NRC·CNRC

Evaluation of TRIUMF

The Office of Audit and Evaluation

June 5, 2023

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Acronyms and abbreviations

AC-225
Actinium-225

ACOT
Advisory Committee on TRIUMF

ACT
Agency Committee on TRIUMF

ALPHA
Antihydrogen Laser Physics Apparatus

ARIEL
Advanced Rare Isotope Laboratory

BDP
Business Development Plan

βNMR
beta-detected Nuclear Magnetic Resonance

CA
NRC 2020-25 Contribution Agreement with TRIUMF

CFI
Canada Foundation for Innovation

CERN
European Council for Nuclear Research

CMMS
Centre for Molecular and Materials Science

CNL
Canadian Nuclear Laboratories

DOE
Department of Energy

EDI
Equity, diversity and inclusion

EEC
Experiments Evaluation Committee

FWCI
Field-Weighted Citation Impact

GAPS
Graduate Students and Postdocs Society

GDP
Gross Domestic Product

IAMI
Institute for Advanced Medical Isotopes

IP
Intellectual Property

ISAC
Isotope Separator and Accelerator

ISED
Innovation, Science and Economic Development Canada

KEK
High Energy Accelerator Research Organization; Japan

LHC
Large Hadron Collider

MeV
million electron volts

MMS
Molecular and Materials Science

MVM
Mechanical Ventilator Milano

NRC
National Research Council of Canada

NSERC
Natural Sciences and Engineering Research Council of Canada

PDF
Post-doctoral fellow

PIF & NIF
Proton and Neutron Irradiation Facilities

PMO
Project Management Office

PMOG
Project Management Oversight Group

PRC
Peer Review Committee

TC-99M
Technetium-99m

TI
TRIUMF Innovations

TIGRESS
TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer

μSR
Muon spin spectroscopy

Introduction

Introduction

An evaluation of TRIUMF was conducted in 2022 and covers the period of fiscal year (FY) 2018-19 to FY 2021-22. TRIUMF was last evaluated in 2019 (covering the period of FY 2013-14 to FY 2017-18). This evaluation was carried out in accordance with the NRC's approved evaluation plan, Treasury Board's Policy on Results (2016) and the requirements of the *Financial Administration Act*.

This report begins by providing a profile of the laboratory. It then presents evaluation findings on the laboratory's scientific excellence, social and economic impacts, relevance, capabilities and governance. Following the evaluation findings are 4 recommendations for improvements to TRIUMF.

In this report, you will see the following symbols:

This symbol indicates information that is useful to know to help understand the findings.

This symbol indicates a quote that helps illustrate or support the main findings.

This symbol indicates information that supports equity, diversity, inclusion and Gender-based Analysis Plus (i.e., factors that illustrate how diverse groups may experience policies, programs and initiatives).

Source(s): These are the methods from which the findings are drawn. The sources are listed at the bottom of each page.

Evaluation approach

Approach

This evaluation used a mixed-methods approach, incorporating qualitative and quantitative data from several lines of evidence.

This allows convergence of results across lines of evidence and increases understanding by exploring different facets of a complex issue in the evaluation findings. In addition, a Gender-based Analysis Plus (GBA Plus) lens was applied throughout the evaluation.

Methods

The evaluation included:

- document review
- data review (administrative and performance data)
- survey of TRIUMF users (n=155, 28% response rate)
- internal NRC-related interviews (n=5)
- internal TRIUMF-related interviews (n=22)
- external interviews (n=13)
- socio-economic impact assessment (report commissioned by the Office of the Vice President for Emerging Technologies)
- bibliometric study
- peer review with national and international experts (n= 8)

Evaluation Questions

1. **Scientific excellence:** To what extent is TRIUMF a platform for scientific excellence?
2. **Socio-economic impact:** To what extent has TRIUMF contributed to social and economic growth for Canada?
3. **Relevance:** Is TRIUMF focusing on the right areas to stay relevant to serve the needs of the TRIUMF community and beyond?
4. **Capabilities:** To what extent does TRIUMF have the capacity, competencies and facilities to achieve its objectives moving forward?
5. **Governance structure:** To what extent is the governance of TRIUMF (e.g., committees, policies, and controls) effective and/or efficient? Are there any efficiencies to be gained?

For more detailed information on the methods, including limitations, refer to appendix A.

Short biographies of each peer review member are located in appendix B.

Profile

TRIUMF is Canada's national particle accelerator centre. TRIUMF was founded to maintain centralized resources, tools and expertise in pursuit of science in ways that no single Canadian university or organization is equipped to provide. TRIUMF acts as a hub for discovery and collaboration, connecting leading universities and research centres across the country and acting as Canada's gateway to international big science projects.

Overview

TRIUMF Inc. is a multidisciplinary fundamental science research laboratory located on the campus of the University of British Columbia

TRIUMF facilities are located in Vancouver, British Columbia (BC). TRIUMF is owned and operated by member universities and is incorporated as a not-for-profit charity. Its **vision** is for Canada to lead in science, discovery and innovation, improving lives and building a better world.

TRIUMF's core operations revolve around **5-year planning cycles** that communicate goals and priorities, as well as inform infrastructure and equipment needs. TRIUMF's 2020-25 Strategic Plan is focused on the 3 dimensions outlined below:

Science and technology

- make ground-breaking discoveries across a multidisciplinary research portfolio
- strengthen its position as a world-leading particle accelerator centre

People and skills

- become a hub for interdisciplinary education and training
- inspire Canadians to discover and innovate

Innovation and collaboration

- translate science and technology into innovation
- drive national and international collaboration in research, technology, and innovation

TRIUMF Innovations (TI), an affiliate that is fully controlled by TRIUMF Inc., is a registered non-profit corporation with its own Board of Directors and CEO

TI manages, supervises and administers services related to technology commercialization and is responsible for managing aspects of TRIUMF's business dealings (e.g., negotiations, transactions or other interactions with prospective clients), intellectual property (IP), commercial opportunities and spin-off companies.

TI aims to:

streamline industry access to expertise and infrastructure across the TRIUMF network

help TRIUMF start-ups succeed by identifying commercial opportunities, navigating IP issues, advising on raising capital, assisting with talent recruitment and development and identifying potential partnerships

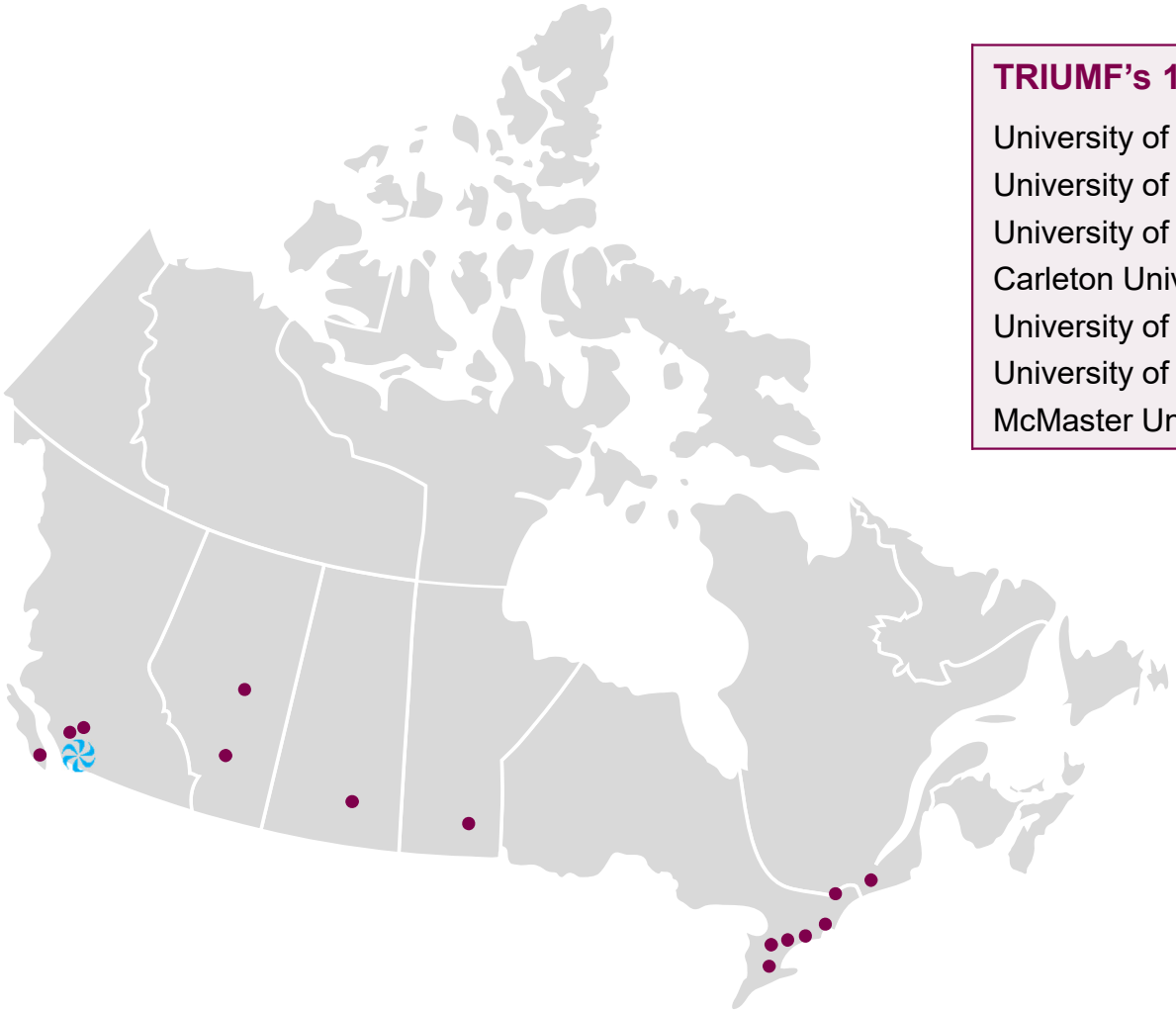
equip students, scientists, technicians and entrepreneurs with skills through a commercialization and entrepreneurship training program

connect scientific inventions and ideas from particle detectors to isotope manufacturing systems to opportunities in the private sector

Source(s): document review, TRIUMF

TRIUMF member universities

TRIUMF is owned and operated by a consortium of Canadian universities. The TRIUMF Board of Governors, which has representation from the Canadian university members, guides the overall direction of the laboratory.



TRIUMF's 14 member universities

University of Alberta	Université de Montréal
University of British Columbia	Queen's University
University of Calgary	University of Regina
Carleton University	Simon Fraser University
University of Guelph	University of Toronto
University of Manitoba	University of Victoria
McMaster University	York University

New university membership

As of March 2023, an additional 7 universities joined TRIUMF as members:

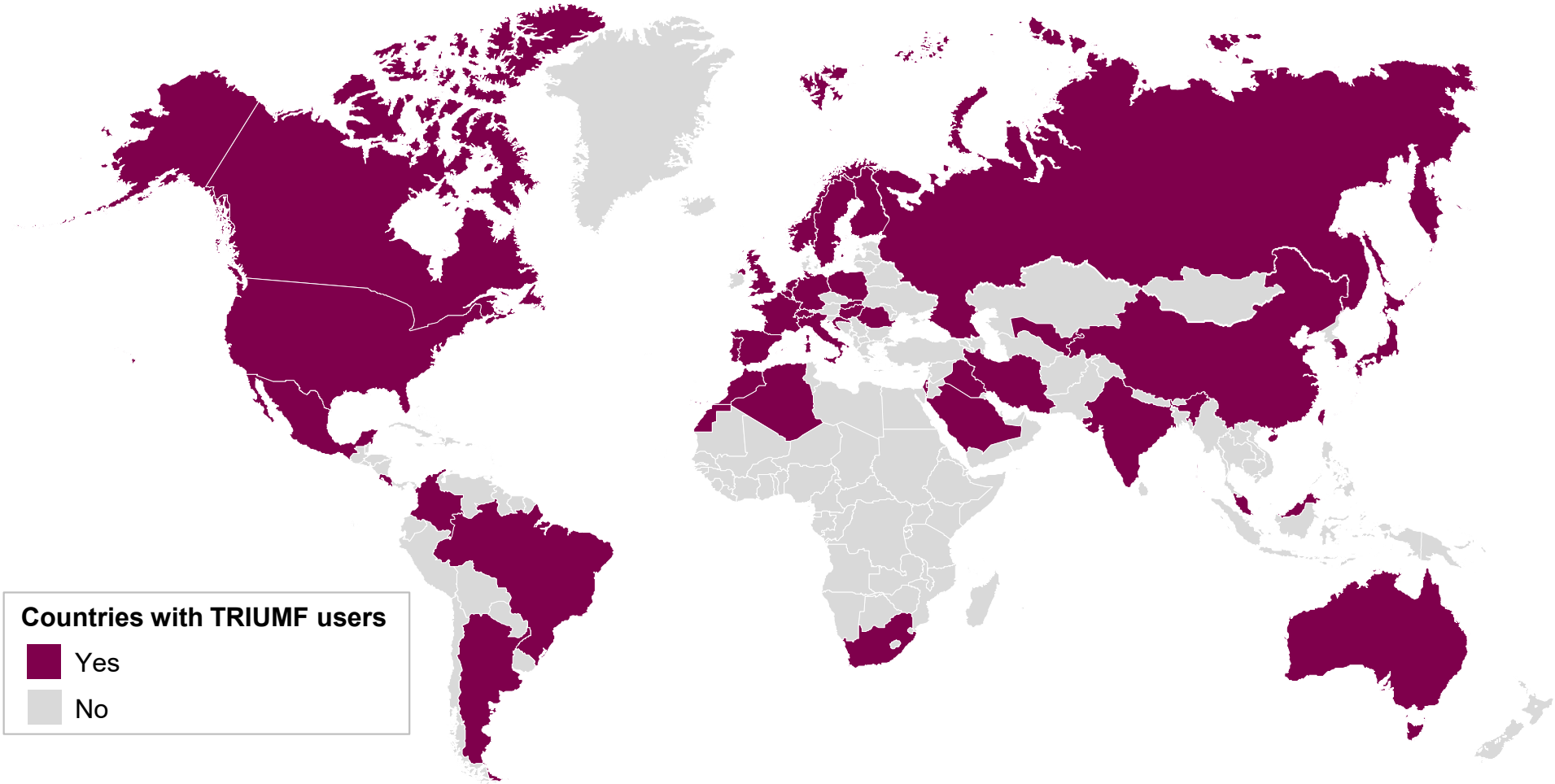
- McGill University
- University of Northern British Columbia
- Saint Mary's University
- Université de Sherbrooke
- University of Waterloo
- Western University
- University of Winnipeg

Source(s): document review

TRIUMF international engagement

TRIUMF has welcomed users and collaborators from over 40 countries since 2012. TRIUMF's global reputation attracts international partnerships to Canada. Internationally, TRIUMF is Canada's portal to global physics research and the chief point of contact for collaboration partners such as the European Council for Nuclear Research (CERN) in Europe, High Energy Accelerator Research Organization (KEK) in Japan and various Department of Energy (DOE) facilities in the United States.

Figure 1. TRIUMF users and collaborators



Source(s): document review

The NRC and TRIUMF

The National Research Council (NRC) provides operational funding to TRIUMF through a formal contribution agreement (CA). The Advisory Committee on TRIUMF (ACOT) and Agency Committee on TRIUMF (ACT) were formed by the NRC to provide oversight and assess activities carried out by TRIUMF.

