BEAMTIME

TRIUMF

News from Canada's national laboratory for particle and nuclear physics

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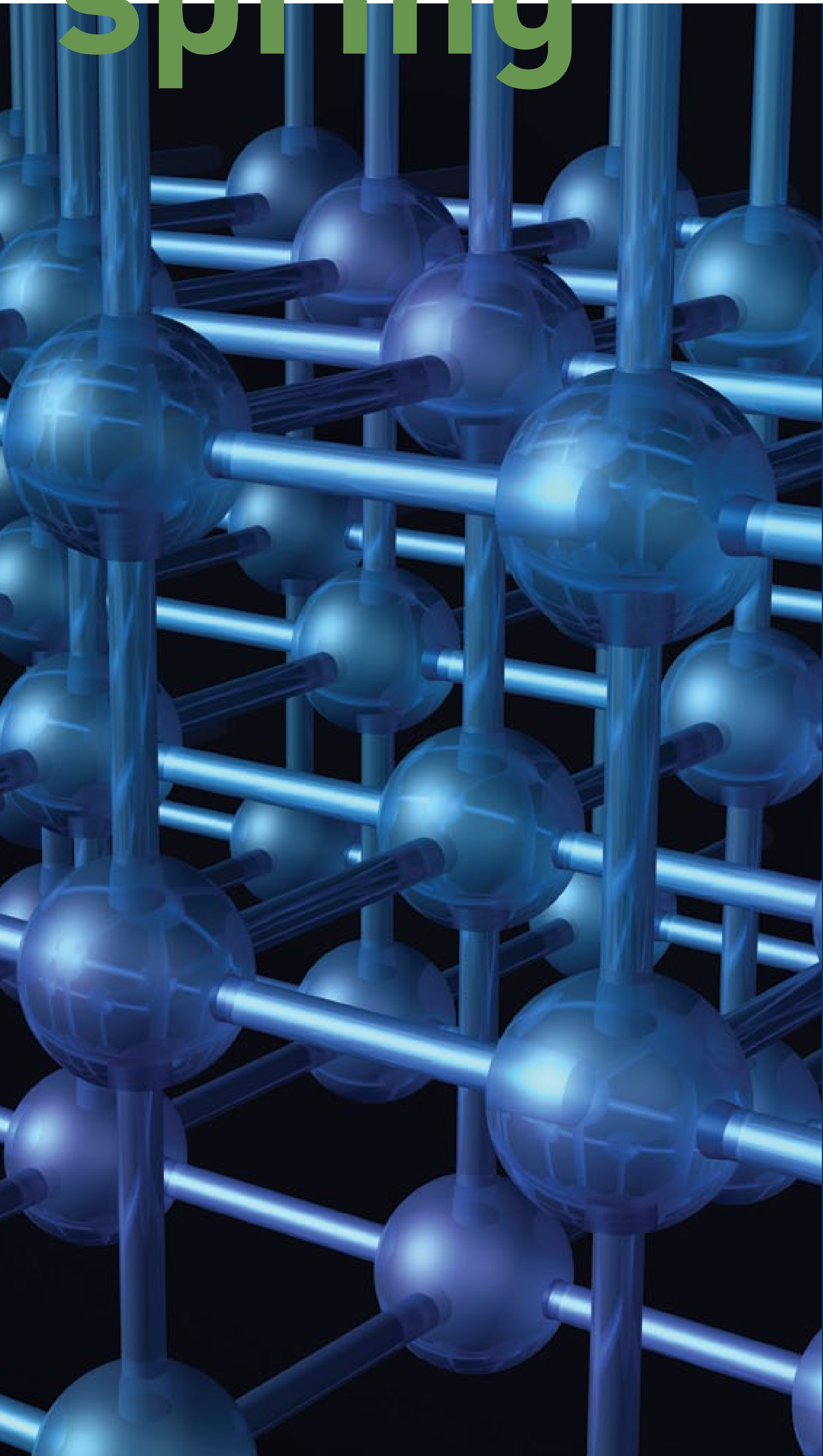
Celebrating 40 Years of Beam at TRIUMF

Inside this issue

spring



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TRIUMF

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The province of British Columbia provides capital funding for the construction of buildings for the TRIUMF Laboratory.

Jonathan Bagger | Director, TRIUMF

Forty Years of Reliability

Just imagine the excitement and sense of achievement that must have swept through TRIUMF forty years ago, when the first beam was extracted from the main cyclotron!

An extraordinary feat of engineering, TRIUMF's 500 MeV cyclotron remains at the heart of the laboratory. A machine so robust that it continues to drive cutting-edge science some four decades later, even being recognized as an Engineering Milestone by the IEEE.

And that first beam really was just the beginning. Reliable beam delivery is critical to the lab's success: it is central to producing high quality science. It attracts an international user community. It marks Canada as a global player in subatomic physics. And it enables us to pursue exciting new opportunities for the future.

This reliability could not be achieved without the world-class scientific and technical expertise, ingenuity, and resourcefulness of the dedicated staff at TRIUMF – from those who first envisioned the laboratory and achieved first beam to those who make TRIUMF what it is today. TRIUMF's rich history serves as a foundation on which to build new capabilities, including the ARIEL project. As we celebrate forty years of beam, we honour the facilities and the tradition of excellence that enable us to continue to be at the forefront globally.

Let's celebrate our past accomplishments such as first beam and have them inspire our future. If we do, I'm confident that in the years to come, excitement and achievement will continue to sweep through TRIUMF, much like they did forty years ago.

"TRIUMF's rich history serves as a foundation on which to build new capabilities"

forty year

Forty Years On

May – December 1974: The cyclotron is completed and brought to life!

By Mike Craddock

With the Herculean task of reshaping the cyclotron magnet completed in April 1974, the lab's efforts shifted to installing the vital equipment needed to inject, accelerate and extract the beam – and finally, triumf-antly, to do just that!

Completion of the magnet shimming (see Beamtime Vol. 11, issue 1) allowed the magnetic field surveying equipment to be removed and the vacuum tank carefully aligned (by adjusting some 500 tie rods) and turned into a clean area. First to be installed were the 80 radio-frequency (rf) resonator sections (each about 5 m × 0.8 m) that had already been carefully assembled, washed, baked, and leak tested – alignment requirements making this a demanding process that took seven weeks on a 14 shifts/week schedule. The 30 cm-diameter transmission line from the 2 megawatt rf amplifier was then connected to the coupling loop, allowing electrical tests to begin. At low power the resonators were adjusted to tune both the first and third harmonics to the design frequency. The resonator Q value was found to be 6400, very close to that expected. Resonator vibrations induced by the cooling water were satisfactorily damped by a combination of mechanical dampers at the tips and the innovative application of "Chore Girl"-brand copper-mesh kitchen cleaners under the header lines.

