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Written submission from TRIUMF Accelerators Inc.

Mémoire de TRIUMF Accelerators Inc.

In the Matter of the

TRIUMF Accelerators Inc.

Application by TRIUMF Accelerators Inc. for renewal of operating licence for its particle accelerator facilities

Commission Public Hearing

March 9 or 10, 2022
(Exact date to be confirmed later)

À l'égard de

TRIUMF Accelerators Inc.

Demande de TRIUMF Accelerators Inc. pour le renouvellement de son permis d'exploitation pour ses installations dotées d'un accélérateur de particules

Audience publique de la Commission

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TRIUMF Class IB Licence Renewal Commission Member Document

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Executive Summary

This document is submitted in support of TRIUMF's application to the Canadian Nuclear Safety Commission (CNSC) to renew our present operating licence PA1OL-01.00/2022 (awarded in 2012) for a ten-year period starting on July 1, 2022.

Located on a 5.2 hectare site on the south west section of the University of British Columbia campus, TRIUMF is Canada's particle accelerator centre. Having produced its first proton beams in 1974, TRIUMF has since grown from its original conception as a "Meson Factory" whose primary purpose was to produce pi mesons and muons in pursuit of pure particle and nuclear physics research, into a multi-disciplinary national laboratory whose programs in scientific research, education, and commercialization have achieved great success in diverse areas.

TRIUMF is owned by its member universities and operated as an incorporated non-profit charity, TRIUMF, Inc. via a contribution through the National Research Council Canada, with building capital funds provided by the Government of British Columbia. Its mission was approved by the TRIUMF Board of Management on December 1, 2017:

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

TRIUMF operates a suite of particle accelerators that includes: one Class IB cyclotron (520 MeV); four Class II isotope production cyclotrons (CP-42; TR30-1; TR30-2; TR13); three Class II linear accelerators (ISAC I RFQ; ISAC I DTL; ISAC II linac); and one Class II electron linear accelerators (ARIEL e-linac). A fifth isotope production cyclotron (TR24) is scheduled to begin operations in 2022 as part of the IAMI facility, presently under construction on the south-west corner of the site.

The accelerators are employed for a variety of pursuits, including: fundamental research into nuclear and particle physics and astrophysics; life sciences research; commercial production of medical isotopes; materials research using subatomic probes; materials / electronics radiation effects studies. TRIUMF also operates several radioisotope labs in support of research conducted by the Life Sciences Division, and to fabricate Rare Isotope Beam (RIB) production targets for nuclear physics research.

Other areas of study pursued at TRIUMF include research into accelerator technologies and theoretical nuclear and particle physics. The broad scope of research and development activities, coupled with the advancement of the enabling knowledge and technologies for these activities makes TRIUMF a unique training ground for the next generation of science and innovation leaders.

TRIUMF looks to continue building on its successes in the next licensing period through an ambitious program that combines areas of proven success with new areas of research and commercialization, while maintaining safe and effective operations in all areas.

1.1 Introduction

1.1.1 TRIUMF Lab Overview

TRIUMF is a national centre for accelerator-based sciences located on a 5.2 hectare site in the southwestern portion of the University of British Columbia (UBC) Campus. In operation since 1974, it has grown from having a single 520 MeV cyclotron used for fundamental particle and nuclear physics research into a diverse multidisciplinary laboratory for both basic and applied research in the physical, material and life sciences.

In carrying out its core mission to advance the pursuit of scientific knowledge and discoveries, it also acts as a steward for the advancement of particle accelerators and detection technologies used both at the lab itself, as well as at other labs around the world where Canadians participate in cutting-edge research as members of international collaborations.

TRIUMF was originally owned and operated as a joint venture by a consortium of Canadian universities. In 2017, the TRIUMF Board of Management initiated a review of its governance framework with the goal of implementing new structures, policies, processes, and practices to help ensure TRIUMF's ongoing success across its strategic endeavours.