Contribution agreement

TRIUMF receives operational funding from the federal government through a CA with the NRC. The CA is a 5-year legally binding agreement, signed by both TRIUMF and the NRC, that outlines the terms and conditions for the contribution the NRC provides to TRIUMF.

The NRC's role is to administer the CA, and a Project Officer is appointed to monitor all matters related to the agreement. The current 5-year agreement is for 2020 to 2025. This CA has evolved from previous iterations of 5-year agreements in response to Government of Canada requirements, associated potential security risks and increasing contribution amounts.

As outlined in the CA, TRIUMF and its affiliates have reporting requirements for activities involving NRC funds and the requirement to develop a new security policy that considers current Canadian and international best practices and guidance on security and the safeguarding of research.

Source(s): document review, TRIUMF website

Advisory Committee on TRIUMF

ACOT advises the NRC on scientific, technological and engineering progress and management of TRIUMF, its commercialization efforts through TI, interactions with other scientific facilities and future directions. On behalf of the NRC, it provides TRIUMF with regular performance assessments and makes recommendations to improve operational efficiency and effectiveness. TRIUMF meets with the ACOT twice per year.

The membership of ACOT is appointed by the NRC Vice-President responsible for the oversight of TRIUMF and is comprised of industrialists and international scientists with expertise in TRIUMF-related fields.

ACOT's mandate includes providing advice to the NRC on all aspects of the TRIUMF program, including commercialization activities undertaken by TI, that relate to the determination and administration of the federal contribution to TRIUMF, as well as considerations to ensure the relevance, impact and global position of TRIUMF.

Agency Committee on TRIUMF

ACT oversees the Government of Canada's investment in TRIUMF and the economic benefits derived from that investment, with a focus on management, financial and commercialization matters.

ACT membership includes representatives from the NRC, the Natural Sciences and Engineering Research Council (NSERC), and Innovation, Science and Economic Development Canada (ISED).

The Committee provides advice to elected officials and to the NRC on matters related to TRIUMF. The Committee meets on an as-needed basis, and other federal organizations with an interest in TRIUMF may be invited to participate as required.

ACOT Observers

Observers include representatives from TRIUMF, NSERC, Canadian Foundation for Innovation (CFI), Institute for Particle Physics, Canadian Institute for Nuclear Physics and the Canadian Association of Physicists.

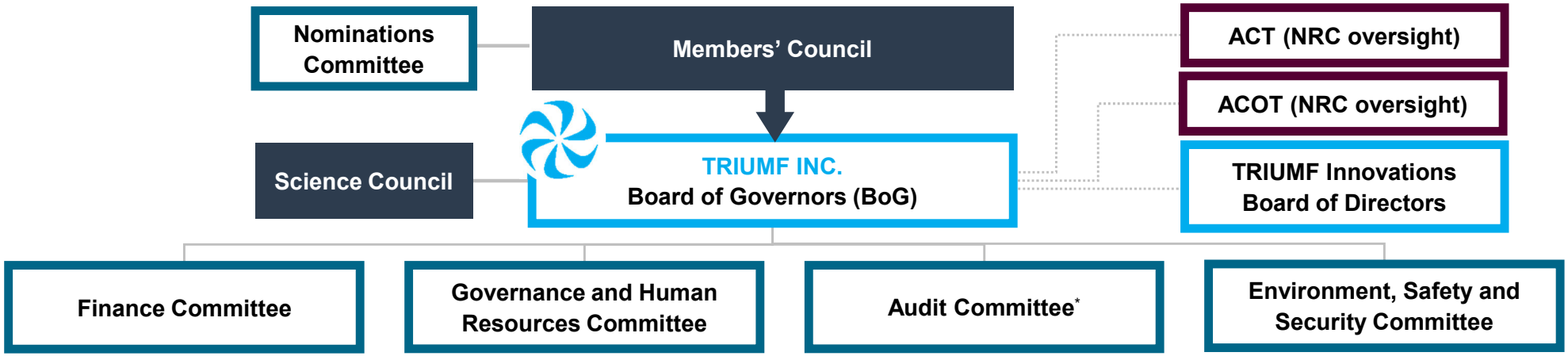
Governance structure

In June 2021, TRIUMF's change from a university joint venture partnership to an incorporated not-for-profit charity brought about significant changes to governance as they moved from a board of 44 members, composed of academic university representatives, to a skills-based board of no more than 11 governors.

Joint Leadership

3 members of the TRIUMF BoG are also directors on the TI Board of Directors. The TRIUMF Executive Director and CEO was a director on the TI Board of Directors until April 2023.

Figure 2. TRIUMF governance structure



Members' Council*

A representative council composed of TRIUMF's member universities who have the responsibility to vote on significant decisions and also receive reports on TRIUMF progress. Each member university selects one representative to sit on the Members' Council.

Board of Governors*

A skills-based board composed of 11 members: university representatives and external partners selected based on the skills and experience needed to oversee TRIUMF's strategic priorities. The Board of Governors are appointed by the Members' Council and includes the Chair of the Science Council.

Science Council*

An advisory body for the scientific direction of the lab composed of representatives from each member university, TRIUMF staff, and selected individuals appointed by the Members' Council.

*An NRC representative sits as an observer on the Members' Council, TRIUMF BoG, Audit Committee and Science Council.

Source(s): document review

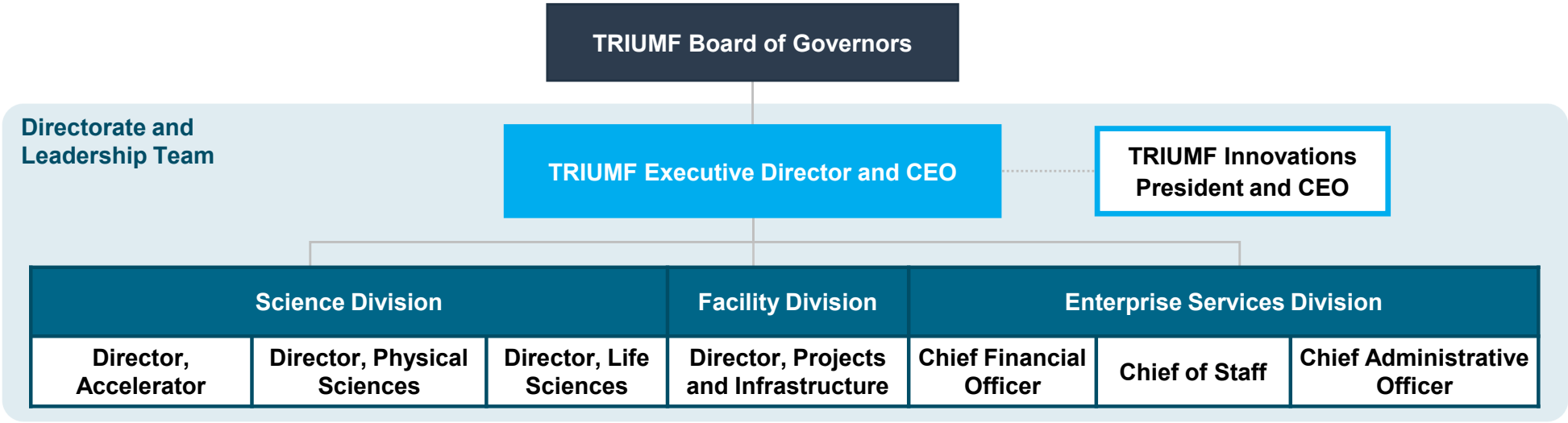
Organizational structure

A new organizational structure was implemented in the spring of 2022. Science division leads (directors) are now fully embedded within the leadership team in order to promote scientific excellence and keep science drivers front and centre.

Joint Leadership

The President and CEO of TI is a member of the TRIUMF Leadership team.

Figure 3. TRIUMF organizational structure



Source(s): document review

TRIUMF and TRIUMF Innovations financial resources

Funding and revenues

TRIUMF secured $360.6 million in funding and revenues over the 4-year evaluation period (2018-19 to 2021-22), of which $291.7 million was from public sources. Funding provided through CAs with the NRC comprise 79% of all public funds.

TRIUMF provided TI $3.8 million over the course of the evaluation for services TI provided to TRIUMF.

Figure 4. TRIUMF Funding and revenues, 2018-19 to 2021-22

Provincial funds: province of BC, BC Knowledge Development Fund

Other federal funds: CFI, NSERC, Western Economic Development, CERN cryomodules fund and construction funds for the Institute of Advanced Medical Isotopes (IAMI)

Other revenue: investments, commercial revenues, repayments from TI and funds from internal sources and affiliated institutions (see figure 11 for additional detail)

NRC: 4 years of funding over the evaluation period were provided under 2 separate CAs (2015-2020 and 2020-2025)

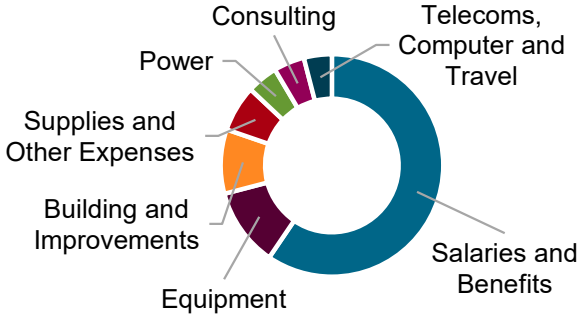
Source(s): document and data review

Expenses

Over the evaluation period, TRIUMF expended $360.9 million in operational and building expenses, with salaries and benefits composing 60% of its expenditures.

Over the evaluation period, TI expended $6.8 million in operational expenses, with salaries composing 39% of its expenditures.

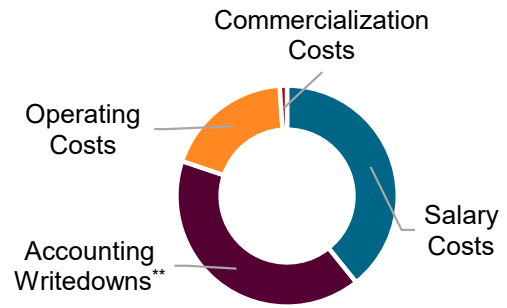
Figure 5. TRIUMF expenses, 2018-19 to 2021-22



TRIUMF expenses by fiscal year	
2018-19	$82.8 million
2019-20	$85.8 million
2020-21	$88.9 million
2021-22	$103.4 million*

*TRIUMF expenses in buildings and improvements were higher in 2022 due to IAMI construction and other infrastructure improvements

Figure 6. TI expenses, 2018-19 to 2021-22



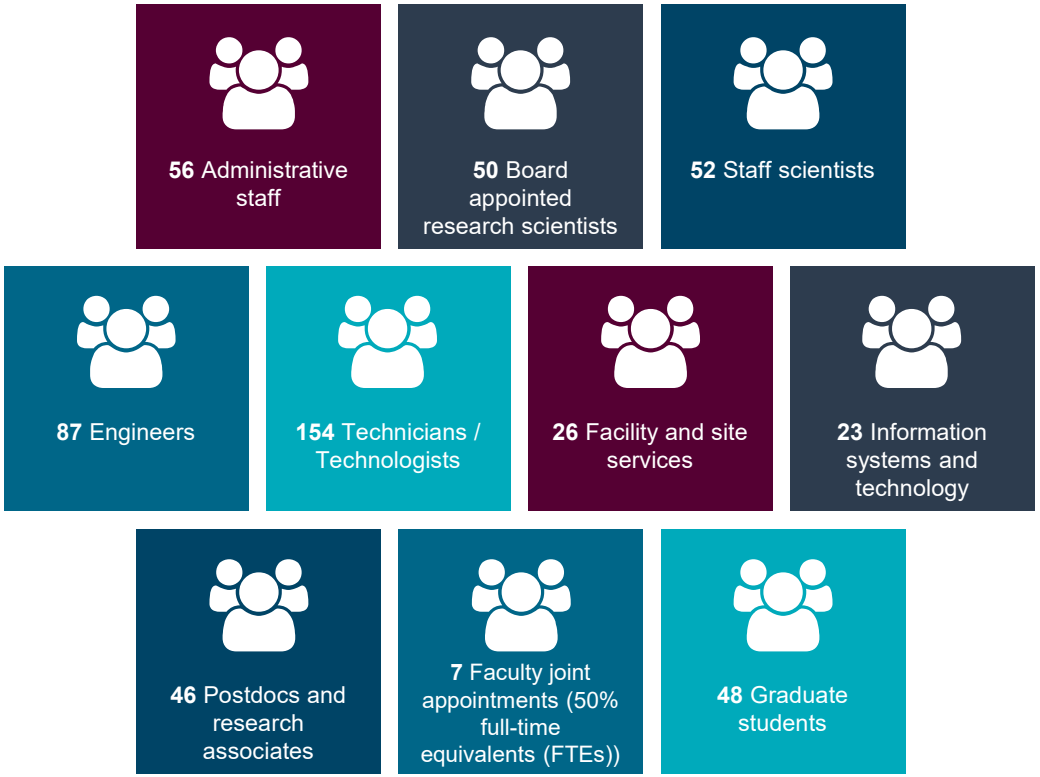
TI expenses by fiscal year	
2018-19	$1.6 million
2019-20	$2.8 million
2020-21	$1.5 million
2021-22	$0.9 million

**Includes costs for reorganization of TI's support of spinoff companies

Human resources

Workforce

As of March 2022, TRIUMF had a total of 549 staff*, with 411 (75%) funded by the NRC through the CA. Staff levels remained relatively consistent throughout the evaluation period.



*Undergraduate students are not included in the staff counts, as they are hired for short-term assignments over 3 separate terms annually. Rates of undergraduate students (summer and co-operative placements) can be found in figure 12.

Gender, diversity and inclusion

TRIUMF revised its Equity, Diversity and Inclusion policy and Workplace Bullying and Harassment policy in 2021 and has taken steps to improve diversity in hiring, such as hosting workshops on implicit bias and preferential hiring. Human resources targets for gender equity in hiring have also been established.

According to an internal survey in 2018, 75% of respondents identified as male and 25% identified as a visible minority.

During the evaluation period, annual female undergraduate applications ranged from 26-32% and female hires ranged from 22-36%.

In 2020, TRIUMF was granted special approval from the BC Human Rights Tribunal to preferentially hire women and an exemption was granted to preferentially hire Indigenous persons.

The Azuma Undergraduate Summer Fellowship program was introduced in 2021 to recruit promising undergrads from under-represented groups. 2 students were hired during the evaluation period.

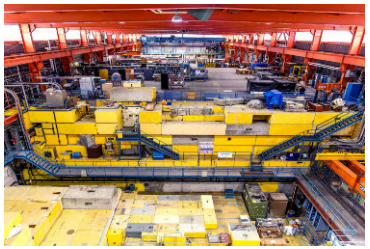
In addition, 2 Indigenous undergraduate students were hired over the evaluation period.

For a list of staffing levels throughout the evaluation period, refer to appendix C.

Source(s): document and data review

Facilities

The TRIUMF campus is home to large-scale research facilities that provide centralized infrastructure to support or enable research across multidisciplinary research topics. Key TRIUMF facilities include:



Main Accelerator Building

TRIUMF's first and largest research facility, includes several distinct areas: the 520 MeV cyclotron, as well as other core components such as the proton and neutron irradiation facilities (PIF & NIF), centre for molecular and materials science (CMMS), ultracold neutron facility (UCN) and the TR-13 cyclotron.