Interior view of the 500 MeV TRIUMF cyclotron with the tank wide open.
Photo credit: Gordon Roy

Meanwhile, the turbo pumps, sublimation pumps and 20K cryopanels had been installed, and by early September a tank vacuum of 5×10^{-7} Torr had been achieved – in the absence of rf fields. But rf power tests led to unacceptable hydrogen outgassing, and a rapid decision was taken to replace the sublimation pumps, with their low capacity for hydrogen, by oil diffusion pumps. This allowed rf operation at 50 kV and, after the discovery and correction of an uncooled resonator section and further conditioning in October, at 90 kV – sufficient to accelerate H^- beam around the centre post.

As a 100 μA H^- beam had already been achieved through the horizontal section of injection line in April, the summer was devoted to installing and commissioning the vertical section. This was followed in October by installing the spiral inflector, allowing injection of a 6 μA H^- beam into the cyclotron. By this time at least one each of the centring, low-energy and high-energy beam probes were in place and operational, along with a variety of correction plates and collimating devices in the central region and the extraction foil for Beam Line 4. Outside the cyclotron a host of other activities crucial to its successful operation had been under way: developing an effective control system, building an external beam line, providing electrical services and water cooling, laying cables, and so on.

Accelerating the H^- ion beam

By November 16th all was ready for the challenging task of coaxing the H^- beam through the cyclotron by fine adjustments to the magnetic field – one of unprecedented difficulty because of the large number of orbits, high rf harmonics, weak vertical focusing and large pole gap. Fortunately, though, we had a champion cyclotron tuner – the Director himself, Reg Richardson – dubbed admiringly a "ten-knob man" at Berkeley for his dexterity at the controls. Thus the final preparation was to move his office armchair into the Control Room, where he installed himself for this last task – manually adjusting the 54 circular trim coils and 78 harmonic coils.

For the TRIUMF users of course this was just the beginning – their challenge was to put this powerful tool to effective use – as it was of the staff to develop the facility's full potential.

On that first day, good progress was made through the tricky first turns, and two days later the beam had been guided out to 2 m-radius orbits, at an energy of 22 MeV, with the excited entry in the logbook, "Radiation in vault!!" Steady progress was made and, in spite of losing 7 days to breakdowns, 295 MeV had been reached by December 1st. But the orbits crowd closer together at high energies, making tuning very difficult, on top of which 6 days were lost to breakdown of the ISIS 300 kV power supply, so that by December 14th we were still only at 363 MeV. The next day, though, it was again clear sailing and Reg took only an hour to bring the ions to the long-awaited goal of 500 MeV. Beam line 4V magnets were then turned on and when the H^- ions were allowed to hit a stripper foil, protons were immediately detected in the vault. It then took just over an hour to steer and focus the beam to a 1 cm-diameter spot on a scintillator screen – a great demonstration of the simplicity of extraction by stripping.

TRIUMF Director Reg Richardson at the controls, with the author right behind him and the 500 MeV beam spot showing on the screen.

Smiles all round in the Control Room, December 15th, 1974: the Director, Reg Richardson, and Associate Director, Erich Vogt (centre) lead an impromptu celebration for TRIUMF's first 500 MeV proton beam.

It would be hard to exaggerate the relief and exhilaration everyone felt at having finally achieved the aim we had worked towards for so many years. The news spread like wildfire and the Control Room was soon inundated with visitors from both inside and outside the lab, many of them thoughtfully bringing refreshments for an impromptu celebration.

For the TRIUMF Users of course this was just the beginning – their challenge was to put this powerful tool to effective use as it was of the staff to develop the facility's full potential. Happily, 40 years of highly productive research in a wide variety of fields show how well both groups have succeeded.

For previous articles chronicling the cyclotron's construction, see www.triumf.ca/home/for-media/publicationsgallery/newsletter

Celebrating the first 40 years of science at TRIUMF

Highlights from the "cyclotron era"

By Jean-Michel Poutissou

TRIUMF was established in 1968 with a vision to provide a flexible tool for nuclear physics research with nucleon or pion beams. TRIUMF evolved into a versatile world-leading lab making important contributions to nuclear and particle physics, molecular and material science.

Fig. 1: TRIUMF scientist inspecting the world's first operational time projection chamber, built by TRIUMF, Carleton University, and the National Research Council.

The lab's versatility arose from the 500 MeV negative hydrogen-ion cyclotron, which permits simultaneous extraction of variable-energy (70-500MeV) polarized or unpolarized protons to service diverse experiments. This versatility allowed TRIUMF to develop a broad range of research competencies that have served the lab well over the decades.

Early research efforts began with direct proton beams, where a comprehensive program was mounted to measure nucleon-nucleon (NN) scattering, starting with the BASQUE collaboration, and others using the Medium Resolution spectrometer employing polarized beams and targets and polarimeter detectors. The resulting NN phase shifts between 200-500 MeV are still used today [1]. In the early 80s, quasi-monoenergetic neutron beams at the "Chargex" facility allowed for a program of nucleon charge exchange measurements. One highlight was the determination of Gamow-Teller transition matrix elements in nuclei around iron, used subsequently to determine the electron-capture cross sections needed in novae simulations (see e.g. [2]).

In parallel, the pion-nuclear physics program generated a comprehensive body of high-quality cross sections on key nuclei at and below the dominant (3,3) resonance energy. In the late 80s and early 90s a precision pion-proton scattering program, for which the unique CHAOS spectrometer [3] was built, produced high-quality data which became (together with data from other meson facilities) key inputs for nucleon chiral perturbation theory today, impacting e.g. ab-initio light nuclei calculations, and electro-, photo-, and neutrino-pion production reactions.

TRIUMF's versatility was manifest early on when the lab's intense pion and muon beams were exploited for weak interaction studies via searches of rare or highly-suppressed decays. A program of forbidden muon-decay searches began in 1977 and culminated in the best upper limit for muon-to-electron conversion in titanium [4], made possible in part by the world's first operational time projection chamber (see Fig. 1) built by TRIUMF and Carleton/NRC. Another program studied normal muon decay, which immediately showed that the (then) newly-discovered (at CERN) W boson had no right-handed partner, and eventually set the best constraints on non Standard Model interactions in purely leptonic systems [5]. Two incarnations determining the $\pi \rightarrow e\nu$ branching ratio precisely have provided crucial tests of lepton flavor universality and potential non-standard interactions. Later, a tour de force experiment measured the tiny parity-violating effects of the Z boson in polarized proton scattering on hydrogen [7]. It was made possible by an unique high-intensity laser-polarized proton ion source developed with Japanese and Russian colleagues, technology eventually transferred to the RHIC accelerator at Brookhaven.

