Beamtime

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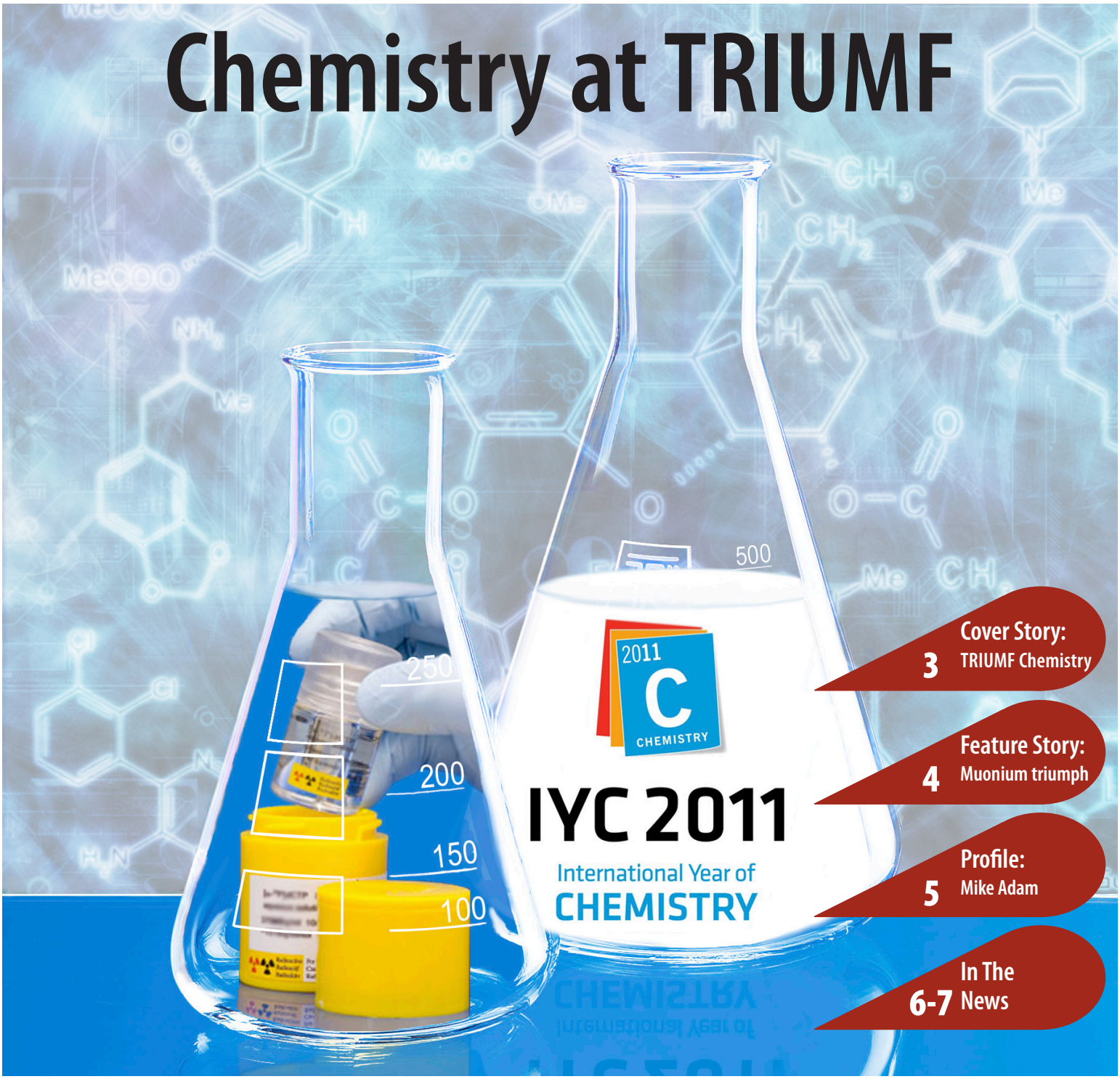
TRIUMF

