DRAFT – TRIUMF 20-Year Vision

April 2022

Executive summary

As Canada's particle accelerator centre, TRIUMF is a hub for discovery and innovation. From the fundamental to the applied, TRIUMF solves problems and delivers impact—from the hunt for the smallest particles in our universe to research that advances the next generation of batteries or develops isotopes to diagnose and treat disease. We tackle problems too large and complex for any single researcher or institution. Essentially, we enable Canada to compete at scale in the global science and innovation enterprise, driving its contributions to extending the frontiers of knowledge.

As we look forward to the next 20 years, science will undoubtedly continue to be a driver of innovation and technological developments that benefit people everywhere. We are excited about the opportunities for TRIUMF to contribute further scientific breakthroughs and solutions to complex societal challenges. And we are confident that our talented people, multidisciplinary research programs, global network and unique, large-scale accelerator infrastructure will enable us to keep thriving and contributing in the most transformative era in our history.

Our 20-year vision is both bold and realizable. It considers how to leverage past investments by government and build on our strengths to deliver a new level of top-tier science, training and innovation to Canada. Here's how we envision TRIUMF in 20 years:

1. A global leader in discovery science, delivering breakthroughs that unlock the deepest mysteries of the universe:

Strengthening Canada's leadership in groundbreaking frontier particle & nuclear physics

2. A world-class accelerator centre driving use-inspired research—from the life sciences to quantum and green technologies:

Leveraging our unique infrastructure to pursue research in Canada that will change the world

3. A leader in a flourishing national Big Science ecosystem:

Catalyzing the success and growth of Canada's network of major research facilities

4. A national innovation hub translating discovery science into health and sustainability solutions:

Responding nimbly to complex societal challenges for the benefit of Canadians

5. An inclusive multidisciplinary talent incubator, attracting and developing the best people from around the world:

Producing Canada's future science leaders and innovators

Messages from Executive Director & Chair of the Board

[to be written once rest of content finalized]

- Why a 20-year vision and how it relates to our 5-year strategic plans
- Value of a long-term perspective

- Key opportunities and challenges on the horizon
- Excitement about the future of science and TRIUMF's potential
- Path forward will be guided by TRIUMF's core values and strengths

TRIUMF today: A unique resource for Canada and the world

As Canada's particle accelerator centre, TRIUMF is a hub for discovery and innovation. Inspired by more than a half-century of ingenuity in answering nature's most foundational questions, we advance world-leading discovery, applied and multidisciplinary research for science, medicine and business. From the fundamental to the applied, TRIUMF solves problems and delivers impact—from the hunt for the smallest particles in our universe to research that advances the next generation of batteries or develops isotopes to diagnose and treat disease.

Our track record of excellence is a direct product of billions of dollars of investment over 50 years, both provincial and federal, in the laboratory's core infrastructure in Vancouver, British Columbia. Our state-of-the-art accelerator complex—featuring the world's largest cyclotron and the most powerful superconducting electron linear accelerator—is the foundation upon which our competitive advantage rests.

As the only laboratory operating at this scope and scale in Canada, TRIUMF tackles problems too large and complex for any single researcher or institution. Essentially, we enable Canada to compete at scale in the global science and innovation enterprise, driving its contributions to extending the frontiers of knowledge, particularly in nuclear and particle physics and the life and material sciences.

By collaborating with our academic and industry partners, both in Canada and globally, we drive compelling research and create ideas and innovations that benefit humanity. We offer unique-hands-on research and work opportunities often transcending individual disciplines. We also broaden and deepen the national talent pool by attracting top talent from around the world, developing the skills that Canadians need to succeed in the knowledge economy, and strengthening the science, technology, engineering and mathematics (STEM) pipeline.