Other research areas explored during the lab's early years have since blossomed into core science programs. For example, with the help of a strong team of Japanese collaborators, dedicated muon channels and spectrometers were built in the mid 70s to exploit the muon's spin as a sensitive magnetic probe in materials, these days focussing on high-temperature superconductors, discovered in 1987. In 1977, the first PhD thesis for work done at TRIUMF was awarded to R. Hayano, now professor at U. Tokyo. Muons also have drawn TRIUMF into chemistry, when a strong program investigating chemical reactions involving hydrogen-like muonium atoms ($e^-\mu^+$) was developed, resulting in several groundbreaking results (see e.g. [8]). Today the Centre for Molecular and Material Science (CMMS) attracts many international collaborators.

TRIUMF's versatility was manifest early on.

TRIUMF's early forays into nuclear medicine have since expanded into an entire laboratory division! The early pion cancer-therapy facility conducted clinical trials for many years, which ultimately showed little advantage over conventional methods, but led to the highly-successful proton eye-cancer therapy facility, unique in Canada. It also illuminated the role high-intensity cyclotrons could play in nuclear medicine. For example, TRIUMF personnel developed a "generator" technique for producing strontium-82 by irradiating rubidium targets with a low-energy proton beam.

Fig. 2: Dr. Brian Pate and TRIUMF Director Erich Vogt (centre) posing at UBC Hospital with BC's first positron emission tomography scanner and the team who designed and built it at TRIUMF.

The generator technology was later transferred to Nordion (operating on site) which markets it worldwide, generating royalties for TRIUMF. This and other early successes with medical isotopes spurred efforts in 1981 to create a positron emission tomography (PET) program (see Fig. 2) based upon new, low-energy cyclotrons from TRIUMF. In association with the Pacific Parkinson Research Centre and the BC Cancer Agency, the Life Sciences Division has grown steadily in importance as it makes further advances into PET imaging and cancer radio-therapeutics.

The Test ISOL facility (TISOL) began humbly in the mid 80s to conduct experiments with secondary radioactive-isotope beams created by a proton beam. One highlight was the determination of a key reaction [9] controlling the carbon-to-oxygen conversion in stellar red giants. TISOL led to TRIUMF's ISAC radioactive-isotope facility, now dominating the on-site science program with research into nuclear astrophysics, nuclear structure, material science, and fundamental symmetries. The many successes during the "ISAC era" are highlighted in reference [10].

Thanks to dutiful maintenance and upgrades by accelerator division staff, the TRIUMF cyclotron operates better than ever, delivering reliable beams fulfilling the scientific promise of its founders, and spawning new areas research not envisioned forty years ago. The cyclotron and its newborn electron accelerator sibling are a formidable duo sure to provide new research highlights for decades to come.

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The ARIEL-I electron linac project

TRIUMF builds first new driver beam in 40 years

By Shane Koscielniak, TRIUMF Accelerator Scientist

> Already in 2005 it was realized that ISAC's science productivity at its three experimental areas was severely bottle-necked by the single isotope-production proton beam from the cyclotron. The solution – build two new isotope-production beamlines to service all three areas simultaneously.

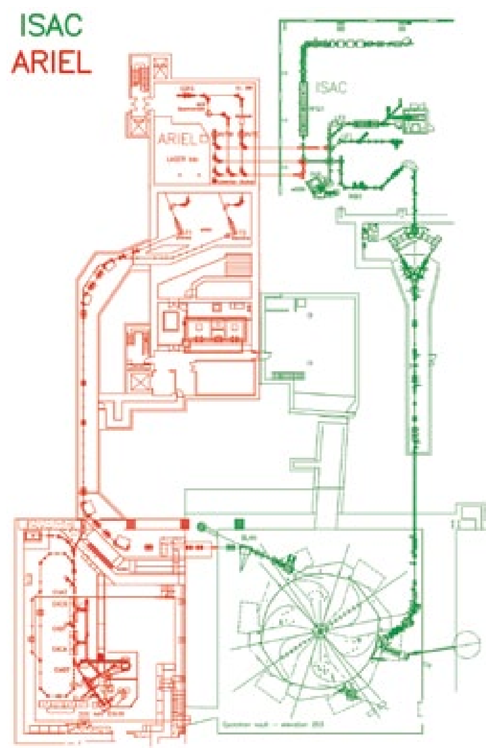
The ISAC facility sports 14 experimental stations across three (low, medium and high energy) experimental areas, but only one can receive a radioisotope beam (RIB) at a time. Clearly science productivity could be tripled with three isotope-production beams and associated production targets. Adding a second proton beam is straightforward: an unused cyclotron extraction port could feed a new beam into a near twin of the existing beamline. In 2007 the third beamline emerged when (then) TRIUMF Director Nigel Lockyer championed three ideas – RIB production by fission rather than spallation; an electron drive beam; and super-conducting radio-frequency (SRF) accelerating cavities – that became a new vision: ARIEL – the **A**dvanced **R**are **I**sotop**E** **L**aboratory.

Gamma-ray induced nuclear fission ("photofission") using photons produced from a primary electron beam is an invented-in-Canada RIB production mechanism complementary to proton-induced nuclear spallation. Photofission creates more neutron-rich isotopes with lower isobaric contamination, where lower production cross sections are compensated by more intense electrons beams of around 10 mA at 50 MeV. Fortunately, such beams are relativistic and straightforward to produce, allowing compact, constant-frequency accelerating structures. Niobium SRF structures operating in 2K liquid helium are a mature technology after decades of development by the high-energy physics community. An electron linear accelerator (e-linac) with these SRF cavities offers continuous rather than pulsed operation and much reduced operating costs compared to normal-conducting copper cavities. Consequently an e-linac provided TRIUMF an opportunity to master SRF technology, opening up potential future high-energy physics collaborations, and initiating a technology-transfer opportunity with a local company, PAVAC Industries.

ARIEL-I

With the decision made to proceed with ARIEL, things moved quickly. The conceptual designs were written in 2007-8; the funding proposal (sponsored by the University of Victoria) was made to the Canadian Foundation for Innovation (CFI) in 2008. The following year ARIEL became the centre piece of the 2010-15 Five-year Plan and the CFI awarded $18 million for the e-linac construction. 2010 saw matching funds for civil construction from the Province of B.C and the September start of the ARIEL project.

Civil construction consisted of the Stores & Design Office building, the Badge building, the ARIEL building, and the helium compressor building, all completed by December 2013. The Accelerator and Engineering divisions were deeply engaged in 2010-11 specifying the building spaces, functions and services. In 2012 the former Proton Hall was cleared of obsolete science equipment and massive concrete shielding was poured to create the Electron Hall to the south and the BL4N pit to the north.



