TRIUMF PUBLIC TOUR GUIDE

TRIUMF

DOCUMENT 180140

INTRODUCTIONS AND ACKNOWLEDGEMENT

TRIUMF's Public Tours program is presented as part of a longstanding cultural imperative to communicate and share the science and engineering wonder of our facilities. Every year, the lab welcomes thousands of visitors onto our campus, from the general public and school groups, to academics and VIPs.

The Public Tour Guide is a practical tool that is intended to equip both guides and staff with the information necessary to provide a general-audience introduction to the history, scale, and scope of the laboratory's multi-faceted operation.

The structure of the guide follows the approved public tour route. The included map lays out the route, with numbered markers along the path highlighting key areas of interest that could be covered during a one-hour tour. Due to the scope of details used here, it is not essential that every point be captured in every tour; rather, this guide provides an assortment of details that can be tailored for each tour.

This guide has been adapted from several approved sources, including TRIUMF's Five-Year Plan 2020-2025, where all included statistics were first published. Additional information and content have also been provided by the Communications group, with feedback from various members across the TRIUMF staff.

WHAT DRIVES US

OUR VISION

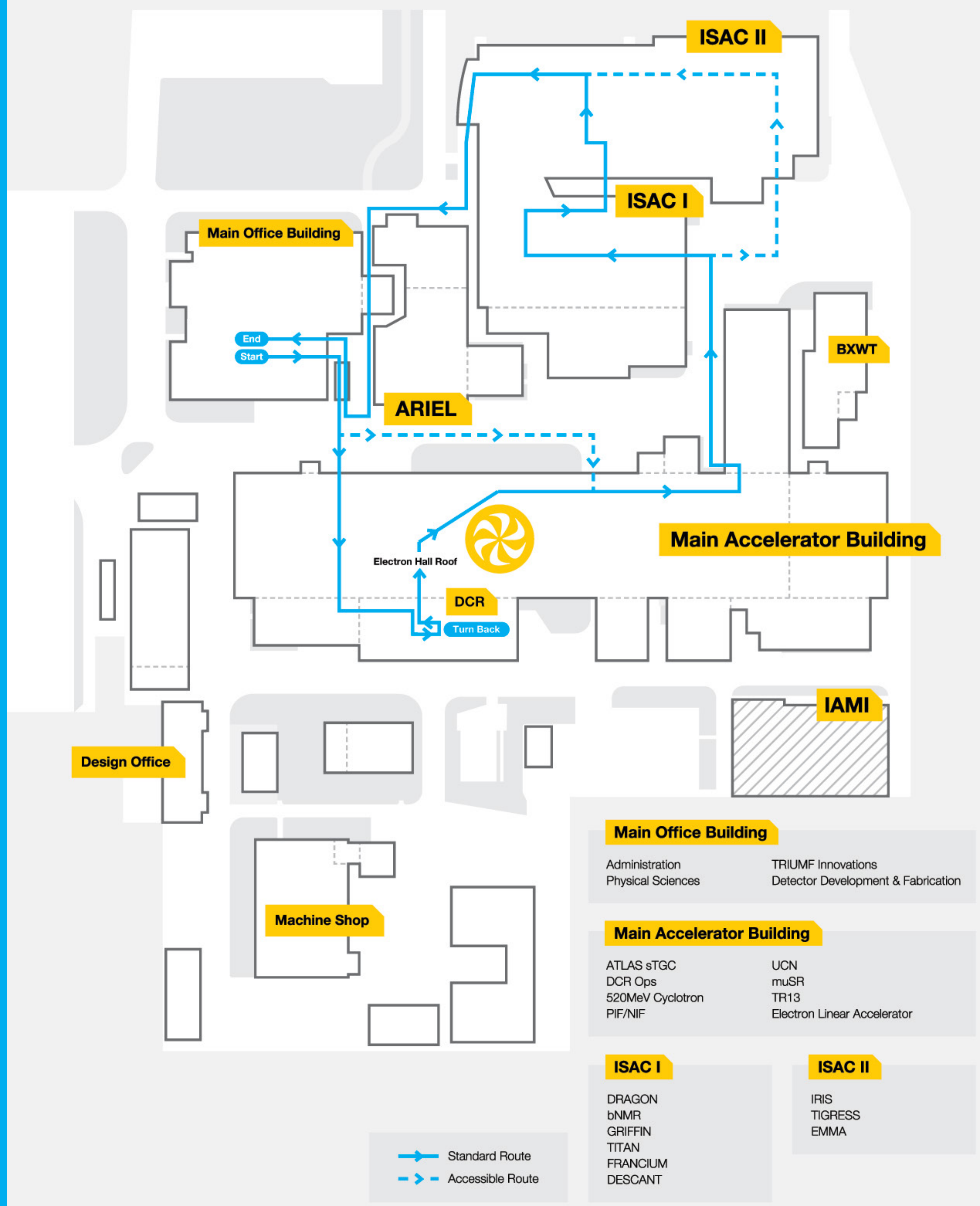
Our vision is for Canada to lead in science, discovery, and innovation, improving lives and building a better world.

OUR MISSION

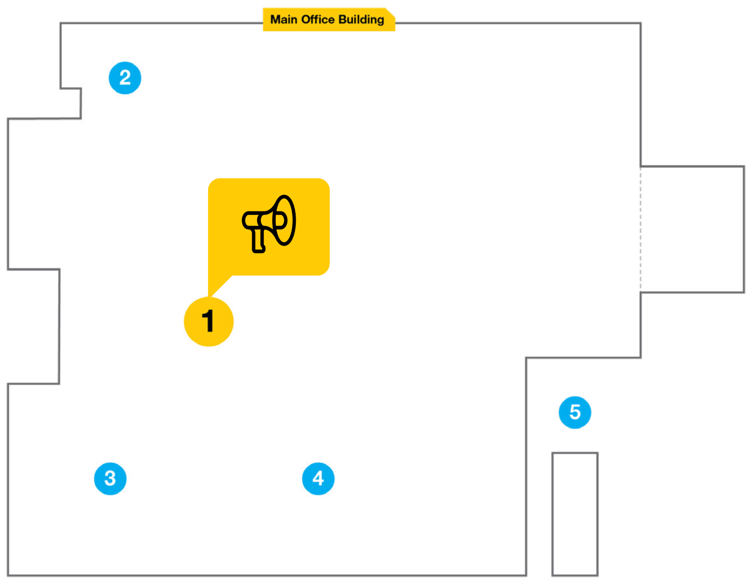
TRIUMF's mission is to serve as Canada's particle accelerator centre. We advance isotope science and technology, both fundamental and applied. We collaborate across communities and disciplines, from nuclear and particle physics to the life and material sciences. We discover and innovate, inspire and educate, creating knowledge and opportunity for all.

OUR VALUES

Excellence & Integrity, Safety & Accountability, and Equity & Inclusion



SAFETY ANNOUNCEMENTS & RULES OF ENGAGEMENT



PERSONAL INTRODUCTIONS

Public Tour guide name and welcoming remarks as appropriate — e.g. *"While I'm not a scientist I can provide an overview of the scale and scope of operations, and help illustrate the significance of TRIUMF's contribution to science, technology, and engineering internationally."*

SITE SAFETY REMINDERS

Follow standard and publicly accessible tour routes only due to radiation safety restrictions, unless group is accompanied by staff with appropriate training and coordinated with Driver Control Room (DCR) and ISAC Control Room Operations ***beforehand***.

- Closed toe shoes with little or no heel are required for guests to access areas behind the fence.
- No food or drink is permitted when behind the fence.

GUEST SAFETY ANNOUNCEMENTS

IMPLANTED MEDICAL DEVICES

Ask if any guests have sensitive implanted medical devices that their life depends on?

- We ask this question because there are strong magnetic fields present at the lab that can interfere with such devices — if guests have sensitive electrical devices, the tour *Must follow the* **Accessible Tour Route***,* marked by a dotted line on the public tour site map, to access to the Meson Hall.
- For any other implanted medical devices this is a case of personal comfort. Should guests feel unwell at any time address the concern: **call x7333 for first-aid support** if necessary, move towards an exit for fresh air, or stop to rest.

NUCLEAR MEDICINE SCAN

Ask if any guests have received one within the last week.

- We ask this question because an isotope metabolizing in the bloodstream may set off the portal monitors when accessing the site — in these cases **call x7333** and let the Driver Control Room know, before departing on tour.

RULES OF ENGAGEMENT

GROUPS

Request guests store all bags in provided lockers — use the washrooms and drinking fountains ***before departing***.

- Groups must stay together when behind the fence.
- Guides are responsible for carrying DRD dosimetry, and maintaining head counts when entering/after departing all restricted areas.

GENERAL

TRIUMF is a 50+ year old industrial facility that sits on a 13+ acre site.

- There is a requirement to walk up and down several flights of stairs — if required, follow the **Accesible Tour Route** to remain at ground level.
- Be careful of ground-based obstructions and mindful low overhead clearances along the tour path.
- Everyone should wash hands thoroughly with soap after the tour.

TRIUMF AT A GLANCE

TRIUMF is situated on a 13-acre site which is home to the world's largest cyclotron (as certified by the Guinness Book of World Records) and a new high energy electron linear accelerator for isotope production.

Founded in 1968, TRIUMF, which originally stood for Tri-University Meson Facility. Now no longer a working acronym, the name remains as a nod to the lab's history and its three founding member universities (University of British Columbia, University of Victoria, and Simon Fraser University).

The lab has a rich and storied legacy of advancing world-leading research in the fields of nuclear and particle physics, in Canada and abroad.

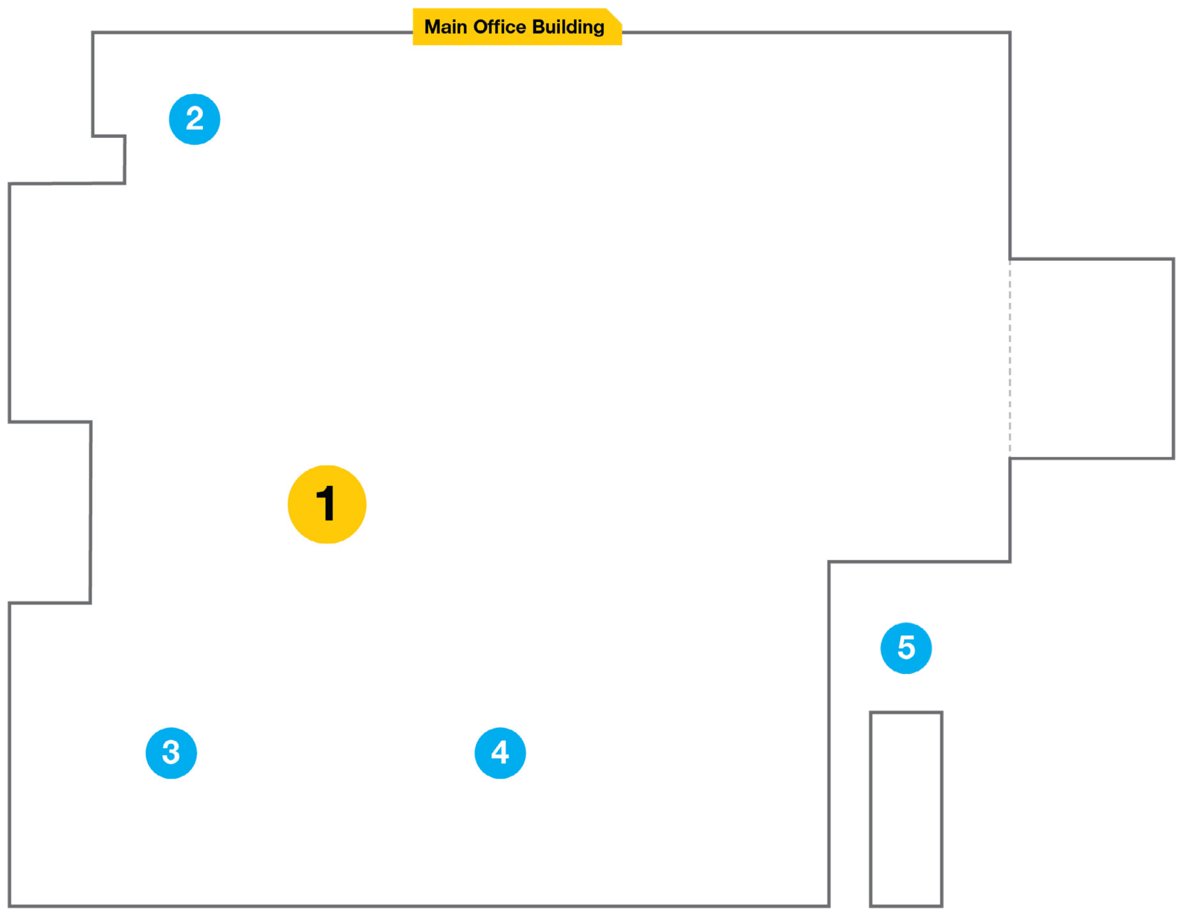
Since its founding, TRIUMF has grown to become a global leader in medical isotope research and production. Annually, TRIUMF enables the production of over two million patient doses of medical isotopes that are used locally, such as at UBC and BC Cancer, and also shipped to over a dozen countries.