Our vision for TRIUMF in 20 years: A global science and innovation leader

As we look forward to the next 20 years, we are excited about the opportunities for TRIUMF to drive further scientific breakthroughs and solutions to complex challenges facing Canada and the world, such as climate change and health. Science will undoubtedly continue to be a driver of innovation and technological developments that benefit people everywhere. And addressing grand challenges will require even broader collaborative research approaches across disciplinary boundaries.

We know that our talented people, multidisciplinary research programs, global network and unique, large-scale accelerator infrastructure will enable us to keep thriving and contributing in the most transformative era in our history. With the Advanced Rare Isotope Laboratory (ARIEL) and the Institute for Advanced Medical Isotopes (IAMI) coming fully online over the next decade, TRIUMF will be home to some of the world's most powerful isotope research facilities, reinforcing our status as a true jewel in Canada's STEM crown.

Our 20-year vision is both bold and realizable. It considers how to leverage past investments by government and build on our strengths to deliver a new level of top-tier science, training and innovation to Canada.

Here's how we envision TRIUMF in 20 years:

1. A global leader in discovery science, delivering breakthroughs that unlock the deepest mysteries of the universe.

Strengthening Canada's leadership in groundbreaking frontier particle & nuclear physics

What are the fundamental building blocks of matter? What are the forces driving the evolution of the universe? These are some of the biggest and exciting scientific questions facing the world. The foundation of TRIUMF's work will continue to enable discoveries at the frontiers of particle and nuclear physics to help answer these questions and unlock the mysteries of the universe. This unique expertise will allow Canadians to continue in leadership roles in large-scale international efforts, based both in Canada and abroad, and conduct breakthrough experiments at TRIUMF that expand the frontiers of knowledge.

With the discovery of the Higgs boson and confirmation of the Standard Model of Particle Physics, particle physics has entered uncharted territory. We know that dark matter and neutrino mass both require new physics beyond the Standard Model. To help find the answers, TRIUMF will play a major role in determining the properties of elusive neutrinos, discovering the nature of dark matter and the origin of the matter-antimatter asymmetry in the world, and discovering new particles and forces.

This will include expanding our portfolio of groundbreaking high-precision experiments at TRIUMF as well as contributing to advanced detector and accelerator systems for large-scale international particle physics projects in Canada and abroad, including ATLAS at the CERN Large Hadron Collider and future colliders, multi-ton-scale detectors deep underground (e.g., at SNOLAB), and long baseline neutrino experiments in Japan and North America. We will also continue to support the Long Range Plan of the Canadian Subatomic Physics Community. Next-generation breakthroughs in fundamental physics will require the application of new materials

and technologies for future detectors while the ever-increasing amount of data produced in these experiments requires advances in high-performance computing, artificial intelligence and quantum computing. Achieving breakthroughs also requires even more global collaboration, further strengthening the role of major research facilities like TRIUMF.

The impact of this work will fundamentally reshape the future of science and technology as we understand it, similar to how relativity and quantum physics produced completely unanticipated advances of new technologies that now permeate everyday life. TRIUMF—and Canada—will be recognized as a major contributor to establishing the New Standard Model of Particle Physics.

Using the advanced capabilities of ARIEL and expanded state-of-the art experimental facilities, we will also solve some of the greatest enigmas in nuclear physics. We will deepen understanding of the detailed nature of the nuclear forces and how atomic nuclei emerge from them. We will seek to unlock mysteries such as what role atomic nuclei play in the life and death of stars, and where in the universe and how the heavy chemical elements—from iron to uranium—are produced in cataclysmic stellar processes. Our results will inform supercomputer astrophysical simulations of neutron star mergers and star explosions and enable interpretation of multi-messenger astronomical observations.

The combined effort of cutting-edge nuclear theory and experiments will define the field globally, firmly reinforcing TRIUMF's position as a world leader in nuclear science. The pursuit of these questions will not only advance our understanding of the origin of our world and its building blocks, but also enable technological innovations relevant for nuclear energy, diagnosis and treatment of cancer, as well as quantum technologies.