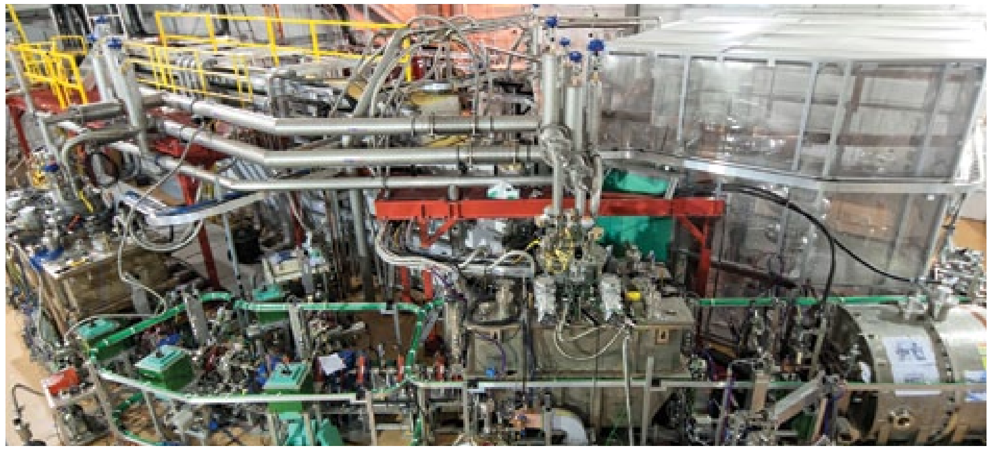
Schematic diagram showing the layout of the existing cyclotron and ISAC facility isotope-production complexes (green) and the plans for the full ARIEL-II e-linac facility.

E-linac design and construction followed multiple parallel paths. The e-linac water cooling services were completed in

May 2013, while all power supplies and instrumentation services were completed later that summer. The e-linac's 10 MeV injector cryomodule was fast tracked under a collaborative agreement between TRIUMF and the Variable Energy Cyclotron Centre, Kolkata, with the first cryomodule completed January 2014. After a 2.5 year design phase and a 100 keV protoyping stage, the 300 keV electron source began operation in November 2013. The e-linac 10 to 70 MeV beamline optics design and tendering was completed in 2012, with all quadrupole magnets arriving by August 2013. The five dipole types were tendered in 2013 and delivered by May 2014. The 30 MeV beam dump was designed mid-2013, with component arrival and installation beginning in September 2014.

The cryogenic and high-power radio frequency systems were both long-lead items supplied by contractors. The 4K cold-box, helium compressor, gas management and purification systems was tendered late 2011 and received by March 2013, becoming operable that November. 2K helium is produced by sub-atmospheric (SA) Joule-Kelvin expansion pumping on 4K liquid. The SA pumps were received mid-2013, and the heat exchanger was ordered in July and delivered in November. The 300 kW klystrons and their 60 kV 600 kW DC power supplies were first delivered March 2013 and August 2014, respectively.

The final phase of the e-linac installations and pre-commissioning in 2014 was fast paced and exhilarating. The 10 MeV injector was moved from the ISAC test stand to the e-hall May 1st, injector services were connected by June 1st, followed by the 10 MeV medium energy beam transport installation in June, and the 30 MeV momentum analysis beamline in July. The transport to the Electron Hall beam dump and the periodic section in the ARIEL tunnel were both installed in September. The accelerator cryomodule, containing one SRF cavity, arrived in the hall August 29th. After a frantic year, success was achieved on September 30, 2014, when the two cryomodules accelerated an electron beam to 23 MeV.



The first stage of the ARIEL superconducting radio frequency electron linear accelerator at TRIUMF, showing the electron gun (cylinder far right), injector cryomodule (bottom centre) and accelerator cryomodule (far left).

ARIEL-II

The ARIEL building and e-linac completion constituted the end of the ARIEL-I project. The full ARIEL facility still requires a second proton beamline, the isotope-production target stations, the front end mass separation and isotope ionization sections, and the transfer lines to ISAC. These constituted the ARIEL-II proposal to the Canadian Foundation for Innovation, led by the University of Victoria on behalf of TRIUMF's 19 member universities. Funding was announced in June 2015 and detailed designs have begun in earnest.

ARIEL-II is envisioned to proceed in five stages. Phase 1 will realize lithium-8 beams for materials science research at the βNMR facility, dramatically expanding user beam availability in this fast-moving field. This stage requires an electron target station with a solid photo-converter, and associated separator and hot cell systems.

The subsequent two phases will implement production of neutron-rich nuclei with a 100 kW beam from the e-linac, one of ARIEL's overarching goals, requiring actinide targets, the ALIS resonant laser ion source, and integration with the CFI-funded CANREB facility. Accumulating purified radium isotopes to generate alpha-emitting astatine isotopes for nuclear medicine studies will be a key deliverable.

For more information:
www.triumf.ca/ariel

The final two phases will bring ISAC to full multi-user capability with the highest rates achievable for fission-produced neutron-rich nuclei. These stages require a new 100 μA proton beamline (BL4N) from the main cyclotron and its associated front-end, and adding a second e-linac cryomodule and new targets to achieve the maximum-possible beam power.

The staged approach will ensure the fastest way to have competitive science delivered, it will expand the scientific reach with each project phase, and it will deliver a continuous stream of scientific discoveries. When fully built, ARIEL-II will establish TRIUMF as a world-leading facility advancing isotopes for science, medicine and business. And with the cyclotron performing better than ever, TRIUMF will enter its fifth decade ready to meet future scientific challenges for many years to come.

TRIUMF's new ARIEL building, housing the target hall, remote handling facilities, mass-separation and radioactive beam front end, and electrical and mechanical services.