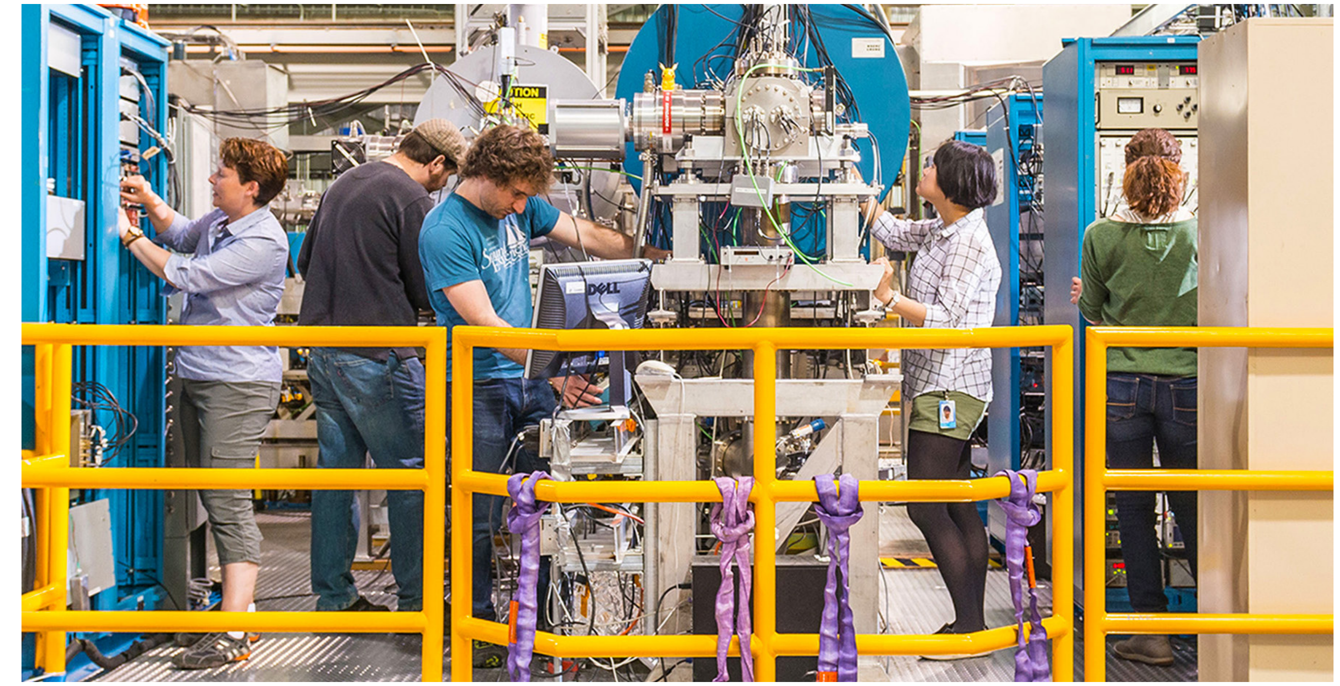
The laboratory is one of just a few locations in the world that generates beams of muons, and the only place to offer a new technique – Beta-NMR – for the study of advanced molecular and quantum materials science.

As a unique training ground for the next generation of STEM researchers and innovators, TRIUMF serves as a significant pillar in Canada's knowledge and innovation economies.

THE STORY OF CANADA'S FIRST PROTON BEAM AND TRIUMF'S GLOBAL CONTRIBUTION TO SCIENCE TECHNOLOGY

MAIN OFFICE BUILDING





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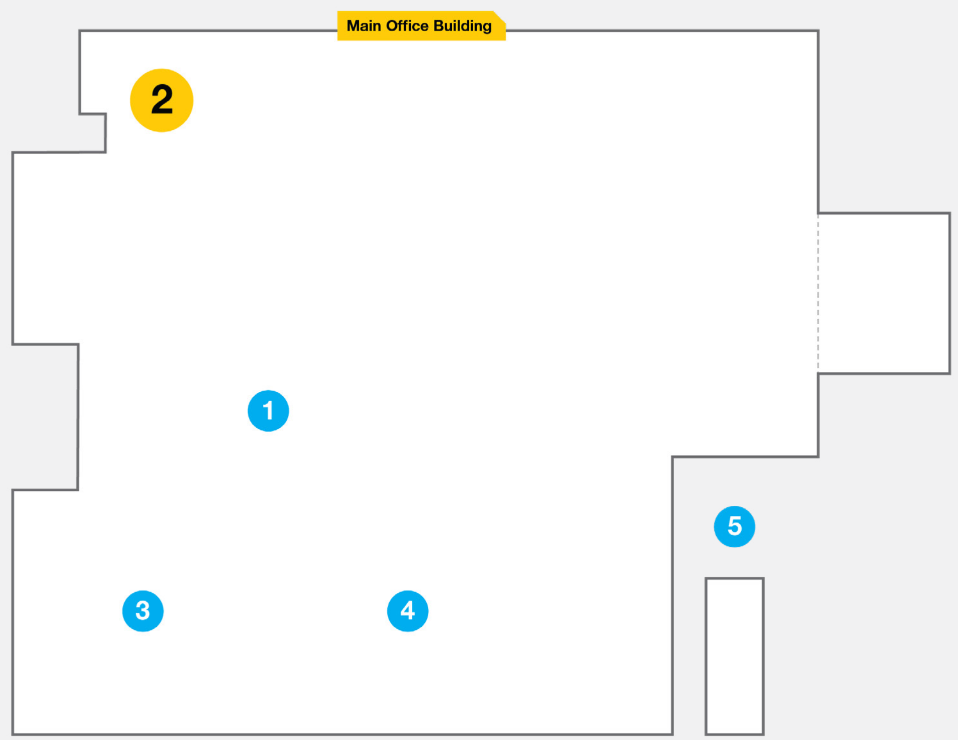
Main Office Building Reception

WELCOME AREA

Established in 1968 in Vancouver, the lab is a hub for discovery and innovation inspired by a half-century of ingenuity in answering nature's most challenging questions. From the hunt for the smallest particles in our universe to research that advances the next generation of batteries or develops isotopes to diagnose and treat disease, TRIUMF drives more than just scientific discovery.



2 Main Office Building Elevator Foyer
THE CLOUD CHAMBER

The Cloud Chamber is one of the first type of particle detectors pioneered in the 20th century. This device allows you to 'see' the background radiation that exists all around us at all times.

- The larger clouds that disappear slowly are alpha particles (helium nuclei) from the decay of heavy atoms.
- The thin straight trails are protons and muons from cosmic rays.
- The zig-zag lines are either electrons or anti-electrons from atomic decay.

Natural radiation is always present and is present at some level in everything, including rocks, cosmic radiation from space, the people around you, and even foodstuffs, such as milk and bananas.

Here at TRIUMF, the risk posed by radiation is very low, and in most areas it does not even surpass levels you'd find in nature. TRIUMF's Office of Environment, Health and Safety – which includes Safety Systems and Radiation Protection groups – monitors and proactively manages most of the regulatory programs on site to ensure the safety of staff, visitors, and the surrounding community. TRIUMF facilities are licensed by the Canadian Nuclear Safety Commission, who carries out regular inspections to ensure TRIUMF remains compliant with regulations across a number of safety and control areas.

3

Main Office Building

MAP & TIME TUNNEL

In April 2018, the lab celebrated its golden jubilee. Fifty years prior, the three founding universities (University of British Columbia, Simon Fraser University, and University of Victoria) lobbied the federal government for the initial $19M required to construct TRIUMF. This tri-university partnership is the basis of TRIUMF's name, which was originally an acronym for the Tri-University Meson[1] Facility. Despite these humble beginnings, TRIUMF quickly attracted interest from other partners, including the University of Alberta (which joined shortly after TRIUMF's founding).

[1] Mesons are a subatomic particle – composed one quark and one antiquark, bound together by strong interactions – that were of interest to researchers in the 1960s and 70s.

Additional Details:

SCOPE AND SCALE

Today the lab is home to more than 500 personnel. More than 200 students – from high school to graduate students – and postdoctoral fellows pass through the laboratory each year. TRIUMF was founded because it provided scientific infrastructure and expertise at a level beyond what would be possible for a single academic institution, and it thrives today because it continues to deliver this collaboration-driven impact for both the domestic and international research communities.

Education and Outreach
By the Numbers

211 students and postdocs hosted in 2017 (+40% since 2012)

28 graduate students via UBC/ TRIUMF IsoSiM CREATE program

141 students graduated (2013-2017)

Connected with > 23,000 members of the public in 2017

Today, TRIUMF is owned and operated by a consortium of 21 Canadian universities from Victoria to Halifax, and the scope of our research has expanded far beyond the original focus on meson science. This growth notwithstanding, the name TRIUMF has remained an enduring reminder of the laboratory's legacy.

TRIUMF HIGHLIGHT

In collaboration with 21 Canadian universities, TRIUMF's diverse community of nearly 600 multidisciplinary researchers, engineers, technicians, tradespeople, staff, and students comprise a unique incubator for Canadian excellence, as well as a portal to premier global science initiatives.

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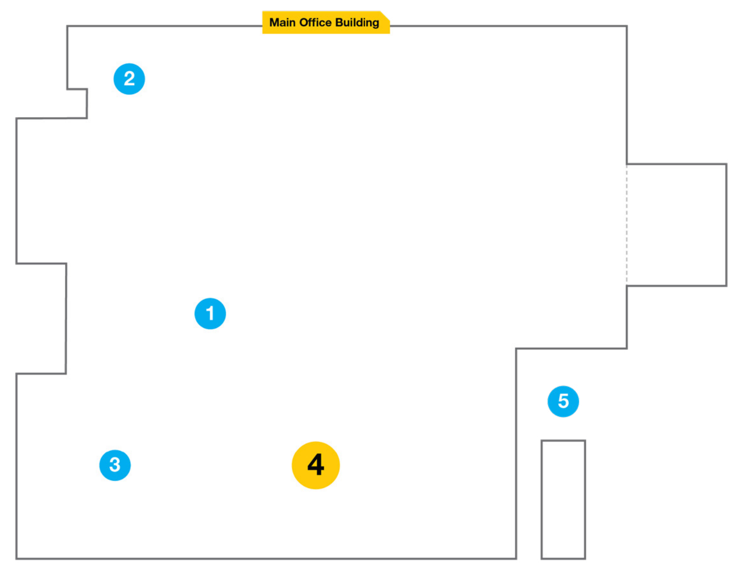
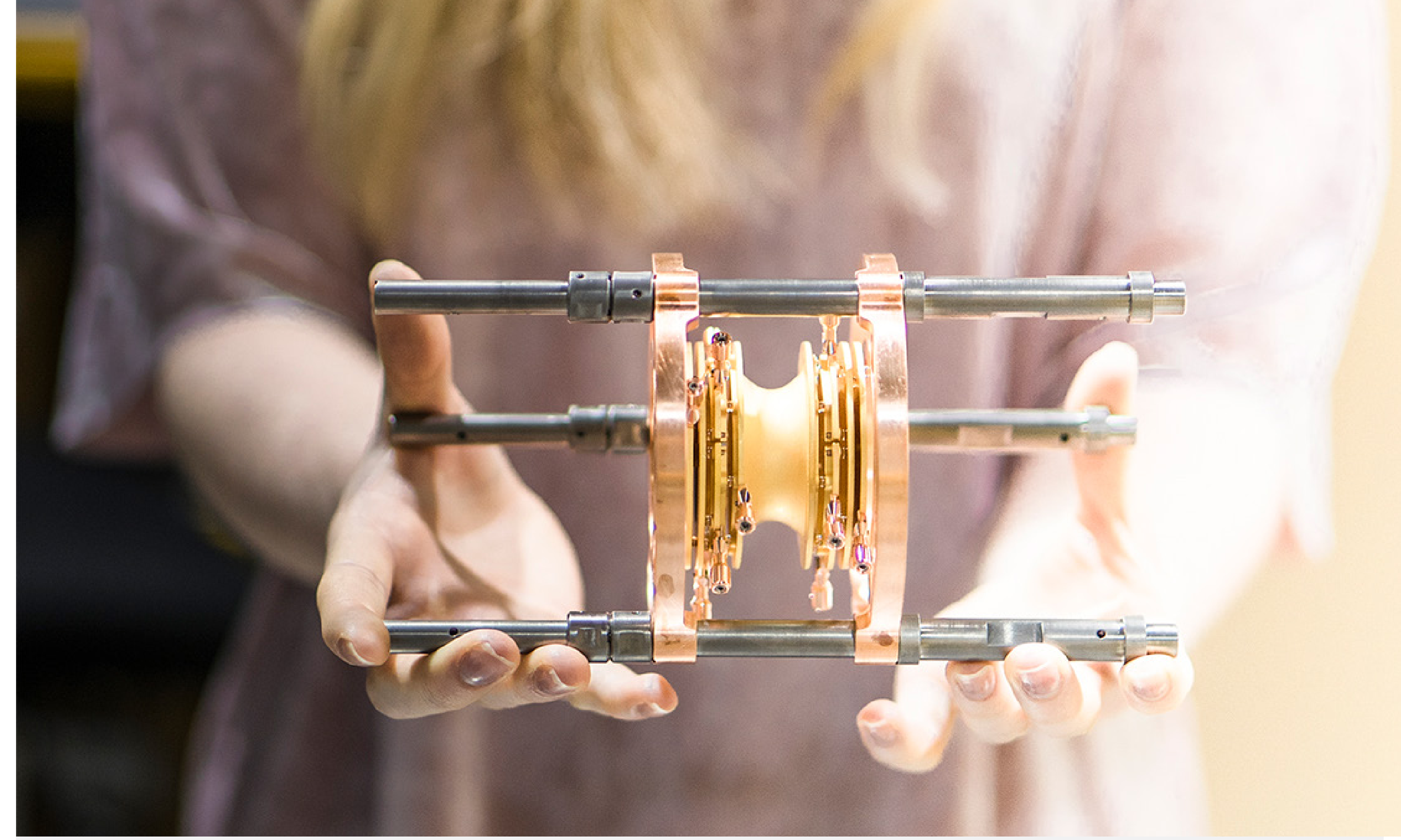
Main Office Building Exit

LONG HALLWAY





The Main Office Building houses TRIUMF's main administrative functions, as well as the offices of many of those in the Physical Sciences[2] division. This building is also host to TRIUMF Innovations (the lab's commercialization arm) and several lab and detector facilities that support activities across TRIUMF's wide scope of research.