News from Canada's National Laboratory for Particle and Nuclear Physics

Chemistry at TRIUMF



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Director's Voice

TRIUMF: Canada's Laboratory for Nuclear and Radiochemistry

This issue of Beamtime is about chemistry—nuclear chemistry or sometimes just called radiochemistry. So what is nuclear chemistry? In simple terms, nuclear physicists concern themselves with the core of the atom, the nucleus and its properties. Chemists study, design, and manipulate molecules. Molecules are collections of atoms connected together. Nuclear chemistry is the merging of those two fields, at the interface where properties of the atom and/or its stability affect the behaviour and utility of the larger molecule. Nuclear chemistry then is the study of materials, soft or hard, such as living tissues, unusual liquids, as well as a range of interesting solids such as conductors, semiconductors and superconductors.

> *"a key strength of TRIUMF's research program is its diversity: from accelerators to . . . chemistry"*

Chemistry is an important component of nuclear medicine. An unstable atom can be combined with an interesting molecule; when the atom decays, it emits a particle than can travel through the human body and register in an external detector, thereby identifying where the molecule is located. Chemists design and make these very special molecules that include radioactive atoms. Knowing the location of a molecule in the body provides powerful information to a doctor. These molecules could be flagging the presence of cancer, responding to some type of brain function, or simply tracking healthy blood flow.

Chemistry is important in materials science. TRIUMF uses beams of particles, such as muons (an elementary particle similar to the electron but heavier and decays with well known and specific properties), to probe the details of materials. We primarily study the local behaviour of magnetic fields on or within materials, but many other topics of interest to basic research and practical applications are on the menu.

A key strength of TRIUMF's research program is its diversity: from accelerators to physics, from chemistry to medicine. It is with this combination of knowledge, skills, and capabilities that TRIUMF assists Canada in merging basic research with practical outcomes to maintain Canada's standard of living and keep pace with the rest of the world.

• Nigel Lockyer

Cover Story

Chemistry at TRIUMF

Exploiting unstable nuclei and exotic atoms

Notwithstanding the label "Canada's national laboratory for particle and nuclear physics" there is lots of chemistry in the research carried out at TRIUMF. Some areas of nuclear science are traditionally labelled chemistry – Marie Curie, Frederick Soddy, the Joliots, Otto Hahn and Glenn Seaborg all won the Nobel Prize in Chemistry. That tradition is well alive at TRIUMF, where ISAC scientists Corina Andreiou, Krzysztof Starosta and John D'Auria (emeritus) of SFU, and Andrew MacFarlane of UBC, are professors in their respective chemistry departments.

The traditional view of chemistry involves "cookery" – synthesis of chemical compounds. That finds a special place at TRIUMF for generating molecules utilizing radioactive isotopes used for radiotracer diagnostics (e.g. positron emission tomography) and radiotherapy. TRIUMF scientists Mike Adam (see profile on page 5), Tom Ruth and Paul Schaffer are involved in such work, with valuable input from local chemistry professors Chris Perrin and Chris Orvig (UBC) and Tim Storr (SFU). A less traditional synthetic technique is being developed by another chemistry professor, Paul Li (SFU), who is collaborating with Paul Schaffer on the use of microfluidics for the rapid production of ^{11}C-labelled compounds. In fact radiochemistry is a rapidly growing research area at TRIUMF.

The most fundamental chemistry at TRIUMF is surely the work of Don Fleming (emeritus, UBC), whose studies of gas-phase chemical reaction dynamics utilize either a light isotope of hydrogen (muonium Mu, a hydrogen-like atom where the proton nucleus is replaced by the positive muon) or a heavy equivalent (muonic helium, where one electron is replaced by a negative muon). His work is highlighted on page 4. Muonium kinetics is also at the heart of a collaboration between Khashayar Ghandi (Mt. Allison) and Paul Percival (SFU), but here the focus is on a specific application – rate constants are being determined for reactions in superheated water as part of a national program to develop a supercritical-water-cooled nuclear power reactor.

Khashayar Ghandi also studies muonium chemistry in other media – supercritical carbon dioxide and ionic liquids. In this case the end application is "green chemistry", i.e., the development of chemical processes that are more environmentally benign by virtue of more efficient use of energy and feedstock and/or less toxic materials.