After an extensive review, in September of 2018, the 14 full member universities of TRIUMF voted overwhelmingly in favour of a new governance model that included its incorporation.

This governance structure provides for a smaller skills-based Board of Governors, the creation of a Members' Council, which allows Member Universities to retain the responsibility to vote on significant decisions, and the creation of a Science Council, that provides scientific advice and guidance to TRIUMF.

This governance structure is consistent with modern governance best practices, creates a clear division of responsibility between the Member Universities that own TRIUMF, the Board of Governors, and TRIUMF Management. This new model also provides for a strong balance and focus on both the science and stewardship of TRIUMF.

TRIUMF INC. is an incorporated not-for-profit registered charity that is owned and operated by its Canadian member universities.

1.1.2 Location and Setting

The TRIUMF site is located near the extreme southern extent of the UBC campus. Directly to the east of TRIUMF are forested lands that are part of Pacific Spirit Regional Park. To the west are the UBC Centre for Comparative Medicine, UBC Farm, and the Strait of Georgia; to the southwest is the National Research Council of Canada Institute for Fuel Cell Innovation; and to the south are the UBC composting facility and the UBC Library Preservation and Archives (PARC) facility.

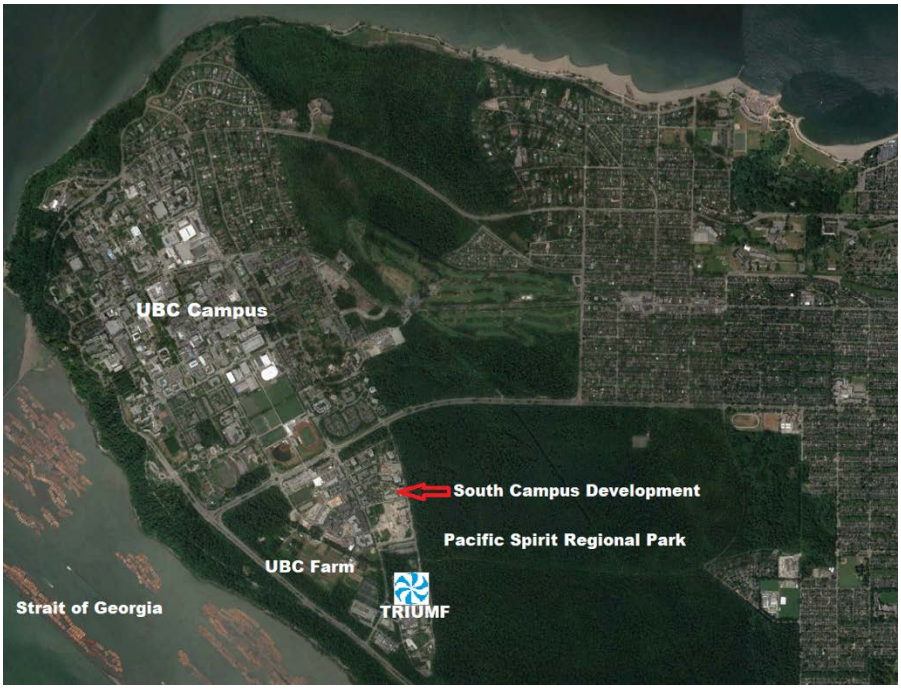

Figure 1 Location and setting of TRIUMF site

The nearest residential communities are the South Campus Development at a distance of approximately 0.4 km to north and northwest of the site, with other nearby residents located to the northeast along 16th Avenue, and to the east in Point Grey, both at a distance of approximately 1.5 km. A satellite image of the TRIUMF site and surroundings can be seen in Figure 1.

1.2 Background

1.2.1 TRIUMF Facilities

Figure 2 shows the layout of the TRIUMF site and the locations of accelerators and beam lines. Subsequent text describes their functions in TRIUMF's operations. All accelerators at TRIUMF are operated by the Accelerator Division.