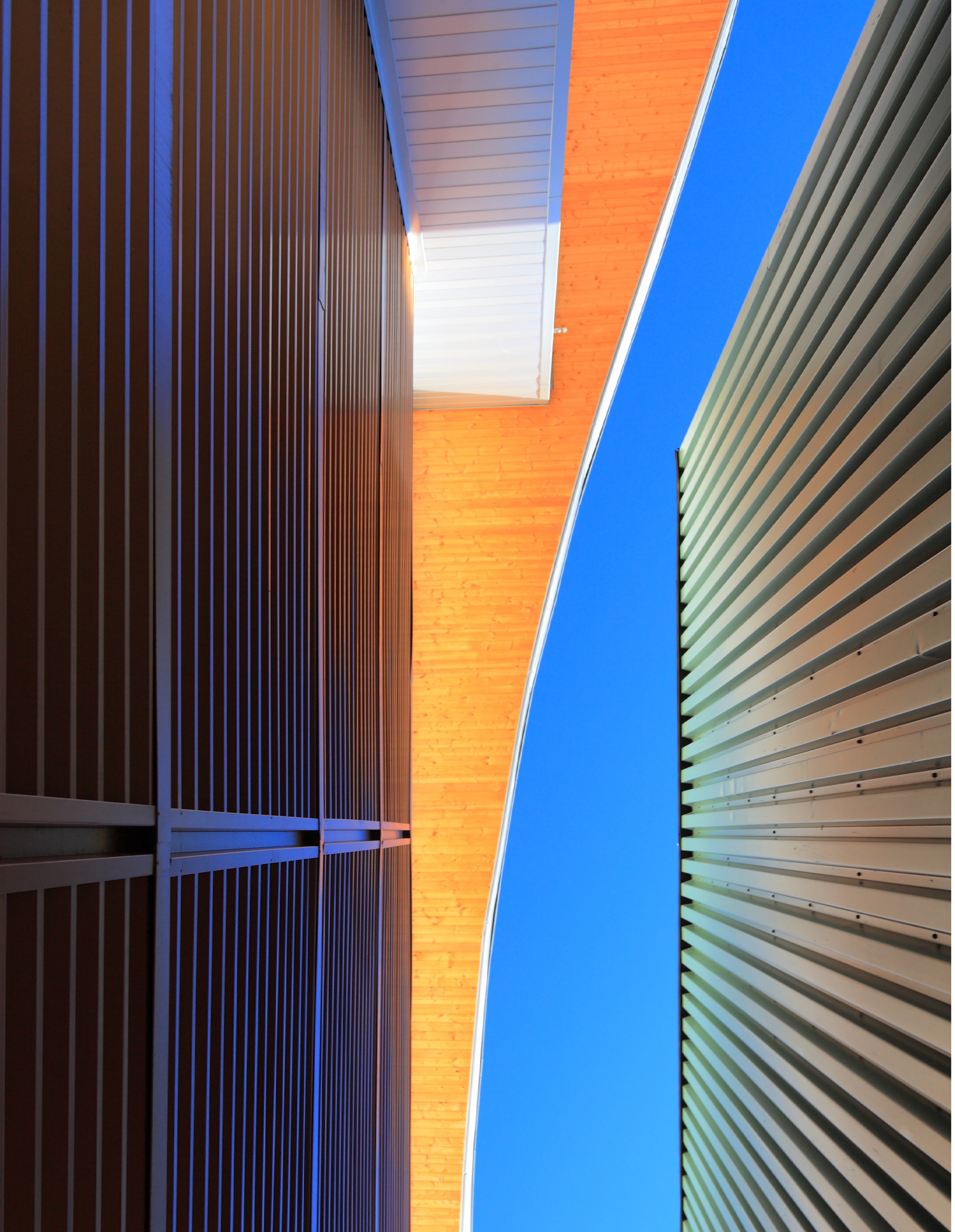
TRIUMF INNOVATIONS

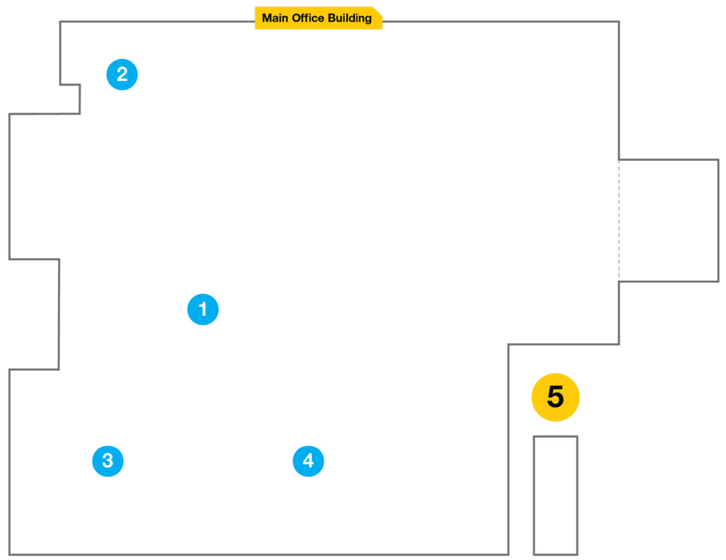
Additional Details:

BUILDING THE FUTURE

Because most of the work that takes place at TRIUMF requires specialized components and tools, TRIUMF utilizes a vertically integrated manufacturing model. From technical design to manufacturing, TRIUMF handles the development and maintenance of many high-tech components in-house. Some of the unique capabilities TRIUMF has on site include: special remote handling facilities to work with radioactive components; a fully featured machine shop with capacity to work with both common materials (stainless steel, aluminum, copper, etc.), as well as exotic metals (titanium, tantalum, niobium, molybdenum, and more); and highly specialized welding and cutting machines capable of extremely tight tolerances.

[2] At TRIUMF this includes the particle, nuclear, and theoretical physics groups – as well as other sub-divisions in areas such as detector development and research computing.





5 THE BADGE ROOM

The badge room is a control point that serves as the primary entry and exit point to many facilities on the TRIUMF campus. To the left of the badge room is the Advanced Rare Isotope Laboratory (ARIEL[3]) – the most significant operational expansion in the lab's 50-year history.

Funded by the Canada Foundation for Innovation (CFI), six provinces, and with the backing from 21 universities, ARIEL will be commissioned and operational across phases between 2020-2026.

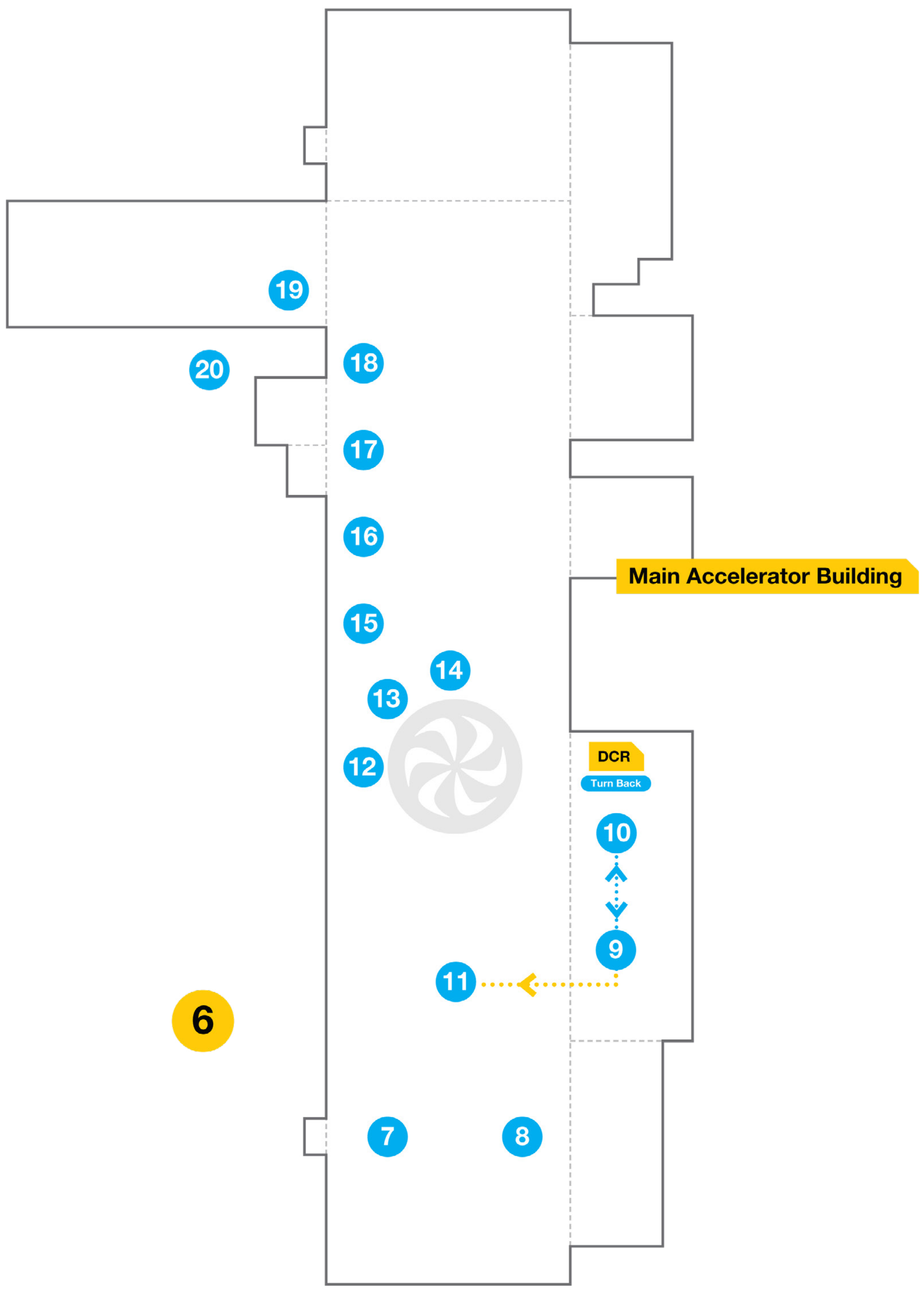
Additional Details:

RADIATION FACTS

The fence that encloses the TRIUMF site demarcates the secured area that's under 24/7 monitoring required by the regulations and operating licence, set out and enforced by the Canadian Nuclear Safety Commission. On earth, we are exposed to several forms of radiation daily — from the sun, ground, and food. Over the course of an hour-long tour here at TRIUMF, you're exposed to about the same amount of radiation as eating a banana, a fraction of what you would receive on a short airplane flight. The badge room serves as a control point to ensure no radiation contamination leaves the site.

[3] For more information, visit TRIUMF's Five-Year plan website: *https://fiveyearplan.triumf.ca/platforms/ariel/*

MAIN ACCELERATOR BUILDING



6 THE MESON HALL

The Meson Hall is about four stories high and four stories below our feet. Underground, this building houses a concrete vault that is home to the heart of TRIUMF – the laboratory's 520 MeV cyclotron – certified by the Guinness Book of World Records as the largest accelerator of its type in the world. Heavily shielded to protect the surrounding environment and people working on site, this machine and the surrounding facilities are the core drivers of TRIUMF's scientific programs.

It is important to understand that the cyclotron is not a nuclear reactor. In contrast to reactors, which typically produce power, accelerators are tremendous consumers of power, which in the case of our main 520 MeV cyclotron, is used to accelerates H- ions to ¾ the speed of light. With this acceleration of particles, some radiation is produced; referred to as prompt radiation. Once power is cut to the machine the prompt radiation ceases, and residual radiation diminishes quickly.

Additional Details:

ATOMIC PARTICLES

A majority of science at TRIUMF begins with creating H- ions from hydrogen atoms – one proton and one unpaired neutral electron – because electrons carry a negative charge, adding one or more makes an ion negatively charged.