Another TRIUMF project which employs muonium to probe the details of chemical reactions is a collaboration between Paul Percival (SFU) and Bob West (University of Wisconsin-Madison). They detect and characterize samples for studies of muoniated radicals formed from novel organosilicon and organogermanium compounds. An example drawn from a recent paper is shown in Figure 1. The focus of such studies is to learn about the reactivity of novel molecules. In recent years Percival and West have been sent unique samples from specialists in organic synthesis situated in Canada, Germany, Israel, Japan, and the USA. The International Year of Chemistry 2011 is a worldwide celebration of the achievements of chemistry. It is therefore fitting that this issue of Beamtime highlights chemistry research at TRIUMF.

• Paul Percival

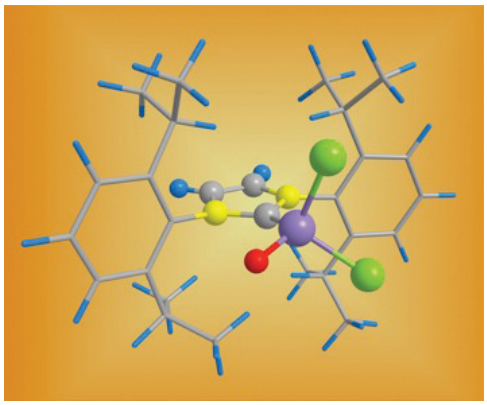


Fig. 1. The structure of a novel free radical detected at TRIUMF (Mu red, N yellow, Si violet, Cl green, C grey, H blue).

For more: www.triumf.ca/chemistry

Feature Story

A Triumph for Muonium Chemistry

Kinetic Isotope Effects Measured Over an Unprecedented Mass Range

Chemical reaction rates lie at the heart of not only chemistry, but biology, biochemistry, and chemical engineering as well. The effect of different isotopes on reaction rates can be crucial for both experiment and theory. Isotopes have the same number of electrons but different nuclear masses, and since atomic motion determines the reaction dynamics, varying the nuclear mass can have a huge impact on reaction rates. Studies at TRIUMF have made a unique contribution to this field probing the kinetic isotope effects of the simplest atom of all: hydrogen.

Chemists seek a detailed theoretical understanding to the most basic reaction $H + H_2 \rightarrow H_2 + H$ (the "quark" of the molecular world), which has been subject to ever more detailed experimental and theoretical study since its first study in the mid-1930s by Harold Urey. Comparing deuterium (D, mass=2amu) versus H-atom (mass=1amu) reaction rates have provided a limited theoretical tests of theory of this reaction, whereas tritium (mass=3 amu) is dangerously radioactive. Thus it has fallen to muon science to extend the H-atom isotopic mass scale to offer an unprecedented test of quantum rate theory in the process.

The lightest isotope of hydrogen is muonium ($Mu = \mu^+e^-$), an electron orbiting a positive muon "nucleus", and with an atomic mass of 0.113 amu. TRIUMF began studies of Mu reactivity in gases in 1978, with a first study of the fundamental $Mu + H_2$ reaction rate following shortly thereafter. Recently TRIUMF succeeded in creating "superheavy hydrogen" (4Heμ) by the capture of negative muons (μ^-) on helium (4He). The μ^- replaces one of the helium electrons, but it is located next to the helium nucleus, thus "shielding" one of the (positive) proton charges, forming a charge-neutral muonic He atom, ^{4}Heμ (mass=4.11 amu) with the same chemical properties as hydrogen, but 4x heavier, and 36x heavier than Mu. See Figure 1.

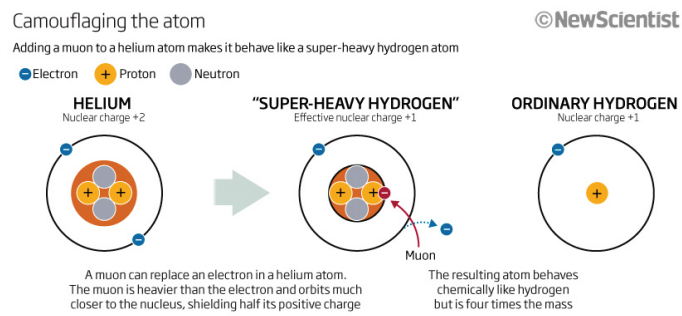


Figure 1.