ariel

The ARIEL science program

New facility will boast unique multi-user capabilities

By Reiner Kruecken, TRIUMF Deputy Director

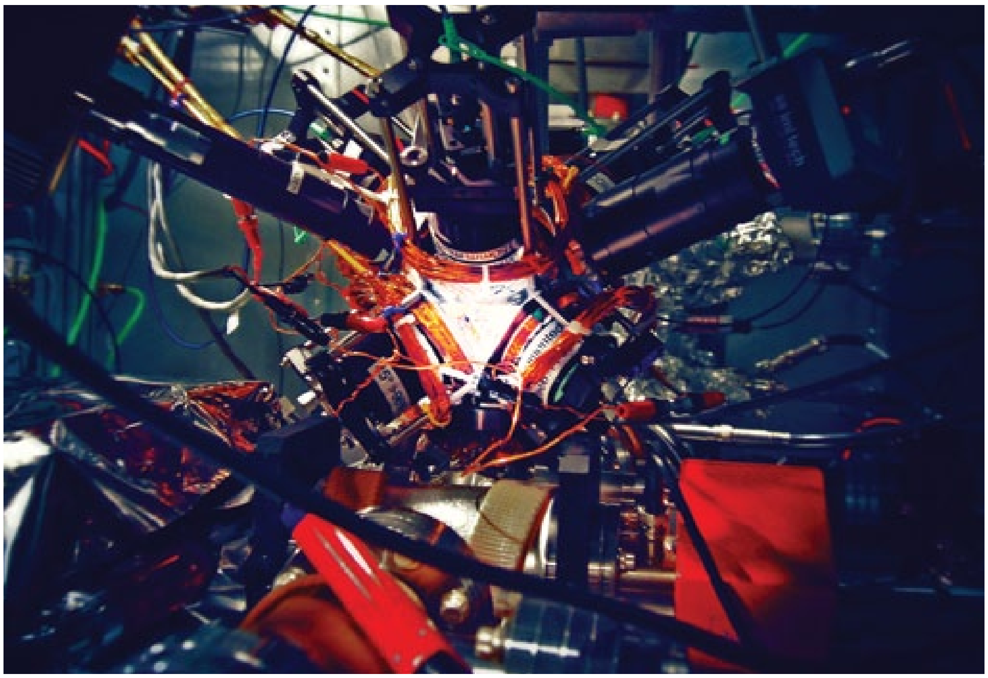


Fig. 1: Closeup view of the TRIUMF francium trap, which will trap rare isotopes of francium for precision laser spectroscopy and studies of physics beyond the standard model.

TRIUMF recently completed the first stage of ARIEL, the Advanced Rare Isotope Laboratory which will significantly expand the laboratory's rare isotope beam (RIB) program for nuclear and particle physics, nuclear astrophysics, nuclear medicine and materials science. ARIEL will allow more experiments with new and expanded capabilities that will place TRIUMF at the forefront of isotope research.

Isotopes are atoms with the same numbers of protons and electrons (hence same chemistry) but different numbers of neutrons. The radioactive forms not found in nature, so-called rare isotopes, have distinctive properties making them powerful tools for scientific discovery, from determining the structure and dynamics of all atomic nuclei, understanding the process of elemental creation in the Universe, to enabling precision tests of fundamental particle-physics symmetries. They have applications in modern medicine, from imaging techniques to therapeutic treatment of cancerous tumours, and they also can serve as sensitive probes of the electronic properties of composite materials at surfaces and interfaces.

Rare isotope beams are created by bombarding large atomic nuclei with high energy beams and filtering out the isotope of interest from the spray of atomic fragments. TRIUMF's present ISAC facility utilizes a proton beam from the cyclotron for isotope production via spallation and fission reactions. At its heart, the new ARIEL facility contains a new 500 kW, 50 MeV electron accelerator (e-linac, see article this issue) to produce isotopes via photo-production and photo-fission, as well as a second 100 μA proton beam line (BL4N) from the cyclotron. TRIUMF will therefore go from the current single ISAC RIB production target to parallel production on three target stations. This unique multi-user capability will proceed in stages with the ultimate goal to exploit the existing experimental facilities at ISAC much more efficiently.

Probing nanomaterial interfaces

The first stage will produce lithium-8 beams via photoproduction for the depth-controlled beta-detected NMR (βNMR) program, which investigates local electronic properties of surfaces and interfaces as a function of depth with nanometer resolution. Interfaces are the new frontier of condensed-matter physics as they become increasingly important as microelectronic devices shrink in

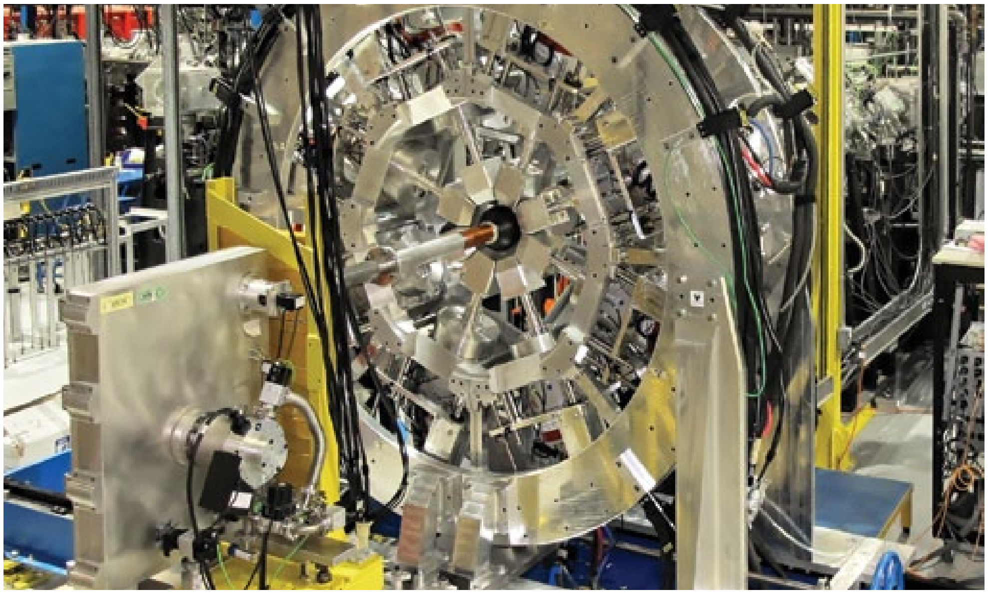


Fig. 2: The newly-commissioned GRIFFIN gamma-ray spectrometer for precision decay spectroscopy at ISAC.

size. The TRIUMF βNMR facility (see Fig. 3) is unique and will have impact battery materials, high-temperature superconductivity, nanodevice functionality, as well as quantum computing. By providing substantially more beam time for this vastly oversubscribed facility, ARIEL will invigorate a fast-moving field where new materials must be characterized quickly.

Neutron-rich nuclei

The first stage will be followed by production of neutron-rich nuclei, created by the e-linac through photo-fission on actinide targets. In nature very neutron-rich nuclei only exist for fractions of a second in violent star explosions or mergers of neutron stars during the so-called astrophysical r-process. At the same time they hold they key to our understanding of where in the universe the chemical elements heavier than iron were produced. The e-linac will bring the nuclear physics of supernova explosions into the laboratory and will enable the identification and study of the r-process nuclei.

Measuring the properties neutron-rich nuclei is critical also for the quest to develop the long-sought unified nuclear theory describing all nuclei based on the underlying fundamental force at work inside protons and neutrons, quantum chromo-dynamics. Characterization of these neutron-rich nuclei will be enabled by the beams provided by ARIEL in concert with the existing state-of-the-art experimental facilities at ISAC, for example the GRIFFIN gamma-ray spectrometer (see Fig. 2).