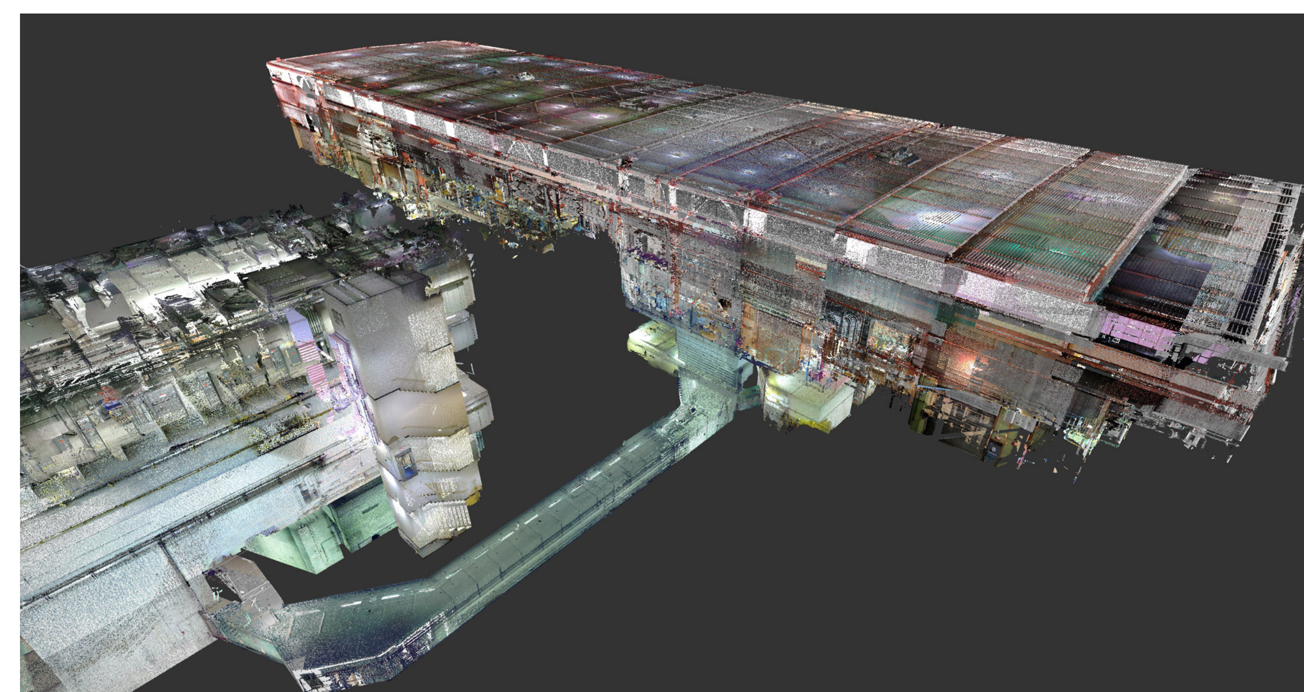
TRIUMF HIGHLIGHT

When the founders of TRIUMF broke ground on the Main Office Building, they also planted a single apple tree: a direct descendant from the apple trees that grew on Isaac Newton's family farm in Lincolnshire, England. These same trees are famous for inspiring Newton's understanding of one of the four fundamental forces in nature - gravity.

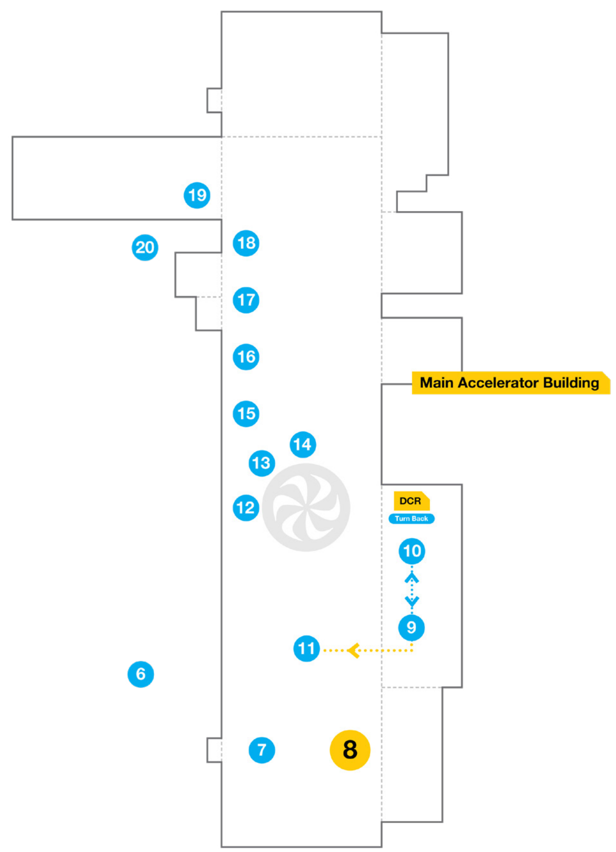
7 THE PROTON HALL EXTENSION

TRIUMF may not look exactly like what many picture as a particle and nuclear physics laboratory. While certain areas on site match the image of meticulous clean labs staffed by those in white lab coats, this doesn't reflect the reality around much of the site. TRIUMF is a working industrial facility. You can think of TRIUMF like a "science factory".

This facility also provides a second proton beam line to ARIEL for isotope production via proton-induced spallation, fragmentation, and fission.



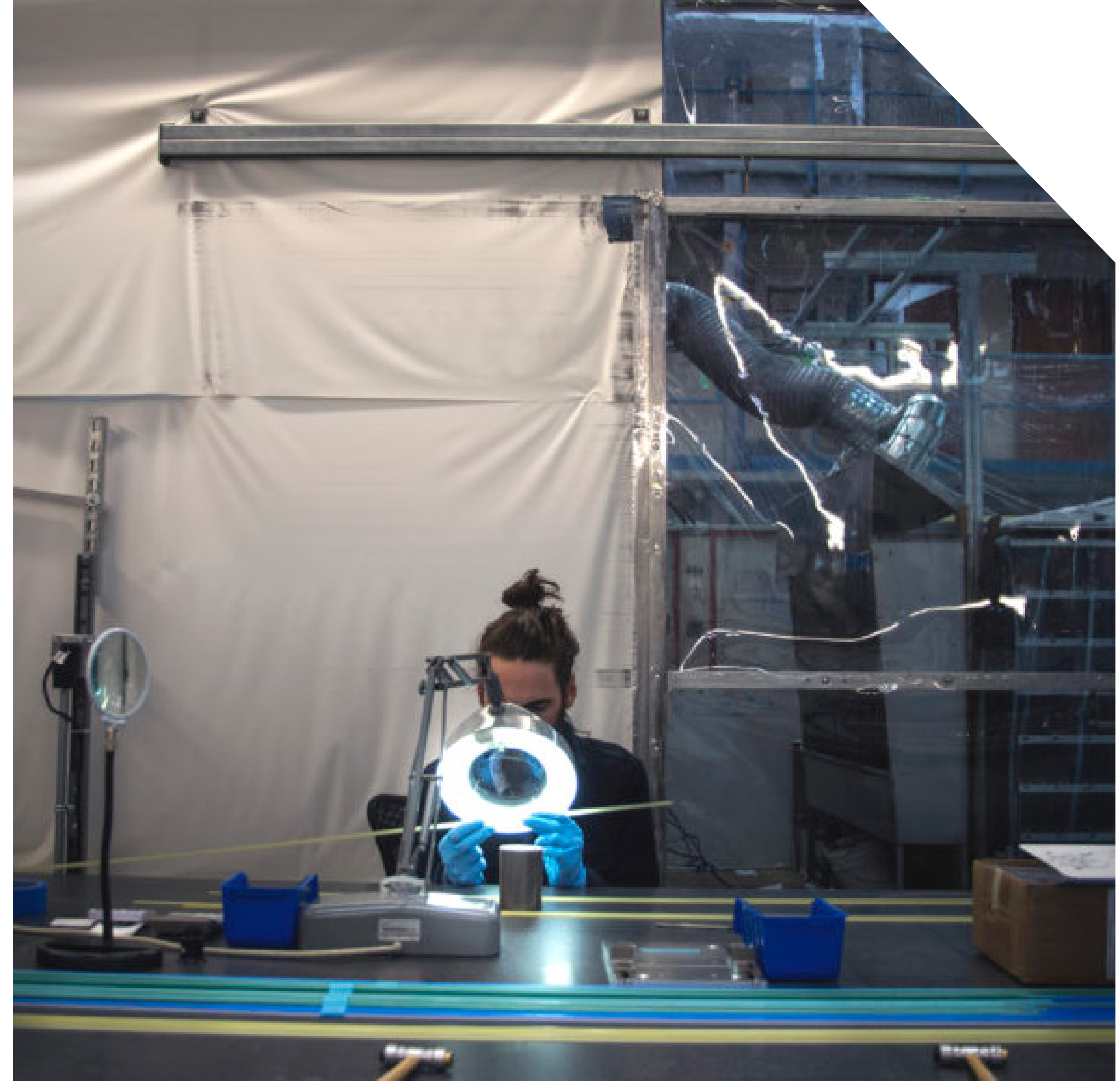
LIDAR imagery (light imaging, detection, and ranging) captured by TRIUMF's Beamlines Group



8 THE STGC[4] CLEANROOM

This is one of many examples of cleanrooms in use at TRIUMF. This space is being used for the construction of components for one of world's largest particle detectors – the ATLAS experiment located at CERN in Europe. TRIUMF staff, students, and collaborators work together to design and assemble new components for the detector. These components are required to take advantage of the ongoing upgrades to CERN's Large Hadron Collider.

[4] sTGC stands for small-strip Thin Gap Chambers – key components for the New Small Wheel upgrade to ATLAS that TRIUMF is helping construct.



TRIUMF HIGHLIGHT

ATLAS, which is based at CERN's Large Hadron Collider (LHC), is one of the world's largest scientific experiments. As part of the ATLAS-Canada collaboration, TRIUMF scientists, engineers, technicians, and students have provided critical expertise to the detector design, construction, installation, and data analysis for this global experiment.

9 HISTORIC PHOTO

Located in the Service Annex Extension is a historic photo taken during the construction and installation of the main cyclotron's magnet sectors, which are comprised of 4400 tonnes of steel.

This image highlights the sheer scale of the main cyclotron, and some of those who helped build this iron giant, that is still the heart of TRIUMF's science and research programs. During the era of its construction, few companies were able to build a machine of this size and magnitude; shipbuilders were one of the few with this capacity.

What is not included in this picture is a large vacuum chamber that sits on top of electrified magnets. Inside this chamber, a near perfect vacuum is created, to help accelerate the H- ions to 75% of the speed of light.

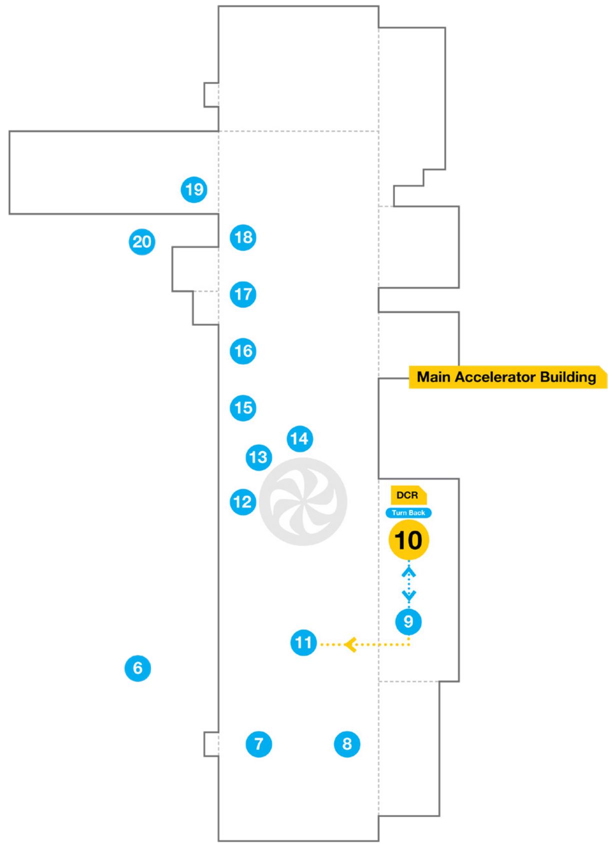
TRIUMF HIGHLIGHT

The 520 MeV cyclotron was declared commissioned in December 1976. Despite the pinwheel shape, the 520 MeV cyclotron doesn't spin. An electric field changes direction 23 million times a second to accelerate charged particles to 224,000 kilometers per second inside a high vacuum chamber. To put this into perspective, this speed is what it would take to send you to the moon and back in 3.4 seconds.

Additional Details:

CYCLOTRON FACTS

- Davie Shipbuilding from Quebec led the construction of the cyclotron's magnets. When they delivered these sector magnets on flatbed rail just prior to this photo, they also included a captain's wheel, as is the tradition in shipbuilding. So although TRIUMF didn't get a ship, we still received a wheel – a neat historical artifact that's on the wall in the Main Office Building reception area.
- Built without computer assistance, this machine incorporated very wide tolerances into its design; this reality – combined with modern electronics systems, controls, and regular maintenance – means operators are able extract more out of the cyclotron than was ever envisioned by its original designers.
- The cyclotron operates nearly 24 hours a day for 7 days a week for 9 months of each year; from December to March, the machine is shut down and the residual radiation is allowed to drop to safe levels, so that regularly scheduled maintenance can be performed. This helps ensure stable operation for the remainder of the year.
- TRIUMF's famous logo is based on the shape of the cyclotron's magnet sectors; not pictured here is the cyclotron's vacuum tank and other supporting infrastructure.
- This machine accelerates H- particles to 75% of the speed of light through the use of magnets and electricity; there are no moving parts involved in acceleration.
- The magnets are thinner in the middle of the machine and wider at the outside to help keep the particles on a spiral path. As the velocity of the particles increases towards the speed of light, their coeffective mass increases 1.5x in line with the relativistic laws of nature, and so the magnet field strength needs to increase accordingly.
- Once the desired energy is reached, the H- ion has its electron removed using a stripping foil, where beams (of just protons) can be extracted simultaneously and delivered to specific facilities or experiments via multiple beamlines.



