TRIUMF

TRIUMF is Canada's National Laboratory for Particle and Nuclear Physics

TRIUMF Accelerator Hall

On April 8, 2006, TRIUMF's ISAC-II era began. The 20 ISAC-II medium-beta superconducting radio frequency cavities, housed in five cryomodules, boosted the energy available at ISAC from 1.5 MeV/u to 6 MeV/u.

The first ISAC-II experiment with radioactive beam will run in the fall of 2006, and the full ISAC-II experimental program is expected to begin in the spring of 2007 after CNSC licensing approval.

Look for updates on TRIUMF's new ISAC-II experimental programs in future issues of this report.

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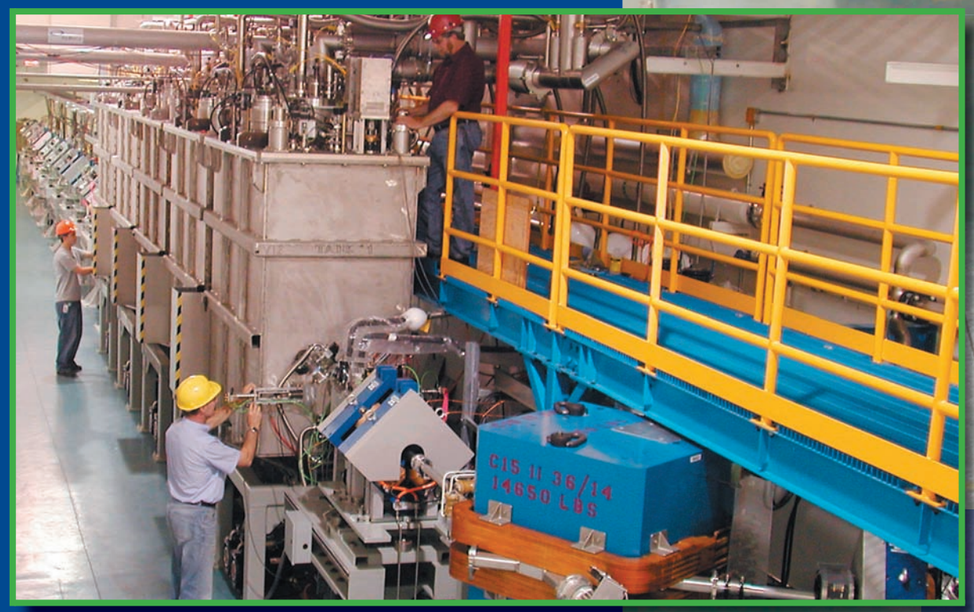
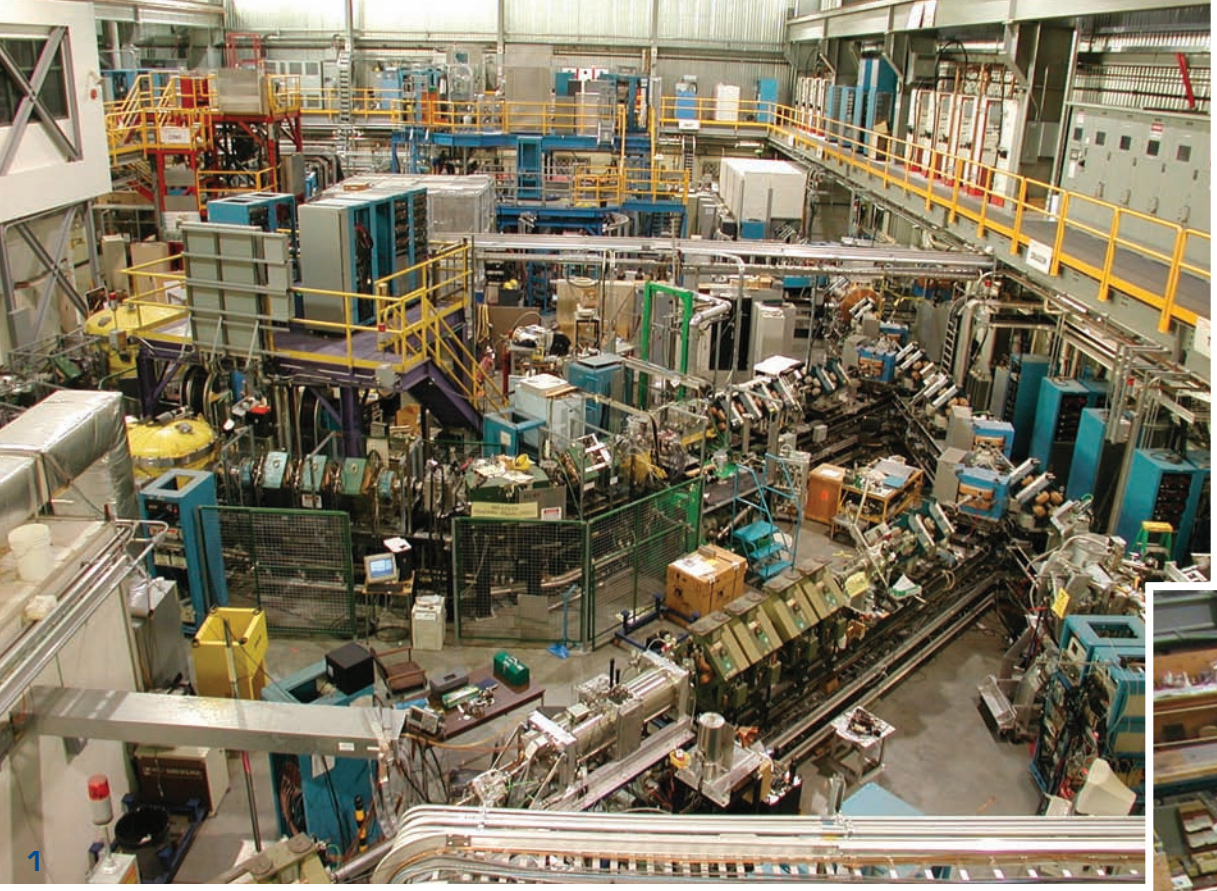


Annual Financial & Administrative Report

2005-2006



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TRIUMF is Canada's national laboratory for particle and nuclear physics, managed as a joint venture by a consortium of Canadian universities. It is operated under a contribution from the Government of Canada through the National Research Council of Canada.

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Director's Report

TRIUMF Director
Alan Shotter

TRIUMF, Canada's national laboratory for particle and nuclear physics, is an international laboratory in that our excellent facilities attract scientists from many parts of the world. In addition, TRIUMF staff, in collaboration with faculty and staff from Canadian universities, enable Canadian scientific teams to head up and make major contributions to scientific projects at other leading international laboratories. This aspect of TRIUMF's mission has contributed in no small measure to Canada's worldwide reputation as an advanced scientific nation.

Developments at TRIUMF during this year have particularly emphasized our international role: ISAC-II (phase 1) accelerated its first beam; negotiations for the construction of Canada's Tier 1 CERN Data Analysis Centre at TRIUMF entered its concluding phase, and the Canadian T2K consortium led by TRIUMF received major NSERC funding.

The new ISAC-II accelerator, which delivered its first accelerated beam at the end of the fiscal year, places TRIUMF firmly in position as the world's leading facility for the production and acceleration of exotic atoms. The technology to build the accelerator was acquired by TRIUMF through networking and collaboration with several international laboratories. ISAC-II will open up many new research avenues for Canadian and international scientists and students.

One of the largest scientific experiments ever undertaken to investigate the fundamental nature of matter is located at CERN in Geneva. Over 50 countries are collaborating to build a huge accelerator, 27 km in circumference. The accelerator is scheduled to begin operation in 2007. The experiments that will be carried out on it promise to reveal answers to fundamental questions such as "What is the origin of mass?" and, perhaps, point to the nature of dark energy and matter, which seems to hold the universe together but for which we have no understanding. Canada is part of this international adventure and has already supplied equipment to the value of $66M, funded by the Federal Government through TRIUMF and the Canadian universities.

Experiments carried out on the CERN accelerator will generate such vast quantities of data that a special international network of computing centres will be required to analyse and store this data. Canada has been selected as one of the 10 countries to host such a centre, and over the past year, TRIUMF has worked hard to identify the funding and resources to make this cutting-edge computing centre become a reality for Canada.

In recent years, TRIUMF is proud to have contributed to the success of the high-profile Canadian SNO experiment at Sudbury, Ontario. A natural follow-on experiment called T2K, located in Japan, is an investigation of a related neutrino oscillation phenomenon. Again, this is a large-scale international experiment. During 2005, TRIUMF was pleased to learn that NSERC would support a Canadian team, led by TRIUMF, which will contribute significantly to this next generation experiment.

TRIUMF's excellent facilities attract many international scientists. To make their visits as productive as possible, TRIUMF provides extensive support facilities and personnel as well as convenient, nearby and comfortable accommodations. The latter is supplied by TRIUMF House, and I am pleased to report that the first full year of operation of the new TRIUMF House has been very successful.

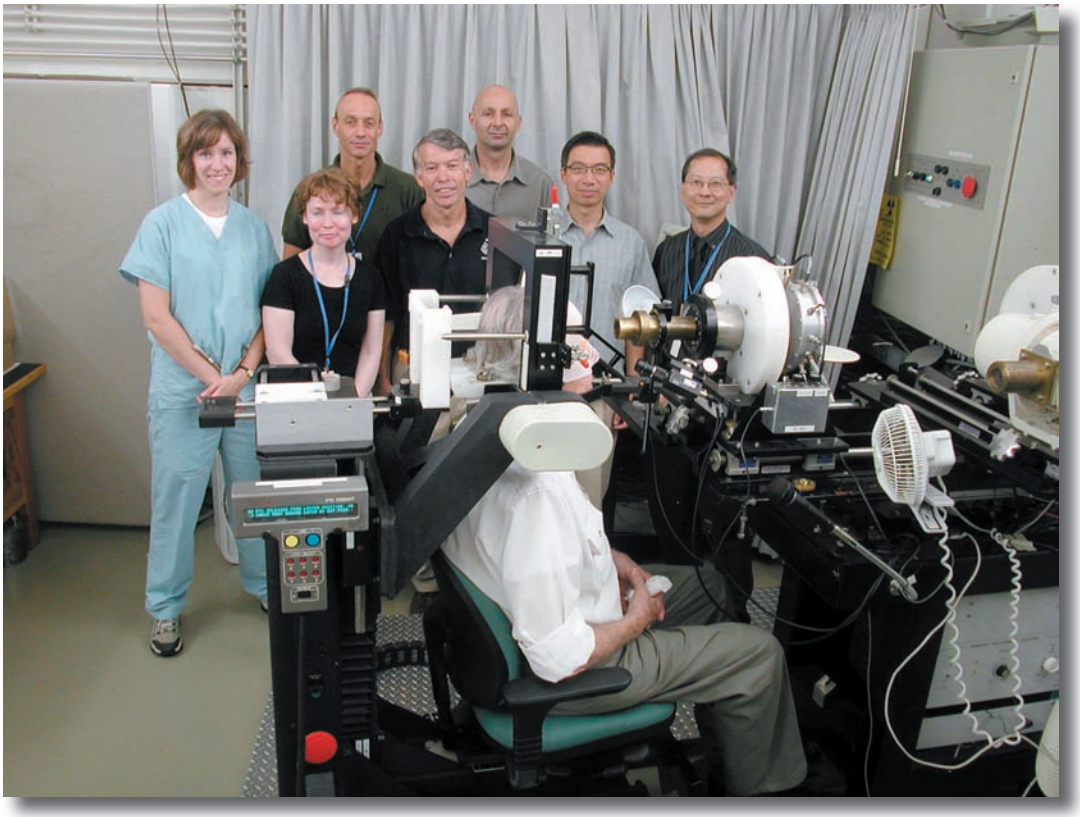
Another important, and successful, aspect of TRIUMF's mission is the transfer of its skills and knowledge to

society when this is possible and appropriate. In 2005, the 100th patient was treated for ocular melanoma using a special proton therapy treatment at TRIUMF. Also, for the past few years, TRIUMF has collaborated with the BC Cancer Agency (BCCA) in the establishment of a clinical and research PET facility at BCCA headquarters. This successful collaboration has enabled BCCA to establish their facility using the expertise and facilities available at TRIUMF. This collaboration will touch the lives of thousands of people in a beneficial way for years to come.

Another part of TRIUMF's mission is to nurture the scientific curiosity of young people. Tours of the TRIUMF facilities and the student summer school and scientific summer school programs have proven to be particularly effective ways of developing young peoples' interests in science. Over the past few years, TRIUMF has also worked with B.C. science teachers to develop a program that provides teachers with new ways to arouse the enthusiasm of their students for science.

The relevance of basic concepts to advanced scientific ideas excites students' imaginations. In 2005, TRIUMF produced its first educational video for schools. The video takes a TRIUMF scientific research topic and translates it into basic science concepts for classroom learning. This video is in great demand and is now circulated to many schools across Canada. In recognition of this achievement, TRIUMF has been awarded an NSERC grant to produce further videos.