520 MeV Cyclotron (Class IB)

A magnified more detailed drawing of the 520 MeV cyclotron and beam lines is shown in Figure 3. TRIUMF's original accelerator is an isochronous, sector-focused cyclotron which accelerates H^- ions to a peak energy of 520 MeV.[1] The acceleration of H^- ions

[1] 520 MeV is the maximum possible energy of the cyclotron, but it has been operated at a maximum energy of 480 MeV since 2011. The lower energy is favoured for two reasons: to reduce the quantity of neutron-induced air activation produced in air spaces around the cyclotron and primary beam line production targets, which is the dominant airborne emission from TRIUMF; and to reduce the residual activation level of the cyclotron and ancillary systems.

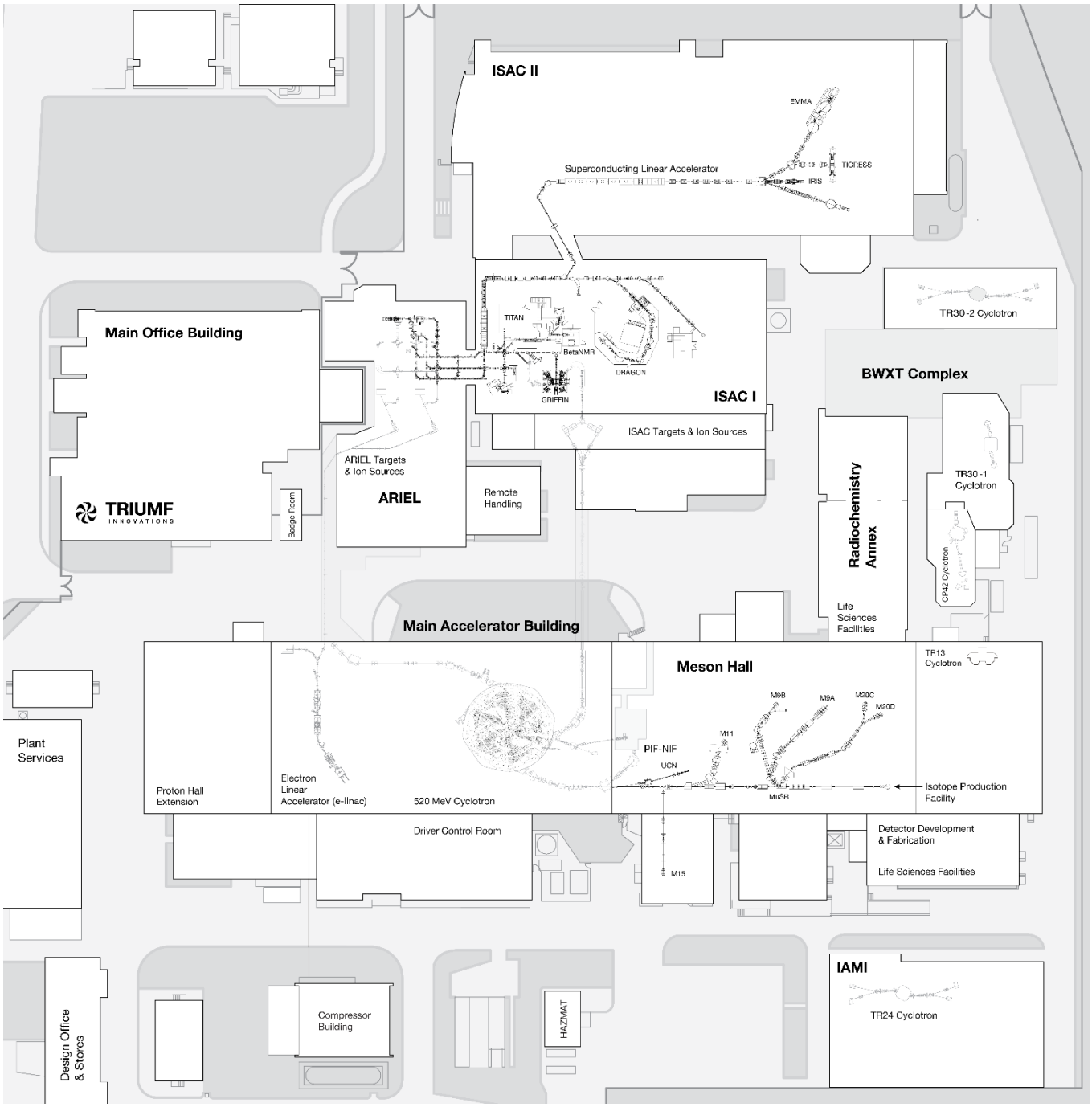

Figure 2 Map of TRIUMF facilities

enables the simultaneous extraction of several beams of different energies, which are transported along beamlines for use in different facilities:

1. The Meson Hall for the production of pi-meson and muon beams and ultra-cold neutrons;
2. ISAC for the production of radioactive ion beams;

3. The Proton Irradiation Facility / Neutron Irradiation Facility (PIF/NIF) for material radiation damage studies (BL1B and BL2C1);
4. The BL2C4 Irradiation Facility for the production of medical radioisotopes (BWXT);