The most basic reaction of the 4Heμ isotope $^4He\mu + H_2 \rightarrow [^4He\mu]$ H+H has now been studied, exploring an unprecedented range of isotopic mass effects (36x, compared to $Mu + H_2$), the first time such a mass-range comparison has even been possible, a unique Canadian research contribution. Figure 2 shows the chemical reaction rate constants for both the basic Mu and 4Heμ reactions, overlayed with theory. This is one of the very few examples of such a level of agreement between rigorous theory and experiment in molecular quantum mechanics. It is the muon science program that has made this possible, and its a triumph for chemistry at TRIUMF.

• Don Fleming

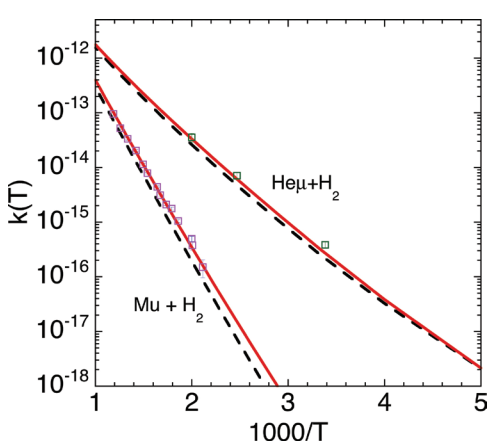


Figure 2. Reaction rate constants for basic Mu $+H_2$ and Heμ $+H_2$ reactions (points) overlayed with Theory (solid, dashed lines)

For more: D.G. Fleming et al., J. Chem. Phys., 135, 184310 (2011)

Profile

Mike Adam

Bettering health through chemistry

Mike Adam is a chemist that works at TRIUMF—a physics lab. As you may have guessed, Mike's story is unique. When Mike was hired in 1980, many people had no idea as to why TRIUMF would need a chemist. The director himself, Jack Sample, when discovering that Mike Adam had been hired responded with "What the hell do we need an organic chemist at TRIUMF for?"

Mike Adam had been hired to work on a new and emerging technology; Positron Emission Tomography (PET). The technology was in its infant stages and TRIUMF wanted to develop mastery for Canada at the lab. Mike spearheaded the PET radiopharmaceutical part of the project at TRIUMF and it has been nothing but successful ever since. With 31 years of hard work at TRIUMF behind him, he is clearly a dedicated and crucial member of the TRIUMF team.

> "a dedicated and crucial member of the TRIUMF team"

Mike was fortunate enough to be offered a job before he even received his PhD in Chemistry from the University of British Columbia. In October 1979, Mike was approached by Brian Pate, one of the associate directors of TRIUMF at the time, and was offered the exciting opportunity to work at TRIUMF. Although Mike was an expert in fluorosugar chemistry he had no professional training in radioactivity at the time, and had not even graduated. He eagerly accepted the offer and started at TRIUMF on Feb. 1, 1980 shortly after defending his Ph.D.

Being a chemist amongst physicists has brought with it both challenges and rewards over the years. Like most new employees, Mike needed to prove himself, and his misplaced title made the feat much more difficult. Over time, Mike's accomplishments spoke for themselves. The PET program at TRIUMF, with Mike as Head of PET chemistry, has expanded significantly over the years, and has lead to extensive collaborations with researchers at UBC, UVIC, SFU, BCCA, VGH, and local biotech companies such as Nordion.

At one point, Mike considered being a physicist himself, but he personally found chemistry more interesting. What Mike liked, and still likes, most about chemistry is the "hands on" aspect to it, specifically in regards to synthetic chemistry. He enjoys the practical applications of what he creates, such as chemical agents for medical imaging.

Currently, Mike is still working on developing PET pharmaceuticals, as well as being an Adjunct Professor at the University of British Columbia. Some of his other work includes collaborations alongside fellow UBC professor Dr. Chris Orvig, to develop carbohydrate radio-metal conjugates with Tc-99m and Re-186/188 for potential use as imaging and therapy agents.