Advanced Rare Isotope Laboratory (ARIEL)

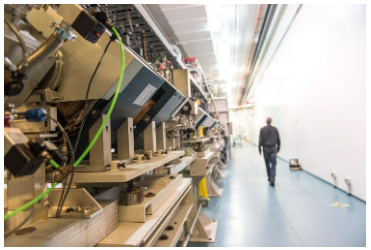
With an anticipated completion date in 2027, the ARIEL is expected to be one of the world's only purpose built multi-user rare isotope facilities. It will be equipped with a Canadian-made linear electron accelerator, allowing research on the structure of atomic nuclei and the origin of heavy elements.

IAMI

A multidisciplinary R&D and clinical translation facility working in the areas of medical isotope production, clinical imaging, radiopharmaceutical development, cancer therapies and accelerated drug development, featuring a dedicated TR-24 medical cyclotron and a suite of medical grade laboratories for conducting clinical trials. IAMI construction is complete and is expected to be fully commissioned in 2023.

Isotope Separator and Accelerator (ISAC) I

The experimental hall contains additional infrastructure that enables the separation, and re-acceleration of isotopes for use in purely experimental physics research. ISAC I produces a variety of approximately 70 different rare isotopes and is host to nearly 20 separate experimental facilities.



ISAC II

Houses a superconducting linear accelerator used for higher energy experiments and houses 3 distinct experimental facilities (ISAC Charged Particle Reaction Spectroscopy Station (IRIS), ElectroMagnetic Mass Analyser (EMMA), TIGRESS).

Source(s): document review, TRIUMF

Scientific excellence

TRIUMF acts as Canada's representative in major international collaborations, enabling Canadian scientists access to leading global facilities and infrastructure. TRIUMF is regarded as a leading national lab for subatomic physics and accelerator science. It is the only laboratory operating at its scope and scale in Canada.

TRIUMF has a high output of scientific discoveries, contributions and publications, and its publications have high regard in the international scientific community. TRIUMF researchers are well-recognized on national and international stages, evidenced by awards, international collaborations and board appointments. Researchers conducting collaborative research through TRIUMF have a high success rate with Canadian funding bodies.

Knowledge generation, discovery and advancement

Technology, technical and research expertise within TRIUMF rival that of large international labs in similar fields. TRIUMF has contributed to knowledge generation and experimentation that is on the leading edge of global scientific discovery.

TRIUMF is considered by stakeholders to be a major national science facility. They rate TRIUMF facilities and infrastructure as excellent and a **hub for international science**.

Due to an intensity of some beams that cannot be replicated at other labs and its accelerator infrastructure that enables research in rare medical isotopes and positive muons, TRIUMF researchers are involved in collaborative research that produces **world-leading results**. Some high profile research in which TRIUMF is involved includes:

- leading role in CERN's ALPHA antihydrogen experiment: the laser cooling of antihydrogen was a world first and was highly recognized in the journal 'Nature' in 2021
- TRIUMF's UltraCold Neutron group (TUCAN) experiment produced the first ultracold neutrons in collaboration with Japan's KEK, which was published in 2019
- Detector of Recoils and Gammas of Nuclear reactions (DRAGON) experiment measured the first-ever radiative proton capture on a nuclear isomer using the only tool worldwide for astrophysical reactions. Results were published in January 2022
- producing novel or difficult to acquire medical isotopes with pharmaceutical and academic institutions, such as actinium-225 (Ac-225) and technetium-99m (Tc-99m)
- leading role in the Mechanical Ventilator Milano (MVM) collaboration, which designed low-cost ventilators to improve health outcomes for COVID-19 patients, starting in 2020

"Colleagues from different countries know about TRIUMF and are shocked at how small it is. Given the funding it receives and the number of individuals, it punches above its weight."

—TRIUMF internal interviewee

"TRIUMF has high intensity, low emittance radioactive and stable ion beams combined with first class experimental facilities and equipment. The low energy beams that TRIUMF provides via the ISOL method have no direct competition in North America, so one would have to travel to Europe or Asia to find beams that are as good. But the existing experimental equipment at those labs is inferior and they are oversubscribed. TRIUMF offers the prospect of performing highly precise measurements due to its unique combination of high-quality beams and apparatus."

—Survey respondent

Source(s): TRIUMF internal interviews, external interviews, survey, document review

Knowledge generation, discovery and advancement

The PRC recognized new discoveries and technological advancements by TRIUMF's 5 program areas (accelerator science, particle physics, nuclear physics, materials and molecular science and nuclear medicine and life sciences).

Accelerator science

The PRC found the TRIUMF accelerator and facilities division is internationally outstanding and has achieved major global scientific contributions. The cyclotron supports the Muon spin spectroscopy (μSR) program, ultra-cold neutron source and radioisotope production, including Ac-225.

The major new ARIEL accelerator has demonstrated operation at its commissioning goal of 10 kW beam power, the limit of the beam dump in the e-hall, which is noted by the PRC as a significant accomplishment that demonstrates the outstanding capability of the accelerator group and the TRIUMF laboratory.

The ARIEL project achieved a recent milestone with the extraction of a beam from the 520 MeV H-cyclotron into the new beamline (4N) that will eventually feed a new target station, which is seen as a recent major milestone.

Researchers are contributing knowledge and technology to CERN's Large Hadron Collider (LHC) and are positioned to collaborate on future projects such as the Electron Ion Collider.

Particle physics

According to the PRC, TRIUMF particle physicists play an active role in setting the national priorities. This enables them to simultaneously articulate a local research strategy and support the intellectual interests of member universities in service of a pan-Canadian research program.

The division maintains unique facilities and technical expertise, enabling Canada to compete on the world stage. The group designs, creates or operates key parts of large international experiments that cannot be created elsewhere.

TRIUMF's particle physicists direct work in the construction or operation of large-scale international experiments towards detector elements that provide key data for physics analyses that Canadian physicists are pursuing.

The division also invested in a scientific computing group to help particle physicists learn to apply new machine learning and artificial intelligence tools to solve pressing issues in theoretical simulations or data analysis.

Source(s): Peer Review Committee (PRC)

Knowledge generation, discovery and advancement

Nuclear physics

The division has proven impactful in the field and impressed the PRC with the breadth and impact of unique facilities and scientific staff.

The PRC noted that new directions in theoretical nuclear astrophysics and modeling and precision studies of radioactive molecules have clear and powerful synergies to the division's existing portfolio and to TRIUMF's Strategic Plan.

TRIUMF has a sound strategy for implementing a new storage ring for neutron capture reactions, which would create a world-unique facility with high impact for understanding neutron capture cross sections at the heart of several nucleosynthesis processes.

Molecular and materials science (MMS)

The PRC found that research in the MMS division has contributed much to broaden and diversify the visibility and scientific impact of TRIUMF on the international scene.

Research in MMS employs μSR and beta-detected Nuclear Magnetic Resonance (βNMR) methods, which are experimental methods (e.g., neutron scattering, bulk thermodynamic measurements, heat and electrical transport) that contribute to the characterization of those materials.

To ensure high scientific impact, TRIUMF is pursuing fast and versatile access to beam time and end stations allowing measurements in high-magnetic field, high-pressure and low-temperature conditions, as well as providing expert technical support for casual μSR and βNMR users. The PRC noted that TRIUMF is well positioned to continue making significant contributions in MMS research. TRIUMF notes that it is expanding into quantum materials research to reorient its MMS program.

Nuclear medicine and life sciences

The PRC noted that there are very few competitors in the world in life sciences and the division is studying a range of work that has fundamental importance to the field.

They are applying expertise in radionuclide production and radionuclide handling to study a broad range of diagnostic and therapeutic isotopes for medical applications.

TRIUMF has a unique program that leverages βNMR capabilities for studies such as binding configurations or coordination sites in biomolecules. It also has a program to study FLASH radiotherapy with photons and protons, enabling the two approaches to be studied alongside one another.

The division has strong chelator chemistry expertise that enables use of novel radiometals produced by the accelerators for biomedical applications.

In global collaborations, the division produces a significant volume of radiotracers for pre-clinical and clinical imaging for use in research and clinical trials.

The PRC noted that the division's success and impact are evidenced by grant funding, publications and commercial activities, yet it remains small and could expand to beat competition to rapidly evolving markets for theranostic agents/medical isotopes.

Source(s): PRC, TRIUMF

Connector role: international collaborations

TRIUMF acts as Canada's gateway to global science and technology collaborations. For Canadian physics researchers, access to international facilities is primarily through involvement with TRIUMF's collaborations in international research.

TRIUMF facilitates Canadian participation in large and highly recognized global research

From 2018-19 to 2021-22, between 224 and 227 Canadian scientists and students participated annually in international projects through TRIUMF (equivalent to the last evaluation).

Figure 7 demonstrates that the number of visiting international researchers was high in 2018-19 and 2019-20, exceeding TRIUMF's internal target. However, international visiting researchers dropped significantly during the pandemic years, 2020 and 2021, due to international travel restrictions.

Figure 8 shows that TRIUMF researchers have undertaken an increased number of leadership roles in both national and international collaborations over the evaluation period, from 16 leadership positions in 2018-19 to 28 positions in 2021-22.

From 2018-19 to 2021-22, TRIUMF researchers participated in 18 international collaborative projects, while international researchers participated in 14 of TRIUMF's collaborations. These numbers are consistent with the last evaluation, where TRIUMF participated in 15 international projects and international participants were involved in 13 of TRIUMF's projects.

TRIUMF attracts scientists from over 40 countries and has over **75 international agreements** and memorandums of understanding (MOUs) with 32 institutions across 16 countries.

Figure 7. International researchers hosted at TRIUMF dropped due to COVID-19, 2018-19 to 2021-22

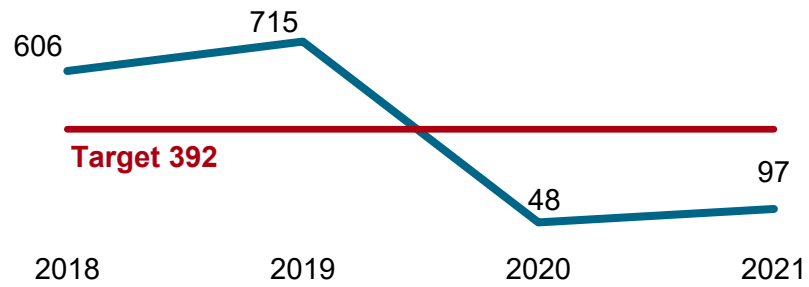
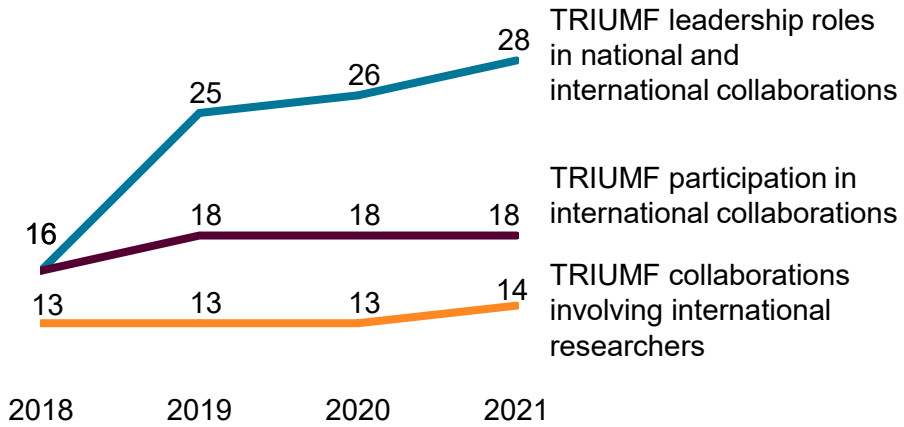


Figure 8. TRIUMF increased participation in national and international collaborations, 2018-19 to 2021-22



Source(s): TRIUMF data

Connector role: international collaborations

TRIUMF and other Canadian researchers play leadership roles and have demonstrated impact in large international experiments due to their involvement with TRIUMF facilities. In the absence of a facility like TRIUMF, Canadian researchers would have reduced access to research facilities and collaborative experiments with international facilities.

According to the PRC, TRIUMF uses its facilities to design, create and operate key parts of international experiments that **cannot be created elsewhere in the world**. For example, TRIUMF draws on its technical and computational expertise to co-host a Tier 1 data analysis center for the ATLAS experiment located at CERN's LHC.

According to stakeholders, without a facility like TRIUMF in Canada, **there are few domestic or international labs where Canadians could conduct comparable research**. As a result, Canadians would incur high travel, user fee and access costs and in some cases the research might be terminated (e.g., medical isotopes produced by ISAC). Access to beam time would be difficult to attain as labs offer beam time to those involved in their collaborative research projects or through agreements with other facilities that enable low-cost or trading of lab time.

In some areas, such as rare isotopes, comparable labs do not produce the same results since work is complementary - the **international science of rare isotopes would suffer without a facility like TRIUMF**.

In addition, the collaborative nature of Canadian universities involved in TRIUMF-related research would diminish and competition for scarce research funds would be stiffer. TRIUMF is working on adding more Canadian universities as members to increase the reach of its network.

TRIUMF's involvement in international collaborations connects Canadian researchers and member universities

Examples include:

- CERN ATLAS includes 100+ researchers from 9 Canadian universities
- CERN ALPHA includes researchers from TRIUMF and 4 Canadian universities (compose 1/3 of the technical team)
- Tokai-to-Kamiokande (T2K)/Hyper-K ultra-cold neutron collaboration with Japan includes TRIUMF, British Columbia Institute of Technology and 6 Canadian university collaborators
- TIGRESS experiments include researchers from TRIUMF, 6 Canadian universities, USA, UK, and France
- EIC Canada Collaboration includes researchers from TRIUMF and Canadian CFI and NSERC recipients, who work on the electron-ion collider in Brookhaven, USA
- MUSE Lepton Universality Test with Paul Scherrer Institute (PSI) in Switzerland uses ARIEL e-linac facilities and involves TRIUMF researchers
- RADNEXT is a global ecosystem of irradiation facilities where TRIUMF's proton and neutron irradiation facility (PIF & NIF) is the only non-European member

Source(s): document review, TRIUMF internal interviews, external interviews, survey, PRC

Scientific publications

TRIUMF publications have high regard in the international scientific community.

TRIUMF produced notable publications with world-leading results, 2017-18 to 2021-22*

Key examples:

- TRIUMF regularly publishes in Nature, including 'Laser cooling of antihydrogen atoms', named a 'Top 10 Breakthroughs of the Year' in 2021 by Physics World.
- TRIUMF regularly publishes accelerator science papers in Physical Review Accelerators and Beams.
- TRIUMF as a collaborator has a number of nominations and awards in Atlas.
- In 2021, TRIUMF scientists published first-principle predictions of which isotopes can/cannot exist for elements from helium to iron in Physical Review Letters.

*Bibliometric data includes publications from 2017-18 to 2021-22 to avoid gaps in data, as the last evaluation included publications up to 2016-17.

TRIUMF publications are high in particle, accelerator and nuclear physics, 2017-18 to 2021-22**

Area of expertise	# publications
Accelerator physics	796
Particle physics	748
Nuclear physics	564
Nuclear medicine	46
Materials science	98

**Comprises a representative set of international publications that may not include all TRIUMF publications. As keywords used to map publications may categorize a publication into more than one area of expertise, the total number of publications sums up to more than 100% of the dataset.