10 DRIVER CONTROL ROOM (DCR) OPERATIONS

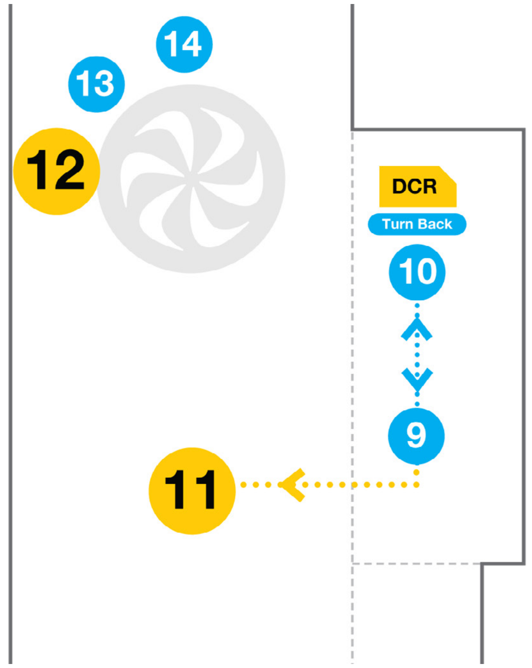
DCR is always occupied by at least two accelerator operators – 24 hours a day, 7 days a week, 365 days a year. It is the base for all security and safety operations on site. The control room has been expanded to also support e-Linac operations as the ARIEL facility is commissioned over the next few years.

TRIUMF HIGHLIGHT

If we consider the main cyclotron to be the heart of the operation, then DCR Ops is the central nervous system. Inside, accelerator technicians monitor 3,000 hardwired devices that produce up to 50,000 signals of information.

11 ELECTRON HALL ROOF

Rare isotopes are produced with beams from the 520 MeV proton cyclotron and the e-linac. Isotopes emerge from the targets ionized, and the rare isotope beam (RIB) of interest is selected via high resolution mass separators, prepared, and delivered to either low energy experiments – accelerated within the ISAC accelerator chain to medium or high energy experiments.



12 TOP OF THE CYCLOTRON INJECTION BEAMLINE

This is the beginning of the journey for the particles accelerated in TRIUMF's main cyclotron. Originating from an ion source, H- particles are accelerated to 2.5% the speed of light (300KeV), and are then injected into the very centre of the cyclotron.

Additional Details:

CREATING IONS FOR ACCELERATION

In simple terms, the cyclotron's ion source is made up of a canister of hydrogen gas connected to a hot filament that emits electrons and breaks up the hydrogen molecules that pass by it. This gas discharge is similar to a flourescent light bulb, only more intense. This discharge contains neutral atoms, bare protons, and negatively charged hydrogen ions. A positive voltage at the chamber's exit attracts the H- ions out of the box and into the pipe that transports them towards the injection beamline.

- 6000-trillion particles of hydrogen are ionized per second via electrolysis.
- Electrons combine with hydrogen atoms to create a H- ion.
- These particles can then be extracted, focused, and steered using magnetic fields from electromagnets throughout the beamline network.
- The environment for the H- ions from this point forward is under intense vacuum - similar to the atmosphere outside the International Space Station 250 miles above, in low earth orbit.

TRIUMF HIGHLIGHT

The lab's beamlines transport charged particles and rare isotopes to a variety of science and experimental facilities. Depending on the target, particles can travel over one kilometer of beamline before reaching their final destination.

13

TOP OF THE CYCLOTRON

VACUUM TANK + CYCLOTRON PROTOTYPES

The cyclotron – 6 metres (20 ft) below the injection beamline – is enclosed in a vault composed of high-density concrete and steel. A red circle painted on the concrete roof represents the outer circumference of the cyclotron beneath, 17.7 metres (58 ft) in diameter.

Each concrete beam on top of the vault weighs 110 tonnes and requires both 56-tonne cranes to move. This concrete is specially formulated to protect staff, users, and the public from radiation, while also extending the life of the blocks themselves.

The 1/20th architectural model is also colour correct. The largest pink and seafoam green machine in existence, these colors were selected by Canadian artist, B.C. Binning, making it TRIUMF's first Arts & Culture collaboration. The colors were intended to serve as a wayfinding and safety countermeasure at the time, supporting visual orientation within such a large and symmetrical structure.

Additional Details:

SCIENCE AND ART

Today the lab continues this practice with artists through several programs and collaborations, including long-standing partnerships with the Emily Carr University of Art + Design and Capilano University's IDEA School of Design.

14

TOP OF THE CYCLOTRON

MAGNETIC CENTER

Inside the cyclotron, the peak magnetic field is 5600 Gauss. Its volume is such that it can deflect compass needles up to 60 metres from the cyclotron, and in particular is strong enough at 20 metres distance to stand paperclips on end. This field is not strong enough to erase a credit card or damage your cell phone, but you can clearly see the effect on items made of magnetic metal, such as coins.

In the Meson Hall models, you can see the beamlines that branch out for a variety of different purposes, presenting a real-world example of applied science in action.

Additional Details:

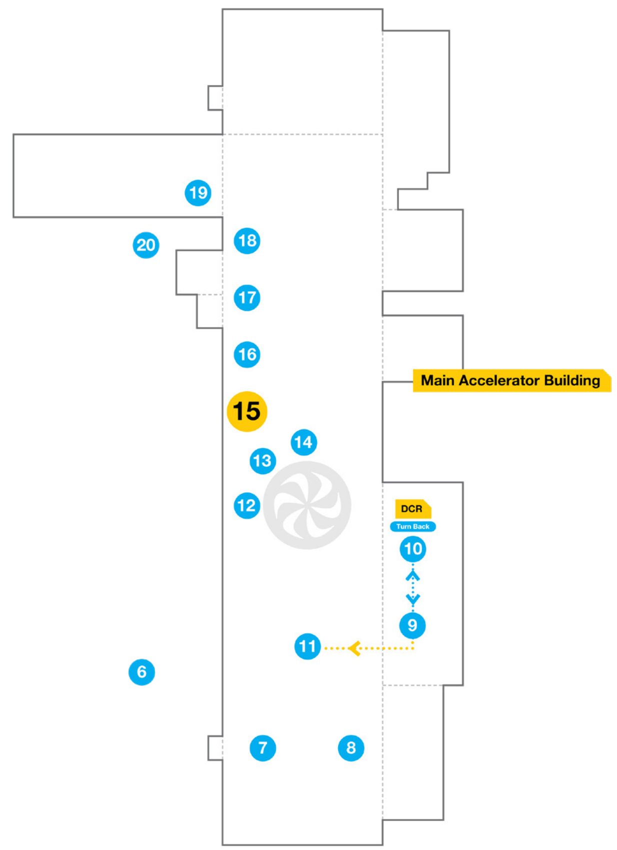
TRIUMF'S SHIELDING BLOCKS

The yellow concrete, sometimes referred to as the lab's LEGO blocks, are used throughout the Meson Hall as radiation shielding for the beamlines and facilities connected to TRIUMF's main cyclotron.

Additional Details:

MAIN CYCLOTRON FACTS

- A 1/10 scale working prototype of the vacuum tank is located at the top of the cyclotron. This tank sits on top of the large sector magnets and counteracts the 2,600 tonnes of pressure to caused by the atmosphere on the outside, and the vacuum inside of the cyclotron tank.
- The H- particles travel linearly through the main injection beamline, are turned 90° on their way down into the machine, then 90° degrees again to begin their outward spiralling journey.
- Inside the cyclotron, electrodes create an alternating 23MHz electric field. At each half turn, the negatively charged particles are pushed or pulled as the electric field alternates from positive to negative (positive field attracts, negative field repels).
- In 1/3 of millisecond, inside a near-perfect vacuum, the H- particles are accelerated up to 75% of the speed of light.
- The cyclotron is a multi-user device, able to deliver protons from low to very high energies depending on the application or experimental requirements.
- A thin stripping foil can be placed at any radius which strips away the electrons, while allowing the proton to pass through. This extracts protons of the energy corresponding to that radius. Energies from 70MeV to 520MeV are possible.
- Magnetic fields are then used to direct the protons out of the cyclotron and into one of the four proton beamlines for use in experimental or industrial applications.



MESON HALL LOADING BAY

15 TRIUMF PROTON & NEUTRON IRRADIATION FACILITY

Over the past five decades, researchers and technicians have leveraged the cyclotron's capabilities in several ways to produce real-world impact. TRIUMF's Proton Irradiation Facility (PIF) is used by partners like the Canadian Space Agency, Cisco, and Boeing to test electronics bound for space. Similarly, the Neutron Irradiation Facility (NIF) is relied upon by aerospace and computing companies; in total, TRIUMF welcomes around 200 international users to these facilities annually.

Additional Details:

DIRECT APPLICATIONS OF PARTICLE BEAMS

- Cosmic rays are a significant source of radiation here on earth, with the amount of radiation increasing as one progresses further into the atmosphere. For example, during a flight from Vancouver to Toronto, you're bombarded by 25x more neutron radiation than you are on the ground.
- Scientists at TRIUMF, using the particle beams from our main cyclotron, are able to simulate the effect of cosmic radiation on electronics. A short time in front of TRIUMF's beams can replicate years of radiation exposure in space or high altitude environments, thereby allowing scientists and engineers to test devices for their durability and improve their radiation hardness – before spending the money to launch the devices into orbit.
- Proton Therapy: TRIUMF's proton beam has also been used to treat cancer. In partnership with BC Cancer, the beam was used for the treatment of ocular melanoma, a rare cancer of the eye. This facility, decommissioned in 2019, operated for more than 25 years, and treated over 200 patients. Today, alternative treatment is offered, while proton therapy centres are available in Boston and Seattle. While our proton therapy facility has ceased operations, TRIUMF and BC Cancer continue their collaboration on several existing and future facilities.

MESON HALL LOADING BAY

16 ULTRACOLD NEUTRON FACILITY

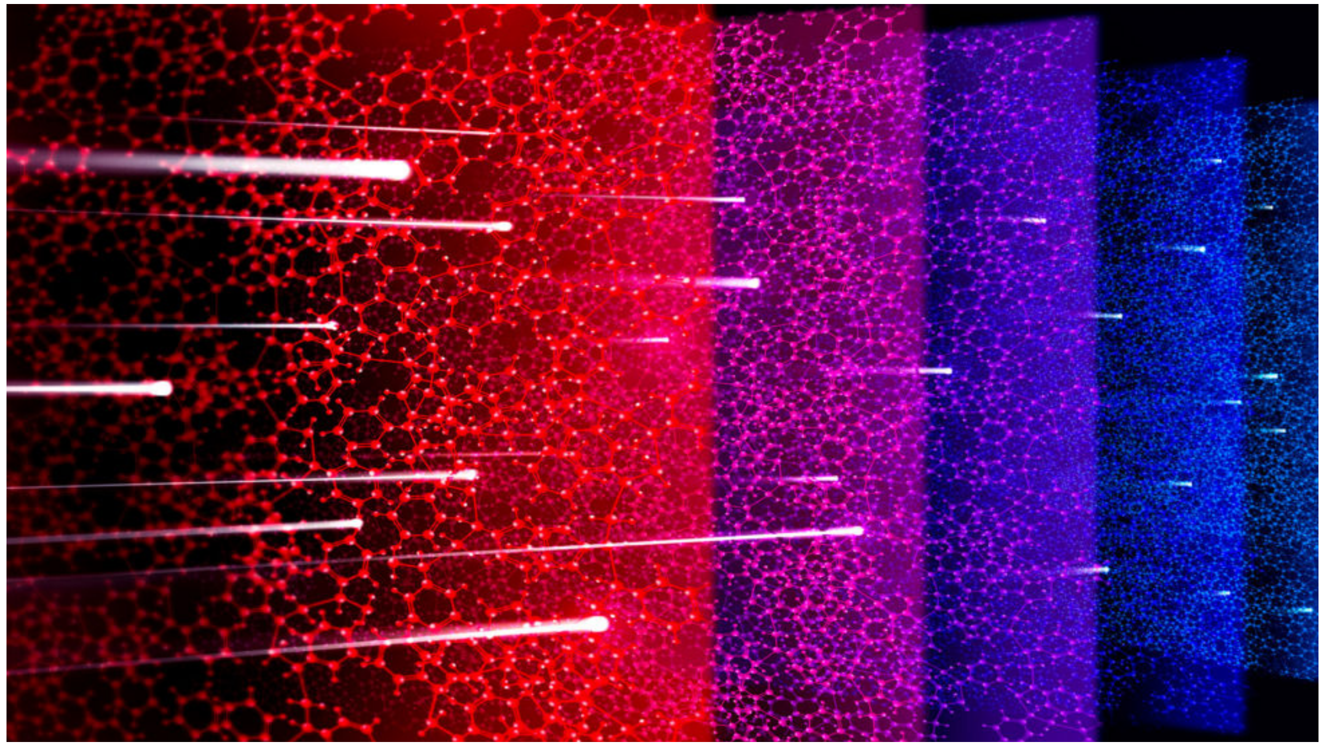
TRIUMF's Ultracold Neutron Facility (UCN) is aiming to be the world's highest-density source of ultracold neutrons. Here a beam of protons is stopped in a block of tungsten, producing fast neutrons. These fast neutrons are slowed by scattering in heavy water at room temperature, then slowed further in superfluid (liquid) helium to reach an observable speed of 7 metres per second, or 25km per hour. At this speed, neutrons can be trapped inside special bottles and observed.

The flagship experiment for the UCN facility will be a world-leading search for the neutron electric dipole moment of the neutron, which may help us better understand matter-antimatter asymmetry and progress research beyond the Standard Model of particle physics.

Additional Details:

HELIUM RECAPTURE FACILITY

TRIUMF uses a tremendous amount of helium for experiments across the lab; however, helium is a finite resource, and since global supplies are diminishing, cost for the gas is increasing dramatically. This facility captures, recompresses, stores, and distributes the majority of the helium used on site. This green initiative has dramatically lowered TRIUMF's consumption of helium and generated significant cost savings for the lab.