5. The 520 MeV Isotope Production Facility for radioisotope production and Thermal Neutron Facility (BL1A).

N.b. all primary proton and electron beamlines, as well as secondary beamlines in the Meson Hall as shown in Figure 2, Figure 3, and Figure 4 are on the sub-basement (B2) level relative to ground level.

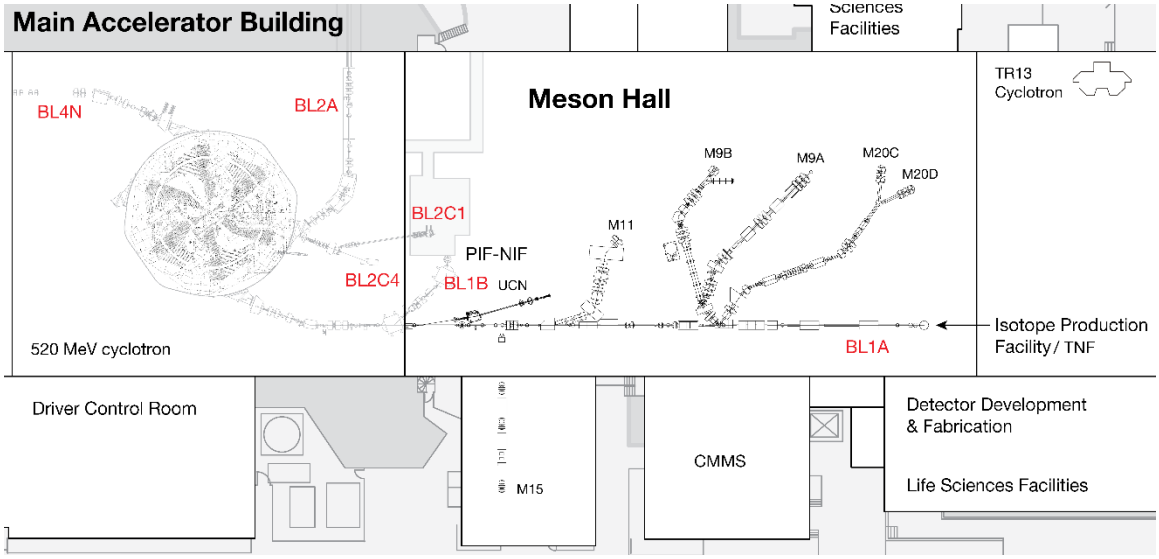

Figure 3 Detail of Main Accelerator Building

The cyclotron is housed in a 4-5 m thick concrete vault to shield surrounding accessible areas from prompt neutrons and gammas. The highest prompt dose rates occur at production targets along the beamlines. At these locations the shielding includes a closely fit geometry of inner layers of steel in addition to concrete. The cyclotron vault resides in a large (34 m × 170 m) outer building, the Main Accelerator Building (MAB). The Central Safety System (CSS) utilizes Access Control Systems (ACSs) for areas with very high prompt dose rates to prevent occupancy when the machine is in operation via interlocks on equipment needed to accelerate and/or steer beam. A complementary Radiation Monitoring System (RMS) outside the shielding also has the capability to turn off the cyclotron and halt beam delivery when either gamma or neutron dose rates exceed a predefined dose-rate threshold.