Source(s): bibliometric study, TRIUMF data

TRIUMF had highly regarded publications between 2017-18 and 2021-22

- TRIUMF researchers collaborated on 1,536 publications and TRIUMF MMS users produced 31 publications, of which **40% are affiliated with big science projects**.
- TRIUMF publications were cited 29,773 times in 14,291 distinct documents, with 85% of TRIUMF publications cited at least once.
- 97% of TRIUMF's publications have at least one external collaborator organization, with an **average of 73 collaborators** (one-third are co-authored by 200 organizations or more, which is considered high by international standards).
- TRIUMF has **higher collaboration rates than the Canadian average**: 71% of TRIUMF publications have at least one Canadian collaborator (Canada=17%), while 88% of TRIUMF publications have at least one international collaborator (Canada=50%).
- 11 TRIUMF publications were cited in 16 patent documents, which is on par with the Canadian average.
- The PRC found the nuclear medicine and life sciences publication record is strong and its national prominence is growing.

Some **external μSR users publish without co-authorship of TRIUMF MMS researchers** (~300 publications, 2018-22), as users can access the MMS division and beam time without an internal TRIUMF author. Although publications may recognise use of TRIUMF facilities, the PRC suggested TRIUMF examine ways to better capture the MMS division's contribution as an indicator of scientific impact.

Scientific publications

In relation to Canada, the world and comparable organizations, TRIUMF publications have a high degree of citations in particle, accelerator and nuclear physics. TRIUMF consistently met or exceeded internal publication targets.

Compared to Canada and the world, TRIUMF's field-weighted citation impact (FWCI)* ratings are high

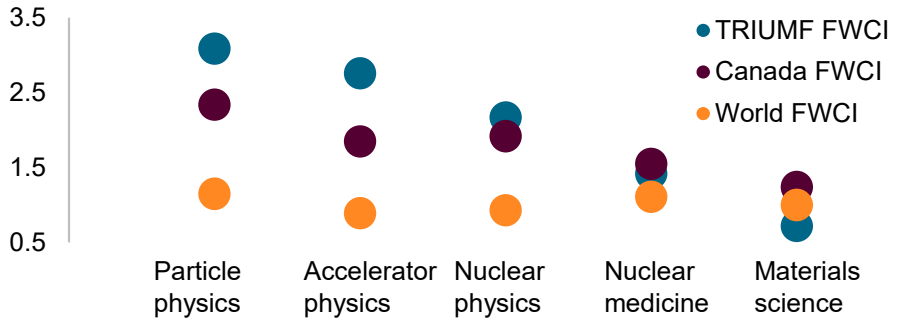
TRIUMF's overall FWCI is more than **double the world average** (TRIUMF=2.15; world=1.0). Thirty-two percent of its publications have an FWCI above 2.0, while 11% have an FWCI above 5.0.

TRIUMF's expertise-based FWCI rates **are higher than the world average** in every area of expertise except materials science (MMS), which is currently one of its smallest programs (plans to expand this program and increase its access to beam time are in development).

TRIUMF has **higher FWCI rates than Canada** in particle, accelerator and nuclear physics.

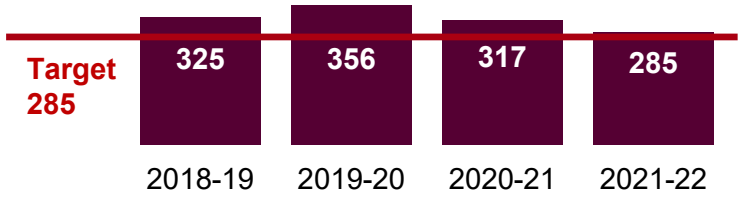
*FWCI: citation metric comparing an entity's publication citations with average citations for similar publications in Scopus. FWCI higher than 1.00 indicates citations are above what is expected based on global averages.

Figure 9. TRIUMF's FWCI rates are higher than those of Canada and the world in particle, accelerator and nuclear physics, 2022



Source(s): bibliometric study, TRIUMF data

Figure 10. The number of TRIUMF's annual internal publications met or exceeded targets, 2018-19 to 2021-22**



**Figures only include internal TRIUMF publications.

TRIUMF publications are cited frequently

TRIUMF's FWCI was ranked **second** compared to 10 identified organizations*** in particle and accelerator physics and ranked **third** in nuclear physics.

With 1 exception, publications by all comparators (10 organizations per area of expertise) have higher FWCI ratings in particle, nuclear and accelerator physics when co-publishing with TRIUMF than in their publications without TRIUMF.

Organizations citing TRIUMF the most fall in top 10 lists for highest FWCIs and highest publications: France's centre national de la recherche scientifique (CNRS) cites TRIUMF publications 904 times (in all areas of expertise), while CERN cites TRIUMF's publications 772 times (in all areas except materials science).

***TRIUMF identified 10 comparable organizations for each of its areas of expertise. See appendix D for the complete set of comparator organization and associated FWCI rankings.

Recognition and funding success

TRIUMF researchers are very involved in national and international committees, boards and associations. The amount of funding TRIUMF secures from major funding bodies, universities and governmental bodies points to its societal and global relevance, as well as to the value it is projected to provide to the global scientific community.

TRIUMF staff have board, committee or editing roles with highly regarded organizations such as:

- RIKEN
- Fermilab
- Residential Center for Nuclear Physics, University of Osaka
- McDonald Institute
- Canadian Association of Physicists, Particle Physics Division
- Paul Scherrer Institute (PSI)

The number of TRIUMF researchers on national and international working groups, boards, journals and committees more than doubled from 2018-19 (n=45) to 2021-22 (n=97). This is more than 4 times higher than in the last evaluation (2017-18, n=22).

Researchers and students note that involvement with TRIUMF has been essential to the granting of awards and funding.

Key awards granted to TRIUMF researchers and students include:

- Tier 1 Canada Research Chair, 2018
- New Frontiers in Research Fund (Exploration), 2018 and 2019
- Fellow of the Royal Society of Canada, 2019
- GENCO Young Scientist Award, 2019
- Royal Society of Canada Rutherford Memorial Medal in Physics, 2020
- American Association for the Advancement of Science Fellow, 2020
- Canadian Association of Physicists Vogt Medal 2019, 2020 and 2022
- Canadian Nuclear Isotope Council Not-for-profit Advocacy Award, 2022

TRIUMF has high success in being awarded funds through major Canadian funding bodies.

In 2020, 67% of proposals to the CFI Innovation Fund were successful, with 60% of requested funds awarded. TRIUMF's success rate is higher than the average CFI rate of 36%, though their success rate decreased from 83% in the last evaluation.

In 2018, 2019 and 2021, 70-83% of TRIUMF's applications to NSERC's Subatomic Physics Major Resources Support program were successful (45% success in 2020 as NSERC gave 1-year extensions due to the pandemic). Of these applications, TRIUMF received 78% of requested funds (similar to the 77% of funds awarded in the last evaluation).

Granting of CFI funds

CFI funds are not awarded directly to TRIUMF, but to academic institutions for research infrastructure. Member universities regularly apply for funding to enhance TRIUMF's infrastructure.

Source(s): TRIUMF data, survey, document review

Social and economic impact

TRIUMF, with support from TRIUMF Innovations, engages in knowledge generation, technological development and commercial activities that result in social and economic benefits for Canada. TRIUMF activities and partnerships have resulted in positive outcomes and generated economic benefits and cost savings in BC and Canada. TRIUMF enables a competitive advantage for Canadian industry by providing access to cutting-edge research and unique infrastructure and by fostering collaboration between industry and academia.

Economic impact: return on investment

Economic modeling demonstrates an economic impact to Canada's GDP and government tax revenues, relative to public investments provided to TRIUMF.

A positive economic impact was achieved in Canada and BC based on public investment in TRIUMF

In the last 4 years, public investment in TRIUMF created direct and induced* economic impacts, increasing Canada's Gross Domestic Product (GDP) by $489.7 million in the short-term (**1.68 times Canada's investment in TRIUMF**), and British Columbia's GDP by $447.5 million (**9.34 times BC's investment in TRIUMF**). In the last evaluation, Canada achieved a short-term return of 1.5 times its investment and BC achieved 10.2 times its investment.

The long-run economic return model indicates impact after the initial $291.7 million public investment is deducted from calculations. After the deduction, TRIUMF contributes $198 million to the Canadian GDP for a return of **0.68 times the government's contribution**.

The return to government** indicates an economic return on investment based on generated tax increases. TRIUMF provides an increase of $99.1 million in tax revenues, which accounts for a **0.34 return on the government investment in TRIUMF**.

*Induced effect: result of increased personal income and measures of increased household-to-business activity. Businesses with increased revenue increase payroll expenditures and households increase local spending.

**The economic impact model was updated from the previous evaluation to account for structural changes in the Canadian economy, such as the division between labour and capital in the production of goods and services. The difference in GDP results is negligible. However, results for other returns are not directly comparable due to the difference in calculations.

Positive economic return to government relative to public investment in TRIUMF, 2018-19 to 2021-22

Return on investment	GDP increase ($ millions)	Economic return on investment ratio
Return to British Columbia (BC's GDP increase)	$447.5 million	9.34
Short-term return to Canada (Canada's GDP increase)	$489.7 million	1.68
Long-run return to Canada (Canada's GDP increase after public investments are repaid)	$198.0 million	0.68
Return to government (Canadian tax return increase)	$99.1 million	0.34

Total 2018-19 to 2021-22 public investment in TRIUMF was **$291.9M** (includes all public funding: provincial, NSERC, CFI, NRC).

NRC's share of public investment in TRIUMF was **$232.1M**.

BC's share of investments in TRIUMF was **$47.9M** (includes direct funds of $10.3M and BC's share of federal investments at $37.7M).

According to the Council of Canadian Academies, the relative likelihood of impact for investment in TRIUMF is similar to that of other public research organizations and academic institutions: knowledge generation, employment and social impacts are moderate-high, while the creation of new ventures, GDP and tax impacts are low. TRIUMF's economic return on investment ratio is similar to those of comparable labs, such as SNOLAB, FermiLab and Argonne.

Source(s): socio-economic impact assessment (report commissioned by the Vice-President's Office), Wikipedia

Economic impact: expenditures and revenues

TRIUMF contributed positively to the Canadian economy over the evaluation period.

Canada was rendered direct economic impacts based on activities undertaken by TRIUMF

Economic impact was calculated through: TRIUMF and TI expenditures in Canada; Canadian business revenue attributable to a relationship with TRIUMF; and spending by TRIUMF conference delegates in Canada.

TRIUMF's expenditures within Canada during the evaluation period resulted in a direct **economic impact to Canada of $336.4 million**, while TI expenditures had a **Canadian economic impact of $6.8 million.***

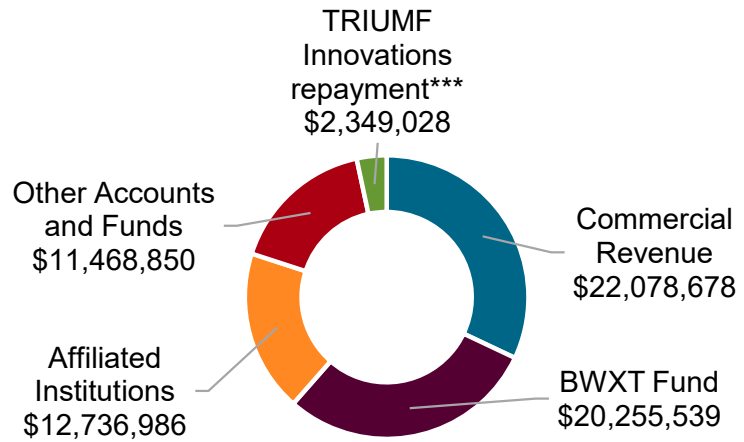
TRIUMF and TI reduced annual foreign purchases since the last evaluation, from an average 31% of annual purchases made outside of Canada over the last evaluation period to 15.9% annually from 2018-19 to 2021-22.

Canadian businesses** self-reported $27-30 million/year in revenues ($113.7 million total) from 2018-19 to 2021-22 that are attributable to a relationship with TRIUMF, which is **more than double the annual Canadian business revenues from the last evaluation** ($13 million/year; $79.3 million total).

The number of conference delegates from 2018-19 to 2021-22 had a valued spending of $6.4 million despite TRIUMF hosting no conferences during 2020 and 2021 pandemic years. **Conference spending almost doubled since the last evaluation**, from $737K/year to $1.3M/year.

*$2.3 million of the $6.8 million was reimbursed to TRIUMF for expenses.
**This does not include an exhaustive list of companies benefitting from TRIUMF.

Figure 11. TRIUMF revenues ($68.9 million total), 2018-19 to 2021-22



***Repayments from TI to TRIUMF for expenses that TI incurred through TRIUMF

Figure 11 outlines TRIUMF's revenues from commercial sources, institutional affiliations and other non-public sources, which totalled $68.9 million. The total does not include royalties or service fees. Work during this evaluation period on licensing Tc-99m production and expanding irradiation services may result in future revenues; however these cannot yet be calculated.

Source(s): socio-economic impact assessment

Business innovation

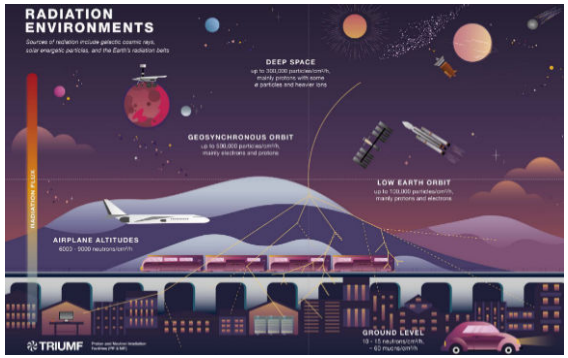
TRIUMF Innovations creates market opportunities for TRIUMF's physics-based technology, enables industry access to TRIUMF infrastructure and connects TRIUMF researchers and technologies to the world via industry partnerships, licensing and business development.

Work with industries results in benefits for partners and for Canada, such as increased expertise and revenues, improved healthcare and decreased cost of products

TRIUMF Innovations helps start-ups navigate complex intellectual property management, assisting with patent filings, invention disclosures, fundraising, partnering and investment.

In addition to 5 long-standing spin-off companies (revenues and royalties are included in figure 11), TI is pursuing a portfolio of business development projects. These include expected revenues from licensing Tc-99m production technology to ARTMS Inc., early-stage work on radiopharmaceutical development and production of new isotopes within good manufacturing practice (GMP) facilities at TRIUMF (examples include gallium-68 and actinium-225), expansion of the proton and neutron irradiation (PIF & NIF) services and a spin-off out of BC Cancer, which will soon close its first round of venture funding.

TRIUMF and TI **provide Canadian industry access to unique technology**, such as high-performance computing, nanofabrication and beamlines, which have been used to develop new products, processes and services. Currently, TRIUMF and TI primarily focus innovation and industrial partnership activities in 4 areas: irradiation services, isotope production and chemistry, technical consulting and professional training.



The newly constructed IAMI facility will provide certified infrastructure for isotope production, enabling the development of new diagnostic and therapeutic substances by industry partners.