In a brief account of the year, I can only mention a few of many highlights. I would like to thank all the TRIUMF staff for their efforts, because it is only through their dedication and hard work that TRIUMF is the success it is.



The proton eye treatment team preparing the 100th patient for treatment.

Board of Management

It is with great pleasure that I present the TRIUMF 2005-2006 Annual Financial and Administrative Report and brief you on the activities of the TRIUMF Board of Management.

Chairman
Feridun Hamdullahpur

Alan Shotter, TRIUMF's Director, will be completing his term in April 2007. The search for a new director is underway, and I am delighted with the interest of the international community in this position as well as the calibre and quality of the short listed candidates. The Board of Management hopes to make its decision by November 2006. While there will be formal and informal events to acknowledge Alan's many contributions to TRIUMF as a leader and as a scientist, I would like to take this opportunity, on behalf of the Board of Management and the entire TRIUMF community, to express our gratitude for his deep commitment and visionary leadership.

One of the regular and most challenging items on the Board of Management agenda is the governance structure of TRIUMF. Since its inception in 1968, the TRIUMF Joint Venture has had a unique and transparent governance structure, which has enabled our partner universities to share equal responsibility and ownership of this world-class facility. However, as more stringent accountability requirements emerge from various government sectors, we need to adapt and modify our governance structure. While we have maintained the Joint Venture structure to govern our scientific, administrative and financial affairs, we have created TRIUMF Accelerator Inc. as the legal entity to manage TRIUMF's Canadian Nuclear Safety Commission (CNSC) licensing requirements and related activities.

In September 2006, TRIUMF submitted its Operating Licence Renewal application to the CNSC. TRIUMF is also in the process of establishing a decommissioning fund should the need ever arise for either a planned or an unexpected decommissioning of the laboratory some time in the future. We are continuing our discussions with the National Research Council, the Treasury Board and Industry Canada to finalize the financial part of creating this fund.

For many decades the scientific community in Canada and around the world has enjoyed the many groundbreaking scientific discoveries and innovations that have emerged from TRIUMF. Just this year, ISAC-II delivered its first accelerated beam, and the Canada Foundation for Innovation, recognizing the many opportunities the ATLAS Tier-1 Data Centre can offer Canada, has agreed to fund a Canada-wide collaboration for a cutting-edge computing centre to be built at TRIUMF. We look forward to the continuation of our scientific success and worldwide leadership in nuclear and particle physics research and related sciences.

On behalf of the Board of Management, I would like to thank everyone who has contributed and continues to contribute to the success of TRIUMF.

With kind regards,
Feridun Hamdullahpur

by Chris Ruiz, Jac Caggiano, Michael Trinczek & Christof Vockenhuber

The age-old question of "Where does it all come from?" remains vigorously researched today. However, despite all the research that has been carried out in modern physics and astronomy, we still do not understand many things about the origin of the universe and why it behaves the way that it does. Conventional wisdom says that about 14 billion years ago the "Big Bang" created the light elements: a mixture of about 75% hydrogen by mass and 25% helium, along with traces of lithium and beryllium. The heavier elements, from carbon all the way up to uranium, were made in relatively small quantities by stars when they died catastrophically by exploding. These thermonuclear explosions, known as supernovae, liberated huge amounts of energy (see Figure 1). About 4.6 billion years ago our solar system was formed, and the Earth was formed with all of these elements incorporated into it, making us literally "children of the stars."

Type of explosion	Energy released in the explosion, in kilotons of TNT
Nuclear bomb at Hiroshima	15
Nuclear bomb at Nagasaki	21
Typical hydrogen bomb	1,000
May 18,1980 Mount St. Helens	350,000
Meteor impact that wiped out dinosaurs 65 million years ago	100,000,000,000
Typical nova	10,000,000,000,000,000,000,000,000
Typical supernova	10,000,000,000,000,000,000,000,000,000,000

Figure 1: Comparison of terrestrial and extraterrestrial explosions. The yield of a supernova explosion is equivalent to 10 million trillion trillion kilotrons of TNT, while a nova is equivalent to "only" 10 trillion trillion kilotons of TNT.

During nova and supernova explosions, many nuclear-fusion reactions take place. In these reactions, lighter elements combine to form heavier elements and release large amounts of energy. Nova explosions, in particular, eject the newly created elements into the interstellar medium at speeds exceeding 4 million kilometres per hour. These elements are then reincorporated into other stellar systems.

Nova explosions originate in twin-stellar systems where a small, compact white-dwarf star orbits a large, hydrogen-rich Sun-like star which has entered its red-giant phase, expanding and cooling as its nuclear fuel runs out. The white dwarf is roughly the size of the Earth but has a mean density about 200,000 times that of Earth (about 1 Volkswagen Beetle per cubic centimeter). Because of the enormous gravity of the white dwarf, it can pull hydrogen off the Sun-like star and onto its surface. As more and more material is added to the white dwarf, the pressure increases at the bottom of this layer, forming a hydrogen ocean. Once the enormous pressure reaches a critical value, the hydrogen fuses with the "seed" nuclei, carbon, nitrogen, oxygen, neon and magnesium, and this process produces more energy. The excess energy is absorbed and raises the temperature, increasing the reaction rates and causing a "runaway" thermonuclear explosion which ejects the newly synthesized radioactive and stable nuclei into the interstellar medium.

One type of supernova is very similar to a nova, the difference being in the rate at which the hydrogen buildup occurs. So much hydrogen is accumulated that it leads to a much greater release of energy than in a nova, resulting in the entire white dwarf being blown apart. The other type of supernova starts with a star whose mass is at least about 8 times that of the Sun. Near the centre of such a star, the temperature and pressure are such that hydrogen nuclei fuse (burn) to form helium nuclei, much like our Sun. Once the hydrogen fuel is used up, the core contracts and heats up even more. The temperature and pressure rise to such a point that the helium can now undergo fusion reactions leading to carbon. These fusion processes continue producing heavier and heavier nuclei until iron is reached. Rather than generating energy, further reactions on iron nuclei require energy. As a result, the core, which is no longer capable of generating enough pressure to support the mass of material around it, collapses. A shock wave is

by Chris Ruiz, Jac Caggiano, Michael Trinczek, & Christof Vockenhuber

produced when the collapsing core becomes so dense that it cannot shrink any further, and this causes the outer layers of the star to explode.

These explanations of the causes of stellar explosions leave unanswered the important question: "Why do the elements occur in the abundances that they do?" In order to answer this question, many different types of telescopes have been built to look at the stars and learn about the products of stellar explosions. Each of these telescopes is sensitive to one region of the electromagnetic energy spectrum (for example, visible, infrared, radio, or x-ray). With each new type of telescope, we obtain more of this "colour" or wavelength information from the stars and open a new "eye" into the universe beyond our stratosphere. The Hubble telescope removes the "cataract" (atmosphere) from the eye by orbiting the Earth. The images the telescope receives are undistorted by the Earth's atmosphere and are remarkably clear, enabling scientists to obtain more detail about the stars they are studying.

Despite large amounts of data obtained at many different wavelengths, much remains to be learned about what happens inside stars. Because stars are thermonuclear reactors powered by nuclear reactions, it is absolutely essential for us to understand the nuclear processes in play that provide the energy for the explosions and are responsible for the creation of the atomic elements. Therefore, it is imperative to get nuclear information from the stars.

The only way to obtain such data is to observe the production of specific types of atomic nuclei in these explosions. In 1991, the COMPTEL/CGRO space observatory/telescope was launched. This telescope, which is sensitive to radioactive nuclei freshly made in stellar explosions that emitted gamma rays, allows scientists to look at the stars in the gamma-ray wavelengths. Because of the quantum nature of nuclei, the energy of the gamma rays that each nucleus emits is characteristic of that particular type of nucleus. In October 2002, a similar but more sensitive telescope, INTEGRAL, was launched to replace CGRO, pushing observations deeper into the galaxy.

It is impossible to create a star (never mind an exploding one) on Earth, so theoretical models are used to understand the astrophysics behind the explosions. The inputs into the model are the nuclear-physics database, the stellar properties, and the dynamics of explosions. (See Figure 2). We use the data obtained from telescopes to compare to model predictions. Once the nuclear data are understood, we assume that any discrepancies between predictions and observations must be due to astrophysical uncertainties. Because we cannot "touch" the stars, this comparison between laboratory measurement, theory and observation, is the only way we can study their evolution and internal structure.

Our DRAGON group at ISAC endeavors to understand the nuclear reactions in novae and supernovae. Novae are typically simpler explosions than supernovae because only reactions involving protons (hydrogen) are significant, in contrast to supernovae where many more reactions are possible. By studying the simpler novae, it is hoped that astrophysicists will get a solid understanding of the physics involved before moving on to more complicated events such as supernovae.

Many of the nuclear reactions that take place in stars involve short-lived radioactive isotopes. Experimental data are usually acquired by bombarding targets of the isotope in question with either accelerated protons or alpha particles (helium). But, if the isotopes of interest are not found on Earth and are very difficult to create, then accumulating enough of the isotope to form a target suitable for bombardment is not feasible. Hence, rather heavy reliance has to be placed upon nuclear theory, which often lacks the required accuracy and precision for the nuclear-physics database because of the difficulty of making the measurements.

We have found a way to solve this problem at TRIUMF's ISAC facility, where the roles of accelerated particle and target are reversed. At ISAC, we can make a wide variety of radioactive isotopes, select a specific one of interest, and accelerate it. The accelerated isotope, which can have a very short lifespan because the acceleration process takes very little time, can be used to bombard relatively large amounts of either hydrogen or helium. This causes a measurable number of the reactions of interest. In this way, we can obtain new data concerning a number of the processes that occur in stars.

Only a few nuclei have the right combination of lifetime and gamma-ray energy to be detected by the orbiting gamma-ray observatories. In the following sections, we describe three such nuclei: ^{26}Al (aluminum-26), ^{44}Ti (titanium-44) and ^{22}Na (sodium-22) and the different experimental approaches we employ to gain experimental information about them. First, we

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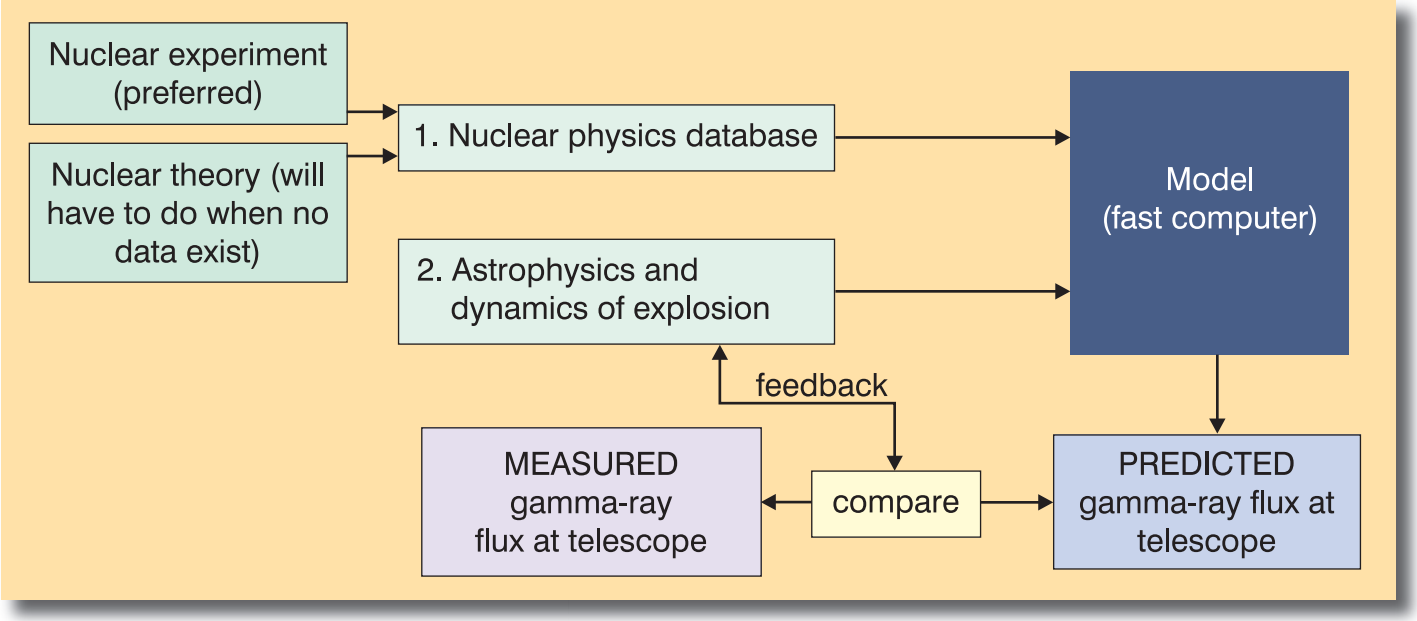

Figure 2: Diagram of the relationship between observation, theory, modeling and experiment in astrophysics.

describe the DRAGON apparatus at TRIUMF and the methodology of a fusion-reaction experiment. Then, in each of the three cases, we focus on the specific method used to make the measurements.