Rare isotopes for physics beyond the Standard Model

The multi-user capability facilitated by ARIEL will be particularly beneficial for those experiments that use rare isotopes of elements such as francium (see Fig. 1) and radon to search for physics beyond the standard model of particle physics. In some cases such experiments can reach sensitivities similar to those achieved in direct particle searches at the LHC. The new proton target will provide intense, clean beams of heavy elements for precision experiments searching for signs of new forces and broken fundamental symmetries. These experiments need to run for hundreds of days per year to achieve the sensitivities required to observe tiny effects, a capability uniquely enabled by ARIEL's multi-user infrastructure.

Medical isotopes

Proton-induced spallation in uranium or thorium is very attractive for the production of radioisotopes of interest to nuclear medicine. In particular, several alpha-emitting radioisotopes (or their parent nuclei) can be produced which have great potential for use combatting cancerous tumours. The production intensities available using a 10 μA 500 MeV proton beam are sufficient to initiate a research program into developing radiopharmaceuticals for tumour therapy. The radioisotopes of interest would be collected following the ARIEL high-resolution mass separator in a new implantation station dedicated to medical isotopes. For example, the isotope astatine-211 offers the possibility of delivering a lethal radiation dose selectively to tumour cells by means such as radio-labeled anti-bodies. Rather than preparing astatine-211directly, the precursor, radon-211, would be produced, captured and purified. In this generator concept the astatine-211 is generated in transit through the decay of radon-211 with a 14.7h half-life.

Step by step, ARIEL will open the door to new isotopes and new experimental capabilities, enabling exciting discoveries in nuclear physics and materials science as well as offer opportunities for the development of new procedures in cancer therapy.

Fig. 3: UBC Professor Robert Kiefl in the βNMR facility for nanoscale material characterization at ISAC.

For more information:
www.triumf.ca/ariel

news & announcements

News & Announcements

TRIUMF celebrates forty years of beam

On December 15, 1974, TRIUMF pioneers gathered in the control room to celebrate (then Director) Reg Richardson's successful extraction of the first beam from the 500 MeV cyclotron. Forty years later, the TRIUMF Alumni and Retirees Association (TARA), including 32 pioneers present that historic day, came back to TRIUMF for their annual general meeting, where they shared memories and learnt of the present status of the lab.

"It speaks about the vitality of the TRIUMF community and the pride of those having been associated with this family," said Jean-Michel Poutissou, TRIUMF Science Director Emeritus, "The cyclotron has matured over the years, but it is not like an old car that is polished regularly and showcased occasionally, but rather a Stradivarius violin that is handed to the best artists and used to perform at top venues."

The TARA meeting included a seminar including talks by Michael Craddock, UBC emeritus professor and former cyclotron beam dynamics leader for the cyclotron, and Ewart Blackmore, TRIUMF Scientist Emeritus and head of the commissioning effort in the mid-70s. A highlight was a recreation of the historic control room celebration forty years ago. TARA then joined the current lab employees at the staff Christmas party on site, where the esprit de corps amply demonstrated that TRIUMF was, and will be, in very good hands.

TRIUMF employees past and present who were at the lab when the first cyclotron beam was extracted gather once again exactly 40 years later to recreate the famous control room photograph (see page 5).

TRIUMF expands student outreach

TRIUMF's outreach program aims in part to provide authentic research experiences to young aspiring scientists. The High School Fellowship program has offered six-week summer internships to outstanding graduating BC high-school students since 2004. This year the program is offering an additional award to such students aspiring to an engineering career. The new "C. Gordon Lindsay Memorial Award" is supported by the Canadian Society of Senior Engineers (www.seniorengineers.ca/csse/) in honour of a long time CSSE member and TRIUMF outreach supporter. The inaugural winner was Ms. Lauren Johnston of West Vancouver, who spent her summer with the Software Engineering group.

TRIUMF has been offering research experiences for undergraduates since the early 70s, recently primarily through university co-op and government scholarship programs, which are not available to first-year students. So TRIUMF partnered with UBC Physics and Astronomy to create the "Erich Vogt First-Year Student Research Experience" award (FYSRE) for UBC students, funded in part through a UBC Development Office endowment (www.phas.ubc.ca/erich-vogt-first-year-summer-research-experience-fysre). This year TRIUMF welcomed its inaugural recipient, Jonathan Zhang of Vancouver, who worked with TRIUMF theorist David Morrisey.

Western University joins TRIUMF consortium

TRIUMF gained a new family member when the Board of Management recently approved the admittance of Western University in Ontario (www.uwo.ca) as an associate member, joining the existing 18 Canadian universities in the consortium.

"At the heart of TRIUMF is an engaged and committed community of university members from across Canada and we are delighted to welcome Western University as a new member," said Dr. Steven Liss, Chair of the TRIUMF Board and Vice Principal of Research at Queen's University. Dan Sinai, Associate Vice-President (Research) at Western University added "We are pleased to officially be a part of TRIUMF's ambitious plans for the future. This partnership provides meaningful contributions to nuclear medicine for the betterment of Canadian health."

Western University · Canada

Western has a strong research program in health sciences that complements TRIUMF's existing nuclear medicine program. Dr. Frank Prato, Imaging Program Leader at Western University and its affiliated hospital-based Lawson Health Research Institute, collaborates with TRIUMF on the Natural Resources Canada-funded Isotope Technology Acceleration Program project to demonstrate commercially-viable production of Tc-99m using hospital-based medical cyclotrons.

"TRIUMF is a valuable resource for nuclear medicine research," said Dr. Prato. "We look forward to many years of collaboration to help keep Canada at the forefront of nuclear medicine."

McPherson new ATLAS Deputy Spokesperson

Robert McPherson of the University of Victoria Physics and Astronomy and Institute of Particle Physics has been selected as the Deputy Spokesperson of the ATLAS Experiment (www.atlas.ch) at the CERN Large Hadron Collider (LHC) at the ATLAS Collaboration Board meeting in October 2014. Resident at TRIUMF, McPherson was previously spokesperson for ATLAS-Canada (www.atlas-canada.ca).

This prestigious position effectively titles McPherson the vice president of ATLAS, where he will work with spokesperson Dave Charlton (University of Birmingham) to oversee all aspects of ATLAS, ranging from detector and computing operations, R&D for detector upgrades, and physics analysis. McPherson will also managing the relationship between ATLAS and international funding agencies.

"This is an exciting time in particle physics," said McPherson. "The Higgs observation (in 2012) was an appetizer that demonstrates the capabilities of ATLAS and the LHC, and our upcoming run will finally allow us to probe the scales where we expect to make the breakthrough discoveries needed to understand how energy gained mass to become matter in the early universe."