The ISAC facility (Figure 4) is the destination of high-energy proton beams of up to 100 μA, transported via beam line 2A, where they interact with production targets made of materials of diverse atomic weights from carbon to uranium, depending on which RIB radionuclides are needed for different nuclear physics experiments. The radionuclides are selected magnetically by mass and accelerated to maximum energies of 1.5 MeV (20 MeV) per atomic mass unit in the ISAC I (ISAC II) experimental halls. Because of their much lower energies relative to primary proton beams, RIBs are far less likely to produce prompt

radiation hazards, although neutron production is possible in some cases[2] from their interactions. There can also be residual radiation hazards from the decays of the accelerated beams, which for short-lived RIBs can effectively be considered to be “prompt” radiation. Because the radiation hazards associated with RIB delivery are relatively minor, shielding in the experimental halls is typically limited to the vicinity of specific devices that produce x-rays. The fixed radiation monitoring system includes gamma monitors only in the ISAC I experimental hall, while the ISAC II experimental hall has both gamma and neutron monitors.

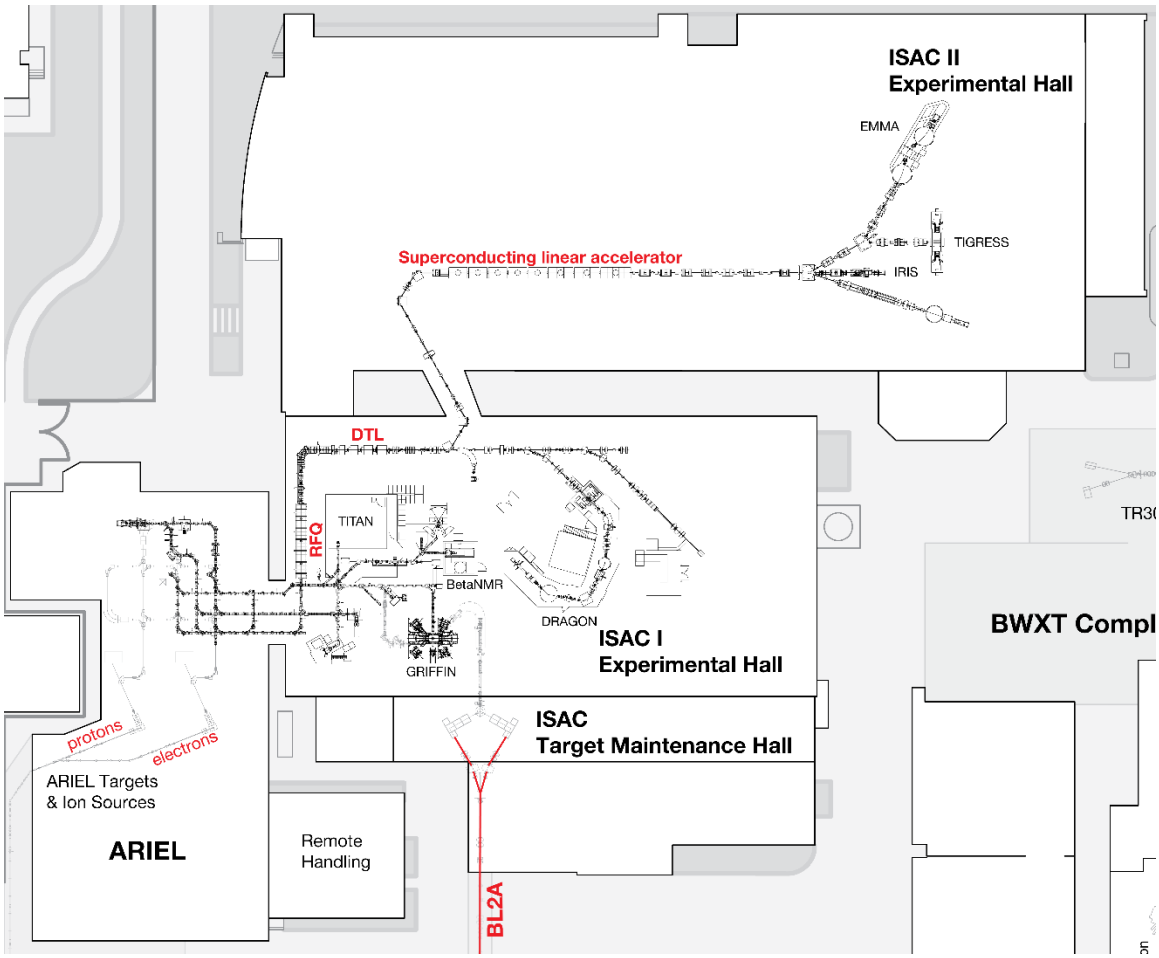

Figure 4 ISAC and ARIEL Facilities

There are two ISAC target stations at the downstream end of BL2A which do not operate simultaneously, i.e. only one at a time can receive proton beam.

The ARIEL RIB facility, presently under construction, is also shown in Figure 4. When completed, it will have two target stations, one at the end of a new proton beam line, Beam Line 4 North (BL4N), the other at the end of an electron beam from a Class II superconducting linear electron accelerator (“e-linac”, described below). The RIBs produced at ARIEL will be used for research at ISAC experimental facilities. In addition to irradiating

[2] In addition to the mass and energy of the accelerated RIBs, prompt neutron production also depends on the composition of the materials with which they interact.