DRAGON

The DRAGON facility (Detector of Recoils And Gammas Of Nuclear reactions) at ISAC is designed to measure directly radiative-capture (fusion) reactions on hydrogen and helium. A beam of the exotic nuclei to be studied passes through a cell containing a small amount of hydrogen or helium gas. As it passes through the gas, the beam loses energy and, near the centre of the target, passes through the resonance energy, where the reaction probability is greatly enhanced because of nuclear-structure effects. Thus, some of the beam nuclei fuse with the gas nuclei to form an excited product nucleus, which promptly emits one or more gamma rays. These gamma rays are detected by an array of bismuth-germanate (BGO) crystals, which almost completely surround the gas target, giving very high detection efficiency.

Because a background level of gamma rays, from natural radioactivity in the surrounding environment, is present during any measurement, we also detect the reaction-product nuclei to give a very clean, background-free measurement. The reaction products have nearly the same momentum as those beam particles that have not fused with the target nuclei, but they have a different mass. Thus, they can be separated, in this case using a two-stage electromagnetic separator.

The separation of beam from recoils is never perfect, so a small amount of beam also makes it to the end of the separator. It is therefore desirable to have a means of particle identification, either measuring the particle energy and position (recoils have different energies than beam nuclei) by using a double-sided silicon-strip detector (DSSD) or determining its proton number, Z, by measuring the particle's energy loss in an ionization chamber (IC). The recoil particles, detected in coincidence with the prompt gamma rays from the reaction, provide the reaction yield that, when divided by the number of incident beam particles, uniquely determines the strength of that particular fusion reaction. This is the way that a conventional radiative-capture experiment is performed at DRAGON, offering such important advantages as a relatively background-free measurement with pure beam and target materials.

^{26}Al(p, γ)^{27}Si

Radioactive ^{26}Al has been a hot topic in astrophysics since its detection in our galaxy in the early 1980s. Its signature is a 1.809 MeV gamma ray which is emitted after ^{26}Al decays to the first excited state of ^{26}Mg. This gamma ray has been seen by gamma-ray sensitive instruments on the COMPTEL, RHESSI, and INTEGRAL satellites.

Aluminum-26 has a half-life of about 700,000 years, which means that it must have been created in a

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stellar event which occurred relatively recently on an astronomical timescale. However, the lifetime is long enough that the ^{26}Al will have spread out from the source that created it; hence, it is unlikely that we will be able to associate a particular patch of ^{26}Al with a specific stellar event. What we can do is map out the galactic ^{26}Al distribution as seen from its gamma ray and infer information about the origin of the ^{26}Al based on the structure of this distribution.

The COMPTEL all-sky map shows that ^{26}Al is concentrated in the spiral arms and the core of our galaxy, regions where it is thought that many stars are being born. This concentration is one of the reasons astronomers believe that the ^{26}Al probably comes mainly from young massive stars which lose material via their hot stellar winds or end their lives violently in a supernova explosion. In a recent letter in the journal *Nature,* there is a discussion of the galactic ^{26}Al distribution based on current theoretical and experimental knowledge of the nuclear reactions that create and destroy ^{26}Al, along with the latest stellar models, in which there is an estimate of the galactic star formation rate. In the article, it is assumed that the ^{26}Al is predominantly formed in the young, high-mass stars. However, it has been shown that older stars, in particular classical novae, can contribute a small but significant amount of ^{26}Al to the interstellar medium.

To predict the amount of ^{26}Al that is made in a classical nova, complex computer codes, which contain a huge number of interrelated, temperature-dependent nuclear reaction rates, are required. The most significant reactions for the production of ^{26}Al in novae are the radiative proton-capture reactions around it. Of those reactions that have a dramatic influence on the amount of ^{26}Al made, the most uncertain experimentally are the ^{25}Al(p,γ))^{26}Si (the fusion of protons with ^{25}aluminium to form ^{26}silicon with the release of gamma-ray radiation) and ^{26}Al(p,γ)^{27}Si reactions. The ^{26}Al(p,γ)^{27}Si reaction is thought to be dominated by a single resonance corresponding to an excited state in ^{27}Si, with a resonance energy of 188 keV. The strength of this particular resonance is the crucial quantity needed as input to the nova simulations to predict the amount of ^{26}Al formed, because it is the principal reaction that destroys ^{26}Al in these environments. Thus, the higher the probability of this reaction, the smaller the amount of ^{26}Al that is synthesized.

Using DRAGON, we measured this resonance strength by generating a beam of radioactive ^{26}Al, accelerating it to an energy just above that of the resonance, and passing it through the DRAGON windowless hydrogen-gas target. The gradual energy loss of the beam as it went through the gas target caused its energy to sweep through the reaction's resonance region. Gamma rays from the reaction were detected by the DRAGON BGO detector array, while the reaction products were separated from the beam and detected with the DSSD at the end of the DRAGON electromagnetic separator.

The strength of the 188 keV resonance was thought to be so weak that for every three trillion ^{26}Al particles that passed through the gas target, only one reaction would occur. So in order for us to have enough reactions to measure with reasonable statistical accuracy, we needed a very intense ^{26}Al beam impinging upon the gas target for a long time. In order to do this, we made use of the TRIUMF Resonant Ionization Laser Ion Source (TRILIS), which was described in last year's report. After acceleration to about 2% of the speed of light, the ^{26}Al beam had an intensity of up to five billion particles per second, which is extremely intense for a radioactive beam.

Unfortunately, ^{26}Na, which is also created in the ISAC target and ionized efficiently along with the ^{26}Al, is very close in mass to ^{26}Al. Our beam, therefore, contained a component of ^{26}Na. We were able to measure the level of ^{26}Na contamination in the beam with a gamma-ray detector because, while ^{26}Na decays emitting the same energy gamma rays as ^{26}Al (1.809 MeV), it does so with a much shorter half-life (about 2 seconds).

The gamma rays from ^{26}Na were the biggest source of background in our experiment because their high rate in the BGO array caused chance coincidences with incompletely separated beam particles at the end of the separator. By a careful combination of a mechanical-iris device installed before the gas target (designed to clip the beam's "halo," which might otherwise stop on the gas-cell entrance, decay and contaminate the BGO rate) and some ISAC and TRILIS tuning, the contamination rate in the BGO array was reduced to that of natural room background.

We identified the true ^{27}Si reaction products using two measurements. One was the measurement of the particle energies in the DSSD at the end of DRAGON that arrived in coincidence with gamma rays of the correct energy detected in the BGO array. The other measurement was the time it took these particles to travel in the separator from the target to the energy

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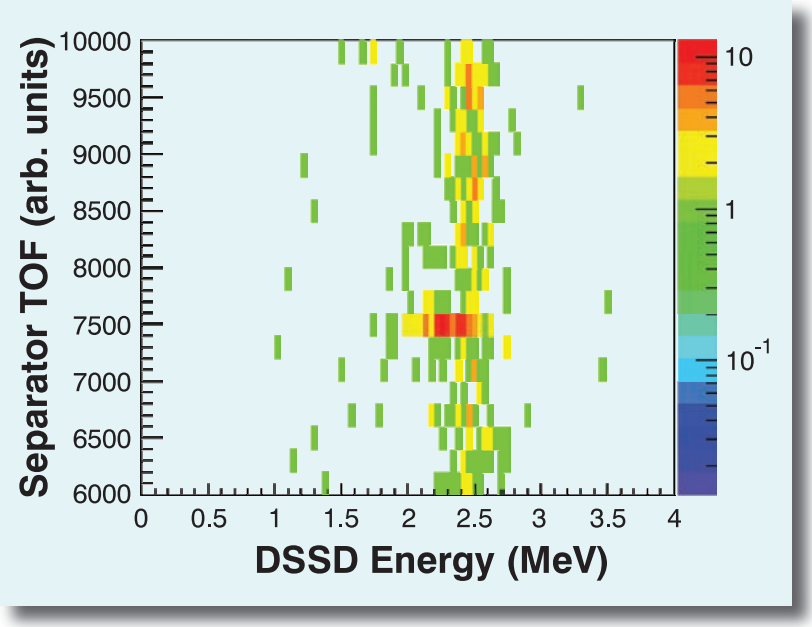

Figure 3: Spectrum of particle time-of-flight through separator versus DSSD energy for coincident events in the ^{26}Al(p,γ) experiment. The true recoils are bunched tightly in time-of-flight and have a lower mean energy than the "leaky" beam particles.

detector. Using these measurements, we achieved a very clean identification of the reaction products, over one hundred of which were detected. Figure 3 shows some of the data we collected.

After careful analysis, the strength of the resonance was found to be weaker than previously thought by approximately 40%. Therefore, less ^{26}Al will be destroyed in a nova explosion compared to the previously assumed destruction rate. Therefore, more ^{26}Al would be left over to be distributed into the interstellar medium. We also found that the resonance energy was slightly lower than previously thought. This has a small effect on the reaction rate but is not as significant as the reduction in resonance strength.

Because of their importance for determining the nova contribution to the Galactic ^{26}Al abundance, these results have been published in *Physical Review Letters*. This experiment represents a great synergy between the beam-development, ion-source and experimental groups at TRIUMF and is a world-class measurement that took DRAGON to the limits of its capability.

^{40}Ca(α,γ)^{44}Ti

Another type of radioactive nucleus that has been observed by COMPTEL and INTEGRAL is ^{44}Ti. It has been observed in at least one supernova remnant called Cassiopeia A by detection of the characteristic gamma rays emitted during its decay. Compared to ^{26}Al, ^{44}Ti decays much faster, with a half-life of only 60 years. The fact that ^{44}Ti is observed proves that nucleosynthesis is still happening today.

Titanium-44 can also provide insight into one of the most energetic phenomena in the life of stars, a supernova explosion. Stars much heavier than our Sun usually exist for only a few million years because they use up fuel much faster than does our Sun, which has existed in its (remarkably constant) present state for 4.6 billion years. To begin with, stars "burn" the lightest element, hydrogen, until it is used up, then the next heaviest element, helium, and so on until iron, the heaviest element which can be created by this burning process, is reached. At the end of its life, a massive star has an onion-like structure, the many layers of "skin" containing different elements which are the ashes of the sequential burning phases. Because nuclear properties prohibit the burning of elements beyond iron, the massive star eventually runs out of fuel, and energy is no longer released by thermonuclear fusion. As a result, the star can no longer hold out against gravity, and the inner core of a few thousand kilometres collapses. The outer layers are heated by the resultant shock wave to a few billion degrees, much higher than previously achieved. New elements are created by additional processes which allow synthesis of elements far beyond iron. All this happens in a gigantic explosion which lasts only fractions of a second, an instant on astronomical timescales which usually are measured in millions and billions of years.

Titanium-44 is believed to be produced in these explosions, more precisely in a cooling process in the alpha-rich freeze-out phase after the explosion. This process occurs just above the collapsing core, which makes the ejected amount of ^{44}Ti very sensitive to the exact boundary between material expelled and material collapsing. If the amount of ^{44}Ti produced by the underlying nuclear reactions is sufficiently well known, the observed ^{44}Ti (like that seen in the supernova remnant Cassiopeia A) can be used to test and refine our understanding of supernova explosions.

As far as we know, ^{44}Ti is produced in the following way: The enormous heat created by the shock wave after the core collapse disassociates the elements in the

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outer layers into protons, neutrons, and alpha particles. During the ensuing expansion, the temperature drops and alpha particles become available to fuse with heavier nuclei. Starting from ^{28}Si, the end product of the oxygen-burning phase, new nuclei are formed by a series of alpha-particle captures and the emission of gamma rays. This leads to the formation of ^{32}S, ^{36}Ar and ^{40}Ca, all stable nuclei, and finally ^{44}Ti. The last reaction, in scientific notation ^{40}Ca(α,γ)^{44}Ti, is directly responsible for the production of ^{44}Ti. This is a very simplified picture; in reality more than 100 reactions have to be considered for a detailed understanding of the production of ^{44}Ti. For many of these reactions, only a limited number of measured reaction cross sections or reliable theoretical predictions exist; thus, the reaction rates have large uncertainties. However, a systematic theoretical study reveals that only a few reactions have a big influence on the final amount of ^{44}Ti produced. One of these reactions is ^{40}Ca(α,γ)^{44}Ti.