TRIUMF's PIF & NIF test site uses beam lines that simulate years of space and terrestrial radiation exposure in a matter of minutes, enabling accelerated testing of electronics. A large proportion of the users are Canadian space-related companies, such as MDA Corporation, with a smaller proportion of telecommunications and technology companies using the facilities to stress-test mission-critical components.

Source(s): socio-economic impact assessment, TRIUMF

Social impact: highly-qualified professional (HQP) training

TRIUMF provides highly-specialized training, giving students skills for scientific employment and Canadian companies the competitive advantage of hiring expertise within Canada. Through Canadian university connections, TRIUMF offers programs to promote the growth and development of professional skills for students and post-doctoral fellows (PDFs).

TRIUMF is a large employer of Canadian science co-operative students and has strong graduate student and PDF programs

TRIUMF's undergraduate co-operative and summer programs provided hands-on experience in core research areas, cyclotron operation, medical physics, radiochemistry, engineering and computing to approximately **465 students from 2018-19 to 2021-22**.

TRIUMF trains students in radiochemistry and radiopharmaceuticals, where there is a small pool of talent in Canada. TRIUMF expects that IAMI upgrades will enable training of more professionals in these specialized areas.

TRIUMF worked with member universities to organize the Canadian field of accelerator science to attract students. Some Canadian universities (e.g., University of British Columbia, University of Victoria and University of Saskatchewan) now offer accelerator science courses where students can link to research being completed at TRIUMF facilities.

TRIUMF and the British Columbia Institute of Technology (BCIT) formed a Work-Integrated Learning (WIL) program to give students hands-on work experience in a research facility. TRIUMF also offers undergraduates a professional development program focused on 'soft skills', such as leadership, teamwork and communications.

Source(s): socio-economic impact assessment

Figure 12. Number of students and PDFs increased between 2018-19 and 2021-22* (with some decreases during pandemic years)

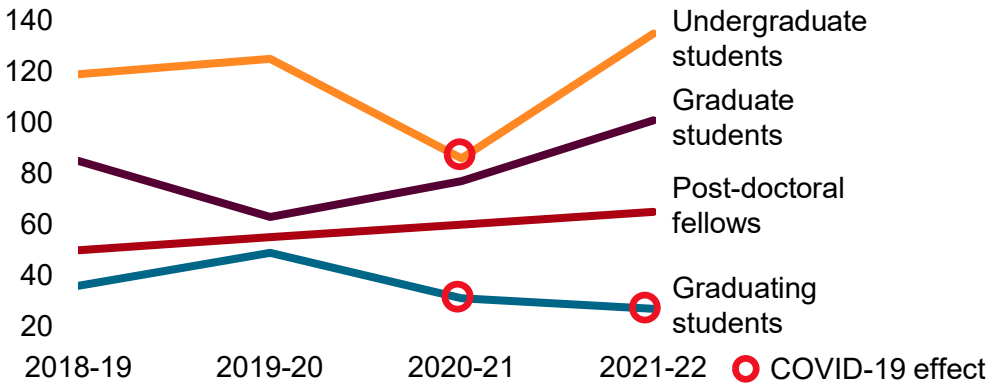


Figure 12 demonstrates that the number of **students hosted at TRIUMF increased** over the evaluation.** There was a decrease in undergraduate students during the 2020 pandemic year, as well as a decrease in graduating graduate students due to pandemic restrictions. Graduate students who could not complete experiments in 2020 were given extensions for graduation.

The number of **PDFs have increased** by 5 every year, which meets TRIUMF's internal target.

*Figure 12 includes students and PDFs hosted at TRIUMF (persons on staff payroll as well as unpaid students hosted through member universities or MOUs).

**An increase in graduating students in 2019 corresponds with a decrease in graduate students, as students graduating partway through the year are not captured in year-end graduate student figures.

Social impact: highly-qualified professional migration

TRIUMF provides important training to highly qualified students, both international and domestic, due to linkages to a network of universities and research facilities. TRIUMF also provides opportunities for involvement in international research and large grant funding.

TRIUMF supports international students and early career researchers

In 2019, KEK (Japan's high-energy accelerator research organization) and TRIUMF jointly established the KEK-TRIUMF Exchange Program for Early Career Researchers for those working in accelerator science and its related fields.

In 2019, TRIUMF received a $500K 5-year grant from the Royal Bank of Canada to enhance student participation in its co-operative program. The grant stipulates that TRIUMF needs to increase the number of undergraduate students by 10% per year until it reaches 150 students.

"Because of the high profile science done here, TRIUMF attracts talent from around the world. It's an open international search for post-docs and there a lot of applicants."

"The only reason I came to Canada was TRIUMF. If TRIUMF was not there, I don't think I would be in Canada. TRIUMF is among the premier institutes, particularly in subatomic physics."

"TRIUMF has incredible global brand recognition, a desirable place to be where you'll do good research."

"TRIUMF helps us bring the cutting-edge level technology to the table. And people will come here because of that."

—TRIUMF internal and external interviewees

The PRC found that student and PDF recruitment is strong and TRIUMF is a destination of choice in its core areas, noting that student presentations showcased excellent training, competence and enthusiasm from the next generation of scientists.

According to TRIUMF's Graduate Student and Postdoc Society (GAPS), international students have faced challenges, mainly due to immigration issues and the high cost of living in Vancouver, which limits TRIUMF's ability to hire internationally. One of the TRIUMF HR objectives for 2022-23 is improvement in communication of and support for immigration matters.

GAPS acts as a student voice. According to ACOT, GAPS works well to integrate and connect students and PDFs to management and was valuable during the pandemic when in-person interactions were limited. However, GAPS articulated concerns, including inadequate HR support, communication and transparency issues, access to scientific journals, cost of living and salary and management of harassment. In 2021, an ombudsperson role was created to help students and PDFs manage interpersonal and professional relationships, which could include issues with harassment.

Source(s): TRIUMF internal interviews, external interviewees, survey, socio-economic impact assessment, PRC

Social impact: health innovation and delivery

TRIUMF contributes to healthcare improvement and provides Canada cost savings on isotopes and technology for medical imaging through the in-Canada production of high-demand medical isotopes.

TRIUMF enables industry-academia collaborations that result in cost savings and a greater supply and variety of medical isotopes, most of which have half-lives ranging from 6 hours to 10 days and were previously unavailable to Canadians

In 2020, TRIUMF and collaborators announced the approval of a **new technology and method** to produce medical isotope Tc-99m (most widely used isotope for medical scans: over 50 million medical and diagnostic tests/year globally; ~80% of medical scans in Canada).

TRIUMF anticipates this method and new IAMI infrastructure will help **alleviate global disruptions** in Tc-99m supply. Adoption of TRIUMF-produced Tc-99m is targeted for use in Canadian hospitals. IAMI infrastructure advancements will also enable development of novel Fluorine-18 chemistry with industry partners.

Started in 2019, the Canadian Medical Isotope Ecosystem (CMIE) industry-academia collaboration aims to bring Canadian-made healthcare products to clinical trials faster, increase Canadian commercialization and manufacturing, and keep IP within Canada. In Nov. 2020, a proposal was submitted to Innovation, Science and Economic Development Canada's (ISED) Strategic Innovation Fund (SIF) to **increase the Canadian supply chain of isotopes**. At the time of the evaluation, the results were not announced.

TRIUMF contributes to wider availability of medical isotopes with a short shelf life by producing and supplying isotopes in partnership with BC Cancer. Through the use of IAMI, the partnership will enable a more sustainable supply of isotopes.

TRIUMF contributed to reduced healthcare costs and improved healthcare technology through the MVM collaboration, which produced low-cost ventilators for COVID-19 patients that could be reproduced globally quicker and easier than other market-available products.

TRIUMF collaborates with Canadian pharmaceutical companies to produce radiopharmaceuticals and treatments based on Ac-225 (recognized internationally as the future of cancer care) and has signed agreements to improve its supply:

- a 2020 agreement with Fusion Pharmaceuticals provides TRIUMF with funding to enhance its Ac-225-producing technology and offers Fusion preferred access and pricing
- a recent TRIUMF-BWXT agreement will further expand production and commercialization of medical isotopes

Once IAMI and ARIEL II are fully operational, TRIUMF will **produce a greater variety, higher volume and more regular supply of isotopes**, leading to a higher supply of isotopes to be delivered across Canada in an appropriate time frame for use.

"TRIUMF is the leading force in Canada for medical isotope production with tremendous expertise and unparalleled infrastructure."

—Survey respondent

Source(s): socio-economic impact assessment, survey

Relevance

TRIUMF's activities and strategic priorities are closely aligned to the needs of the Canadian physics community. TRIUMF also works closely with Canadian member universities (14 during the evaluation period, with 7 added by March 2023) to ensure alignment with key activities and research undertaken in Canadian academia. TRIUMF's 5-year and new 20-year strategic plans have enabled a common vision that creates a process for purposeful and collaborative planning, both nationally and internationally.

TRIUMF has expanded outreach activities and engagement to regions outside of British Columbia, largely as a result of moving to online activities and increasing opportunities for virtual engagement.

Alignment to TRIUMF's strategic plan

TRIUMF's strategic 5-Year Plan (2020-2025) and 20-Year Vision (2022-2042) articulate the continuing and emerging needs of TRIUMF's core program areas and help TRIUMF understand and prioritize future infrastructure needs and improvements.

Alignment with 5-Year Plan

Experts and stakeholders describe TRIUMF as an agile organization with leadership that **keeps a pulse on evolving scientific and technological needs worldwide**. Due to its relatively small size, it has the ability to shift the focus of its strategic narrative to take these evolving needs into account.

An example of TRIUMF's flexibility to meet evolving scientific needs was the establishment of a department of scientific computing in October 2020. This was done in response to an identified lack of machine learning and quantum computing to simulate complex systems that support big data and big science.

By working closely with member universities, TRIUMF is able to align with the key activities and research undertaken by Canadian universities.

However, stakeholders note there are additional **opportunities for greater engagement in collaborative long-term strategic planning** across all member universities and TRIUMF. Greater engagement would ensure plans and research are aligned, avoid duplication and maximize collective resources.

20-Year Vision refocused TRIUMF's planning

TRIUMF's first-ever long-term strategic vision has refocused its planning from project-based goals to goals that align with national, international and university member efforts. These aligned goals can be tracked over time and enable connection to the world's scientific communities.

The PRC commended TRIUMF's ambition to extend its research activities into new areas such as quantum and green technologies. However, the PRC cautioned that TRIUMF must carefully balance resource and leadership focus between strengthening and advancing existing research specialities and opening new areas.

TRIUMF's evolving research activities

Source: TRIUMF 20-Year Vision (2022-2042)

"TRIUMF's strategic plan positions them well to have significant impact in particle physics, nuclear physics, nuclear medicine, accelerator physics, and materials science in Canada and globally."

—Peer Review Committee

Source(s): document review, TRIUMF internal interviewees, external interviews, PRC

Alignment with community planning

TRIUMF's strategic planning is aligned with the physics community through its scientists and its leadership involvement in various planning committees and councils, both in Canada and globally.

Alignment with strategic objectives of the Canadian physics community

TRIUMF scientists and leadership are on the Canadian Subatomic Physics Long-Range Plan (LRP) planning committee. TRIUMF's involvement in the definition of the LRP ensured its strategic planning is aligned with the physics community.

The heavy investment in IAMI and ARIEL demonstrate commitment to a long-term strategic vision that aligns with the physics, life sciences and nuclear science communities. These facilities will have **unique capabilities that address emerging and future needs**.

The PRC noted that TRIUMF particle physicists play an active role in setting national priorities for the field. This enables TRIUMF to simultaneously articulate a local research strategy and support the intellectual interests of member universities in service of a pan-Canadian research program.

However, there is need for TRIUMF to prioritize and focus limited resources to ensure both current and future infrastructure needs of the physics and accelerator science communities can be met.

TRIUMF plays a role in international physics planning

TRIUMF staff play a role in the **prioritization and strategic planning processes of international physics**. This includes sitting on key committees and councils such as the Nuclear Science Advisory Committee, which provides official advice to the Department of Energy on the national program for basic nuclear science research in the US, and the International Cooperation in Nuclear Physics, which has a mandate to look at key issues in nuclear physics worldwide.

Cover of the Canadian Subatomic Physics Long Range Plan 2022

Source: © 2022 Long-Range Planning Committee

Long Range Plan

The Canadian Subatomic Physics Long-Range Plan 2022–2026 is the latest in a quinquennial series of plans developed to guide the progress of subatomic physics research in Canada. The present planning process was co-commissioned by NSERC, the Canadian Institute for Nuclear Physics (CINP) and the Institute for Particle Physics (IPP).

The LRP advises the Canadian subatomic physics research community and relevant stakeholders on priorities for both current and future endeavours.

Source(s): document review, TRIUMF internal interviewees, external interviews, PRC

Awareness and outreach

As per activities outlined in its 5-year plan, TRIUMF expanded its outreach and visibility outside of British Columbia over the evaluation period. During the pandemic, TRIUMF broadened its virtual presence and shifted to online activities.

TRIUMF outreach activities expand

In 2019, TRIUMF expanded outreach with university partners through travelling exhibits and lectures across Canada and by supporting events in Ontario and Nova Scotia. Efforts were halted during the pandemic, but plans to resume activities are underway.

TRIUMF encourages board-appointed employees to work with member universities across Canada to **embed TRIUMF scientists with other research institutions across the country**.

TRIUMF has reported that leadership has recently worked on **enhancing connections and collaborations with Canadian labs** SNOLAB, CNL and Canadian Light Source (CLS), which enables them to leverage each other's local communities.

Other outreach efforts include making connections with local Indigenous communities in BC and Manitoba, and liaising with industry partners and advocacy groups, such as the Canadian Nuclear Isotope Council, to communicate the key role of TRIUMF in the science ecosystem.

Increased online engagement

TRIUMF has developed a new multimedia website (Discover our lab), which provides information, videos, animations, infographics and virtual tours of the lab. Initial feedback has been positive with over 2,000 visitors from over 50 countries in 2021-22. TRIUMF also **expanded its social media presence on all its platforms**.

As of 2021, TRIUMF expanded its social media presence*

- **520,000** Users reached in 2021
- **39%** Year-over-year gain — YouTube channel views
- **22%** up from 2016 — Twitter followers
- **61%** up from 2016 — Instagram followers

*Data is sourced from interviews and the socio-economic impact assessment, and the time points for data collection are varied.

Opportunities for increased awareness

According to the PRC, TRIUMF has **"the makings of a good story as a national resource for the scientific community as evidenced by the broad user groups and publications records. This story and its value proposition to Canada must be articulated clearly and propagated widely to build support for TRIUMF and its activities."**

The PRC found that TRIUMF's narrative has not been sufficiently developed or broadcast in a clear and compelling manner and suggested there may be value in **improving its communication of objectives, strategy, mission and achievements** to the general public.

Source(s): document review, TRIUMF data, TRIUMF internal interviewees, external interviews, PRC, and socio-economic impact assessment

Capacity, competencies and facilities

TRIUMF's international reputation for high profile science and unique technology alongside its hands-on mentorship are key to attracting qualified national and international candidates. Staff retention is an issue and recent turnover has contributed to the need for resource prioritization.

Equity, diversity and inclusion (EDI) has been reframed as a core value in strategic planning. An EDI Officer and policy, harassment training and policy, and diversity on hiring committees were put in place. However, TRIUMF needs to focus on diversity outside of gender considerations.

