESS and permit whole classes of experiments at ISAC-II that would otherwise be impossible.

With modification to the mounting of the preamplifiers, the Livermore Bambino Si CD array and Rochester target chamber employed in the July/August 2006 experiment with two TIGRESS detector systems at ISAC-I will translate directly to the full TIGRESS array at ISAC-II. Bambino currently consists of two CD-S2 detectors with thickness of approximately 150 μm in both the forward and backward hemispheres and with an angular resolution of 1.22^{o} in θ and 22.5^{o} in ϕ. The LLNL/Rochester group plans two new configurations to enhance the capability of Bambino. The first is to add an additional CD-S2 with a thickness of approximately 1000 μm behind the existing one in the forward hemisphere to form a ΔE-E detector for light charged-particle identification. This upgrade will be carried out in FY07. The second is to improve the ϕ resolution by a factor of two by doubling the number of sectors to 32 and will be carried out in FY08-09.

A quad-sectored PPAC detector from Argonne National Laboratory was shipped to TRIUMF in spring 2006 and will be available as a beam/target particle detector for TIGRESS experiments with heavier ion beams from ISAC-II. The LLNL/Rochester group is also beginning a conceptual design to define basic parameters, such as the size of the sphere, the flight path, and the desired position resolution, for the SuperCHICO gas detector. A prototype of the highly pixelated cathode board will begin in the second half of FY07 to optimize the parameters for the amplifier design and a formal proposal to request the full funding for construction is underway.

A highly-pixilated Si detector for TIGRESS is under development at McMaster University. An energy resolution of 24 keV for 5.486 MeV alpha particles from a ^{241}Am source has been demonstrated for the front strip signals and measurements are currently in progress to test the full 160 channels of this detector.

This past year a grant of $1.25M was secured by the University of York Physics Group from the Engineering and Physical Sciences Research Council (EPSRC) in the United Kingdom. This award supports a program of reaction and Coulomb excitation studies at ISAC-II in conjunction with TIGRESS. The funds include approximately $380,000 to build a silicon segmented barrel array for charged-particle detection, surrounding the target inside the TIGRESS array, and a Bragg detector near zero degrees to detect the heavy beam-like particles from reactions and reject beam contaminants. A Post-Doctoral Research Associate has been appointed by the York group and is stationed full time at TRIUMF to aid in the design and commissioning of these ancillary detectors.

A design workshop was held at Colorado School of Mines in February 2006 in which the basic concept of the Si barrel array was defined. Dr. Charles Barton from the York group spent a month at TRIUMF in March to begin work on the Bragg detector and Professor Brian Fulton from York spent a month at TRIUMF in May to work on the silicon array concept. These concepts were discussed further at the TIGRESS meeting in Halifax in June 2006, a workshop was held in York in July to settle details of the silicon array design, and a meeting was held at TRIUMF in August to discuss the issues of chamber design, detector mounting, and extraction of signals. The Si array is now well-defined and will be comprised of a "box" of four pixilated detectors either side of the target, with single 300 μm detectors at backwards laboratory angles and a telescope of 300 μm and 1500 μm detectors at forward angles. The detector strip pitches were fixed at 1mm and 3mm, based on the angular resolution requirements of TIGRESS experiments. Interactions with Micron Semiconductor are underway and the silicon detector order will be placed before the end of 2006. The Daresbury laboratory in the United Kingdom will collaborate on the design of the target chamber, which will have funding contributions from the University of York, Colorado School of Mines, and TIGRESS.

NSERC funding for two new detection systems associated with TIGRESS was also awarded in 2006. A CsI(Tl) charged-particle detector array for TIGRESS was funded with an award of $71,833 and design of the array is underway. The ElectroMagnetic Mass Analyser (EMMA) is a major facility for ISAC-II that will be used in conjunction with TIGRESS and was funded in the 2006 NSERC competition at the level of $2.085M over 5 years. In addition to the NSERC funding, $1M will be contributed to EMMA construction by TRIUMF. It is anticipated that requests for quotations will be issued in autumn 2006 for the large electromagnetic elements, which are the most expensive and longest lead-time components, and an order placed with the successful bidder by January 2007. This will allow delivery of the large electromagnetic components in 2008 and commissioning in 2009.

Design of a new neutron-detector array for TIGRESS, based on the use of deuterated liquid scintillator, has also progressed during the past year. A design study based on GEANT4 simulations calls for a 70-element array, where each element is hexagonal in shape, to close pack the available solid angle in the forward 67.5 degrees of TIGRESS. The front face of the 15 cm thick neutron detector elements will be 50 cm from the target. Based on this design, a $1.79M CFI proposal was submitted in February 2006, with the expected funding decision in November 2006.

Many of the auxiliary detectors mentioned above will require a significant number of electronics channels not included in the TIGRESS grant. To ensure compatibility with the TIGRESS data acquisition system, funding for a pool digital electronics for these auxiliary detection systems was requested through an application to CFI and the Nova Scotia Research and Innovation Trust. This $334,089 funding application has now been approved and will provide approximately 720 channels of TIG-10 and TIG-48 based digital electronics for TIGRESS auxiliary detectors.