A few decades ago, scientists studied the ^{40}Ca(α,γ)^{44}Ti reaction by bombarding a ^{40}Ca target with alpha particles. The production of ^{44}Ti was determined as a function of energy by detecting the prompt, high-energy gamma rays that were emitted. However, in those days, ^{44}Ti did not have the importance it now has because of its observation by space-based telescopes. In these early experiments, the astrophysically relevant temperature regime was only partially covered; in such experiments, the energy of the particles involved in the nuclear reaction corresponds to a certain temperature in the stellar environment. The relevant temperature regime for the alpha-rich freeze-out phase starts at a temperature of about five billion degrees and goes down as the cloud expands and cools to less than one billion degrees when the alpha particles eventually "freeze out."

Recently this reaction was investigated in a completely different way. A helium gas target was bombarded with a ^{40}Ca beam and the resultant ^{44}Ti collected in a catcher foil. As the ^{40}Ca loses energy in the helium gas, a large energy region, and thus temperature regime, was covered. The catcher foil was then chemically treated to collect the ^{44}Ti. This sample was finally analyzed for its ^{44}Ti content using Accelerator Mass Spectrometry (AMS), a very sensitive method allowing single atoms in a macroscopic sample material to be counted. The result of this measurement gives only an integral production yield but clearly showed a significantly higher production than estimated from the older experimental data.

Our approach using the recoil-mass spectrometer DRAGON is a combination of both previous measurements. (See Figure 4). Similar to the AMS experiment, we use a helium gas target and a ^{40}Ca beam. However, we detect the ^{44}Ti reaction products directly using an ionization chamber after the majority of the beam has been removed in the electromagnetic recoil separator (see Figure 5). We can gain several orders of magnitude in efficiency because we do not have the same kind of losses due to chemistry and ionization effects as seen in the AMS measurement. In addition, our gas target is surrounded by the highly efficient gamma-ray detector array, which allows us to use the coincidence signal between the ^{44}Ti at the ion chamber and the prompt, high-energy gamma ray to provide a unique signal for our desired reaction. By analyzing the gamma rays, there is often more than one gamma ray or a cascade, we can get additional information about the energy levels in the ^{44}Ti nucleus.

In contrast to ^{26}Al and ^{22}Na, ^{44}Ti is produced over a wide range of energies, and many excited states in the ^{44}Ti nucleus contribute to the ^{44}Ti yield. The goal of our experiment is a detailed measurement of the ^{44}Ti yield over the astrophysically important energy regime. This requires a wide range of ^{40}Ca beam energies. The beam loses only a small amount of energy in our gas target, so we need about 70 energy steps to cover completely the range for comparison with theoretical models. Because ^{40}Ca is a stable and abundant nucleus, we can use an off-line ion source, which creates calcium ions by a process called sputtering. These measurements require eight weeks of beam time. We hope to confirm previous measurements at certain energies where strong resonances give a high ^{44}Ti yield. We also saw ^{44}Ti yield at energies which have not been covered by the prompt gamma-ray measurements. A detailed analysis of our data is in progress.

^{22}Na(p,γ)^{23}Mg

Why no gamma rays characteristic of ^{22}Na (E_γ = 1.275 MeV) have been observed in connection with nova explosions, despite predictions that we should see them, remains a mystery. Recently, a new energy level in the nucleus ^{23}Mg was identified which falls within the energy region relevant to nova nucleosynthesis for radiative proton-capture on ^{22}Na. The existence of this level may help to explain the absence of the ^{22}Na characteristic gamma rays. If it is found that the radiative capture of protons on ^{22}Na (^{22}Na(p,γ)^{23}Mg) leads predominately to ^{23}Mg in this newly discovered

by Chris Ruiz, Jac Caggiano, Michael Trinczek & Christof Vockenhuber

excited state, and that this occurs with high probability, then the lack of ^{22}Na characteristic gamma rays would be explained. The ^{22}Na would undergo fusion before it had a chance to emit its characteristic gamma rays.

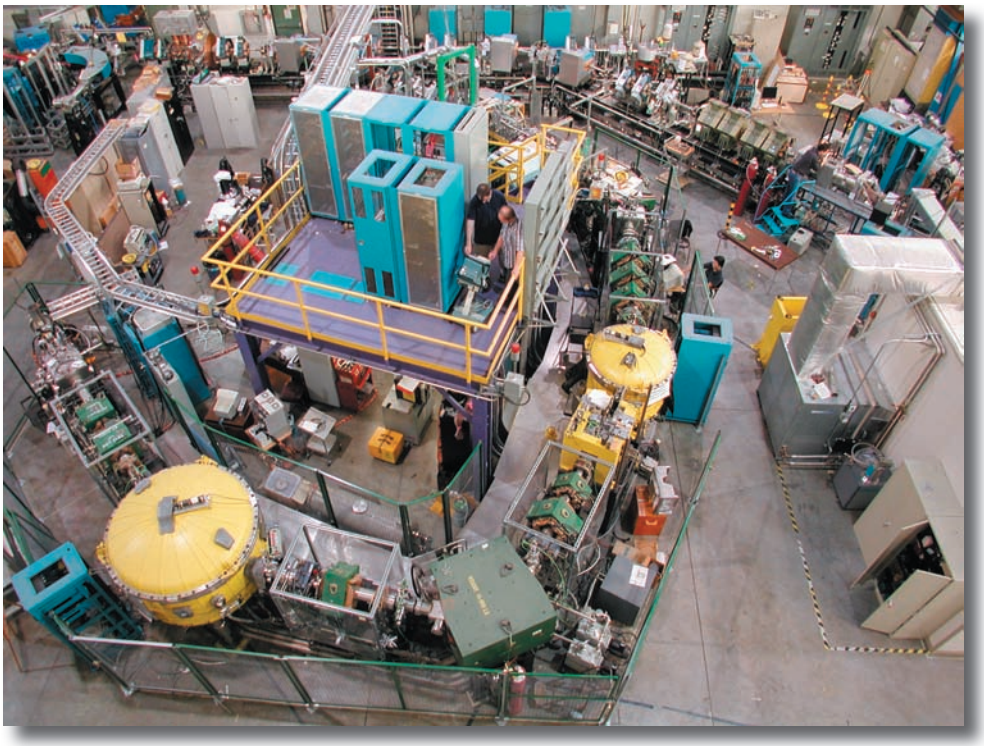


Figure 4: TRIUMF's DRAGON facility recreates the microscopic processes that occur in the evolution of stars in our universe.

DRAGON must be kept free of radioactive contaminants in order to make sensitive measurements. This is normally not a problem because the nuclei admitted into the detector all have either very short half-lives, of the order of a few seconds or less, or very long half-lives, of the order of over 100,000 years. The short-lived isotopes quickly disappear while the long-lived ones decay very slowly causing no contamination problems. But ^{22}Na has a half-life of 2.6 years, and its presence in DRAGON would cause an unacceptable increase in background radiation. Hence DRAGON can not be used to make the measurement. Another technique had to be found in order to determine if our proposed explanation is correct.

Our technique to measure the strength of this resonance reaction takes advantage of the high-intensity ^{22}Na beam available at TRIUMF's ISAC facility to produce a ^{22}Na target that can be bombarded with protons. The project has many distinct stages: implanting stable ^{23}Na into a variety of carefully chosen backing materials; measuring the physical extent and thickness profile of the isotope on the implanted targets by using a strong proton-capture resonance; producing the ^{22}Na targets/sources; and finally, carrying out the ^{22}Na proton-capture reaction measurement. Radioactive ^{22}Na and stable ^{23}Na have almost identical chemical properties, so we can learn much about the properties of our ^{22}Na targets by producing and measuring the properties of ^{23}Na-implanted targets. In addition, ^{23}Na is much easier to work with than ^{22}Na.

Several metal foils were implanted with a variety of doses of ^{23}Na. Implantation was carried out in the low-energy area of the ISAC experimental hall (see 2003-2004 Financial Report) using different energies in the range of 30-50 keV. To produce uniformly distributed layers of ^{23}Na, the beam position was swept many times throughout a 5 mm diameter circle. By adjusting the parameters of this modulation, a uniform distribution with sharp edges was obtained.

The three-dimensional profiles of some of these implanted targets were measured using a strong and sharp resonance in the ^{23}Na(p,γ)^{23}Mg reaction at an energy of 309 keV in the center-of-mass frame. The depth profile was measured by changing the beam energy in small steps. A beam of singly charged, molecular H_3 was delivered from ISAC to the DRAGON facility target position, and gamma rays detected by the DRAGON BGO array were used to determine the resonance profile. Beam currents of up to 6 trillion particles per second were delivered to the target, and the beam was collimated using a 1 mm diameter circular aperture. A two-dimensional translational-motion stage was built to move the target in the directions perpendicular to the beam and thereby measure the lateral profile.

A new target lid for the ISAC collection station was fabricated and installed for the purposes of collecting the ^{22}Na. A coil of liquid-nitrogen-cooled copper tubing was installed just upstream of this target to prevent carbon buildup on the target substrates during collection and also to prevent upstream migration of scattered ^{22}Na. A 5 mm diameter circular aperture was installed approximately 5 mm in front of the

by Chris Ruiz, Jac Caggiano, Michael Trinczek, & Christof Vockenhuber

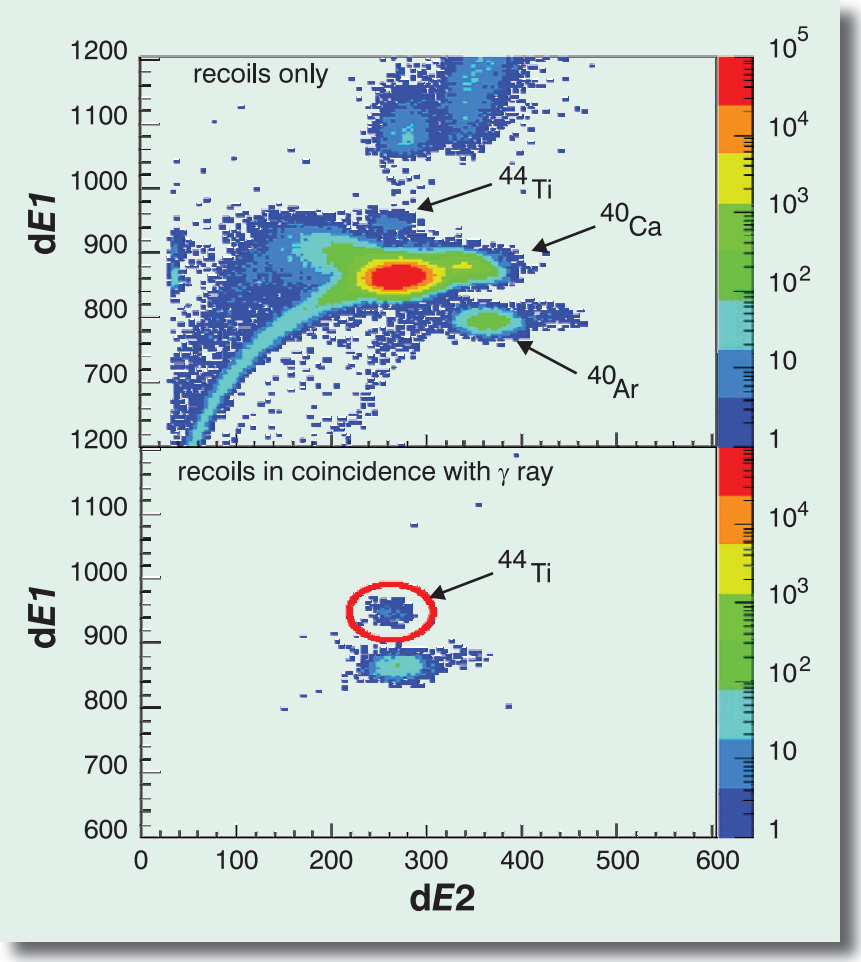


Figure 5: DRAGON ionization-chamber spectrum showing the recoil ^{44}Ti nuclei well separated from the "leaky" beam particles when taken in coincidence with a gamma ray.

target ladder to limit the beam-spot size on the targets. Following installation, one target with a small amount of ^{22}Na activity was fabricated in July 2005, and a few months later an intense beam of ^{22}Na was used to make two target-quality sources containing enough ^{22}Na to be used in the actual experiment.

We will transport the targets to the Nuclear Physics Laboratory at the University of Washington in order to perform the ^{22}Na(p,γ) reaction-rate measurement. This will be done using the "traditional" method of impinging an accelerated proton beam onto the samples at the relevant energy and measuring the gamma rays produced when fusion with the ^{22}Na occurs, the inverse of a DRAGON-style experiment. In this way, we will make the first direct measurement of this particular resonance and ascertain its importance to ^{22}Na production in novae. If successful, we will finally have models of ^{22}Na production in novae which have all of the largest sources of nuclear uncertainty removed.

Conclusion

In the last decade or so, the scientific community has made significant leaps in the fields of gamma-ray astronomy, stellar modeling, and radioactive-beam experiments. With the implementation of the DRAGON program at ISAC, we have combined the world's premier radioactive-beam facility with the world's best instrument for measuring the difficult yet crucial astrophysical reaction parameters. The information obtained from DRAGON experiments, which is almost impossible to obtain elsewhere in the world, has contributed to and will continue to contribute to making up the vast database of nuclear measurements needed to truly understand the mechanisms at work inside stars in our universe.