Direct Measurements of the Temperature, Depth, and Processing Dependence of Phenyl Ring Dynamics in Polystrene Thin Films by Beta-Detected NMR - SOFT MATTER volume 14, September 2018

MESON HALL EAST

17 CENTRE FOR MOLECULAR AND MATERIALS SCIENCE

TRIUMF's Centre for Molecular and Materials Science (CMMS), one of only a few facilities in the world that uses particle beams of muons and rare isotopes to characterize the electronic and magnetic properties of advanced quantum materials under a range of conditions.

As researchers develop new materials and new applications for existing materials, it's often necessary to understand and characterize the materials' atomic-level characteristics.

Scientific Knowledge
By the Numbers

Over 5 years TRIUMF has delivered (2012-2017):

- > 1,500 publications
- > 25,000 hours of proton beam (92% reliability)
- > 52,000 hours of muon and rare isotope beams
- 1st Canadian ultracold neutrons
- 77% involvement in NSERC subatomic physics funding

83% success for 2017 CFI projects

National and International Collaboration
By the Numbers

1000+ users in 2019
(+100% since 2012)

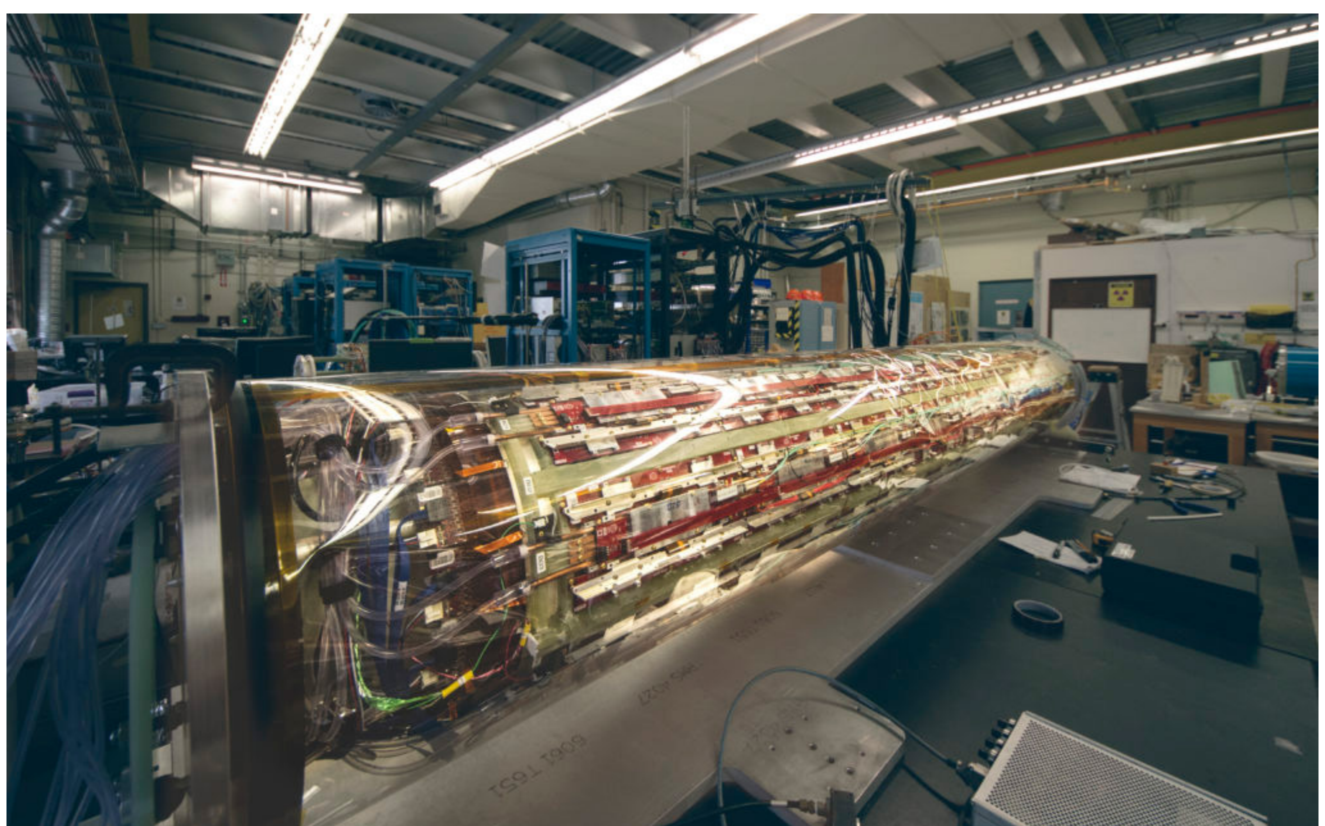
Users from 44 countries (2013-2019)

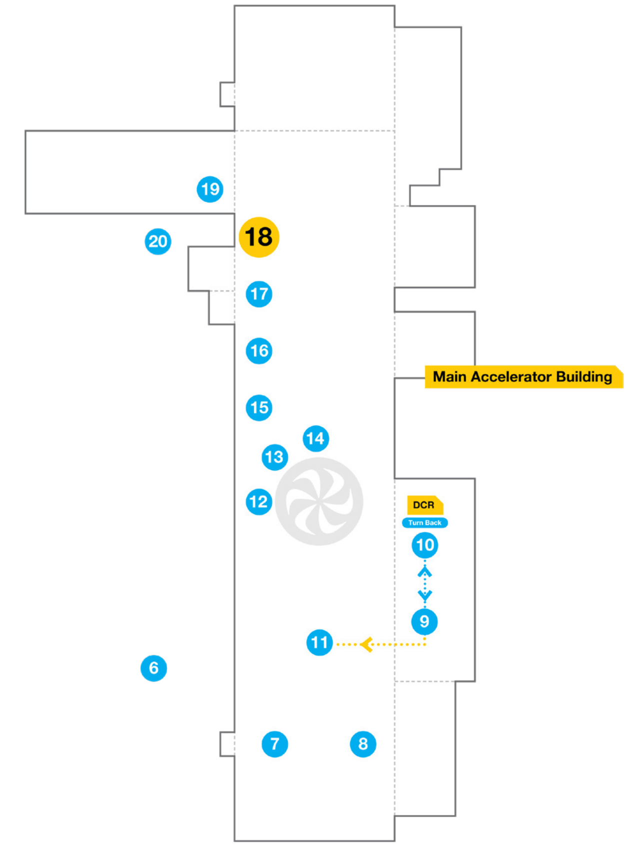
> 60 international partnerships

> 200 Canadian scientists in international projects via TRIUMF

CMMS offers two primary techniques – Muon Spin Resonance (µSR) and Beta-detected Nuclear Magnetic Resonance (ßNMR) – to help probe materials and understand their behaviour at the atomic level, helping to identify new quantum materials that could have applications in building better batteries, electronic devices, and quantum computers.

Each year, more than 150 Canadian and international scientists bring their material samples to CMMS for testing, most notably in areas of magnetic materials, and high temperature superconductors research.





MESON HALL EAST

18 DETECTOR DEVELOPMENT & THE TR-13

This silver structure is a static and dust free clean room used by the lab's Science and Technology Division to construct some of the world's most sensitive particle detectors – for matter and antimatter alike.

Here the air is circulated every 4 minutes and the metallic foil around the vents keeps the temperature in a constant range. This specialized facility is used for the development and production of components for use both at TRIUMF and other major laboratories like CERN in Switzerland – one of the key roles TRIUMF plays in enabling Canadian contributions to international collaborations.

Across from this clean room is the TR-13: the smallest cyclotron on TRIUMF's campus. Contrasted against TRIUMF's main 520 MeV cyclotron, this 13 MeV cyclotron is similar to those installed in most urban hospitals. This cyclotron is used for the production of medical isotopes for research in collaboration with BC Cancer and UBC hospital. These isotopes are transported to UBC Hospital via high pressure pneumatic "Rabbit Line". This line transports short-lived isotopes (such as Carbon-11 and Flourine-18) up Wesbrook Mall at 100km per hour, making the journey from TRIUMF in approximately two minutes.

Complementing the TR-13 are three medical cyclotrons on the TRIUMF site. Operated in partnership with BWXT (a private commercial company), these machines produce over 2 million patient doses of medical isotopes annually, delivering to patients in need as far away as Australia.

On display is one of the first positron emission tomography (PET) scanners in Canada built for neurological research. This PET scanner was hand-built by researchers at TRIUMF and deployed at the UBC Hospital for patient use from the early 1980s until 1996. The machine was dedicated by Queen Elizabeth II in March 1983 during a Royal visit to Vancouver. It pre-dates most commercially available machines and serves as an example of how cutting-edge research tools, in this case detectors for subatomic physics, have commonly been leveraged for healthcare applications.

Additional Details:

PET IMAGING

Unlike MRI or CAT scans that provide structural imaging of the body, PET provides a functional picture of body chemistry. PET scans can be used for studying neurodegenerative diseases like Parkinson's, as well as visualizing metabolic activity within various systems across the body.

For doctors and researchers to use PET scans as a diagnostic tool, an isotope is attached to a biological molecule, like glucose, that's designed to be metabolized within a specific organ. This pairing results in the creation of a radionuclide injected into a patient. Once the radionuclide is absorbed into the targeted tissue, the isotope decays and emits positrons, which annihilate immediately with electrons to, in turn, produce gamma rays – these are picked up by photomultipliers in the PET scanner, and with specialized software, the gamma rays can be translated into an image showing the origin of the bio-molecule in the body.

TRIUMF HIGHLIGHT

The TR-13 cyclotron, made by Richmond, BC-based Advanced Cyclotron Systems Inc. (ASCI), is used to support an in-house life science program that has been operating for over 20 years. This machine is based on a TRIUMF design – a fact that is reflected the name, TR-13, with TR standing for TRIUMF and 13 reflecting the machine's energy level (13 MeV). In fact, it is also the prototype for ACSI's 19 MeV models that have been built and installed at 50+ additional sites.

19

RADIO CHEMISTRY ANNEX

IAMI ARTBOARD

The announcement of funding to construct the Institute for Advanced Medical Isotopes (IAMI) was kicked off by Prime Minister Justin Trudeau during his visit to the laboratory in November 2018. IAMI will be the new home for TRIUMF's Life Sciences program. This facility, equipped with a new 24 MeV medical cyclotron, is under construction on the south end of TRIUMF campus and is expected to be operation within a few years.

IAMI will add state-of-the-art laboratory facilities to help grow TRIUMF's capacity in the life sciences to dramatically increase our ability to help advance isotope-based diagnostic, and therapeutic treatments for a range of diseases, including cancer.

In the coming years, TRIUMF will have the capacity to produce a world-leading amounts of Ac-225; IAMI will help advance this critical research.[5]

TRIUMF HIGHLIGHT

The Institute for Advanced Medical Isotopes is a state-of-the-art facility for research into next-generation, life-saving medical isotopes and radiopharmaceuticals. It will be comprised of a series of medical grade labs, as well as a TR-24 medical cyclotron – one of the most technologically advanced medical cyclotrons in the world. IAMI will significantly increase local and national capacity for the sustainable and reliable production of medical isotopes.

[5] For more information on Ac-225, watch the independently produced short documentary, The Rarest Drug on Earth, to learn more about the impact of this treatment and TRIUMF's role in advancing it further.

TRIUMF GOALS (2020-2025)

SCIENCE AND TECHNOLOGY

Seizing Opportunities, Expanding Frontiers

GOAL 1
Make ground-breaking discoveries across our multidisciplinary research portfolio

GOAL 2
Strengthen our position as a world-leading particle accelerator centre

PEOPLE AND SKILLS

Developing Talent, Increasing Access and Equity

GOAL 3
Become a hub for interdisciplinary education and training

GOAL 4
Inspire Canadians to discover and innovate

INNOVATION AND COLLABORATION

Connecting Science to Society and Canada to the World

GOAL 5
Translate science and technology into innovation and commercialization

GOAL 6
Drive national and international collaboration in research, technology, and innovation

PLATFORMS

ADVANCED RARE ISOTOPE LABORATORY (ARIEL)
Revolutionizing the study of isotopes for science, medicine, and business

INSTITUTE FOR ADVANCED MEDICAL ISOTOPES (IAMI)
A world-class centre for advanced isotope research and development

TRIUMF INNOVATIONS
Translating scientific discovery into commercial opportunities

OUTCOMES

- **Extension of the frontiers of knowledge and global recognition of Canada's contributions to discovery research**
- **Increased capacity for world-class, multidisciplinary research and development in Canada**
- **A new generation of highly skilled Canadians ready to compete in the knowledge and innovation economy**
- **Greater access to STEM opportunities for all Canadians**
- **New game-changing technologies that support business-led innovation and improve the lives of Canadians**
- **A stronger, more competitive Canada in discovery and innovation**