targets for experimental nuclear physics, the proton target station will have a medical target facility located immediately downstream of the “physics target”.

Isotope Production Accelerators (Class II)

TRIUMF also operates three isotope production cyclotrons for the commercial production of medical isotopes sold by BWXT: the CP42 (42 MeV), and two 30 MeV machines, TR30-1 and TR30-2. Isotopes produced on these machines are transferred via pneumatic lines from the target stations to hot cells in labs operated by BWXT under their own CNSC licence. TRIUMF maintains complete responsibility for the operation and maintenance of the accelerators and ancillary systems such as nuclear ventilation.

A fourth isotope production cyclotron (TR13; 13 MeV) is operated by TRIUMF for the production of medical isotopes for research by the Life Sciences Division, and is also used to produce isotopes used for diagnostic positron emission tomography (PET) at UBC. The latter products are transported to several facilities on the UBC campus via pneumatic transfer lines, after first being processed and packaged in labs located on the TRIUMF site in the Radiochemistry Annex, operated by the TRIUMF Life Sciences Division.

Finally, the IAMI facility, presently under construction, will when completed house a 24 MeV cyclotron (“TR-24”) that will be used for the commercial production of Tc-99m for use in the Metro Vancouver region and also produce other isotopes for research by the TRIUMF Life Sciences Division and BC Cancer.

e-linac (Class II)

The e-linac is a superconducting linear electron accelerator with a potential maximum energy of 49 MeV. It is presently licensed to operate (for commissioning) up to a maximum energy of 40 MeV, presently operated at 30-35 MeV. It is located in the Electron Hall (“e-hall”) on the B2 level of the Main Accelerator building, immediately adjacent to the 520 MeV Cyclotron vault. The only beam line presently existing is housed entirely inside the e-hall and terminates in a beam dump whose present shielding allows it to accept a power level of up to 10 kW.