TRIUMF facilities meet the needs of the research community and contribute to training, education and research in TRIUMF-related fields. However, some infrastructure is aging and needs refurbishment and many beam lines are oversubscribed. Access to TRIUMF facilities is considered to be fair and transparent, with a structured process.

Recruitment, retention and succession planning

TRIUMF has global recognition and unique technology that enable recruitment from major international labs. However, it faces issues with recruitment and retention and is working toward documenting formal succession and retention strategies.

Recruitment

TRIUMF widely disseminates its job advertisements since the lab is not well-known outside of the physics community and uses search firms for leadership and international searches.

For positions requiring highly specialized skills, there are few available candidates. To attract candidates to engineering, technical and trades, TRIUMF and BCIT are working to develop opportunities and potential future training programs to produce a pipeline of qualified candidates. TRIUMF also increased joint faculty, PDF and affiliated scientist hires over the evaluation.

TRIUMF recruits emerging talent through undergraduate co-operative and summer programs, hosting 135 students in 2021-22, as well as its PDF program, hosting 65 PDFs in 2021-22. Challenges related to visas have resulted in delays in international hiring.

Succession planning

The TRIUMF Board noted that conversations have centred on compensation and retention and recognizes the need to focus on succession planning. **Work has begun to draft succession plans,** with initial efforts focusing on leadership positions. TRIUMF has indicated that succession planning will include gender considerations, particularly in technical fields.

TRIUMF recently hired early to mid-career staff to train as leadership replacements. In addition, efforts are in place to mentor for senior positions in science technology and management, as it is difficult to maintain progress when institutional knowledge is lost.

Retention

Staff retention is a challenge and turnover has contributed to delays in construction. Some leaders left for US labs with higher compensation and budgets. HR acknowledges that **a formal retention strategy would be beneficial,** and is working toward or has already implemented ways to retain talent, such as pension and benefit plans, HR systems, streamlined organizational and compensation structures, total rewards strategy with recognition and incentives, coaching-based models and merit-based promotions for junior staff. Stakeholders suggest HR look at strategies such as subsidies for housing or childcare. The PRC added that TRIUMF should strengthen its framework for staff development to support career advancement, enhanced recruitment and retention of top-quality staff.

An **expensive housing market and below market salaries are barriers to attracting and retaining talent**. Vancouver's cost of living is high and stakeholders and the PRC acknowledged that TRIUMF and TI salaries are not competitive. A market assessment completed by TRIUMF HR in 2020 brought most roles to 80-90% of 2020 market rates. However, post-pandemic inflation has positioned salaries below 2022 market value. The PRC suggested that TRIUMF may benefit from identifying operational efficiencies to enable operations with fewer, better compensated staff.

Conversely, the PRC described numerous areas of the **lab as short-staffed**, noting that TRIUMF will have limited ability to achieve full potential of new research facilities while supporting its external user base without additional positions.

The PRC found that TRIUMF has an **"exceptional cadre of staff who perform high-impact research, develop new technologies and build and operate expanding unique experimental capabilities."**

Source(s): TRIUMF internal interviewees, external interviews, document review, PRC

Equity, diversity and inclusion (EDI)

TRIUMF recently implemented an EDI committee and policy, hired a new EDI officer and is establishing a plan to better embed EDI into its culture. There are gaps in addressing all dimensions of diversity in existing TRIUMF strategies.

The PRC noted that TRIUMF has made modest progress in addressing equity, diversity and inclusion in its culture

They suggested developing clearly established goals, metrics and a vision for EDI, with a **focus beyond gender to embrace the many dimensions of diversity**. A comprehensive EDI strategy to increase staff in all areas of diversity (particularly leadership) and the fostering of an inclusive culture with equitable opportunities are priorities for TRIUMF to undertake.

The PRC observed that TRIUMF should prioritize creating a workforce that reflects Canada's ethnic diversity and acknowledges socio-economic disadvantages and barriers for persons with disabilities. TRIUMF's student and PDF population is an opportunity for meaningful progress, as university partners have EDI initiatives that can amplify TRIUMF's efforts.

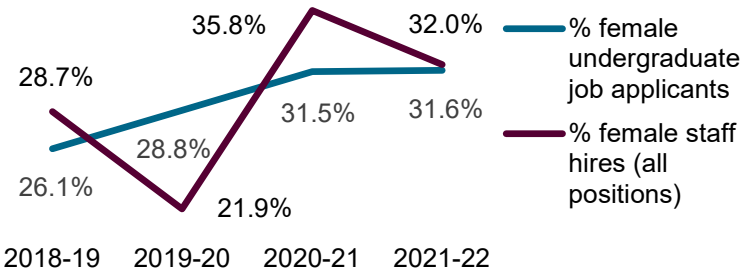
TRIUMF incorporates some diversity practices in hiring

The EDI Committee received approval from the BC Human Rights Tribunal to **preferentially hire women or Indigenous** persons for certain positions. They introduced a summer fellowship for Canadian undergraduates from under-represented groups, hiring 2 students after 2021. Over the evaluation period, TRIUMF also hired 2 Indigenous students.

TRIUMF hosted workshops on implicit bias, preferential hiring and hiring for diversity and includes gender diversity on hiring committees.

The percentage of female hires, including scientists and corporate staff, increased modestly since the last evaluation, yet **remains low** (see figure 13). The percentage of female undergraduate job applicants also remains low, which is partly related to a low rate of Canadian female post-secondary graduates in all STEM fields (36% in 2019). In late 2022, 22.3% of all staff members were female.

Figure 13. Modest percentage of TRIUMF female applicants and hires, 2018-19 to 2021-22



Introduction of new EDI and harassment policies

TRIUMF recently implemented an Equity, Diversity and Inclusion (EDI) policy and a Workplace Bullying and Harassment policy, hired a full-time EDI Officer (2022) and announced a student Ombudsperson (2021) to manage student harassment cases.

TRIUMF introduced harassment training for new hires, delivered a workshop on racism and developed a code of conduct for both laboratories and conferences. To help build a culture of safety and harassment prevention, bystander training was completed to provide tools for responding when unacceptable behaviours are observed.

Source(s): document review, TRIUMF internal interviews, TRIUMF data , PRC, Statistics Canada

Facilities and infrastructure

TRIUMF has world-leading, unique infrastructure that enables significant contributions and meets the research needs of the Canadian physics community.

TRIUMF's laboratory has sought-after technology that does not exist elsewhere

Stakeholders rated TRIUMF infrastructure as world-class, excellent and a hub for international science, noting that it produces beams at higher intensities with certain manipulations that cannot be replicated in other labs. The PRC echoed that TRIUMF has **world-leading and unique infrastructure** in subatomic physics, accelerator science, quantum materials, accelerator science and medical isotopes that "enable forefront and leading scientific programs."

TRIUMF is amongst a small number of facilities that can complete certain types of research. For example, it is the only Canadian lab to create positive muons with a muon spin rotation technique and the only North American facility to mass produce rare medical isotopes.

TRIUMF's beams have high targets, 2018-19 to 2021-22

Type of beam	Target of scheduled beam time delivered	2018-19	2019-20	2020-21	2021-22
520MeV cyclotron hours	90%	85%	95%	86%	93%
TR13 cyclotron hours	90%	94%	97%	97%	97%
Non-accelerated secondary RIB	80%	94%	85%	66%	78%
Accelerated secondary RIB	75%	25%	83%	67%	72%
Secondary muon beam	no target	90%	96%	84%	99%

TRIUMF facilities produce high-quality results

- TRIUMF hosts the **world's largest cyclotron**, which accelerates 1000 trillion particles per second
- ARIEL is the **most powerful** isotope separation on-line technique (ISOL) facility that produces the **highest rate of rare isotopes worldwide**; ARIEL II is expected to triple its isotope production
- TRIUMF is one of few facilities to produce **high quantities of Tc-99m** and radiotherapies with heavy atoms with high atomic numbers
- Isotope Separator and Accelerator (ISAC) is **the world leader in capability and output**; its high power on target delivers higher intensity beams for isotopes than other labs
- TRIUMF facilities for βNMR and muon spin rotation have ways to probe interface materials that give a different picture compared to other methods

From 2018-19 to 2019-20, TRIUMF met or exceeded its targets in all areas aside from accelerated secondary RIB. During pandemic years (see highlights), facilities could not operate at capacity due to limited staffing and were unable to meet all targets. However, they maintained a high number of delivered hours on the cyclotron due to strong COVID protocols that allowed essential staff to continue working onsite.

Source(s): TRIUMF data, TRIUMF internal interviewees, external interviews, data review, PRC

Facility and infrastructure maintenance

Some TRIUMF facilities are aging and require ongoing maintenance or refurbishing to maintain optimal performance.

Aging infrastructure and deterioration

Stakeholders and the PRC reflected that TRIUMF could complete greater research with **needed facility upgrades**. Notably, there is concern regarding infrastructure supporting the cyclotron, which requires refurbishing and upgrading that could lead to downtime and limitations on its future ability to produce world-class science.

The PRC noted that **"deferred maintenance of single points of failure adds significant risk to facility operations"**, leading to the need to replace technology, such as the electrical substation or cooling towers.

Refurbishment of the M15 beamline due to decreasing muon luminosity and several end-of-life components is considered by the PRC essential to continue MMS research.

Under the CA, TRIUMF received $25 million for infrastructure refurbishment and site process improvements. As of March 2022, $8.9 million was spent. Delayed logistics and supply chain issues have shifted schedules; however, plans underway will expend funds by the end of the current CA in March 2025.

Stakeholders also note that some **labs and workspace are insufficient** for conducting scientific or confidential meetings and for completing large projects simultaneously, which has negatively hindered the ability to work efficiently on site.

Remote work during the pandemic could positively affect office space going forward, as TRIUMF's new 2022 remote work strategy includes a mix of remote and on-site activities.

Source(s): TRIUMF internal interviewees, external interviews, survey, PRC

Stakeholders note that TRIUMF could better focus its limited resources on key projects and infrastructure, adjust involvement in projects or allocate a lower percentage of beam time to projects to enable downtime for maintenance.

The PRC noted that **maintenance of existing accelerator facilities has been deferred** for several years, and that system modernization, more advanced remote handling for activated systems and a unified control centre could reduce personnel radiation exposure and minimize the number of operational staff required. They recommended the use of a **register of risks** and opportunities for facilities and infrastructure as a tool to support management and review committees in prioritization.

In recognition of concerns around aging, an accelerator refurbishment and upgrade program and a TRIUMF Facilities Master Plan are in place to guide the laboratory in making strategic, risk-driven investments to refurbish existing infrastructure.

Plans are underway for TRIUMF to implement a site-wide maintenance and asset management system, an upgraded quality management system and an Enterprise Resource Planning system to ensure a safe and healthy workplace and reliable operation of the laboratory.

"TRIUMF has superb facilities that have been driven at the expense at the rest of the lab... The focus has been delivering on ARIEL and IAMI, ultra-cold neutrons and ISAC. They simply don't have enough resources."

—External interviewee

Facility and infrastructure performance

TRIUMF facilities are oversubscribed, yet maintain a high level of performance and delivery of beam time. The allocation of beam time is considered to be respectful and equitable.

Stakeholders express that TRIUMF allocates beam time in a fair and equitable manner through Experiments Evaluation Committees (EECs). There is a structured process that is merit-based, peer-reviewed and guided by codes of conduct. Priority is based on scientific excellence, global impact, funding allocation, publication potential and beam time requested. EECs are gender-balanced and have demonstrated a lack of bias in gender bias reviews. TRIUMF also allows commercial access for proprietary research with user-fees. However, this uses little beam time.

The PRC reflected that internal metrics to measure facility performance from a user perspective, such as time spent to successfully perform an experiment, could assist leadership with resource allocation and be used to track improvement. The agility of TRIUMF to pivot, modify or substitute experiments when complications arise in the delivery of rare-isotope beams is important in conducting a successful program.

TRIUMF facilities are oversubscribed or near capacity, 2018-19 to 2021-22

Facility and experiments		2018-19	2019-20	2020-21	2021-22
SAP-RIB	subscription ratio = # of shifts requested / # of shifts available ratio >1.0 = oversubscription	1.73	1.58	2.09	1.27
MMS-μSR		1.29	1.53	2.1	1.49
MMS-βNMR		1.94	2.36	1.46	1.57
Machine shop	% rate = billable hours / FTE	106%	104%	100%	100%
Design office		104%	105%	102%	105%
Nuclear physics experiments (ISAC)	% rate = hours delivered / 2595 target	93%	96%	57%	98%
MMS experiments	# of hours delivered (no target)*	6583	7042	3127	7649
Life science experiments	# of hours delivered (no target)	669	691	483	377

*The number of hours delivered to MMS experiments is higher than the overall number of cyclotron hours.

Source(s): TRIUMF data, external interviews, PRC

TRIUMF facilities have higher requests for beam time than availability

The machine shop and design office achieved or **exceeded targeted billable hours** (1688 hours/FTE) throughout the evaluation period. During the pandemic, this is credited in part to hybrid work options and COVID protocols that enabled on-site work for essential staff.

Hours delivered to nuclear physics, MMS and life sciences, which account for multiple beamlines, were consistent with the hours delivered in the last evaluation, with the exception of 2020 and 2021 pandemic years (see highlights) when low staffing and facility shut downs limited capacity.

The PRC noted that facility access for MMS experiments, instrumentation development and testing has been constrained by limited beam time, and it is anticipated that **ARIEL-II will increase beam time** for βNMR/βNQR from approximately 4 to 15 weeks/year.

Governance

TRIUMF’s transition to an incorporated non-profit charity and appointment of a skills-based Board of Governors have contributed to governance that provides greater flexibility, efficiency, oversight and accountability. Governance changes and management reorganization brought TI closer to the lab, ensuring alignment between research and commercialization.

Updated reporting requirements under the new governance model and the NRC’s CA better align with recognized financial standards. TRIUMF's IP strategy also has new requirements guided by a security policy to address risk, Canadian interests and potential foreign interference. TRIUMF has strengthened its project management processes, establishing a project management framework to identify project bottlenecks, prioritize resources and rank projects.

TRIUMF governance structure

TRIUMF's new governance structure is consistent with modern governance best practices and has led to greater flexibility, efficiency, oversight and accountability of TRIUMF. There remains opportunity to advance roles and responsibilities for new and existing committees.

Organizational restructuring well-received

Following the appointment of a new Executive Director and CEO in May 2021, TRIUMF leadership reorganized, eliminating deputy director positions and creating new divisions.

Stakeholders and the PRC commended TRIUMF's organizational restructuring, as it **flattens the structure**, raises the visibility of projects and project management and enables operational excellence.

These changes have also been well received by the majority of staff who state that the new structure has enabled **more efficient communication from leadership** to the department level and has increased the hands-on presence and involvement in the lab and operations by TRIUMF leadership.

Despite positive reception of the changes, some staff have expressed challenges with the high rate of change in structure and communication, including frustration among some staff and a couple notable departures.

Increased role clarity

The skills-based board provides **greater efficiency, clarity of roles and responsibilities** and has led to decisions that are more appropriate for TRIUMF as an organization, rather than decisions that benefit the consortium of member universities.

New members for the Board of Governors are now recommended by a nominations committee, with appointment carried out by the Members' Council. Despite increased role clarity, the role of the Science Council and its relationship with the new Board is still evolving.

Stakeholders and the PRC noted that the Board restructuring has **added domain expertise** relevant to operational oversight. Member universities are more focused on the research agenda and priorities. Stakeholders and the PRC noted that the relationships between the Board, Members' Council, Science Council and the NRC appear to be developing well, though there is ongoing work to clarify the relationships.