Mike was one of the first chemists to join the TRIUMF team, but certainly not the last. TRIUMF has expanded over the years to include an entire Nuclear Medicine division, showing that with the hard work of people like Mike Adam, TRIUMF's scientific capabilities are endless.

• Ryan East

In The News

Diagnostic radiology expert from Yale sabbaticals at TRIUMF

From July to December 2011 TRIUMF was privileged to play host to Dr. Yu-Shin Ding, Director of PET Radiochemistry Research & Development and Professor of Diagnostic Radiology at Yale University. A main goal of her six-month sabbatical was to learn to develop methylreboxetine (MRB) at TRIUMF, a tracer that will allow scientists to study the neurotransmitter norepinephrine (NET). This work is ground-breaking since no study has yet done imaging of NET in humans due to lack of a tracer. However, NET plays an important role in many disorders, including Parkinson's disease, substance abuse, and ADHD. TRIUMF does not yet have this capability, so this technology opens the door to new projects and further research, in particular in studies with the Pacific Parkinson's Centre at UBC.

TRIUMF is currently in the process of having the MRB tracer approved for trials in humans. The next steps will involve sampling for a reliable patient population. Thanks to Yu-Shin and her incredible efforts and experience, TRIUMF has become an even stronger player in the field of nuclear medicine.

Medical Isotope Breakthrough

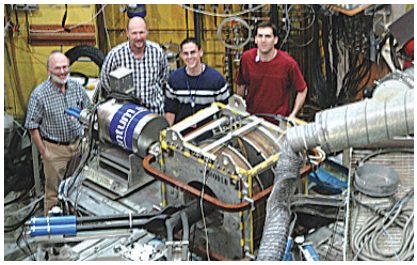
A new study published in the prestigious journal "Physics in Medicine and Biology" uses sophisticated modelling to suggest that conventional cyclotron technology deployable in hospitals could be the answer to recent shortages of the high-demand medical isotope technetium-99m (Tc-99m), which is presently dependent on a few nuclear reactor facilities. Co-authored by Anna Celler of UBC and Tom Ruth of TRIUMF, the study utilizes a detailed theoretical model to determine the most viable, efficient approach for cyclotron-based production of Tc-99m, predicting the peak production rates and the optimal reaction conditions. Researchers can now by-pass expensive (and often restrictive) large-scale process experimentation and focus only on producing isotopes under optimal conditions.

The paper provides critical guidance for the TRIUMF-based team (supported from NRCan's NISP program) presently evaluating the best design for the molybdenum-100 targets used in cyclotron production of Tc-99m. TRIUMF has long been investigating reliable methods of isotope production, and with this and other recent advances, a reliable supply of cyclotron-produced Tc-99m could be within our grasp.

Student finds a glitch, wins an award

Since 1995, the TRIUMF Proton and Neutron Irradiation facilities have delivered low-intensity, energetic proton and neutron beams to test sophisticated electronics, simulating years of natural-radiation exposures in space or terrestrial environments in just a few minutes. Such tests probe the susceptibility of microelectronic devices to "soft errors" (switching a memory bit from 0 to 1, or vice versa). It has been known for over 30 years that natural proton and neutron radiation can cause such errors, but Brian Sierawski, a Ph.D. student at Vanderbilt University, reasoned that ever smaller microelectronics might become susceptible to less-ionizing forms of cosmic radiation.

Brian and his Vanderbilt colleagues used TRIUMF's M20 beamline to demonstrate that soft errors indeed could be induced by low-ionizing muons produced in cosmic-ray proton interactions in the upper atmosphere. Demonstrating muon-induced soft errors earned Brian the Top Student Paper award at the 2011 IEEE International Reliability Physics Symposium. With ever-shrinking microelectronics, Brian's work could impact the design of data servers, medical equipment, and aerospace technology. TRIUMF offers the only such muon beamline in North America for this research.



Brian Sierawski (right) and Vanderbilt colleagues posing in the M20 beamline

TRIUMF could warm neighbourhood homes

TRIUMF's accelerator and high-powered target facilities require a lot of water cooling to maintain operating conditions. Once the new high-powered electron accelerator and isotope production targets of the ARIEL project are completed, the cooling-water plant will discharge 8-10 megawatts (MW) of waste heat regularly from TRIUMF's core accelerator facilities.