1.3 Highlights

In 2012 the CNSC granted TRIUMF a ten year Class IB licence PA1OL-01.00/2022, valid from July 1, 2012 to June 30, 2022. The scope of the licence included operation and maintenance of: the Class IB 520 MeV cyclotron; four Class II isotope production cyclotrons; two Class II radioactive beam accelerators. During the present licensing period a Class II superconducting electron linear accelerator was built and is presently being commissioned.

TRIUMF is seeking a renewal of its licence for another ten year period commencing July 1, 2022.[3]

[3] Although not part of the present application, during the next licensing period TRIUMF will also seek a licence to operate an additional Class II 24 MeV isotope production cyclotron (IAMI, presently under construction; license to construct pending), while also continuing to build out and eventually license for operation the remaining components of the ARIEL project, two beam lines and target stations, one for electrons and one for protons.

As per guidance provided by Directorate of Nuclear Substances Regulation in e-Docs-6397350 (Oct. 8, 2020) and REGDOC-3.4.1, subsequent sections of this document will describe TRIUMF's organizational structure and governance, and provide information of the policies, programs, and processes that ensure compliance with all of the requirements of the different Safety and Control Areas (SCAs) that form the basis of the present licence as described in the Licence Conditions Handbook.

2.1 Business Plan

The TRIUMF mission and business plan are laid out in Section 4.3 of the *TRIUMF Quality Manual* (Document-611).

The laboratory is based upon the exploitation of particle accelerators and associated radiation detection technologies and radiochemistry techniques. The ultimate outcomes of TRIUMF's activities, as captured in the *TRIUMF Logic Model* (Document-129376), are improved quality of life and economic growth in Canada through knowledge creation as well as the development and commercialization of new technologies in the physical and life sciences, with potential applications across sectors and regions. Among the laboratory's key outputs are increased knowledge as documented in refereed publications, Highly Qualified Personnel (graduate students, postdocs), and particle beams and isotopes. TRIUMF strives to generate new knowledge in an accident-free environment, with as low as reasonably achievable (ALARA) radiation exposure to its personnel, users and the public and within the resources provided by the Federal government's annual budget contribution and other peer-reviewed funding from granting agencies.

The core funding for TRIUMF is received in five-year installments through contribution agreements with the National Research Council (NRC), a funding and review cycle that includes the advance preparation of a Five-Year Plan as well as formal Evaluation of TRIUMF by the NRC, which includes an in-depth evaluation led by an International Peer Review Committee.

Additional funds are obtained through individual grants from the Canada Foundation for Innovation and provincial agencies for capital investments into infrastructure. Funding for research support, comes from the Tri-Council agencies (Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council, Social Sciences and Humanities Research Council), Mitacs, and other national and international funding agencies and foundations.

Outside of contributions to federally led initiatives, the Government of British Columbia supplies funding for capital upgrades such as buildings; the most recent investment was $12.25 million for the construction of the Institute for Advanced Medical Isotopes (IAMI). International investment includes partnerships with the U.S. Department of Energy, India's Variable Energy Cyclotron Centre, Japan's KEK laboratory, and other institutes and universities worldwide. The commercial revenue that is generated provides essential additional support for the overall program, as well as all the commercialization and technology transfer activities of TRIUMF Innovations.

TRIUMF is an incorporated not-for-profit charity, "TRIUMF INC." that is owned and operated by a consortium of Canadian universities, 14 at the date of incorporation. The legal and financial agreements that formalize the corporate structure are shown in Table 1 along with the date of the most recent revision.