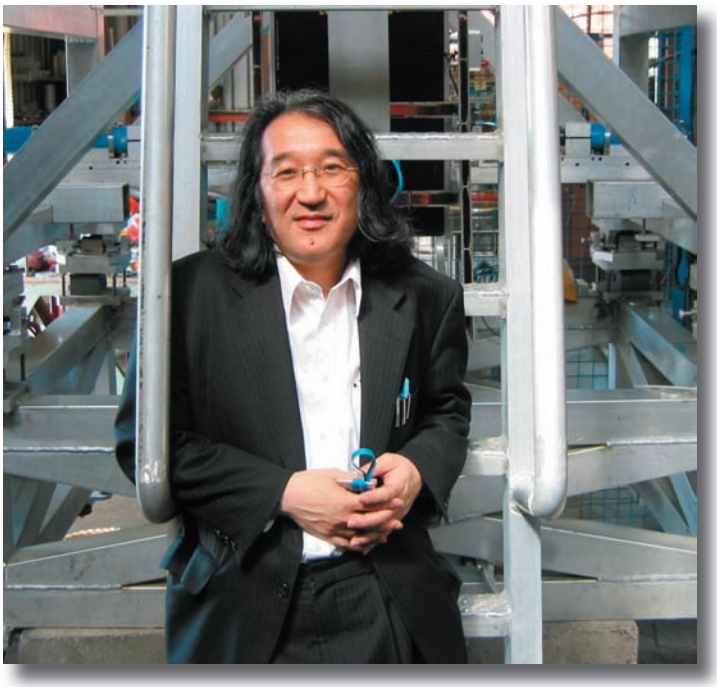
Chris Ruiz is a Postdoctoral Fellow with the DRAGON Group at TRIUMF.
Jac Caggiano is a TRIUMF Research Scientist.
Michael Trinczek is a Postdoctoral Fellow with the DRAGON Group at TRIUMF.
Christof Vockenhuber is a Postdoctoral Fellow with the DRAGON Group at TRIUMF.

by Shirley Reeve

TRIUMF's unique experimental programs in radioactive ion beam physics, materials sciences, and life sciences attract scientists and students from Canada and most of the industrialized nations in the world. Every year, between 300 and 500 scientists visit TRIUMF to discuss science and scientific techniques with our scientists, and to do experiments using our unique facilities. In 2005, we again played host to many interesting people, and we are pleased to profile six of them here.

Yasutomo (Tomo) Uemura is Professor of Physics at Columbia University, New York, and the first winner of the international ISMS Toshimitsu Yamazaki Prize, which is just one of many prizes and awards Professor Uemura has received over the years for his experimental work. Tomo is a pioneer in the study of superconductivity and magnetism in strongly correlated electronic systems, using muon spin relaxation (μSR) and neutron scattering techniques. As Tomo explains, most of his experimental work is done at TRIUMF.

I finished my masters and doctoral degrees on μSR using the TRIUMF research facility, working with Professor Yamazaki's group. After graduating, I was appointed to a faculty position at Columbia University but continued to base most of my experimental program at TRIUMF. TRIUMF provides one of the strongest muon beams in the world.



Yasutomo (Tomo) Uemura

Continuous beam here is better for my work than a pulsed beam. Without TRIUMF, 99% of my work could not be done.

Tomo's unique and high-profile research attracts students interested in the possibilities of solid-state physics.

Eleven graduate students from our group at Columbia University obtained their PhDs on μSR studies performed at TRIUMF. TRIUMF can provide students interested in μSR with high-quality data and unique opportunities for international collaborative research. TRIUMF's μSR facility attracts international collaboration, and our students have the opportunity to work with groups from Canadian institutions, such as McMaster University, Simon Fraser University and the University of British Columbia, as well as with groups from the USA, Europe and Japan.

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Nathalie Lecesne and Hervé Savajols are spending a sabbatical year at TRIUMF. Nathalie is a physicist at the GANIL laboratory in Caen, France. Her area of expertise is the production of radioactive ion beams by the Isotope Separation On Line (ISOL) method.

I deal with the nuclear processes and thermal issues involved in the production targets, with the ion sources that are needed to ionize the radioactive species and with detectors of radioactivity that analyze what has finally been produced from the targets. —Nathalie

Hervé is a physicist at the Centre national de la recherche scientifique (CNRS) France and has been posted at GANIL since 1996. For the past ten years, he has been involved in the study of nuclei far from stability and the construction of new detector systems based on the specific properties of secondary beams.

My scientific program is focused around three activities: the study of light, neutron rich nuclei by direct reaction, mass measurements and complete spectroscopy studies of intermediate nuclei around neutron shell closure. In order to study those nuclei effectively, I have become involved in the development and construction of high-efficiency detectors. —Hervé

During her stay at TRIUMF, Nathalie has been working with the TRIUMF Radioactive Ion Beam (RIB) development group, designing and building a new Electron Cyclotron Resonance (ECR) ion source. This source, named MISTIC (Monocharged Ion Source for the TRIUMF and ISAC Complex), is based on a GANIL concept but has been adapted to TRIUMF's needs and the specific configuration of our scientific apparatus. Nathalie plans to have this ECR source manufactured, installed and tested before the end of her sabbatical.

Hervé has been working with the 8π/TIGRESS group at TRIUMF. In spectroscopy studies with radioactive beams, special attention has to be paid to the beam optics and beam dump. Hervé has taken the lead in designing a dedicated beam dump for the TRIUMF TIGRESS detector. He has also proposed that the group build a new type of spectrometer, built around a high field magnetic solenoid, which will have significant advantages over more conventional approaches to measuring key reactions and making particle identifications.

Hervé will also make use of TRIUMF's ^{11}Li beam, the highest intensity low energy beam of ^{11}Li in the world. In December 2005, TRIUMF's Subatomic Science Experiments Evaluation Committee (EEC) approved Hervé's proposal to use GANIL's MAYA experimental apparatus at TRIUMF to study the spectroscopy of ^{10}Li. This will be the first experiment undertaken at the new ISAC-II facility.

Nathalie and Hervé had never visited TRIUMF before, but they chose the lab for their sabbatical year for a special reason.

> *With the present ISAC Radioactive Nuclear Beam facility and ISAC-II coming online in the near future, TRIUMF has become a pioneer in this field; the lab will be able to offer intense radioactive ion beams not available in Europe or anywhere else in the world at this time. New, highly efficient detector systems being designed or under construction at TRIUMF, like the TIGRESS multi-detector system, will take advantage of the higher energies of ISAC-II to study an expanded range of isotopes, using a broad range of experimental techniques.* —Hervé

Hervé Savajols & Nathalie Lecesne

Nathalie and Hervé, along with their two children, have enjoyed their stay in Canada. The two scientists believe their year at TRIUMF has been very valuable for them and for the lab.

> *I am looking forward to continuing the very profitable collaboration between the RIB groups of TRIUMF and GANIL, particularly on ECR ion sources, laser ion sources and target development.* —Nathalie

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Roby Austin and Jim Waddington are two Canadian scientists at opposite ends of their careers. Roby is Assistant Professor in the Department of Astronomy and Physics at Saint Mary's University in Halifax. Jim is Professor Emeritus with the Department of Astronomy and Physics at McMaster in Hamilton. Both scientists regularly visit TRIUMF to study nuclear structure.

> *During most of my career I have been interested in what happens to atomic nuclei when they rotate very rapidly. When two nuclei collide, they often join together to make*

by Shirley Reeve

a combined, heavier nucleus. This new system is hot and rotates rapidly but it often cools by emitting particles and then gamma rays. We can deduce the structure of the nucleus by detecting these particles and gamma rays. I am interested in the structure of the exotic nuclei that can be produced at TRIUMF's ISAC facility. —Jim

Roby and Jim both collaborate with the TRIUMF gamma-ray group. This large group of forty-three institutions from Canada, the USA, Europe, Asia, Australia and Africa, currently uses the 8π spectrometer, and beginning in Summer 2006, will utilize the TIGRESS detector for experimental work with nuclear structure. In fact, both scientists are involved in building the TIGRESS detector. There is a close connection between the nuclear astrophysics and nuclear structure programs at ISAC-II, and the TIGRESS detector will be one of the many advanced detector systems used to exploit the enormous scientific possibilities of the higher energies available at ISAC-II.

It is not an accident that Jim and Roby are both interested in the same branch of nuclear science and collaborate with the same TRIUMF experimental group: Roby earned her PhD studying and working with Jim. When Jim retired from McMaster University, he was able to spend more time at TRIUMF with the 8π/TIGRESS group doing full-time research, a luxury for a professor who carried a full teaching load, and being involved in the planning for the first tests of the TIGRESS detector using beams from ISAC-I. Roby, too, is excited about the opportunities at TRIUMF, not only for herself but also for her students.

Bringing students to TRIUMF to see and experience real research in action is fantastic! Students have no sense of what big, experimental science is really about until they walk through the gates. —Roby

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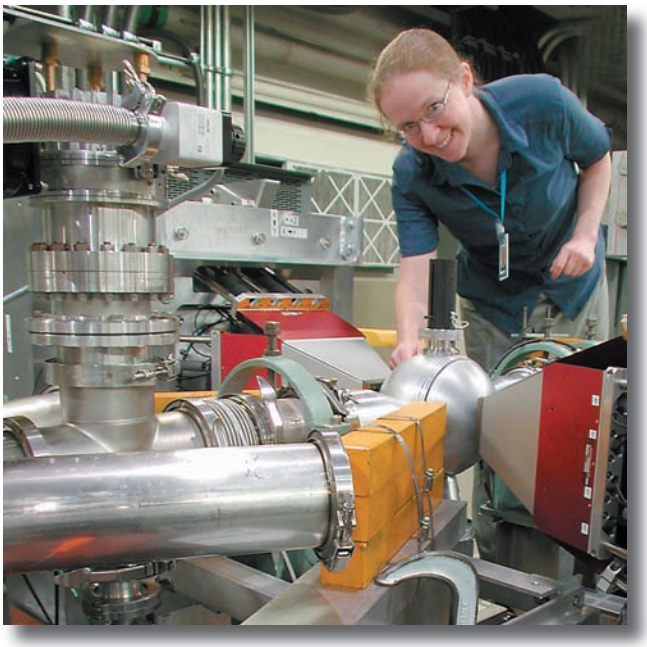
Dieter Frekers is Professor of Physics in the Institute for Nuclear Physics at the University of Muenster, Germany and knows TRIUMF very well; he was a TRIUMF Research Scientist until his return to Germany in 1992. Dieter's scientific interests are broad:

I am interested in so many areas of physics: nuclear physics, nuclear astrophysics, supernovae physics, neutrino physics, cosmology, hadron physics at low and intermediate energies and, most recently, the connection between nuclear physics and double-beta decay. I am also very involved in technology transfer.



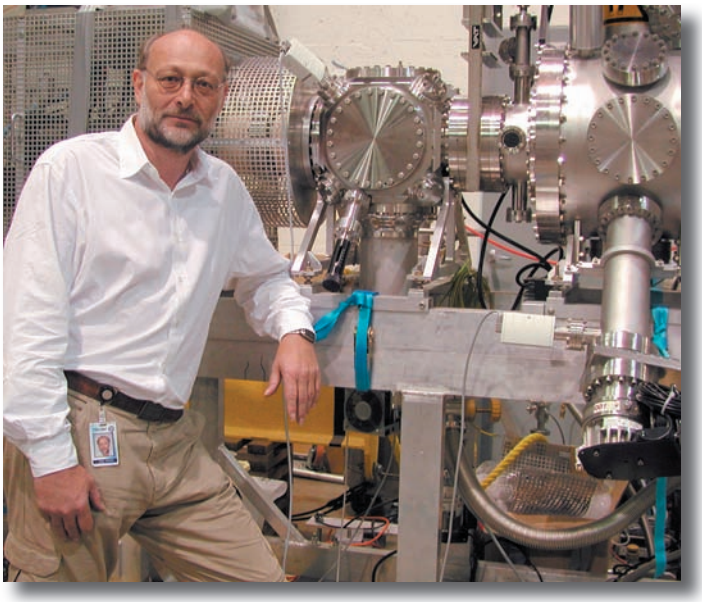
Roby Austin

Dieter lives and works in Germany (where, in 2005, he was awarded a medal and a substantial cash prize for his efforts in technology transfer), but like so many physicists, his experimental programs are carried out in laboratories all over the world and now, particularly, at TRIUMF.