Calendar

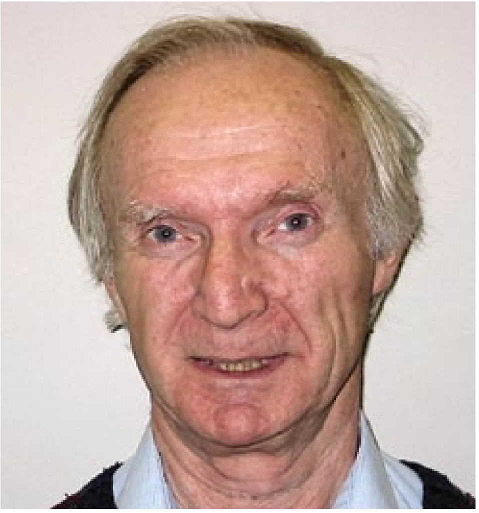
Upcoming Important Events
(at TRIUMF unless otherwise stated)

Nov 12–13	TRIUMF Board of Management Meeting
Nov 25–27 Ottawa	Canadian Science Policy Conference
Nov 26	TRIUMF Alumni and Retirees Association (TARA) AGM
Jan 15–16	Subatomic Physics EEC
Jan 25–26	Molecular and Material Science EEC
Apr 14 TELUS World of Science	Unveiling the Universe Public Lecture with Kip Thorne
Apr 22–23	Advisory Committee on TRIUMF Meeting
May 28	TRIUMF Open House

TRIUMF Event Calendar
www.triumf.ca/home/events-conferences

Michael Craddock

TRIUMF's accelerator man



Over 47 years at TRIUMF, Mike Craddock has seen it all. Educated at Oxford University, he came to UBC in 1964 hoping to conduct experiments at the Physics Department's Van de Graaff accelerator. But that just happened to be the year the department was debating a big accelerator project.

"There was a wide divergence in the physicists' opinion about what it should be," remembers Craddock, "Most had been accustomed to the low energy nuclear physics of structure and reactions. So they thought of [an accelerator] around 20 or maybe 100 MeV, similar to what was being built elsewhere."

But (nuclear physics group head) John Warren and a few others wanted a higher energy machine for particle physics. In 1958 Warren had been unsuccessful in getting a 7 GeV proton synchrotron "He still wanted at least 3 GeV" adds Craddock, "to produce high fluxes of various mesons without the problems of handling high beam currents." Craddock began reviewing various accelerator proposals, but found anything over 1 GeV too expensive, while a meson factory might be affordable and would provide both particle and nuclear physics. In the end both camps were impressed by the research possibilities, flexibility and cost-effectiveness afforded by the 550 MeV, 100 μA, H^- ion cyclotron design of (former Vancouver schoolboy) Reg Richardson at UCLA.

Craddock recalls, "The Canadian Association of Physicists annual meeting happened to be in Vancouver in June 1965. Erich Vogt [about to join UBC] was there, as well as the guys from the [then new] University of Victoria and Simon Fraser University. So all the concerned people had a meeting, where it was formally agreed to go for a scaled-down version of the Richardson meson factory." Craddock took on the role of managing the overall specifications, which settled on 500 MeV at 20 μA to reduce cost and beam handling problems.

The tough job of getting the proposal approved (in 1968) turned out to be simpler than construction. "[That] certainly was a challenge. None of us here had ever built a cyclotron before," admits Craddock. "We exploited Canada's strong consulting engineering base together with cyclotron engineers from Berkeley. When it came to building it, we used Canadian companies wherever possible." In the end, 80% of the machine's cost was spent in Canada.

Craddock left for a sabbatical year in 1972 to work abroad on a particle physics experiment. Upon returning, he learnt that the main magnet did not behave as expected – the measured field was 3% too high (low) at the inside (outside), where the design tolerance was 0.01%! To improve the field, great chunks of steel had been carved away or welded on, and thin "shim" plates were about to be repositioned around the edges. "I ended up being responsible for predicting where the shims should (or shouldn't) be. It was a massive job, with nearly 700 places where they could go. That job lasted 6 or 7 months." After a heroic final push, the cyclotron came to life on December 15, 1974, with Craddock standing anxiously behind Richardson at the controls when the first beam emerged (see pg. 5).

The cyclotron's long life was probably a surprise for everyone involved. Craddock never imagined that 40 years later TRIUMF would still be operating, never mind with such a variety of ground-breaking research. "It was simply designed to meet the requirements that we had in mind at that time," admits Craddock, who for decades after led the accelerator design efforts at TRIUMF. "We thought that probably for 15 or 20 years there was enough physics to do with the machine as it then was, but at least I didn't give any thought to what might go on beyond that. I was just happy to know that there would be something around for 20 years."

For more information:

Michael K. Craddock passed away peacefully on November 11, 2015. Since 2006 he has published in this newsletter ("Forty Years On", see www.triumf.ca/home/for-media/publicationsgallery/newsletter) first-hand accounts of the TRIUMF cyclotron's construction, from the moment it was envisioned, to the day the first beam was extracted (this issue). His invaluable contributions to TRIUMF as scientist and unofficial biographer will be deeply missed.

TRIUMF tech transfer going strong at forty

AAPS set to assume role within TRIUMF enterprise in 2016

By Jim Hanlon, President and CEO, AAPS

Target module for medical cyclotrons to produce the imaging isotope Tc-99m. Developed by a TRIUMF-led consortium, the technology was licensed to AAPS-based ARTMS Inc. for commercial development.

For forty years, and counting, TRIUMF has exploited its accelerator-based technology and expertise for societal and commercial benefit.

The year after the science program began in 1974, TRIUMF began a collaborative program with the BC Cancer Agency, and the BC Cancer Research Centre to develop a pion cancer-therapy facility in the M8 channel for deep-seated tumours. Although, ultimately, the technique demonstrated little advantage compared to conventional chemotherapy, it was realized that there could be other societal benefits accruable from TRIUMF's particle accelerator technologies. The relationships developed with the nuclear medicine community eventually led to the creation of the proton cancer therapy facility through Ewart Blackmore's leadership and funding from the Woodward Foundation. In August 2015, this facility celebrated 20 years of treating over 180 patients with ocular melanoma.

Later, John Vincent developed a generator for producing the medical isotope strontium-82 from the irradiation of rubidium targets from the main cyclotron's low-energy beam. This technology was transferred to (now) Nordion (Canada) Inc., which markets the generator worldwide and returns royalties to TRIUMF. Partnering with TRIUMF for over 37 years, Nordion is a global health sciences company that produces isotopes at their TRIUMF campus used in over 2.5M patient-doses per year. This partnership received the 2004 Synergy Award for Innovation from the Natural Sciences and Engineering Research Council (NSERC).