2. A world-class accelerator centre driving use-inspired research—from the life sciences to quantum and green technologies.

Leveraging our unique infrastructure to pursue research in Canada that will change the world

Large state-of-the-art infrastructure is the bedrock of cutting-edge research and technology development. It enhances our capacity to perform at world-class levels and catalyzes dynamic interactions between disciplines that lead to scientific breakthroughs and innovation. TRIUMF excels in building and operating high-performing, unique accelerator systems featuring a wide variety of particle beams—from protons and electrons to rare isotopes, neutrons and muons.

Unleashing the full power of ARIEL will make us the world's most powerful multi-user rare isotope beam facility and one of the top facilities for accelerator science. Showcasing a made-in-Canada ultra-high-power superconducting electron linear accelerator and using a second proton beam from TRIUMF's original cyclotron—the largest of its kind in the world—our increased production will boost access and support for a variety of projects.

Along with continuing our core multidisciplinary research in particle and nuclear physics, we will leverage and enhance our unique accelerator infrastructure to increase our work in other areas. We have identified the life sciences, quantum technologies and green technologies as three key growth areas in the coming years. We are already engaged and have developed expertise in specific elements of the first two areas. In the face of climate change, we acknowledge the urgent need—and opportunity—to use our unique research capabilities, expertise and infrastructure to help develop solutions to global climate and sustainability challenges.

Finally, we will continue modernizing and upgrading our infrastructure using frontier technologies for sustainable, effective operation. Our aim is to showcase how innovative research can be done sustainably, and also to operate all year round without a major shutdown, thus continuously delivering beam to enable more research and experiments. We will be a leader in sustainably managing resources used in laboratory operations and minimizing our environmental impact, while, at the same time, increasing our research and discovery efforts in a responsible manner.

Diagnosing, treating and curing disease

We envision TRIUMF as a national and international leader in radioisotope technologies and applications for the life sciences and in fundamental isotope research. This requires us to significantly expand our globally recognized life sciences program, which currently focuses on imaging of neurological disease and cancer.

Taking advantage of our unique radioisotope and particle beam capabilities and IAMI coming online, we will boost our research and production capacity—from laboratory development through preclinical studies all the way to human trials. This will help meet the growing demand for known and novel medical isotopes for new radiopharmaceuticals in both the diagnostic and therapeutic realms. We will further integrate our program into the BC health-care system, with translational facilities capable of preclinical in vivo work, but also strong ties to state-of-the-art clinical imaging and treatment at the local universities, hospitals and BC Cancer.

Our expanded capabilities will foster innovation in radiopharmaceutical development, radiation therapy, accelerator research and advanced isotope development, which will open new opportunities for cancer therapy, as well as imaging techniques for the acceleration of drug development. Advances in detector technologies, in part driven by innovations in particle and nuclear physics, will enable imaging with unprecedented spatial resolution, improving cancer diagnosis and treatment and drug development.

In addition, new research avenues that use our technical capabilities for groundbreaking biochemistry applications and the development of pharmaceuticals will accelerate the translation from bench to bedside. Establishing the world's premiere beta-detected nuclear magnetic resonance (beta-NMR) facilities and program for chemical and biological applications will allow us to address biological problems that conventional NMR or other techniques cannot.

Advancing quantum technologies

The quantum revolution is accelerating, driven by the continuing exponential growth in computing power, big data, machine learning and quantum computing. Quantum materials and technologies are key elements in emerging global trends in communication, security, sensing and computing. They are the essential building blocks for next-generation superconductors, spintronics, sensors, transducers for quantum communication, and quantum computers with almost unlimited application potential.

Like many other developed countries, Canada is investing and participating in the quantum race. TRIUMF will leverage the capabilities of our accelerator-based research facilities and associated technologies and expertise to help implement the new National Quantum Strategy with a focus on specific aspects of quantum materials, sensors and computing.