Operational effectiveness opportunities

TRIUMF's governance committees require more time to become familiar with their new roles and responsibilities. Stakeholders and the PRC found that the **new governance model is heavy for a lab of TRIUMF's scale** and encourage the Board, Members' Council, Science Council and the NRC to work together to identify ways to align structures and eliminate duplicative activities (e.g., combining committees such as finance and audit).

Recognizing the role of ACOT as a long-standing independent committee with well-outlined goals and responsibility to advise the NRC and provide recommendations to TRIUMF, the PRC recommended an additional independent body to advise TRIUMF.

The PRC observed the Science Council would benefit from being an independent S&T advisory body that advises the BoG and member universities on research quality, appropriateness and priorities, and also advises the Executive Director and CEO on the state of health of TRIUMF.

Source(s): document review, PRC, TRIUMF and NRC internal interviewees, external interviews

TRIUMF innovations governance

Governance changes and leadership reorganization brought TI closer to TRIUMF lab operations, encouraging tighter alignment between research activities and commercial actions and providing new opportunities to bring knowledge and technologies to market.

TI is a controlled entity of TRIUMF

The governance of TI and its relationship with TRIUMF as a controlled entity are clearly articulated through a management services agreement and business development plan (BDP), which outlines that TRIUMF is responsible for the compliance of TI with the terms and conditions outlined in the NRC CA.

In 2017, TI expanded its mandate from start-up company creation to encompass all commercialization activities for TRIUMF. TI serves as the interface bridging TRIUMF with the business world.

TRIUMF remains the primary signatory to commercialization agreements and commercial projects must be balanced against the research demands of TRIUMF. Commercial contracts entered into by TI are shared with TRIUMF to ensure greater accountability and due diligence.

In response to a recommendation in the previous evaluation, the new CA required TRIUMF to develop a BDP that describes commercialization efforts, including a strategy for the management of TRIUMF's IP. See the following slide for more information on the BDP.

Benefits of increased integration between TRIUMF and TI

To align the 2 organizations, TRIUMF staff actively participate in TI activities and attend routine meetings. The TRIUMF Executive Director and CEO sat on the TI Board of Directors (until April 2023), and the TI President and CEO is a member of the TRIUMF leadership team. Additionally, 3 external members of the TRIUMF BoG are also members of the TI Board of Directors. These connections enable TRIUMF to understand TI's target requirements, and involvement is viewed as necessary to ensure they work together toward common goals.

Internal interviewees agree that these connections help ensure the commercialization arm is involved in the operations of the research facility and that TI works to arrive at the best commercial arrangement on behalf of TRIUMF. For example, TI was essential to engaging TRIUMF in the MVM collaboration during COVID and to bringing the MVM to market.

TI recently hired staff with commercialization expertise and TI staff join TRIUMF bi-weekly project management meetings to determine where products can be commercialized and where there may be conflicts. TI is also committed to launch a training program to further enhance TRIUMF scientists' business skills and strengthen connections with industry.

Source(s): document review, TRIUMF and NRC internal interviews

Business Development Plan (BDP)

The new BDP supports TRIUMF's efforts in maximizing the economic benefits of the federal government investment as per the Contribution Agreement.

New IP strategy requirements benefit Canada

TRIUMF's IP strategy has new requirements guided by a security policy that address risk, Canadian interests and potential foreign interference.

As per new Government of Canada security directives, the CA details due diligence requirements to assess potential risks from loss of intellectual property or patent opportunities, legal or administrative reprisals, loss of potential future partnerships, or tarnished reputation.

This due diligence requirement is a priority. The NRC involves commercialization and security experts to review TRIUMF's commercial agreements with foreign entities to safeguard the outcome of federal investment and maximize the benefit for Canadians.

License agreement review process

TI complies with TRIUMF and federal government security and IP policies. However, TI expressed concern that the length of time needed for the license agreement review and approval process for commercial agreements with foreign entities could lead to delays or renegotiation.

As a result, TRIUMF and the NRC worked collaboratively in 2022 on a **license agreement review process** for commercial agreements to ensure processes and timelines were streamlined. It is anticipated that this new process will enable more clarity in due diligence matters.

Commercialization diversification challenging

There have been recommendations by the NRC, ACOT and the previous evaluation for TI to diversify its commercialization activities.

TRIUMF and TI express concerns about the request for diversification, as the commercialization of fundamental physics research takes years, technology transfer is difficult due to low Technology Readiness Level (TRL) and there are quicker wins in life sciences where TI is active with medical isotopes.

Exploring new opportunities

TI recently hired staff to explore new opportunities, held workshops on commercialization with each division and attended project management meetings to explore ideas.

TI is **exploring research in water cleanliness projects, energy technology and mining technology using muons**.

The PRC noted that **TRIUMF has had significant success in commercialization,** particularly in nuclear medicine and life sciences where technology transfer and licensing to market have been successful. The PRC remarked that it's likely that current research in life sciences will lead to further opportunities if the theranostics market continues to grow.

The cost of getting technology in life sciences to market readiness is significant and TI could develop strategies or collaborations with other entities and industries to support this work.

The PRC also recommended that TRIUMF engage researchers in IP education to ensure a shared vision for future commercialization opportunities.

Source(s): document review, TRIUMF and NRC internal interviews

Tracking and reporting

Under the new governance model, the volume of internal meetings and reports has increased. In addition, TRIUMF's financial reporting requirements have increased in the most recent CA. There may be opportunity to align and harmonize meetings and reporting.

Increased meetings and reports

The volume of new internal committee, Board of Governors, Members' Council and Science Council meetings and reports have added to the workload of TRIUMF leadership.

TRIUMF's financial reporting requirements to the NRC through the 2020-25 CA have increased in frequency, volume and scope in response to the Government of Canada's financial management best practices and the size of contribution funding provided to TRIUMF.

In addition, there have been challenges managing short timeframes between activities and reports (both NRC-related and internal reports). As a result of changes to reporting requirements, TRIUMF hired a full-time employee to manage increased reporting. Overall, **stakeholders view routine reporting to the NRC as beneficial as it provides structure**.

Internal reporting does not align with CA reporting

TRIUMF's internal schedule and fiscal year fiduciary responsibilities do not align with the timing outlined in the CA for financial reporting. For example, TRIUMF's annual budget needs approval from TRIUMF leadership, finance committee and Board; however, the NRC budget approval process happens prior to these internal approvals.

TRIUMF stakeholders have indicated a desire to examine opportunities to align and harmonize reporting.

Frequency

Performance and financial reporting shifted from trimester to quarterly reporting in response to advice from the NRC Finance Branch to align with the quarterly release of funds. Quarterly reporting is a recognized standard within the federal government. The current CA requires reporting on previous quarter spending and forecasted next quarter spending to enable the NRC to track TRIUMF's spending and release appropriate quarterly advances.

Volume

New government-wide reporting requirements, aligned with ISED priorities, aim to safeguard sensitive IP, technology and R&D activities to ensure national security for the benefit of Canadians.

Scope

Reports changed to provide greater context on all TRIUMF operations, activities and construction funded through the NRC (previous reports were focused on scientific outcomes).

"The current process for collecting and compiling information is manual and appears time-intensive for all involved. A simple, web-based tool to collect and collate information required with clear understanding from staff as to what is needed could streamline this process significantly."

—Peer Review Committee

Source(s): document review, PRC, TRIUMF and NRC internal interviewees, external interviews

Project management

TRIUMF improved its Project Management Office's (PMO) processes over the past 5 years. They developed a project management framework to monitor project commitments and introduce new standards and tools into work processes, and updated the membership and length of time the project management oversight group (PMOG) spends reviewing projects.

Improvements have been made to project management

TRIUMF has implemented a 2-day quarterly review process where projects in each portfolio are given 5 minutes to present their latest status to identify bottlenecks, prioritize resources and rank projects (84 projects in 2022) in a transparent manner.

The PMO uses the process of **value engineering to see where savings can be made through scoping projects**, which has been successful in guiding limited human and capital resources to deliver projects as closely as possible to the anticipated timeframe.

TRIUMF implemented a new administration system (Workday), which has an element for budgeting. Faced with growing inflation and fixed budgets, the improved data provided through this system enables leadership to make informed choices on key operational decisions.

Focus needed for resource planning and prioritization

Leadership tends to work by adding more resources to projects when timelines are impacted and stakeholders suggest that they **need to focus on improving the use of existing resources**, rather than pulling resources from other work to keep construction moving.

TRIUMF staff reported "change burnout" from continuous task re-prioritization to match available resources and continue operations while building large projects.

Internal and external stakeholders agree there are opportunities for more proactive resource planning in the future. An example would be accounting for inflation in funding applications whenever possible.

"While delivery of projects has improved under the new approach, a very large number of projects are being actively managed and tracked for a lab the size of TRIUMF."

—Peer Review Committee

Finding a balance

External stakeholders commented that TRIUMF would benefit from a system to better forecast, budget and track human resource aspects of projects to ensure all projects are completed on time.

Stakeholders and the PRC recommended that TRIUMF find the right balance between advancing construction of ARIEL II and providing radioactive beams, as users have raised concerns on reduced ISAC beam time.

Project management oversight group (PMOG)

PMOG is responsible for approving projects by determining if they have merit and align with TRIUMF's strategy.

PMOG decides on mission-critical upgrades, assigns project weight and resolves prioritization or other major issues for projects and infrastructure upgrades.

This oversight group evolved to include leadership from all TRIUMF Divisions and TI.

Source(s): document review, PRC, TRIUMF and NRC internal interviewees, external interviews

Communications

TRIUMF developed communications plans to ensure that internal and external partners were kept abreast of changes in governance and leadership with the majority of staff viewing recent internal communication efforts positively.

Communication improvements

TRIUMF implemented **improvements to its communication practices**, including a communications toolkit with strategies (e.g., governance transition, Workday implementation, town halls) and an internal communications evaluation to asses awareness among internal and external audiences of key issues, such as incorporation, governance changes and evolving COVID-19 directives.

Overall, the majority of TRIUMF staff view recent internal communication efforts positively.

However, there is **some staff dissatisfaction with communication volume**. Although it is felt that the flow of communication to all staff has increased and effectively portrays what is going on in the organization, nearly half of staff feel that internal communications contain too much information, while nearly half believe it contains too little information.

Key internal communication changes applauded by TRIUMF staff:

- monthly virtual town halls communicate changes to leadership, reporting or policies
- TRIUMF distributes monthly newsletters and regular email updates from the director
- major changes are communicated through site-wide announcements (site-wide announcements have the highest ratings for satisfaction, usefulness and effectiveness in the Internal Communications Evaluation report)
- site-wide announcements include additional recipients (2020 onward), including GAPS
- divisions hold all-hands monthly meetings, where changes are communicated to all staff
- weekly senior management meetings where division, department and group leaders showcase presentations that can be distributed to all levels of staff

In a 2020 internal survey, TRIUMF staff suggested **opportunities to improve communications**, including:

- increase 2-way communication processes
- improve communication methods about content from senior management meetings, such as sharing meeting materials with all staff
- streamline the amount of information and frequency of delivery to ensure the most relevant information is shared concisely in a timely manner across the organization, with non-time-sensitive detail available through other communication methods. For example:
  - personnel changes and changes to policy are important and should be communicated to all staff in a timely manner
  - organizational achievements should be communicated on a regular basis

Source(s): TRIUMF data, document review, TRIUMF internal interviewees, external interviews

Impact of COVID-19

During the COVID-19 pandemic, research programs slowed, students were unable to complete research, costs increased, supply chain issues contributed to construction delays, commercial revenues were lost and downtime on beams and accelerators was high due to reduced operators.

TRIUMF pivoted operations, programs and procedures to continue some research efforts and engage in new research, such as medical ventilators. TRIUMF staff learned to work remotely, followed strict COVID-19 policies for on-site work and expanded remote engagement opportunities.

COVID-19 impacts

TRIUMF policies limited the spread of COVID-19

TRIUMF developed strict and widely accepted policies to limit COVID-19 transmission in the workplace, including mandatory vaccination (less than 2% of staff were terminated for non-compliance with vaccination). Nevertheless, some COVID-19 illness occurred, causing significant and lengthy staff absences, negatively impacting operations.

Some employees struggled with mental health due to isolation and sudden work changes. Leadership was respected for the level of support provided to staff.

Mechanical Ventilator Milano (MVM) collaboration success

TRIUMF pivoted operations to collaborate in the profitable MVM collaboration that created affordable medical ventilators for the Canadian government and global industry.

As a result of the pandemic, a new work strategy incorporates remote and on-site work.

Research and construction activities decreased

Some **research was slowed or halted**, as reduced operators led to downtime on beams and accelerators. This led to diminished scientific productivity, project delays, increased costs and lower performance.

of survey respondents indicate research delays due to an inability to physically access TRIUMF facilities and very limited remote beam time.

By 2020, extra consideration for remote beam time was given to students and PDF experiments. EEC beam time competitions were not held for 1 year to make up for lost time with existing experiments.

Upgrade plans were halted with only critical maintenance completed, leading to **infrastructure upgrades lagging** by a few million dollars. New construction was delayed (IAMI; ARIEL II), which has long-term implications for productivity and cost.

TRIUMF continues to feel further impact post-pandemic due to **global supply chain issues and significant price increases due to inflation**.

Virtual and remote work enabled continued operations

TRIUMF continued to produce medical isotopes (generating revenues). However, experiments were shorter and **site access was limited to 30 to 40%** of staffing.

Staff learned to work remotely and on-site staff communicated with international researchers to gain apparatus directions. International researchers shifted to virtual meetings, learning environments and access to TRIUMF data. By autumn 2020, productivity for remote experimental runs was 70 to 90% of normal operations.

International visitors were limited and TRIUMF established a quarantine area at TRIUMF House to accommodate small numbers of international researchers.

Some streams of commercial revenue were lost (e.g., TRIUMF House* and irradiation services) due to limited visitors.

*TRIUMF House provides close, affordable accommodations for national and international visitors.

TRIUMF maintained its collaborations through virtual connections, and **"published an impressive amount"** due to its ability to work remotely with international and national users.

—External interviewees

Source(s): document review, TRIUMF internal interviewees, external interviews, survey

Recommendations and Management Response and Action Plan (MRAP)

Recommendations

Governance

The new governance model can be strengthened by advancing the roles and responsibilities for governance members (BoG), BoG committees, Science Council, Members' Council).

The PRC noted the relationship between BoG and Science Council needs greater definition.

The PRC noted that TRIUMF's governance model is heavy and there are opportunities to eliminate or combine activities or committees.

Recommendation 1

The NRC should encourage TRIUMF to advance roles and responsibilities associated with the TRIUMF BoG and its committees, the Science Council and TRIUMF Innovations Board of Directors to enhance efficiency and effectiveness.

Operational excellence

Current TRIUMF processes for collecting and compiling information are manual and time intensive. New tools for data collection and reporting could improve efficiency.

Streamlined business processes help keep the organization on task, prevent errors and increase staff efficiency.

Recommendation 2

The NRC should work with TRIUMF to advance TRIUMF's business processes and reporting tools as part of its commitment to operational excellence. Adjustments should align with resources and program requirements.

Recommendations

Human resource planning

The PRC described some areas as short-staffed, which limits TRIUMF in achieving full potential of new research facilities while maintaining support for existing users.