OUTSIDE RADIO CHEMISTRY

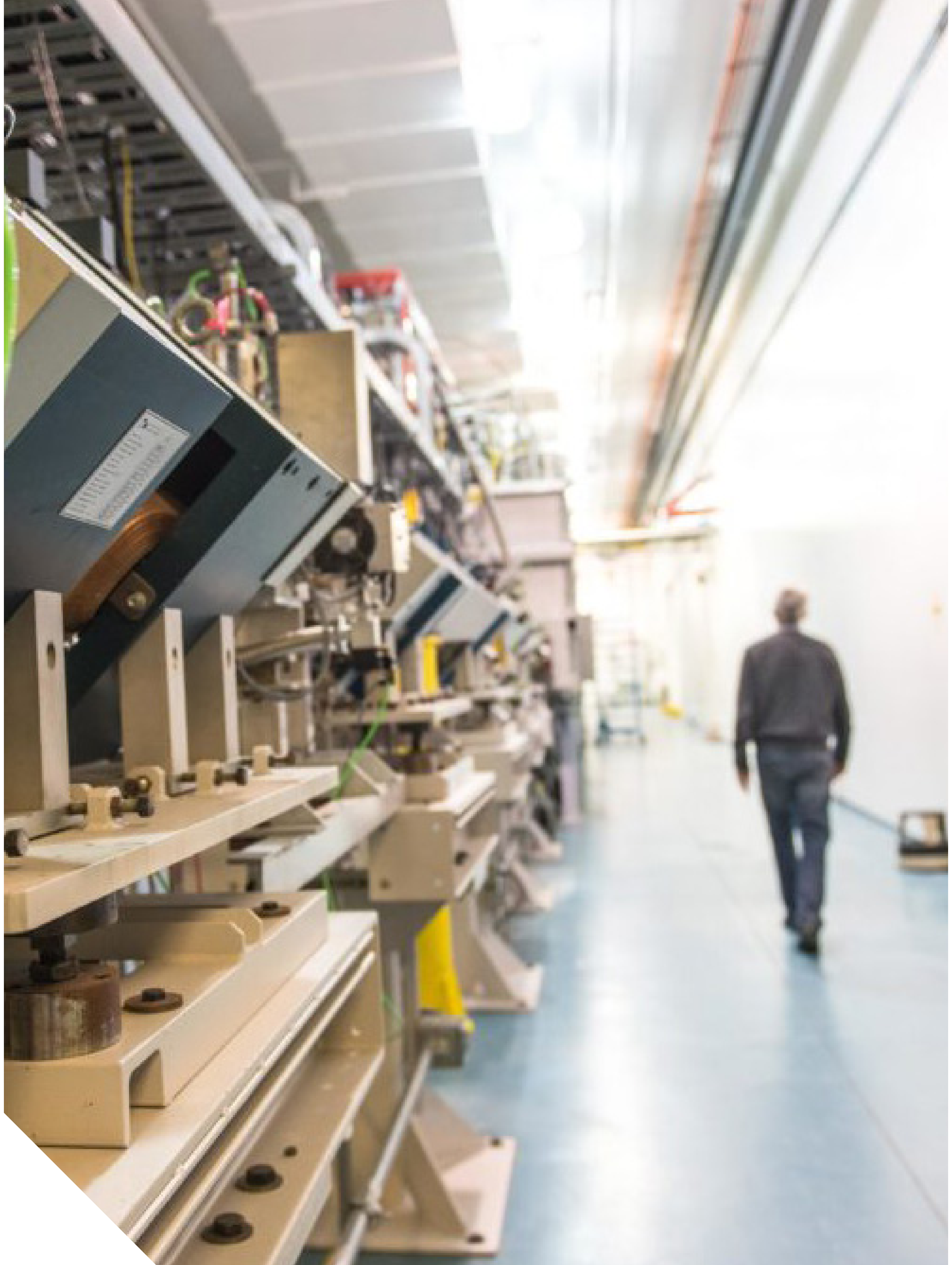
20 INTRODUCING EXPERIMENTAL PHYSICS

The story of the Meson Hall is devoted to how TRIUMF's main 520 MeV cyclotron has been applied to a range of applications, from fundamental subatomic physics and materials science, to radiation testing and life sciences research. The Isotope Separator and Accelerator (ISAC) experimental halls contain additional infrastructure that enables the seperation, and re-acceleration of isotopes for use in experiments.

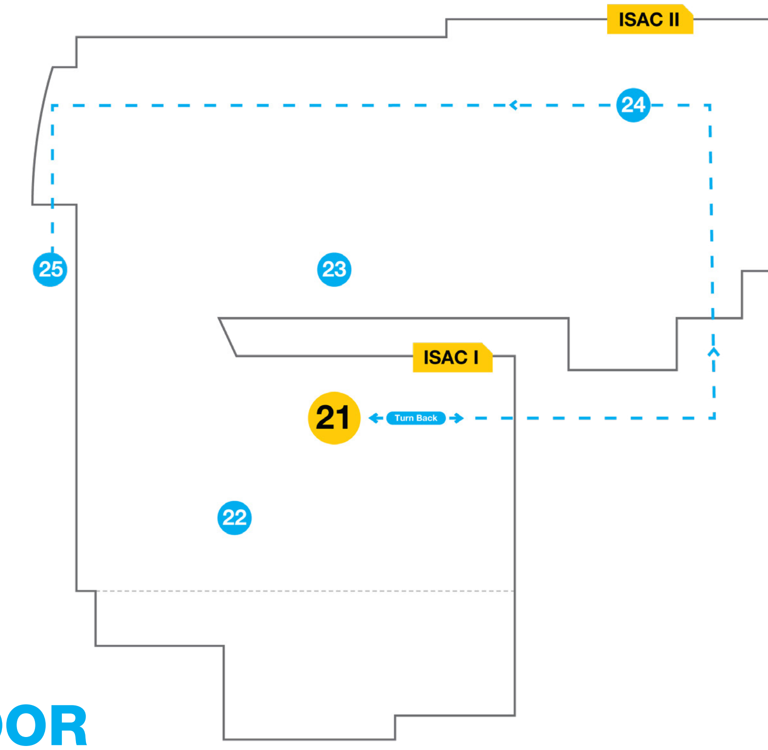
Together, these facilities allow researchers to test the Standard Model and uncover answers to fundamental questions about our universe – some of which have been theorized for decades. In total, ISAC produces a variety of 70 different rare isotopes, separated according to their mass and charge, and delivered on demand to experimental researchers.

TRIUMF HIGHLIGHT

TRIUMF's Isotope Separator and Accelerator halls (ISAC I & II) are rare isotope experimental facilities that include a series of three different linear post-target accelerators that drive isotopes to the energies required by various experiments. The three accelerators operate sequentially, like the gears in a car. Engineered differently for precise operating requirements: the Radio Frequency Quadrupole is a first stage acceleration to approximately 2% the speed of light; the Drift Tube Linac for medium range acceleration; and the Superconducting Linac for the highest energy rare isotope beams, which achieves velocities up to 20% the speed of light, for higher energy experiments inside ISAC II.



ISAC I



21 ISAC I GROUND FLOOR

Throughout the hall, cyan signs indicate the individual research facilities that exist within the space, made possible by ISAC's one of a kind combination of science and engineering technology. In total, TRIUMF is host to nearly 20 separate experimental facilities.[6]

The Detector of Recoils And Gammas of Nuclear Reactions Facility (DRAGON) is one of ISAC's longest standing and most well-known facilities.

- DRAGON gives astrophysicists a clearer view of our stardust origins by simulating the rapid nuclear reactions that take place in exploding stars.
- It is one of the only facilities in the world capable of experimentally measuring many sensitive astrophysical reactions – reactions that allow us to understand how most of the elements in the universe are created.
- The precision data derived from DRAGON is used by researchers worldwide to provide physicists and astrophysicists alike with new information to understand the elemental story of the cosmos.

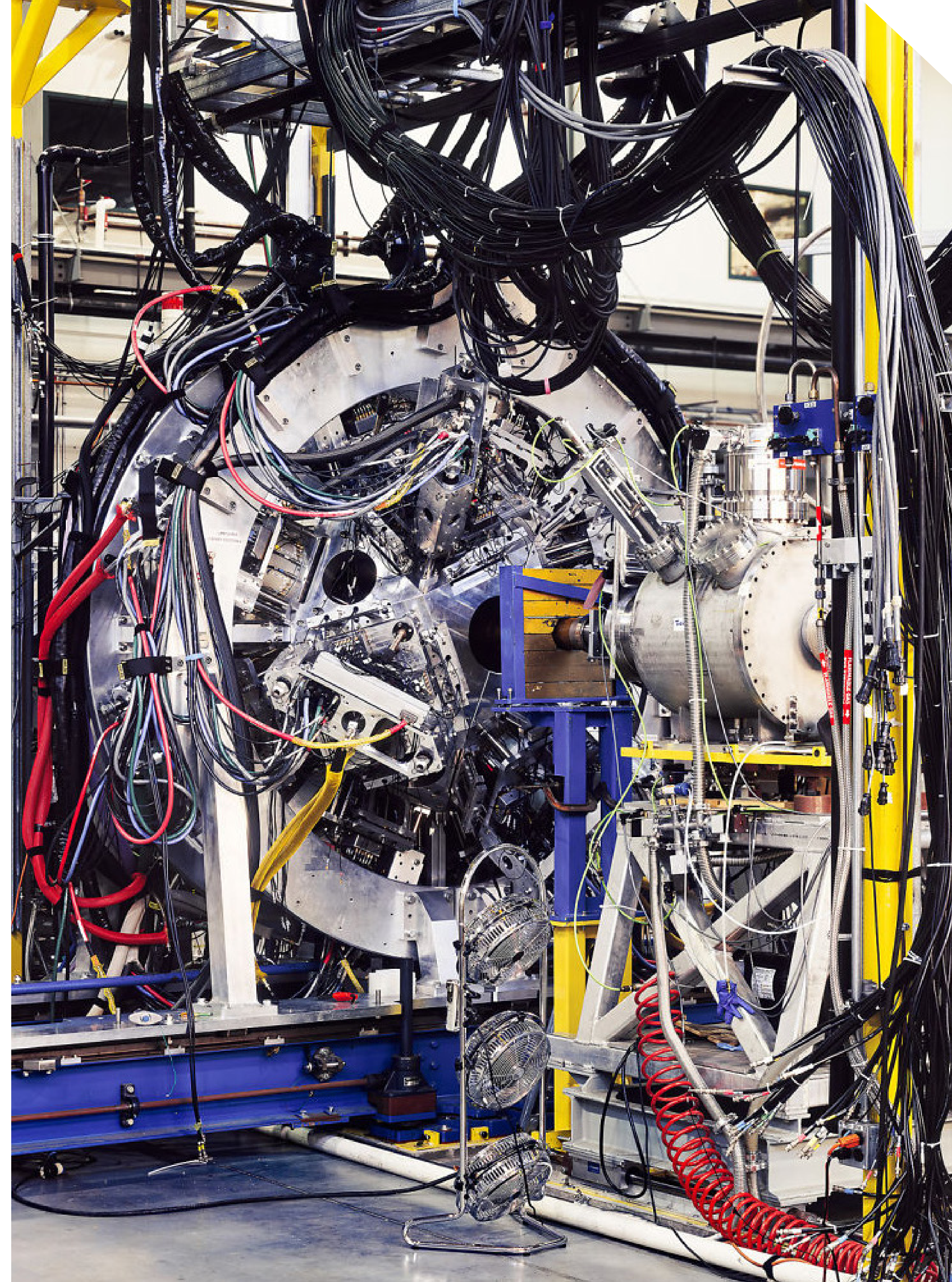
[6] For more information on experimental facilities, visit TRIUMF's Five-Y ear plan website: *https://fiveyearplan.triumf.ca/teams-tools*

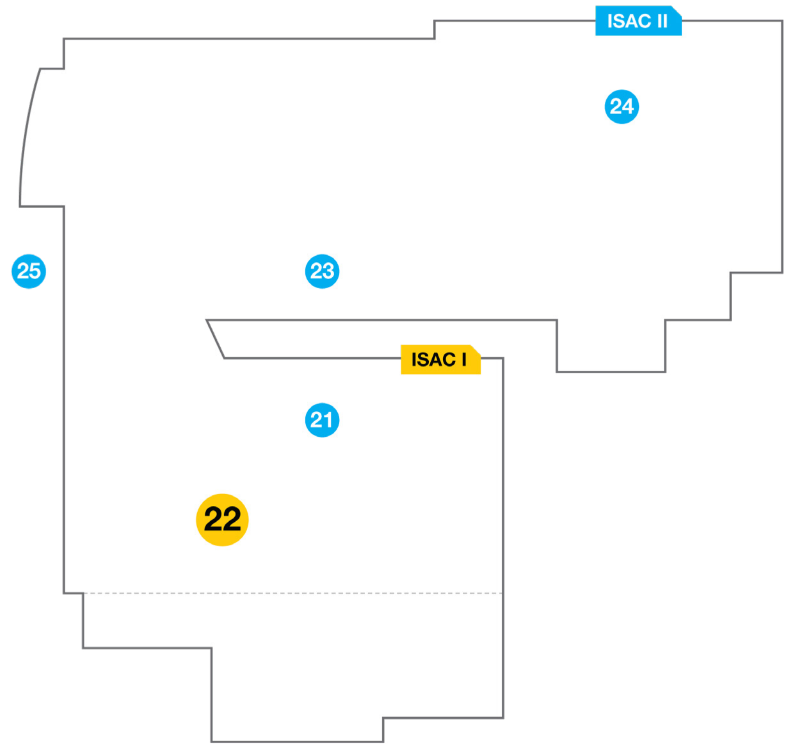
TRIUMF's Beta-detected Nuclear Magnetic Resonance (ßNMR) facility is unique in the world.

- The facility uses radioactive isotopes to take inside-out, atomic-level snapshots of the electrical and magnetic properties in and between the layers of materials.
- Applications for these capabilities include the advancement of superconductor development, battery research, and even our understanding of cellular processes.

The Gamma Ray Infrastructure For Fundamental Investigations of Nuclei (GRIFFIN) serves as the world's most powerful tool for the decay spectroscopy of rare isotopes.