We will further expand the quantum research and materials characterization capabilities of our Centre for Molecular and Materials Science (CMMS). This will help drive the development of crucial new functional materials that fully leverage quantum phenomena to enable and manipulate on demand the emergent new properties such materials promise. Using a multitude of probes at our muon and rare isotope facilities, which are unique in North America, and establishing new opportunities, such as using the ARIEL e-linac to produce coherent infrared radiation in the THz range, we will advance understanding of underlying material structures and emerging quantum phenomena to transform a variety of technologies and sectors. These range from high-performance computing and big data to next-generation batteries, nanotechnology, earth and environmental science, as well as medicine, physics, the role of trace metals in biomolecules and the chemistry in advanced nuclear reactors.

Our world-renowned expertise in the development of radiation detector systems will continue to enable leading Canadian contributions in advanced nuclear and particle physics experiments. It will also drive the development of quantum technologies, in particular photon sensors, for use in environmental monitoring, quantum communications or more precise navigation of self-driving cars or autonomous drones.

Building on our existing partnerships with Canadian industry and academia and the Helmholtz Association (Germany), we will support the Canadian quantum computing community in its ambitions by enabling access to relevant TRIUMF's expertise and capabilities.

Enabling green technology solutions

Individual research groups are already using our CMMS facility for climate relevant research, such as developing green chemistry processes using muons and studying diffusion process in potential future battery materials. It is now time, however, for TRIUMF to take a more deliberate and coordinated approach in this area to amplify the efforts in the scientific community. We will therefore launch a new climate and sustainability research program with dedicated support for both internal and user-driven work in green technology development.

The program will invest dedicated funding to seed new initiatives and strengthen collaborative efforts via a visitor program and rapid access to the required facilities, such as the CMMS beamlines. We see its future growth as akin to the evolution of our medical isotope program, from a small opportunistic effort at its inception into a globally significant program today. Promising research opportunities include energy production and storage (in applications for nuclear power, batteries and hydrogen storage), efforts to reduce greenhouse gas emissions, and leveraging of green chemical processes for sustainable food and water production.

Particle accelerators and associated technologies have broad applications in the context of sustainability and climate challenges. We will leverage our expertise to advance initiatives for accelerator-driven nuclear reactors for energy production and nuclear waste transmutation. And our beams will be used for the characterization and qualification of materials for next-generation small modular reactors. Our unique know-how in areas such as cryogenic and superconductive technologies will help advance technologies for CO₂ and hydrogen liquification.

By fostering new partnerships with researchers from across our network of universities, we will also significantly enhance environmental tracer research based on the unique spectrum of radioisotopes and tracers that can be produced at TRIUMF. This ranges from research related to the role of phytoplankton in the global carbon cycle to the tracking of nanoplastics in wastewater.

3. A leader in a thriving national Big Science ecosystem.

Catalyzing the success and growth of Canada's network of major research facilities

TRIUMF is a natural leader in Canada's Big Science ecosystem. We are a pioneering major research facility (MRF) bolstered by an active and growing network of university members, strong relationships with government, direct links within and between research communities, and longstanding partnerships with both domestic and international laboratories. As humankind continues to push the frontiers of knowledge, major breakthroughs in science will increasingly rely on research done at MRFs, both nationally and internationally.

As our infrastructure and facilities continue to evolve and improve, we will boost Canada's contributions to international Big Science through next-generation experiments in Canada and collaborations at major international facilities. In addition, we see a tremendous opportunity to serve as the convenor of key partners and stakeholders in a coordinated national network of MRFs. We will build on our long history as the connective tissue between academic, industry and public-sector stakeholders across Canada and our work across disciplines. We can provide unparalleled direction and alignment of partner needs in the context of university-owned and -operated facilities.