TRIUMF is, in many ways, unique. It pools an enormous expertise in all the areas I am interested in and offers experimental possibilities that are not found to this extent anywhere else in the world. In particular, research into the physics of ion traps is a new field and ion traps, particularly the way they will be operating at TRIUMF in conjunction with the radioactive beam facility, are perfect tools to measure nuclear physics properties. These properties are directly connected to double-beta decays. The study of double-beta decays is high on the agenda in particle physics, particularly in Europe, and TRIUMF has the best facility and in-house expertise to carry out this research.

by Shirley Reeve

Dieter's research program at TRIUMF has already been a rewarding one. Recently, Dieter and his TRIUMF collaborator Jens Dilling presented a proposal to the Subatomic EEC to use the TRIUMF ion trap TITAN to study specific aspects of beta decay. The experiment received a high-priority status from the Committee.



Dieter Frekers

The priority given to our experimental proposal is very rewarding, but even more rewarding is that the project will allow Canadian students and students from abroad to become involved in very good physics, with the clear prospect of earning a masters or PhD degree on this project.

Most scientists and students visiting TRIUMF are here for limited periods of time. They have come to TRIUMF for an experimental run, to work on the design and construction of experimental apparatus or for meetings with colleagues. With such limited time, providing them the resources to work efficiently and well in the time they have is important. In their own words:

TRIUMF is very effective in providing the support visitors working at TRIUMF need, whether the support is on the experimental floor, in the Business Office or through TRIUMF Housing Group. The TRIUMF support staff always seems to find a way to provide what is needed when it is needed. —Tomo Uemura

Working at TRIUMF is completely different from most of the laboratories in the world. It is a much more collegial and welcoming place. TRIUMF's hospitality works very well and TRIUMF House is an important link in the chain. Having a home and office away from home is really wonderful. —Roby Austin

Deciding to take your family to a foreign country for an extended stay is never an easy decision, but the TRIUMF support staff and the TRIUMF Housing group make the whole process easy and straightforward.
—Nathalie Lecesne and Hervé Savajols

TRIUMF's location in the heart of a beautiful metropolis adds to its reputation as a desirable place to visit and work.

I have always felt that Vancouver, the city itself and the surrounding mountains and sea, provide an incredibly inspiring atmosphere to work in and I know that I am not alone in this assessment. TRIUMF, Vancouver, Canada is a very good address to do new and interesting things. —Dieter Frekers

Jim Waddington in the TRIUMF House lounge.

by Shirley Reeve

TRIUMF House is an integral component of TRIUMF, and of TRIUMF's success as an international laboratory. While at the TRIUMF laboratory, visiting scientists and students prepare and carry out their experiments and accumulate experimental data, which they will analyze back at their home institutions. They work long, irregular hours in order to make the most of the limited accelerator time they have been allocated and, depending on the work to be done, their stays can vary from overnight to a month or more at a time.

The current TRIUMF House is a brand new, 35-room guesthouse. The guesthouse has all the amenities a visiting scientist or student could wish for: a state-of-the-art communal kitchen, a comfortable dining room and lounge, both with a fireplace, a TV room, reading room, computer room and comfortable bedrooms, some of which have small kitchens, and all of which have internet access. The house is surrounded by a beautiful verandah that takes advantage of Vancouver's mild climate, and is further surrounded by the forests and trails of the University of British Columbia campus, acknowledged to be one of the most beautiful campuses in the world. This new TRIUMF House opened its doors in December 2004, but there has been a TRIUMF guesthouse since the very early days of the laboratory.

In 1974, TRIUMF had almost completed building a state-of-the-art cyclotron, one of only three in the world at that time. Knowing that the laboratory would attract scientists and students from across Canada and from around the world, TRIUMF recognized that a convenient and economical guesthouse could play a vital role in the laboratory's success.

To that end, TRIUMF rented an old and run-down fraternity house from the University of British Columbia (UBC). The house had 12 double rooms and shared bathroom facilities. It took some effort to make the house suitable for visiting scientists and students, but by 1975, when TRIUMF's first cyclotron beams were ready for experimenters, TRIUMF House and its small staff were ready for their first guests.

In 1986, the University of Alberta, recognizing the enormous value of TRIUMF House to their scientists and students, made a substantial donation that enabled a major upgrade of the guesthouse. The number of available beds was increased to 32. The communal dining areas and other shared facilities were also renovated to make the facility more comfortable and useful to our guests. At this time, TRIUMF entered into a 20-year lease with UBC for TRIUMF House, and the guesthouse's worldwide reputation for excellence began to grow.

> ***"I do a lot of experiments at other labs and get to hear many comments about residences and guesthouses. One thing I discovered, and which is always a source of pride to me, is that TRIUMF House is the gold standard to which other lab residences are compared. I don't know how many times I have heard that such-and-such is not as good as TRIUMF House."***
>
> Des Ramsey, The University of Manitoba

In 2003, the lease with UBC was nearing an end. Recognizing TRIUMF's importance to the Canadian university community and the importance of TRIUMF House to TRIUMF, UBC offered the laboratory a 99-year lease on a prime campus building lot, just a short 15-minute walk from the laboratory. Because TRIUMF did not want to change the TRIUMF House "at-cost" operating policy for the benefit of our Canadian and international user community, who rely on government grants or other government funding to support their research, finding sufficient funding to build the new guesthouse was a challenge. However, by early 2004, and with the assistance of the TRIUMF Joint Venture member universities, funding was found, and construction of the new facility began. The new TRIUMF House opened its doors on December 10, 2004.

TRIUMF House, TRIUMF's new guesthouse located on the UBC Campus, opened December 2004.

TRIUMF House

by Shirley Reeve

> ***"In my experience, traveling around to other laboratories in many parts of the world, we have never found a housing arrangement the equal of TRIUMF House. Where else can one arrive in the middle of the night and find lodging exactly as arranged? Where else can a tired experimenter find as complete a kitchen available at every hour of the day? It has been as perfect a home-away-from-home as one could ever expect to find."***
>
> Bob Ristinen, University of Colardo, Boulder

TRIUMF House, like TRIUMF itself, has a worldwide reputation for excellence, and like TRIUMF, this reputation did not happen by accident. The TRIUMF House staff of Housing Manager, Reservations Clerks and Housekeepers work extremely hard to create a home-like atmosphere at the guesthouse. The facility is kept spotlessly clean. The furniture, fixtures and accessories are comfortable. The communal kitchen is available for guests at any time of the day or night. Guests arriving at 2:00 in the afternoon or 2:00 in the morning will find their rooms ready for them. Scientists and students working experimental shifts at the laboratory know they can come "home" to the guesthouse at any time of the day or night and sleep or work without interference or noise from the staff or other guests.

The TRIUMF House dining room opens onto a large covered verandah.

The guesthouse is not the only housing for which the TRIUMF House staff is responsible. TRIUMF maintains several apartments year round for TRIUMF visitors staying several months or more. When TRIUMF apartments are not available or not suitable for a visitor and his or her family, the TRIUMF Housing Manager can assist with arranging an appropriate sublet of a nearby house or apartment.

The TRIUMF user community will always have an abiding fondness for the old TRIUMF House. Despite the many physical shortcomings inherent in a facility converted from an old fraternity house, it was a clean, quiet, comfortable and familiar home to the TRIUMF Canadian and international physics community for 30 years. It was with some sadness that members of the user community gathered together on December 10, 2004 to make the short walk from the old TRIUMF House to the new facility. But it was a celebration too. Over the past 30 years, TRIUMF has developed a worldwide reputation for excellence in particle and nuclear physics, in medical research, treatments and applications, in condensed matter sciences and, most recently, at the new ISAC facilities. TRIUMF's updated facilities and reputation for scientific excellence continues to attract a large number of Canadian and international scientists and students to the laboratory. Our new TRIUMF House will ensure that scientific Visitors who want to use the TRIUMF laboratory will have a home-away-from-home for many years to come.

If you are visiting TRIUMF and accommodation is needed, please visit the TRIUMF House website at www.TRIUMFHouse.ca or contact our reservations office at housing@triumf.ca.

Shirley Reeve is TRIUMF's Financial Officer.

TRIUMF House has 4 small suites, complete with small kitchen and eating area.

Functional Imaging With PET

by Thomas J. Ruth

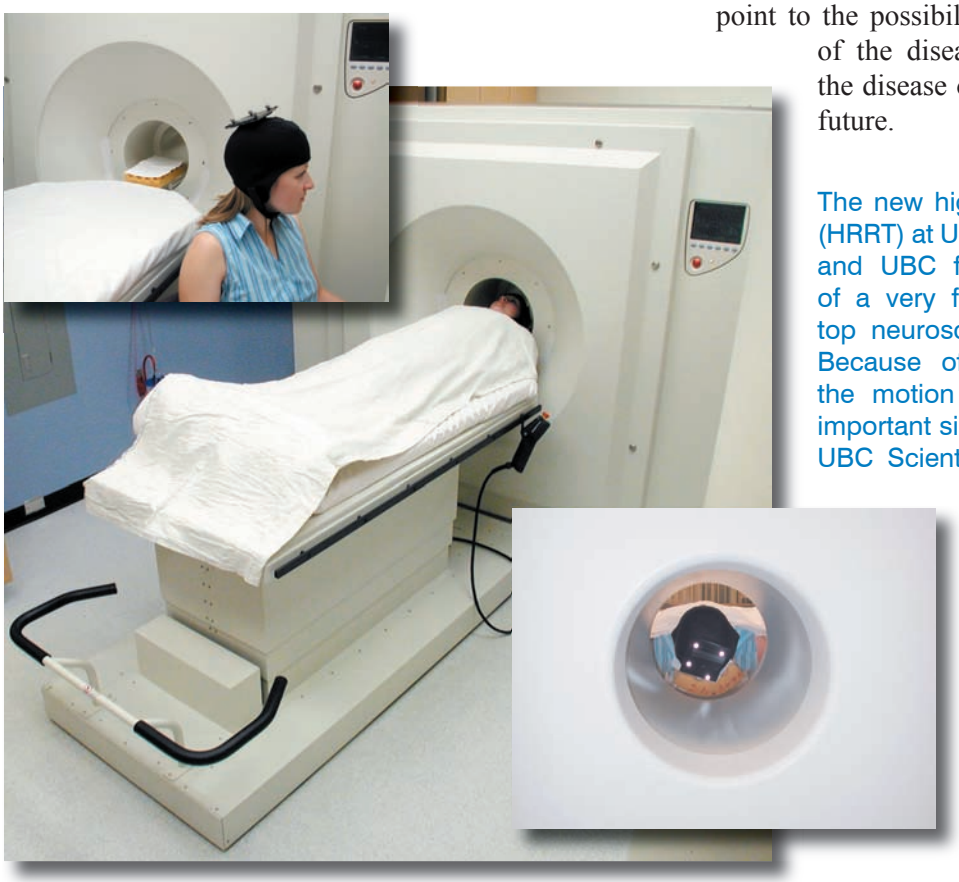
Since the early 1980's, positron emission tomography (PET) has been the primary focus of the Life Sciences Program at TRIUMF. This program, carried out in close collaboration with the Faculty of Medicine at the University of British Columbia (UBC), has proven to be a very effective and successful one.

The primary focus of the collaboration has been with the Pacific Parkinson's Research Centre and its predecessors at the Movement Disorders Clinic at UBC. The aim was to study the origins, progression, therapy and complications of therapy, in Parkinson's disease (PD). To date, the team has made a number of major findings that have altered the way in which PD is now understood and treated. These include the fact that the PET technique can detect changes in a patient's neurological system caused by PD even before the patient and his or her doctor is aware that a problem is developing. As time goes on, the changes progress and, eventually, patients go on to show all the symptoms of full-blown clinical PD. The importance of such a finding is that if treatments are found and can be applied at an early stage the morbidity associated with PD may be lessened.

Another finding of our group was that the involuntary movements known as dyskinesias, which affect approximately 40% of PD patients, are most likely associated with how the particular patient's brain reacts to dopamine and not, as previously thought, caused by their medication. The implications are huge in that the mode of treatment may be adjusted to match more closely the personal needs of the patient. This is a step towards personalized medicine for patients.

More recently, we have demonstrated that the placebo effect actually exists as a phenomenon where, in anticipation of receiving a therapeutic effect when taking a pill (in this case a sugar pill), PD patients release the neurotransmitter dopamine. This finding has opened a whole new area of PET research as we and others try to understand the limits of this phenomenon and how to exploit it to help PD patients and, perhaps, those suffering from other disorders manage their disease with less medication, and consequently, fewer complications.

The sum of our findings over the years has led to the "event hypothesis" of Parkinson's disease, i.e., PD is caused by an event or a small number of events closely spaced in time during which some neurons are killed, others damaged and still others spared. Over time the damaged neurons die prematurely, which results in the progressive nature of the disease. These findings point to the possibility of finding a cause, or causes, of the disease and perhaps even preventing the disease or its progression sometime in the future.