Maintaining specialized expertise, particularly where candidate pools are limited, is critical to preserving institutional knowledge and a reputation of scientific excellence.

Mentoring staff with high-level expertise to take on senior roles sustains continuous research excellence and collaborative work.

The PRC recommended moving EDI strategies beyond gender to reflect Canada's diversity and leveraging member university EDI policies and programs.

Recommendation 3

The NRC should invite TRIUMF to formalize an overarching HR Plan to deliver future key areas of strategic focus and embed practices into TRIUMF's culture. The plan should include:

a. a formal retention plan

b. a formal succession plan

c. a broadened EDI strategy with metrics that incorporate the many dimensions of diversity

Project management

The PRC recommended implementing a risk registry as a tool for management and review committees to prioritize efforts and allocate resources for new construction, required maintenance and project delivery.

The PRC noted that management should streamline projects to weigh oversight against resources and priorities.

Recommendation 4

The NRC should encourage TRIUMF to develop risk-based tools and processes for project prioritization and resource management.

Management Response and Action Plan

Recommendation 1			
Governance The NRC should encourage TRIUMF to advance roles and responsibilities associated with the TRIUMF BoG and its committees, the Science Council and TRIUMF Innovations Board of Directors to enhance efficiency and effectiveness. **Risk-level:** Moderate			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Agreed **Action:** The NRC, through ACOT, will work with TRIUMF to continue discussions in order to mature the governance model at upcoming BoG and Science Council meetings.	• A formal report on governance will be discussed at the Spring 2025 ACOT meeting	Vice-President's Office, Emerging Technologies	Spring 2025 ACOT meeting

Management Response and Action Plan

Recommendation 2			
Operational excellence The NRC should work with TRIUMF to advance TRIUMF's business processes and reporting tools as part of its commitment to operational excellence. Adjustments should align with resources and program requirements. **Risk-level:** Moderate			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Agreed **Action:** The NRC, through ACOT, will work with TRIUMF so that they continue maturing core administrative services, business processes and reporting tools to align with resourcing and program accountability requirements. This will support TRIUMF's overall commitment to operational excellence.	• TRIUMF shares plan of new business processes and reporting tools at an upcoming ACOT meeting • TRIUMF shares results of a pilot of new tools and processes at a future ACOT meeting	Vice-President's Office, Emerging Technologies	Fall 2024 ACOT meeting Fall 2025 ACOT meeting

Management Response and Action Plan

Recommendation 3
Human resources planning The NRC should invite TRIUMF to formalize an over-arching HR plan to deliver future key areas of strategic focus and embed practices into TRIUMF's culture. The plan should include: a. a formal retention plan b. a formal succession plan c. a broadened equity, diversity and inclusion strategy with metrics that incorporate the many dimensions of diversity **Risk-level:** Moderate

Management Response	Measure of Achievements	Proposed Person(s) Responsible	Expected Date of Completion
Response: Agreed **Action:** The NRC will work with TRIUMF to support them in the development of the 2026-2030 plan to address resourcing and talent management challenges.	• 5-Year plan that includes HR resourcing and EDI considerations tabled at ACOT and ACT	Vice-President's Office, Emerging Technologies	Fall 2023

Management Response and Action Plan

Recommendation 4			
Project and resource management The NRC should encourage TRIUMF to develop risk-based tools and processes for project prioritization and resource management. **Risk-level:** Moderate			
Management Response	**Measure of Achievements**	**Proposed Person(s) Responsible**	**Expected Date of Completion**
Response: Agreed **Action:** The NRC, through ACOT, will work with TRIUMF to develop project prioritization tools and processes.	• TRIUMF shares plan of new prioritization tools and processes • TRIUMF shares results of a pilot of new tools and processes	Vice-President's Office, Emerging Technologies	Spring 2024 ACOT meeting Fall 2025 ACOT meeting

Appendices

Appendix A – Methodology

Data review

TRIUMF's administrative and performance data for 2018-19 to 2021-22 were reviewed to provide information on the laboratory's resources (staff and students), infrastructure utilization rates, collaborative research and funding excellence. This included key performance indicators, financial data, human resource data and project data.

Key informant interviews

Interviews were conducted to collect information such as personal experiences, opinions and expert knowledge related to the laboratory's scientific excellence, social and economic impacts, engagement, capabilities and governance. Information provided through the interviews provided contextual information and was used in conjunction with the other lines of evidence.

A total of 36 stakeholders were interviewed for this evaluation:

- 5 NRC internal interviewees (NRC staff and ACOT members)
- 22 TRIUMF internal interviewees (directorate and leadership team and current and incoming university members)
- 13 external interviewees (representatives from Canadian and international laboratories, associations and funding institutions)

Document review

Internal and external documents were reviewed to provide context and to complement other lines of evidence in assessing relevance and performance. Documents included strategic and implementation plans, ACOT and ACT reports, previous evaluations, websites and terms of references for various committees.

Peer review committee

An international Peer Review Committee (PRC) was convened at TRIUMF November 29th to December 1st 2022 to assess TRIUMF's performance during the evaluation period. The PRC was made up of 8 individuals in total, 7 with expertise TRIUMF's main research areas and 1 with expertise in commercialization.

The committee was provided with the preliminary findings of the evaluation ahead of the site visit as well as other supporting documentation. The committee was asked to provide a preliminary assessment based on their review of these documents. The peer review site visit took place over 3 days and included a series of presentations by TRIUMF staff as well as question and answer periods, a tour of the TRIUMF facility, and a student poster session. Following the site visit the PRC, led by the chair, finalized a report, including recommendations which was reviewed for factual accuracy by TRIUMF and the NRC VPO. The findings of the PRC were integrated into this evaluation report.

Appendix A – Methodology

Bibliometric study

A bibliometric analysis of TRIUMF was conducted by NRC's Library and Information Management Services for the 2017-2021 period to support the TRIUMF evaluation. In order to evaluate TRIUMF's research performance, a bibliometric study was commissioned for the 5 domains of expertise for TRIUMF. Publication and citation, subject areas and collaboration analysis were performed for each of the 5 domains of expertise.

User survey

An online survey was conducted to explore the effectiveness, relevance and efficiency of TRIUMF through its users' perspectives. The questionnaire mimicked the survey instrument used for the last evaluation to allow the potential of exploring trends over a longer period of time.

Prior to the survey launch, TRIUMF sent a note to their users to validate the legitimacy of the survey and encourage participation. The NRC evaluation team followed with an invitation email containing the link to the survey.

The survey was sent to all of TRIUMF's non-commercial users (n=548) and with 155 surveys completed this represents a response rate of 28%.

Survey respondents were predominantly from Canadian (73%) or foreign (22%) entities including universities, government and industry. The remaining 5% did not specify.

Appendix A – Methodology

Limitations and mitigation strategies

Although the evaluation encountered some challenges, methodological limitations were mitigated, where possible, through the use of multiple lines of evidence and the triangulation of data. This approach was taken to establish the reliability and validity of the findings and to ensure that conclusions and recommendations were based on objective and documented evidence. Details on limitations and their associated mitigation strategies are described below.

Lack of labour market data for TRIUMF fields of study limited GBA Plus analysis

TRIUMF's research requires their students and staff to sometimes have very specific skills and experience in narrow fields of study. These fields of study are not represented in labour market data, limiting comparison opportunities to validate if the TRIUMF workforce diversity was representative of the Canadian labour market. The lack of a large talent pool for these fields of study also limits TRIUMF's diversity goals

Mitigation

To mitigate the lack of labour market data in TRIUMF fields of study, similar study groups, such as STEM, were used as a comparison.

Some TRIUMF user surveys sent to spam folder

Some users reported finding the user survey in their spam folder. It is unknown how many users did not complete the survey due to this issue.

Mitigation

The response rate for the survey was 28%, which is the same rate as the last evaluation. Since this event affected random users and the response rate was high, it did not affect the survey results significantly.

TRIUMF's demographic data focussed primarily on gender

TRIUMF's EDI focus was primarily on gender and a lack of data on the other dimensions of diversity limited the GBA Plus data analysis.

Mitigation

To mitigate the lack of diversity data from TRIUMF, qualitative data acquired from interviews with staff gave an appropriate perspective on TRIUMF's EDI priorities and focus.

Appendix B – Peer Review Committee Members

Dr. Kimberly S. Budil (Committee Chair)
Director, Lawrence Livermore National Laboratory

Dr. Souzan Armstrong
Executive Director, WORLDiscoveries

Dr. Simon R. Cherry
Distinguished Professor of Biomedical Engineering/Radiology, University of California Davis

Dr. Alexandra Gade
Professor of Physics, National Superconducting Cyclotron Laboratory, Michigan State University

Dr. Michel Gingras
Professor, University of Waterloo and Canada Research Chair in Condensed Matter Physics & Statistical Mechanics

Dr. Brad Sherrill
Scientific Director, Facility for Rare Isotope Beams, Michigan State University

Dr. Elizabeth H. Simmons
Executive Vice Chancellor, University of California San Diego

Dr. Frank Zimmermann
Future Circular Collider (FCC) Study Deputy Leader, CERN

Appendix C – TRIUMF staffing

TRIUMF staff by fiscal year

	2018-19	2019-20	2020-21	2021-22
Administrative Staff	48	56	61	56
Board Appointed Research Scientists	52	52	51	50
Staff Scientists	53	50	48	52
Engineers	93	97	96	87
Information Systems and Technology	23	18	21	23
Technicians and Technologists	161	165	162	154
Facility and Site Services	34	33	32	26
Postdoctoral Fellows & Research Associates	38	49	46	46
Graduate Students	29	36	34	48
Faculty Joint Appointments (50% FTE)	10	10	9	7
Total Staff	**541**	**566**	**560**	**549**
NRC Funded Staff	**425**	**433**	**432**	**411**

Source(s): TRIUMF data

Appendix D – Bibliometric data for comparator organizations

TRIUMF-identified comparator organizations in nuclear physics

FWCI Rank	Organization	Country	# publications	FWCI	# TRIUMF co-publications	Co-publication FWCI
1	DOE's Argonne National Laboratory	USA	849	2.60	140	4.58
2	University of Washington	USA	713	2.38	132	4.49
3	**TRIUMF**	**Canada**	**564**	**2.17**	**-**	**-**
4	University of Jyvaskyla	Finland	707	2.10	27	1.49
5	European Organization for Nuclear Research (CERN)	Switzerland	1,226	1.86	173	3.65
6	Michigan State University (MSU)	USA	1,155	1.79	190	3.24
7	Australian National University	Australia	353	1.50	8	N/A
8	RIKEN	Japan	1,091	1.46	44	1.64
9	GSI Helmholtzzentrum für Schwerionenforschung GmbH	Germany	1,515	1.41	74	2.29
10	Chinese Academy of Science's (CAS) Institute of Modern Physics	China	1,267	1.05	16	2.28
11	Grand accélérateur national d'ions lourds (GANIL)	France	419	0.82	22	1.37

TRIUMF-identified comparator organizations in particle physics

FWCI Rank	Organization	Country	# publications	FWCI	# TRIUMF co-publications	Co-publication FWCI
1	DOE's Stanford National Accelerator Center (SLAC)	USA	1,177	3.27	453	3.93
2	**TRIUMF**	**Canada**	**748**	**3.09**	**-**	**-**
3	Paul Scherrer Institute (PSI)	Switzerland	834	3.01	11	7.18
4	NIKHEF	Netherlands	1,440	2.93	410	3.93
5	DOE's Brookhaven National Laboratory	USA	1,907	2.65	449	3.87
6	Deutsches Elektronen-Synchrotron (DESY)	Germany	2,707	2.58	419	3.95
7	DOE's Fermi National Accelerator Laboratory	USA	1,655	2.54	34	4.23
8	High Energy Accelerator Research Organization (KEK)	Japan	1,527	2.40	468	3.78
9	CAS's Institute of High Energy Physics	China	2,420	2.30	428	3.92
10	CERN	Switzerland	4,407	2.17	467	3.84
11	Joint Institute for Nuclear Research	Russian Fed.	3,404	1.80	452	3.94

Source(s): bibliometric review

Appendix D – Bibliometric data for comparator organizations

TRIUMF-identified comparator organizations in accelerator physics

FWCI Rank	Organization	Country	# publications	FWCI	# TRIUMF co-publications	Co-publication FWCI
1	MSU	USA	1,063	2.89	474	3.80
2	**TRIUMF**	**Canada**	**796**	**2.76**	**-**	**-**
3	PSI	Switzerland	1,093	2.50	8	N/A
4	DOE's Brookhaven National Laboratory	USA	1,715	2.24	446	3.97
5	Joint Institute for Nuclear Research	Russian Fed.	2,952	1.96	460	4.00
6	CERN	Switzerland	5,234	1.75	492	3.82
7	GSI Helmholtzzentrum für Schwerionenforschung GmbH	Germany	1,343	1.44	24	4.91
8	RIKEN	Japan	863	1.39	16	2.18
9	CAS's Institute of Modern Physics	China	1,078	1.15	6	N/A
10	DOE's Thomas Jefferson National Accelerator Facility	USA	367	1.76	11	6.64
11	GANIL	France	172	0.68	8	N/A

TRIUMF-identified comparator organizations in nuclear medicine

FWCI Rank	Organization	Country	# publications	FWCI	# TRIUMF co-publications	Co-publication FWCI
1	Hammersmith Hospital	UK	37	3.37	0	N/A
2	Memorial Sloan-Kettering Cancer Center	USA	750	2.27	0	N/A
3	University of Wisconsin-Madison	USA	381	2.11	4	N/A
4	University of Pennsylvania	USA	794	2.06	2	N/A
5	Université de Sherbrooke	Canada	111	1.89	0	N/A
6	Turku PET Centre	Finland	110	1.71	0	N/A
7	National Taiwan University Hospital	Taiwan	110	1.71	0	N/A
8	University of Ottawa Heart Institute	Canada	123	1.60	0	N/A
9	**TRIUMF**	**Canada**	**46**	**1.42**	**-**	**-**
10	University of Alberta	Canada	188	1.28	0	N/A
11	DOE's Los Alamos National Laboratory	USA	36	0.95	0	N/A

Source(s): bibliometric review

Appendix D – Bibliometric data for comparator organizations

TRIUMF-identified comparator organizations in molecular and materials science

FWCI Rank	Organization	Country	# publications	FWCI	# TRIUMF co-publications	Co-publication FWCI
1	University of Oxford	UK	110	2.67	2	N/A
2	DOE's Oak Ridge National Laboratory	USA	189	2.18	17	0.81
3	Paul Scherrer Institute (PSI)	Switzerland	364	1.57	16	0.67
4	Max Planck Institute for Chemical Physics of Solids	Germany	163	1.22	0	N/A
5	National Institute of Standards and Technology's (NIST) Center for Neutron Research	USA	57	1.13	0	N/A
6	McMaster University	Canada	54	1.01	15	0.80
7	Rutherford Appleton Laboratory (including ISIS Neutron and Muon Source)	UK	447	0.99	13	0.62
8	DOE's National High Magnetic Field Laboratory	USA	95	0.95	2	N/A
9	Japan Proton Accelerator Research Complex (J-PARC)	Japan	56	0.95	3	N/A
10	Institut Laue-Langevin	France	102	0.82	2	N/A
11	**TRIUMF**	**Canada**	**98**	**0.72**	**-**	**-**

Source(s): bibliometric review