We envision a coordinated MRF network featuring a strong advocacy group of facilities (and their university owners and users) that works with the federal government to establish a long-term MRF road map and lifecycle approach, prioritizing key investments in areas of strategic value. Long-term success and growth of the overall portfolio will require facilities to work collaboratively towards national goals and objectives. The MRF network will share best practices and adapt them to optimize performance across a portfolio of laboratories and research. This will allow stakeholders to better identify and take advantage of synergies and be more transparent about the full lifecycle costs associated with coordinated MRF investments rooted in clear national priorities.

The result will be a robust Canadian Big Science ecosystem viewed internationally as a strong and efficient collection of resources; central to this will be the network of university-owned MRFs of which TRIUMF will be the flagship. Channelling the expertise and ambition of its university members, the network will serve Canada's science and innovation needs, effectively and efficiently stewarding the investments made by government. Leveraging new economies of scales, this network will deliver results with more agility and speed than previously possible. Canada will be regarded as a partner of choice and a global leader that punches far above its weight in science, technology and innovation.

Within the next 20 years, the Canadian scientific community will be on track to construct a major new accelerator facility. An accelerator-based neutron source or a next-generation light source are potential options on the table. Driven by Canada's scientific community and clear government priorities, TRIUMF—as Canada's particle accelerator centre and a leader within a strong Big Science ecosystem—will be a principal partner in the ideation, development and construction of this new infrastructure. Co-location with existing accelerator facilities will lead to efficiencies in operation and use, as well as easy access to our expertise and governance and regulatory framework for building and operating large-scale accelerator infrastructure.

4. A national innovation hub translating discovery science into health and sustainability solutions.

Responding nimbly to complex societal challenges for the benefit of Canadians

TRIUMF has a history of working with a range of partners to successfully apply multidisciplinary science to solve difficult problems. Many of our discoveries and technologies are successfully translated to application with real-world impact: from radiopharmaceuticals based on isotopes we produced to diagnose and treat diseases, to using accelerator-based technologies to advance the development of materials for the next generation of quantum computers and new batteries for green energy solutions.

We have also made key contributions to the development of solutions for the production of the most-used imaging isotope (Tc-99m), developed imaging technologies for the mining sector that help minimize environmental impact of exploration, and developed a mechanical ventilator for COVID-19 patients in response to the global pandemic.

With this impressive track record, we are uniquely positioned to be at the centre of local and national innovation ecosystems that drive research, development and commercialization of disruptive technologies for the benefit of health outcomes and sustainability. As a lynchpin of Canada's MRF network, we can connect the network's reservoirs of talent and infrastructure to key researchers, clinicians, industry and government players to quickly fund and focus collaborative efforts. As a result, we will spearhead global projects that quickly and effectively develop technologies that are urgently needed to help address real-world crises. Not only do we envision TRIUMF responding to emerging national issues, but we also see ourselves working directly with government, foundations and industry to identify and help address major societal challenges on an ongoing basis.

In particular, through TRIUMF Innovations (our commercialization arm), we will leverage our strength in radiopharmaceutical development and radioisotope production to build an innovative and sustainable nuclear medicine ecosystem, from bench to bedside. We will become an "Isotope Valley" hub for nuclear medicine innovation by further expanding our isotope production capabilities through ARIEL and IAMI, and effectively leveraging our infrastructure, talent, project pipeline and incubation/commercialization support. Academic and industry partners will increase their use of our expertise, production capabilities and research infrastructures to develop new radiopharmaceuticals for the diagnosis and treatment of disease. These will be essential as the shift towards more personalized medicine continues.

We will also drive the development of new isotope production paradigms, including novel accelerator technologies using world-leading expertise from across the lab, such as in superconducting and high-power target technologies.

Our new climate and sustainability research program will provide the research capabilities to address key scientific questions across a wide spectrum of topics from sustainable energy solutions and greenhouse gas reduction to environmental monitoring. We will use our expertise and infrastructure, through the MRF network, to help build domestic resilience and home-grown climate and sustainability solutions.