The new high resolution research tomograph (HRRT) at UBC purchased through CFI/BCKDF and UBC funds. This PET scanner is one of a very few state-of-art scanners built for top neuroscience centres around the world. Because of the extremely high resolution, the motion of the patient's head becomes important since the motion will blur the image. UBC Scientists track the motion by using a swim cap with markers on it. These markers are tracked by an infrared camera, and the final images are adjusted to a common position to correct for any motion during the scan. The patient wears the swim cap with the markers on top. The infrared camera is behind the scanner viewing the top of the patient's head through the opening in the back of the scanner.

by Thomas J. Ruth

In recognition of the efforts and strengths of the program over the years, and the potential of the group to continue to perform outstanding science, the Canadian Institutes of Health Research (CIHR) has designated our group as a CIHR Team in Parkinson's disease. This award is in the form of a research grant of nearly $4.5 million over 5 years.

The research program we propose to carry out with this grant includes examining the genetic component of PD using PET and other techniques. The goal here is to determine the vulnerable segments of gene expression that may play a critical role in who becomes affected by the disease in the general population. We will continue our studies in following the progressive course of disease and understanding the underlying compensatory mechanisms, and the changes that the body undergoes to try and make up for the loss of the neurochemical caused by PD. Following up on our studies of the placebo effect, we will examine the phenomena of reward and expectation of reward and its role in treatment.

Probably the most critical component for increasing the effectiveness of PET is the development of more specific tracers. A tracer is a biologically active compound that has been tagged with a radioactive isotope so that it can be tracked as it passes through the body and is accumulated by the various organs or systems within the living person. One of the most common tracers is an analog of sugar called ^{18}F-fluorodeoxyglucose or FDG. FDG is absorbed by tissues that use sugar for energy, such as the brain while we are thinking, or in the case of disease, cancer cells, that are very active and accumulate a lot of FDG. While FDG is a very powerful tracer, it is not very specific in that most cells in the body will have some energy demand and accumulate FDG. Other tracers we use, such as a compound called Fluorodopa (FD), are more specific. FD accumulates in the brain cells associated with movement, the basal ganglia. There is little uptake in the regions devoid of the cell type that uses FD as can be seen from the image on the following page. As the physical limitations of detection are approached, the remaining avenue is to increase signal to noise by having tracers that are uniquely suited to imaging the function in question.

What does the future hold for functional imaging with PET? Two major areas related to tracer development are ripe for exploitation. One is the miniaturization of the chemistry for preparing tracers. With the advent of *lab-on-a-chip* technology, the automated syntheses of tracers on a wafer that can be discarded are not far behind. Such developments will speed the availability of tracers for widespread human use because of the possibility of mass production of the miniature chemistry sets under sterile conditions.

The other area is in achieving higher specificity of the tracer. This will most likely occur in the use of oligonucleotides (ODN) or short strands of our genetic material, our DNA. ODNs will be specific for particular changes in our genetic make up due to disease. Being able to clearly identify a unique characteristic of the disease in a population could overcome some of the shortcomings related to PET's sensitivity. This approach would truly introduce personalized medicine.

Of course, these concepts may be oversimplifying the challenges facing us in the treatment of PD but they do provide hope for controlling this debilitating disease.

FDG production in progress at the BCCA radiochemical laboratory beside TRIUMF's TR-13 cyclotron.

More recently, the TRIUMF PET team has assisted the British Columbia Cancer Agency (BCCA) to establish a Centre of Excellence for Functional Imaging in Cancer. This Centre's first project was to put in place a clinical program using the PET technique to image patients with suspected cancer and to follow up with patients who have received treatment to determine the efficacy of the treatment.

by Thomas J. Ruth

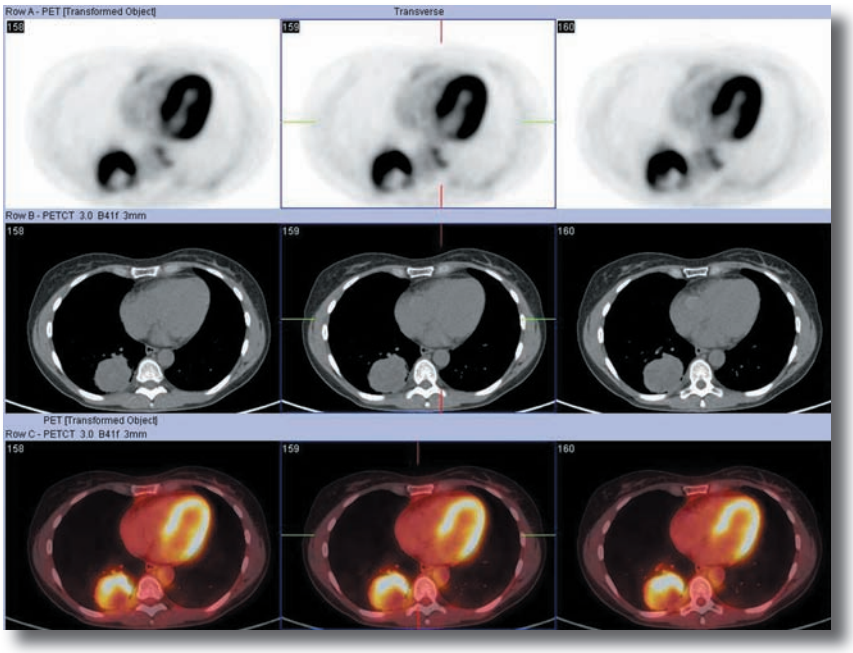
To carry out this program, the BCCA acquired a PET/CT system, which is a combined PET and CT scanner that allows sequential scans of a patient, thus providing a functional image from PET and an anatomical image from the CT scanner. The PET scans are based on the radiotracer FDG, (see previous page) an analog of glucose or sugar. Since most cancers cells are rapidly dividing, they need more energy than the surrounding healthy tissue and, because of their higher metabolism, can be located by the PET scan. This technique alone has proven to be very powerful because it can be used to detect very small and perhaps distant metastatic tumours. However, because the metatises may be located just about anywhere within the body, having a physical landmark to determine their precise location and whether the cancer cells have invaded critical organs becomes extremely important. This is where the CT scan coupled with the PET scan has found its place in clinical diagnostic medicine.

In Phase II of the BCCA Functional Imaging program they will acquire a cyclotron for the production of FDG. More importantly, they will be then be able to prepare radiotracers for their envisioned research program in cancer biology. They will build radiochemistry laboratories as well as a distribution centre in anticipation of supplying FDG to other PET centres within British Columbia. These new facilities are to be completed by the Fall of 2007.

While waiting for the completion of the BCCA facilities, TRIUMF is playing host to scientists and technicans from BCCA, providing them with the space and equipment required for the preparation of the FDG needed for their clinical program. Twice a day the FDG produced at TRIUMF is shipped to the BCCA clincal site some 10 km away, where it is used to scan 10 to 12 patients. From July 2005 to May 2006, BCCA scanned more than 1,200 patients. The importance of such a diagnostic tool is shown by the fact that in 30% of these cases, as a result of the additional diagnostic information revealed, patients' treatments were changed to better fit their particular needs.

PET remains the most sensitive technique for imaging the functioning of the living human body. Although radioactivity is used to acquire the images, the amount of radiation associated with a PET scan is much lower than one would receive in having a diagnostic CT scan. The PET technique is truly a window on the body.

Thomas J. Ruth is a TRIUMF Research Scientist and Director of the TRIUMF/UBC PET Centre.



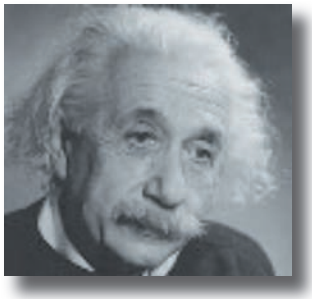
These panels depict images from a PET scan, a CT scan and the 2 images fused together. The top row shows 3 slices through the abdomen of a patient who has received an injection of FDG (see text). The image uses what is called a gray scale where the darker image, the higher the uptake. The reader should note that the "horseshoe" shaped object is the myocardium or heart muscle. The heart can use sugar for its energy source which is illustrated by this high uptake. More importantly for diagnostic purposes is the uptake towards the bottom of the image. Since the images are "slices" through the body, the top represents the front of the body, and the bottom the back. The uptake is associated with a tumour and is indicative of high metabolic activity or the tumour is actively growing. The middle growth shows the same region as seen in a CT (x-ray) imaging showing the body's structures. The heart is shown in the middle right, and the suspected tumour on the bottom (back of the patient). The bottom row shows the two sets of images fused together so that the functional image (FDG/PET) can be compared to the CT (structural image). Having the two sets of information can have an impact on treatment planning for the cancer doctor.

In 1905, Albert Einstein, a 26-year old German patent clerk, published three revolutionary theoretical papers explaining experimental observations that had baffled scientists for decades. These papers, called Einstein's "Annus Mirabilis Papers" because they defined 1905 as a "miracle year" for physics, produced a fundamental change in how physicists describe the physical world. In recognition of this miracle year, and to celebrate Einstein's legacy to mankind, the International Union of Pure and Applied Physics (IUPAP) and the United Nations declared 2005 the World Year of Physics.

What were Einstein's revolutionary ideas?

The "Photoelectric Effect," expanded the theory of light popular at that time. Although the idea that light was a form of waves was well established, Einstein showed that light could also assume a particle-like nature, taking the form of discrete energy packets. In this way, he explained the mysterious photoelectric effect, in which light is absorbed and emitted from atomic matter.

Einstein's explanation of "Brownian Motion" helped launch quantum mechanics and provided empirical evidence that atoms really existed. Einstein's statistical discussion of atomic behaviour gave experimentalists a way to count atoms by looking through an ordinary microscope.



"The Theory of Special Relativity" led to Einstein's famous equation $E = mc^2$ and introduced a consistent theory of time, distance, mass, and energy. Einstein's theory described the motion of particles moving at close to the speed of light and gave the correct laws of motion for any matter. Although the predictions of Einstein's theory seemed strange, many decades of experiments have thoroughly confirmed it.

Einstein was one of the greatest physicists who ever lived. He is certainly one of the most famous. Each of the Annus Mirabilis papers was worthy of a Nobel Prize, but some of his 1905 theories were so far beyond what was understood at that time about physics and our natural world that they took some time to be completely understood and accepted. Albert Einstein finally received the Nobel Prize for Physics in 1921 for his explanation of the photoelectric effect and "for his services to Theoretical Physics."

The World Year of Physics aimed to raise awareness of the importance of physics and the physical sciences and physics communities worldwide. TRIUMF shared its vision and passion for physics with the general public by hosting open houses, science fairs and other events and celebrations, including a series of very popular public lectures explaining the wonders of Einstein's scientific legacy.

Although the World Year of Physics ended December 31, 2005, TRIUMF will continue to share its enthusiasm for science with the public. Please check our website (www.TRIUMF.ca) for information on public lectures, open houses, tours of the TRIUMF laboratory and general information on the scientific activities of TRIUMF.

AUDITORS' REPORT

To the Joint Venturers of TRIUMF

The accompanying summarized statements of financial position and combined statement of funding/income and expenditures and changes in fund balances are derived from the complete financial statements of TRIUMF as at March 31, 2006 and for the year then ended on which we expressed an opinion without reservation in our report dated May 19, 2006. Those financial statements were prepared to comply with section 7 of the TRIUMF joint venture agreement and the contribution agreement with the National Research Council of Canada, and are prepared using the basis of accounting as referred to in note 2 to the accompanying financial statements. The fair summarization of the complete financial statements is the responsibility of management. Our responsibility, in accordance with the application Assurance Guideline of the Canadian Institute of Chartered Accountants, is to report on the summarized financial statements.

In our opinion, the accompanying financial statements fairly summarize, in all material respects, the related complete financial statements of TRIUMF in accordance with the criteria described in the Guideline referred to above.

The summarized financial statements, which have not been, and were not intended to be, prepared in accordance with Canadian generally accepted accounting principles, are intended for the information and use of the Joint Venturers and the National Research Council of Canada. Furthermore, the summarized financial statements do not contain all the disclosures required by Canadian generally accepted accounting principles. Readers are cautioned that these financial statements may not be appropriate for their purposes. For more information on TRIUMF's financial positions, results of operations and changes in fund balances, reference should be made to the related complete financial statements.