In parallel, Tom Ruth led the development of a Positron Emission Tomography (PET) program in BC based on low-energy cyclotron production of PET isotopes. This spawned the development of TRIUMF's own medical cyclotron design (TR13), and the technology was transferred to (now) Advanced Cyclotron Systems Inc. (ACSI), located in Richmond BC. ACSI has since installed systems worldwide, including one at the BC Cancer Agency and two at Nordion's Vancouver facility. A "second-order" spin-off, D-Pace Inc. of Nelson, BC, licensed a number of technologies from TRIUMF in 1995 and again in 2001. The D-Pace-TRIUMF partnership also was recognized with the NSERC 2007 Synergy Award for Innovation.

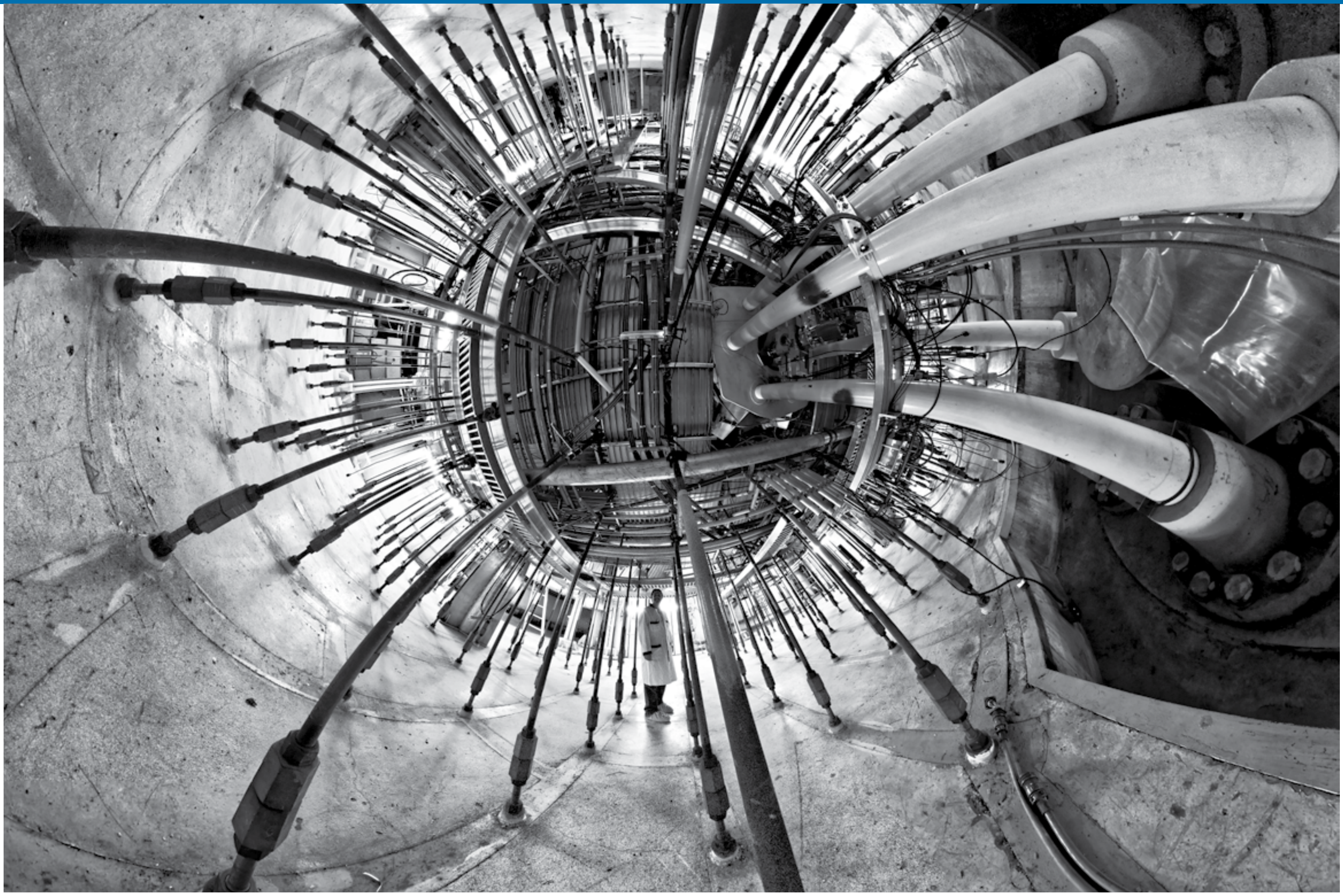
TRIUMF continued to pursue a variety of accelerator-based spin-off opportunities. A recent and very successful technology-transfer partnership occurred with PAVAC Industries Inc., of Richmond, BC, who, for over a decade, collaborated with TRIUMF on superconducting radiofrequency cavity (SRF) technology, first for the ISAC-II isotope accelerator and then the ARIEL electron accelerators. TRIUMF helped PAVAC grow to become one of six manufacturers worldwide capable of producing SRF cavities.

To optimize and grow TRIUMF's knowledge transfer and commercialization opportunities, Advanced Applied Physics Solutions, Inc. (AAPS) was launched in 2008 through Canada's Centres of Excellence for Commercialization and Research (CECR) program. AAPS covers the "D" in TRIUMF's R&D efforts, with the "R" of research and development taking place within the laboratory. AAPS facilitates business transactions including protecting and licencing intellectual property, managing and sourcing new business opportunities, and maintaining a healthy industry-research partnership environment.

AAPS has been very successful in the last five years, establishing five independent spin-offs, each of which has significant potential for creating employment opportunities in Canada, and in some cases, internationally. The first spinoff, Micromatter Inc., was established in 2009 to develop diamond-like carbon thin film technology required for accelerator-based radioisotope production. More recently, Alternative Radioisotope Technologies for Medical Science Products, Inc. (ARTMS) was incorporated to manufacture and sell targets and accessories that will enable hospitals, clinics and radiopharmacies to reliably produce and supply Tc-99m from medical cyclotrons (see figure).

AAPS will graduate from the CECR program at the end of 2015 to become a sustainable company within the TRIUMF enterprise. By focusing on its and TRIUMF's core competencies, AAPS will ensure that TRIUMF's 40-year legacy of leveraging its accelerator-based expertise for societal and commercial benefit will extend well into the future.

For more information:
www.aapsinc.com



Alien Environment

Artist: Rod McLatchy

The main TRIUMF cyclotron contains a huge vacuum tank kept at the same tiny pressure as outside the International Space Station. Atmospheric pressure would crush the tank flat if not for hundreds of tie rods keeping the two sides apart. Like an astronaut in outer space, Rod McLatchy of the Applied Technology Group found himself in a place few people ever visit - underneath the world's largest cyclotron. He digitally stitched together several images (including a selfie!) taken with his fish-eye lens to capture an amazing 360 degree panorama brilliantly evocative of his alien environment.