We recognize that successful commercialization can take many forms. Our flexible model and extensive network will allow us to work with a range of partners across the country. Together, we will explore creative ways to identify game-changing technologies across multiple verticals, transform them into innovative products and quickly bring them to market. In partnership with

TRIUMF Innovations, we will help launch start-up companies. Royalties from these efforts will provide an important source of funding for further improving our facilities as well as contributing to the Canadian economy.

ŀ

As an innovation hub, we will create a collaboration space for staff, students and visitors; a hands-on maker space for students, postdocs, technicians and engineers to innovate, collaborate and bring their ideas to life using state-of-the-art technologies; and an incubation space for supporting start-ups into commercialization. We will also strengthen our partnership with the our academic partners to establish specialized joint facilities for translation, collision and collaboration initiatives on our campus.

5. An inclusive multidisciplinary talent incubator, attracting and developing the best people from around the world.

Producing Canada's future science leaders and innovators

To flourish and grow in the post-pandemic world, Canada must continue to develop and attract a well-educated, highly skilled and flexible workforce. Conducting world-class discovery research and solving society's most challenging problems requires the work of diverse and multidisciplinary teams of scientists, engineers, technicians, tradespeople and other workers with broad sets of skills. Global competitiveness and national prosperity also depend on giving all Canadians a fair chance to succeed.

At TRIUMF, our people are at the heart of our success. That's why we want to be recognized not only for our world-class research, but also for our continuous investment in our people. We are committed to applying innovative approaches to attract, cultivate, promote and develop a diverse range of high-performing talent across all levels of the organization.

Canada is a nation rich in diversity. Our ambitions include establishing TRIUMF as a beacon of equity, diversity and inclusion (EDI), which we believe is integral to research excellence and sustainable science solutions. Our vision is of a community of people from diverse backgrounds and life experiences who reflect Canada's makeup. As they work and innovate together in an inclusive environment, everyone has equal opportunity to thrive and contribute. In particular, we will ensure our staff mix fully represents the Canadian population, including Indigenous voices and experiences. We also expect that gender parity is achieved in the student and postdoc population across programs, and EDI principles are hardwired into our culture.

TRIUMF will become one of the most desirable places in Canada for students and early career researchers. We will help kick-start careers by giving them the opportunity to work in diverse, international, multidisciplinary teams and to build valuable skills, particularly those needed to use the latest technologies and tools. Multidisciplinarity is the way of the future. Students and researchers trained at TRIUMF will therefore have a key advantage over those trained in silos. They will be well-prepared for successful research careers both in Canada and in major research facilities around the world.

We will also help equip students and early career researchers for potential careers in the private sector by offering additional training in entrepreneurship and commercialization, communications, project management and data science. Engineers, technicians and other tradespeople already in the workforce will be given opportunities to upskill and stay abreast of fast evolving technologies.

 We believe that a continuous influx of new ideas and talent will keep us at the leading edge of research and innovation. To help develop and launch this talent, we will increase and strengthen our educational partnerships with industry, colleges, polytechnics and universities for the delivery of more hands-on work experiences (work integrated learning, co-op programs) across the full spectrum of TRIUMF activities, including science, engineering, communications and business. These offerings will complement and enhance existing post-secondary education programs.

To attract a steady pipeline of diverse talent and train future generations of science leaders and innovators who will power Canada's economic future, we must continue to inspire, engage and empower Canadians, starting with schoolchildren. This means collaborating with our network and partners in novel ways, such as using virtual and augmented reality tools, to increase our science outreach and engagement across the country. We will inspire young minds by showing how our groundbreaking discoveries help answer some of the most fascinating scientific questions, and how our applications and innovations contribute to Canada's prosperity. We will also provide professional development opportunities for teachers, educators, journalists and science communicators. TRIUMF will come to be viewed as a national centre for promoting scientific knowledge, literacy and excellence in a thriving national science and innovation ecosystem.