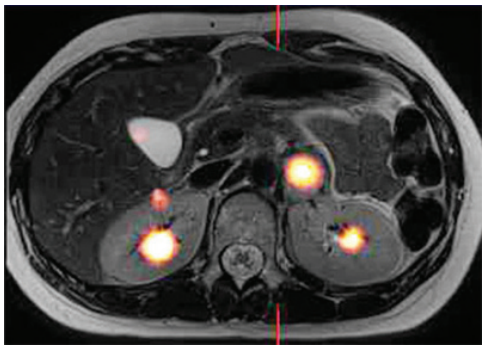
The University of British Columbia has made a public commitment to sustainability. They are exploring options to develop a district-energy system for pooled, shared heating and cooling for a several million square feet residential housing complex near TRIUMF. The heating requirements for this neighbourhood would vary seasonally but the peak would be less than 10 MW.

Following the lead of some European laboratories, TRIUMF and UBC are exploring the feasibility of a pilot project to use excess energy from TRIUMF's cooling systems to generate heat and/or energy for the nearby residential areas. Preliminary studies have begun with UBC Campus and Community Planning. This district-energy system would be the first of its kind in North America and would demonstrate a new level of energy efficiency and partnership in innovation to achieve greater levels of sustainability.

F-DOPA PET/CT tumour detection demonstrated

Fluorodopa (F-DOPA) is a medical isotope long produced by TRIUMF's nuclear medicine group to study Parkinson's disease with the Pacific Parkinson's program at UBC. F-DOPA is the radioactive 'cousin' to L-DOPA, a biochemical treatment used to increase dopamine concentrations in parkinson's-afflicted brains. However, F-DOPA also accumulates in neuroendocrine tumours, a fact exploited by TRIUMF scientists and colleagues for the first-ever diagnosis employing PET/CT imaging of a patient with paediatric neuroendocrine syndrome.

Earlier this year, TRIUMF's Mike Adam and collaborators from BC Children's Hospital used F-DOPA and PET/CT imaging to provide clear detection and a unifying diagnosis (confirmed by genetic testing) of a young patient with a neuroendocrine tumour syndrome, after conventional magnetic resonance imaging and iodine-123-labelled mIBG SPECT imaging failed. Subsequent studies showed PET/CT scanning to be the fastest (2h total) and most efficient method of detecting neuroendocrine tumours, exhibiting 100% sensitivity in a 14-person test group, compared to 71% with traditional nuclear medicine mIBG imaging (up to 48h). These exciting results were reported in the journal "Paediatric Radiology".



PET/CT image using F-DOPA tracer of a patient with a neuroendocrine tumour.

Calendar

Feb 16-20, 2012	AAAS Conference in Vancouver
Feb 28, 2012 TRIUMF	AAPS Board Meeting
Mar 23, 2012 TRIUMF	BOM Board of Management Meeting
April 16-20, 2012 TRIUMF	IAEA Isotopes Conference
May 2, 2012 TRIUMF	CNSC Hearing on Licence Renewal
May 11-12, 2012 TRIUMF	ACOT Advisory Committee on TRIUMF

Back to School

Visitors view TRIUMF artwork displays at the BC Year of Science finale event in Victoria.

Pacific Institute for the Mathematical Sciences and UBC First Nations House of Learning "Emerging Scholar", high school student Gabriel Stewart, joined TRIUMF in July.

TRIUMF High School Fellowship winners Adam DeAbreu, Kiel Strang and Saige McVea (L-R holding certificates) pose with TRIUMF's Reiner Kruecken (back row) and their supervisors (L-R) Oliver Stelzer-Chilton, Connie Hoehr, and Jennifer Fallis.

SFU professor and TRIUMF scientist Michel Vetterli explaining the origins of the universe to students attending the 2011 ATLAS Masterclass in March.

TRIUMF scientist Stan Yen demonstrates the wonders of liquid nitrogen at the University Neighbourhoods Association "Barn Raising" at the UBC Old Barn Community Centre in September.

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