PricewaterhouseCoopers LLP

Chartered Accountants
Vancouver, B.C.
May 19, 2006

TRIUMF
Statement of Financial Position
As at March 31, 2006

	2006 $	2005 $
Assets		
Cash	5,102,209	5,967,433
Funding receivable	956,356	1,103,237
Due from joint venturers	24,723	31,263
	6,083,288	7,101,933
Liabilities		
Accounts payable	564,408	1,667,229
Funds received in advance	2,025,816	1,462,916
Bank loan	1,199,995	1,519,999
	3,790,219	4,650,144
Fund Balances		
Restricted		
Natural Sciences and Engineering Research Council Fund	2,240,299	3,001,993
MDS NORDION Inc. Fund	100,000	100,000
Canada Foundation for Innovation	(170,975)	(54,681)
	2,169,324	3,047,312
Other		
Commercial Revenue Fund	979,935	1,085,994
General Fund	16,465	3,171
TRIUMF House Building Fund	(1,934,789)	(2,413,204)
Intramural Accounts Fund	1,062,134	728,516
	123,745	(595,523)
	2,293,069	2,451,789
Total liabilities and fund balances	6,083,288	7,101,933

Encumbrances and commitments

Economic dependence

TRIUMF

Statement of Combined Funding/Income and Expenditures

As at March 31, 2006

	2006 $	2005 $
Funding/income		
National Research Council Fund	44,000,000	40,000,000
Natural Sciences and Engineering Research Council Fund	4,688,242	5,300,363
MDS NORDION Inc. Fund	4,523,406	4,299,391
Canada Foundation for Innovation	1,923,525	1,203,511
Affiliated Institutions Fund	1,083,601	1,249,940
Commercial Revenue Fund	1,728,178	1,433,679
General Fund	250,428	140,701
	58,197,380	53,627,585
Expenditures		
Buildings and improvements	379,467	3,088,368
Communications	204,282	122,442
Computer	1,248,930	1,168,475
Equipment	8,213,429	6,563,773
Power	1,889,040	1,890,107
Salaries and benefits	34,355,746	33,014,827
Supplies and other expenses	12,065,206	8,997,681
	58,356,100	54,845,673
Deficit of funding over expenditures for the year	(158,720)	(1,218,088)
Fund balances - Beginning of year	2,451,789	3,669,877
Fund balances - End of year	2,293,069	2,451,789

TRIUMF
Notes to Financial Statements

1. Nature of operations

TRIUMF is Canada's national laboratory for particle and nuclear physics, owned and operated as a joint venture by the University of Alberta, Carleton University, the University of Victoria, Simon Fraser University and the University of British Columbia, under a contribution from the National Research Council of Canada. As a registered charity, TRIUMF is not subject to income tax.

Each university owns an undivided 16.7% interest in all the assets and is responsible for 16.7% of all liabilities and obligations of TRIUMF, except for the land and buildings occupied by TRIUMF, which are owned by the University of British Columbia.

These financial statements include only the assets, liabilities, funding and expenditures of the activities carried on under the control of TRIUMF and do not include the other assets, liabilities, revenues and expenditures of the individual joint venturers.

Sources of funding include grants and contributions from the National Research Council of Canada, the Natural Sciences and Engineering Research Council, and governments; advances and reimbursements from other sources; royalty income; and investment income. TRIUMF has established a number of separate funds to account for the various funding sources. The sources and purposes of these funds are:

National Research Council Fund (NRC)

Funding of operations, improvements and development; expansion of technical facilities (buildings excluded); and general support for experiments.

Natural Sciences and Engineering Research Council Fund (NSERC)

Funding to grantees for experiments related to TRIUMF activities. These funds are administered by TRIUMF on behalf of the grantees.

Canada Foundation for Innovation (CFI)

Funding to grantees for capital projects related to TRIUMF activities. These funds are administered by TRIUMF on behalf of the grantee.

MDS NORDION Inc. Fund

Advances and reimbursements for expenditures undertaken at its TRIUMF site.

Provincial Government Building Fund

Funding from the Province of British Columbia and other sources for the construction of new facilities.

Affiliated Institutions Fund

Advances and reimbursements for expenditures undertaken on behalf of various institutions from Canada and abroad for scientific projects and experiments carried out at TRIUMF.

Commercial Revenue Fund

Royalties, revenue and expenditures relating to commercial activities and technology transfer.

General Fund

Investment income for discretionary expenditures incurred by TRIUMF.

TRIUMF House Fund

Contributions from unrestricted funds for the construction of TRIUMF House.

Intramural Accounts Fund

Net recoveries for internal projects and services. The recoveries of expenditures are charged to the appropriate TRIUMF funding source by Intramural Accounts.

Significant accounting policies

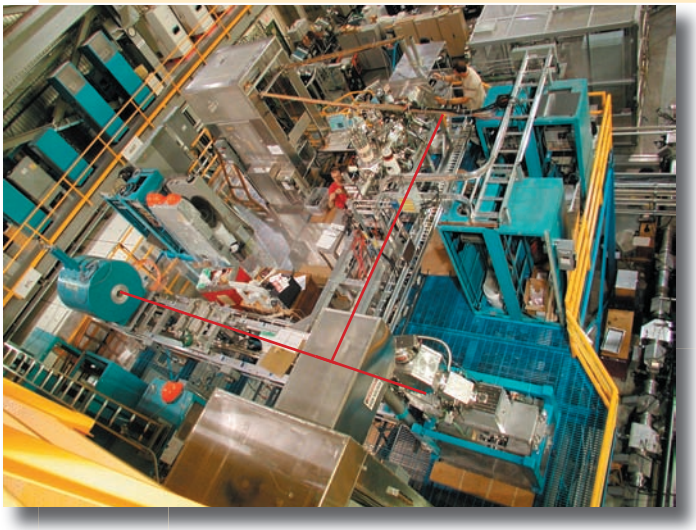
2. Basis of presentation

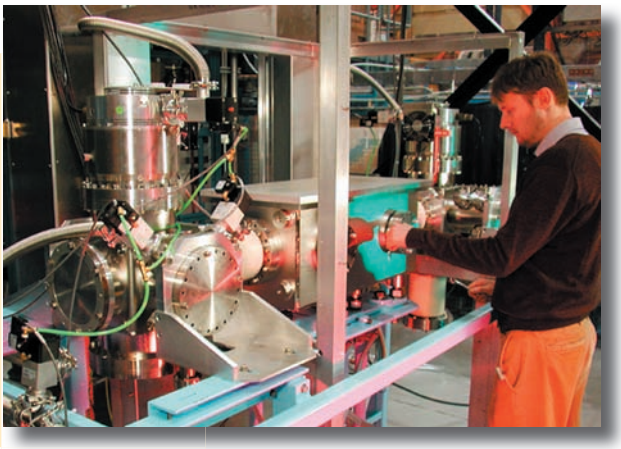
These financial statements have been prepared in accordance with section 7 of the joint venture agreement (note 1) and the contribution agreement with the National Research Council of Canada, and follow Canadian generally accepted accounting principles for not-for-profit organizations as referred to in the Canadian Institute of Chartered Accountants Handbook, except that all property, plant and equipment purchased or constructed for use at TRIUMF and related decommissioning costs (if any) are expensed in the period in which the costs are incurred.


Industry Canada
Agency Committee on TRIUMF
National Research Council
TRIUMF 5 Year Peer Review Committee
Advisory Committee on TRIUMF
Ex-Officio Members
Dr. W. Davidson National Research Council
Dr. H. Robertson Chair, Advisory Committee on TRIUMF
Board of Management
Joint Venture Members
Associate Members
The University of Alberta
The University of British Columbia
Carleton University
Simon Fraser University
The University of Toronto
The University of Victoria
The University of Guelph
The University of Manitoba
McMaster University
L'université de Montréal
Queen's University
The University of Regina
Saint Mary's University
Associate Director J-M. Poutissou
Director A.C. Shotter
Administrative Assistant E. Conning
HR & Administration J. Hanlon
Financial Officer S. Reeve
Advisory Committees
Experiment Evaluation Committees
Subatomic Physics
Molecular and Materials Science
Life Science
Computing Facilities at TRIUMF
TRIUMF Operating Committee
TRIUMF Safety Management Committee
Accelerator Technology Division E. Blackmore
Administration Division A. Shotter
Cyclotron Division P. Schmor
ISAC Division P. Schmor
Science Division J-M. Poutissou
Technology Transfer Division P. Gardner

TITAN

by Jens Dilling





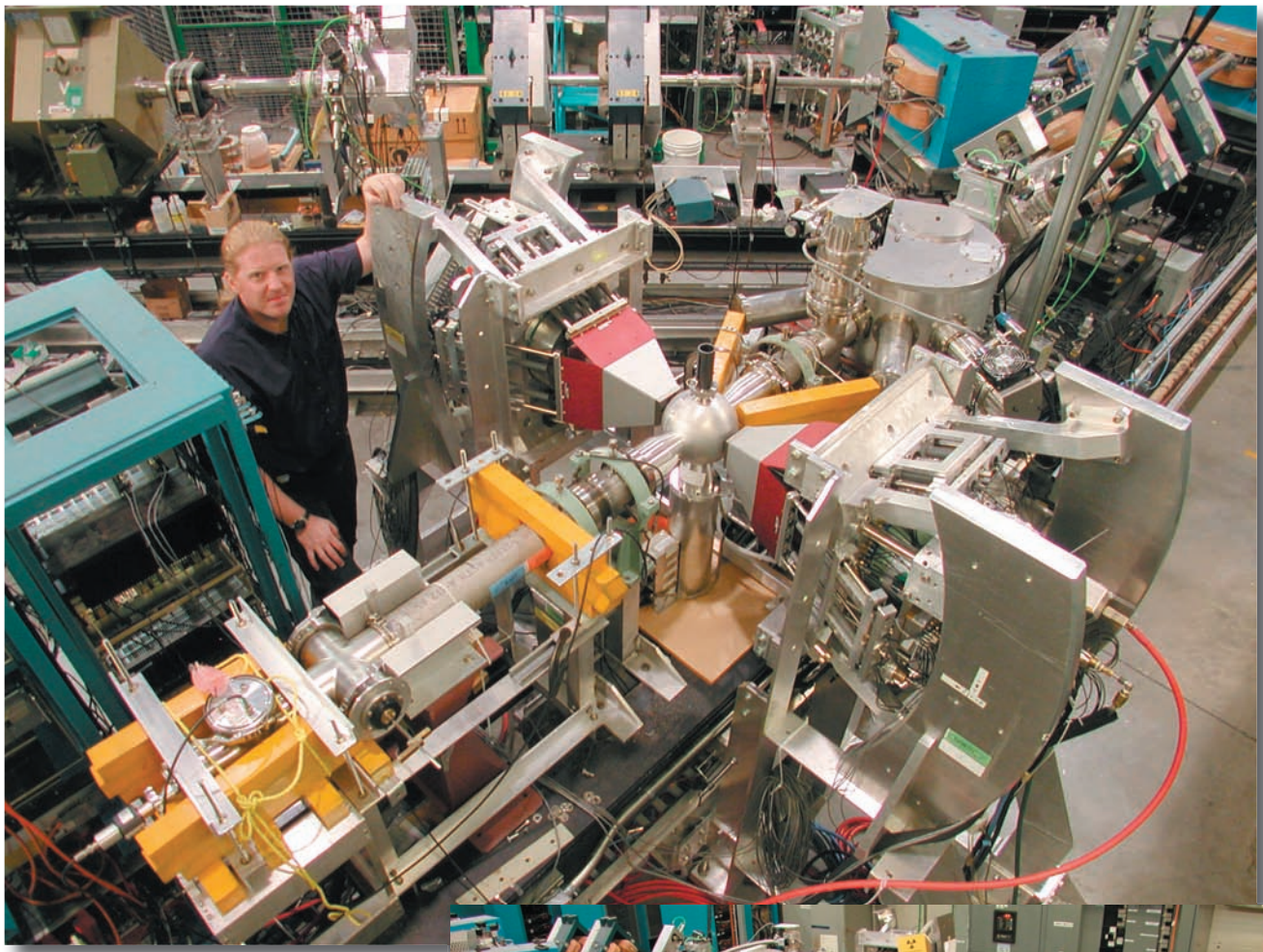
The TRIUMF Ion Trap for Atomic and Nuclear (TITAN) science facility (www.triumf.ca/titan) will provide unique research opportunities for Canadian and international scientists and students in atomic, nuclear, neutrino and particle physics. This multi-component ion trap system is an ideal tool for ISAC experiments. These experiments include high precision mass determination for testing the Standard Model of particle physics and testing the behaviour of nuclei far from the valley of stability. Testing the behaviour of this type of nuclei will also provide a better understanding of Halo nuclei, a new form of matter with a neutron skin. TITAN will provide unprecedented possibilities for laser spectroscopy to obtain information on the structure of nuclei.

TITAN is currently in the commissioning phase, and the first high precision mass measurements employing Einstein's famous formula $E=mc^2$ are planned for the winter of 2006-07.

The TITAN collaboration consits of members from 7 Canadian Universities and 11 countries.

Jens Dilling is a Research Scientist at TRIUMF.

by Gordon Ball



TIGRESS (www.triumf.ca/tigress) is an $8M detector system, funded by the Government of Canada through the Natural Sciences and Engineering Research Council (NSERC). The detector will exploit the higher energies and scientific opportunities available at TRIUMF's ISAC-II facility.

In July 2006, the TIGRESS collaboration performed their first experiment with accelerated radioactive ion beams from the new accelerator at ISAC-II (see front cover story). The top photograph shows the TIGRESS set-up and associated TIGRESS beamline with 2 of the eventual 12 detectors. The lower photograph shows a few of the 48 collaborators from 3 countries who participated in the first experiment with TIGRESS.

Gordon Ball is a Research Scientist at TRIUMF.