- It is a collaboration led by University of Guelph, Simon Fraser University, and TRIUMF.
- This experiment provides scientists with an unparalleled view of the interplay of forces that create nuclear structure by measuring the gamma rays emitted from the radioactive nuclei of rare isotopes after they decay.
- GRIFFIN's detector is a clover-leaf shaped array of 64 high-purity germanium crystals, which can capture as many as 50,000 gamma ray interactions-per-second, thereby creating a spectrum, or an energy fingerprint, that allows scientists to test, clarify, and extend theoretical models of nuclear structure.





22 ISAC I MEZZANINE

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) is one of the world's fastest and most precise tools for measuring the mass of a single atom, and one of the only facilities able to do so with highly charged rare isotopes.

- TITAN's speciality is measuring the mass of rare and highly unstable isotopes, some of which decay in thousandths-of-a-second.
- It currently holds the world record for its measurements of lithium-11, measured in under four hundredths-of-a-second, in addition to records for the mass measurements of lithium's next 10 shortest-lived isotopes.
- Researchers describe the TITAN's capabilities and sensitivities as equivalent to be being able to weigh a fully-loaded jumbo jet, and instantly detecting the removal of a single page from a person's passport.
- TITAN's world-leading precise mass measurements of some isotopes provide unique insights into nuclear structure, allow us to test the Standard Model, and help us undercover key astrophysical reaction paths.

ISAC's experimental measurements provide the foundation for extending nuclear physics as an applied field, which could for example, help us identify new isotopes for nuclear medicine, or uncover novel ways to treat and handle radioactive waste.

ISAC II

23

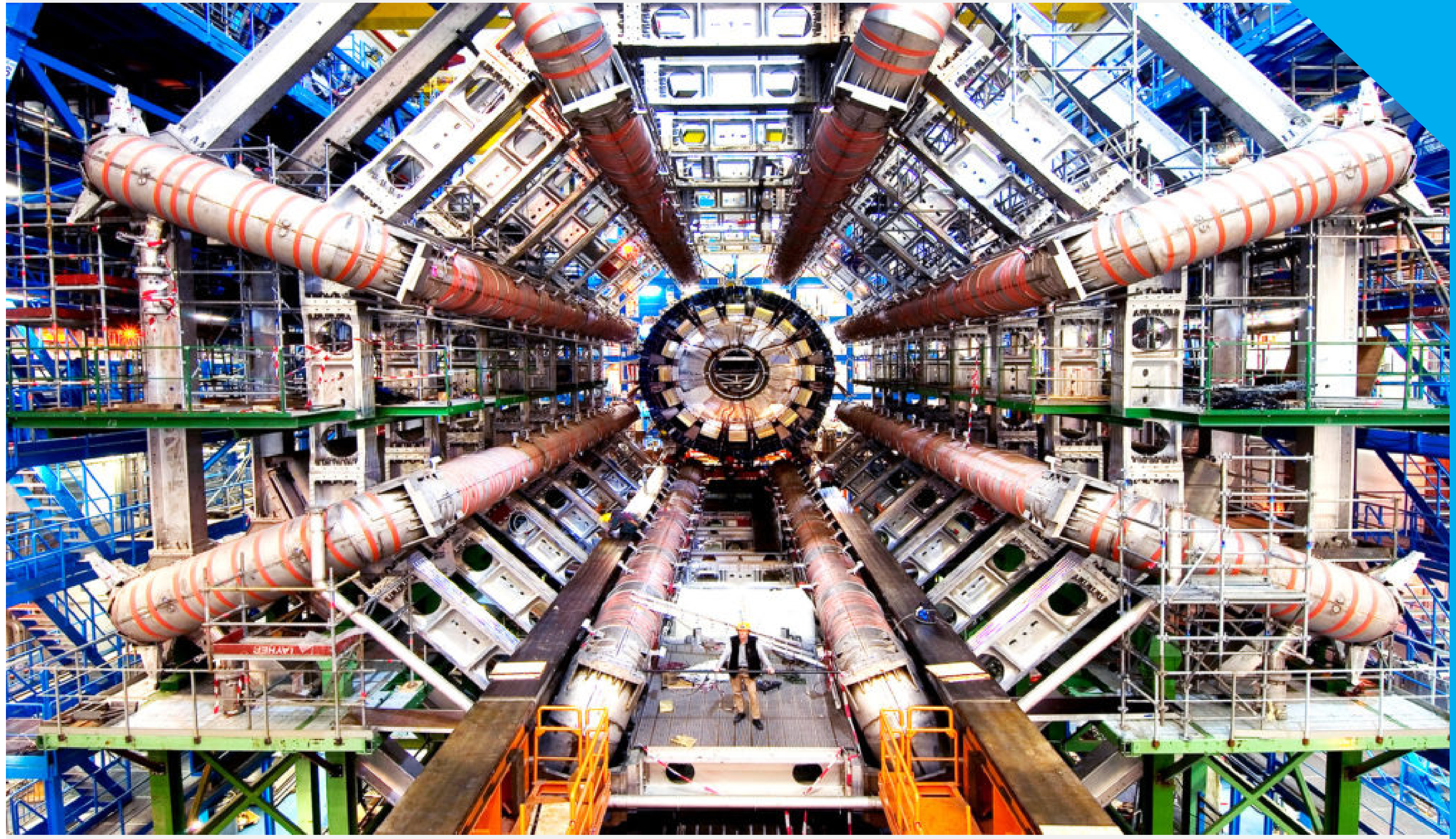
ISAC I ENTRANCE TO ISAC II OFFICES

ATLAS TIER-1 CENTRE

For decades, TRIUMF has served as one of the major portals through which Canadian researchers contribute to and collaborate in major international projects – and nowhere is this clearer than in the longstanding cooperation with CERN in Switzerland.

- TRIUMF has helped lead Canadian contributions to CERN, including the design and manufacture of various accelerator and experimental components over the last several decades. TRIUMF has helped support CERN is through the management of the huge amounts of data generated by the ATLAS experiment.
- From 2006 to 2017, TRIUMF played host to one of 10 ATLAS Tier-1 computing centres located around the globe.
- As Canada's contribution to ATLAS' global computing needs, this world-class facility is managed by TRIUMF staff and played an essential role in the Higgs boson discovery, enabling the data analysis, data reduction, and modeling that confirmed its existence in 2012, resulting in the 2013 Nobel Prize in Physics.

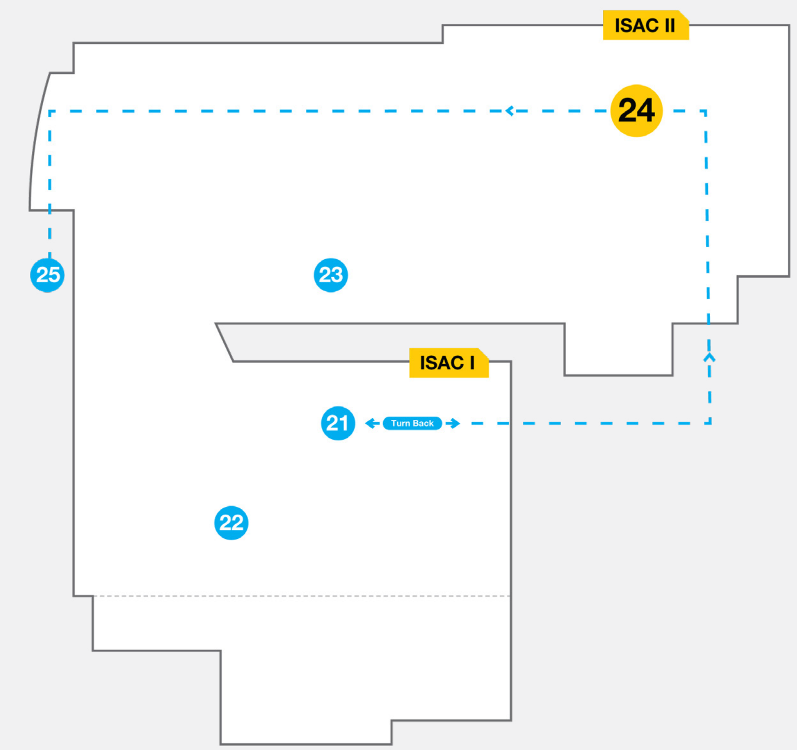
In recent years, the Centre has since been upgraded and moved to SFU where it is currently operating as a federation with the TRIUMF site.



Additional Details:

THE CREATOR OF THE WORLD WIDE WEB

- Tim Berners-Lee, a British scientist, invented the World Wide Web (WWW) in 1989, while working at CERN. The web was originally conceived and developed to meet the demand for automated information-sharing between scientists at universities and international laboratories – including TRIUMF. In 1993, CERN put the WWW software in the public domain. Later, CERN made a release available with an open licence, in order to maximise its dissemination into mainstream use.
- Canada's ATLAS Tier 1 centre provides 10% of the required ATLAS computing resources worldwide. Operating as a federation between TRIUMF and SFU, the current Tier-1 has approximately 12,500 computing cores, 4800 of which are TRIUMF. The newest hardware at SFU currently offers ~40 petabytes of storage capacity. For reference, a single petabyte is equal to 1.05 million gigabytes.



ISAC II

24 ALTERNATE AND ACCESSIBLE ROUTE

Here are three significant experimental facilities made possible by ISAC II's superconducting linear accelerator:

ISAC Charged Particle Reaction Spectroscopy Station (IRIS) gives physicists a unique view of the strong force and unusual transformations in nuclear structure when nuclei are pushed to their limits.

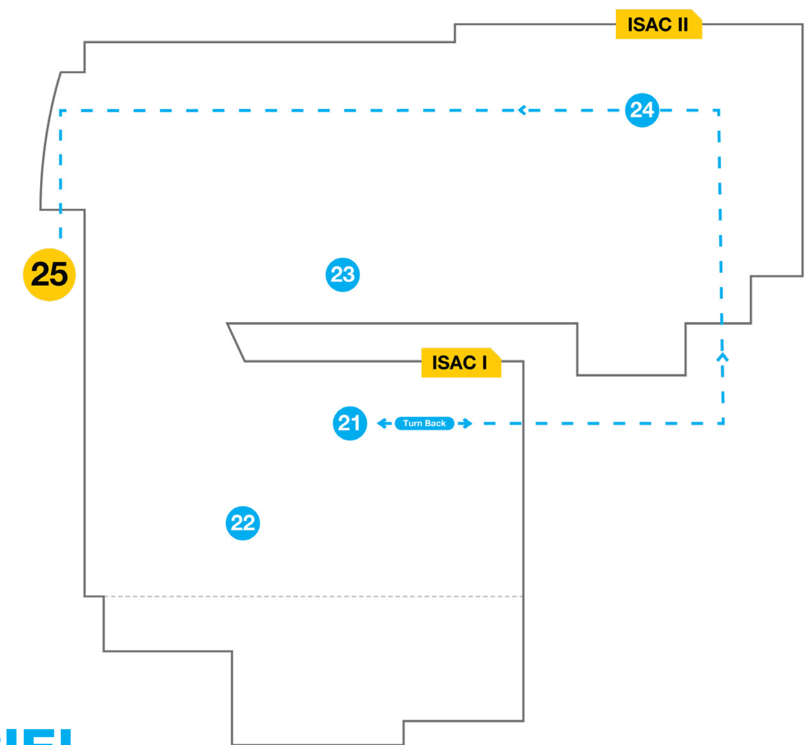
- IRIS leverages ISAC II's ability to produce extreme, short-lived isotopes to induce nuclear reactions, using a solid hydrogen target.
- This experiment enables researchers to construct an unparalleled image of nuclear structure at the extreme, particularly for valence nucleons – those furthest from the nuclear core.

EMMA (the Electromagnetic Mass Analyzer) is a recoil detector in nuclear structure reactions, and a core part of TRIUMF's nuclear astrophysics program.

- EMMA excels at sifting, sorting, and detecting the recoils from a trio of nuclear reactions that take place in exploding stars, making the facility an ideal star simulator.
- It acts as a testing ground for studying the nuclear reactions in exotic, high-energy cosmic events, such as the X-ray bursts that occur within neutron stars.

TRIUMF-ISAC Gamma Ray Suppressed Spectrometer (TIGRESS) is an in-beam gamma ray spectrometer, which has enabled a new era of high-precision nuclear structure experiments with rare isotopes.

- TIGRESS is particularly powerful at enabling TRIUMF scientists to study how the number of neutrons and protons in a nucleus determines its shape.
- It fuels our understanding around how collective nuclear identity emerges from the basic interaction between protons and neutrons, and in turn, how this influences heavy element formation in stars.



25 ARIEL

The Advanced Rare Isotope Laboratory (ARIEL) is the only purpose-built multi-user rare isotope facility in the world.

- ARIEL is the world's most powerful Isotope Separation Online (ISOL) complex.
- It uses a built-in-Canada linear electron accelerator to enable world-class research on the nature of atomic nuclei and the origin of heavy elements.
- ARIEL will be instrumental in future development and production of quantum materials, biomolecules, and medical isotopes.

The ARIEL facility will massively expand the rare isotope program by providing more exotic isotope species with very high intensities. Together, the added production stations will allow TRUIMF's global community of researchers and students to more fully exploit the existing experimental facilities onsite.

TRIUMF HIGHLIGHT

TRIUMF's story – past, present, and future – is written by approximately 600 staff and students, thousands of users from around the world, and a growing network of public visitors and alumni, who all play a part in helping TRIUMF achieve excellence. Together, we discover and innovate, inspire and educate, creating knowledge and opportunity for all.

TRIUMF

4004 Wesbrook Mall
Vancouver BC V6T 2A3
Canada

t 604.222.1047

www.triumf.ca
@TRIUMFLab

Discovery, accelerated