Table 1 Agreements and contracts relevant to TRIUMF governance and land use

AGREEMENT	DATE
UBC land Lease between UBC and TRIUMF INC.	March 31, 2008
UBC Lease Assignment, Assumption & Amendment Agreement	June 1, 2021
Indemnity Agreement	June 1, 2021
TRIUMF / UBC Parking Lot License	2018/08/01
TRIUMF INC. Letters Patent & Original Bylaws	2020/02/18
TRIUMF - Membership Agreement	June 1, 2021
Amended & Restated CNSC Financial Security & Access Agreement	June 1, 2021
Amended & Restated Fund Contribution Gap Agreement	June 1, 2021
Amended & Restated Escrow Agreement	June 1, 2021

Strategic Planning

Since its inception as a local university facility, TRIUMF has evolved into an internationally renowned laboratory with strong ties to the research programs of Canadian universities. The science program has expanded from nuclear physics to include particle physics, molecular and materials science, and life sciences. TRIUMF provides research infrastructure and tools that are too large and complex for a single university to build, operate, or maintain. For more than 50 years, TRIUMF has been a key contributor to Canada's successes on the world stage—driving global advancements in physics through its world-class facilities, talent, and expertise in leading technologies, including accelerators. There are over 500 scientists, engineers, students, and staff performing and supporting research on the TRIUMF site. TRIUMF typically attracts around 1000 national and international researchers every year and provides advanced research facilities and opportunities to over 220 students and post-doctoral fellows each year.

TRIUMF's strategic planning revolves around a five-year planning cycle aligned with the funding cycle for TRIUMF's core operations. This is articulated in a TRIUMF Five-Year Plan, a blueprint that defines TRIUMF's vision and mission, communicates the lab's goals and strategies, and lays out an action plan for the specified planning cycle and beyond.

In 2017 the Board approved the current Five-Year plan and TRIUMF's vision statement:

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

Recently, TRIUMF has launched a 20-Year Vision process that is being led by an internal planning group and a steering committee with high-profile national and international members. The 20-year vision document identifies long-term goals and a planning trajectory for the laboratory.

The Science Council is composed of representatives from each member university, five TRIUMF staff and five external individuals. The Science Council provides advice to the Board on the scientific direction of TRIUMF under the Five-Year Plan, TRIUMF's engagement strategy with the scientific community and major funders of TRIUMF, as well as TRIUMF's scientific risk appetite statement and major scientific risks. The

Science Council also advises on priorities for major new funding proposals, such as Canada Foundation for Innovation competitions. The chair of the Science Council is a member of the Board of Governors.

The Five-Year Plan is developed by an internal committee, led by the Deputy Director, Research, and guided by a Steering Committee, chaired by the TRIUMF Director, of national and international experts. The Five-Year Plan is developed with extensive stakeholder consultation of the scientific community, of the TRIUMF member universities, the international user community, as well as the Science Council and the Advisory Committee on TRIUMF (ACOT). The Five-Year Plan is reviewed and approved by the Board of Governors.

ACOT is appointed by the NRC and is composed of scientists, engineers, and management and commercialization experts from Canada and abroad. ACOT reviews the scientific, engineering, management and commercialization functions of TRIUMF twice per year, and advises the NRC and TRIUMF on those functions. Among other matters, the ACOT monitors TRIUMF's interactions with international physics laboratories and communities and the current needs and possible future directions of the national and international users' communities.

In delivering on its strategic goals, TRIUMF leverages past investments by government and builds on the laboratory's strong brand and global network to deliver a new level of top-tier science, training, and innovation to Canada.

The implementation of sizable projects at TRIUMF is overseen by the Project Management Oversight Group (PMOG), which is responsible for the general implementation and oversight of the project management process at TRIUMF, in accordance with TSOP 15: Project Governance. PMOG is chaired by the Director, Project Management and includes executives from all across the whole laboratory as well as TRIUMF Innovations, TRIUMF's commercialization arm. PMOG reviews and prioritizes project initiatives and reviews resource use and planning across TRIUMF's full portfolio of projects and resolves inter-project resource conflicts and resource allocation problems for individual projects.

TRIUMF Innovations connects scientific inventions and ideas from particle detectors to isotope manufacturing systems — and the innovators behind them — to opportunities in the private sector. TRIUMF Innovations is overseen by a Board of Directors that includes industry leaders and the TRIUMF Director.

Finally, specific requests for TRIUMF resources in terms of isotope beams for materials science, subatomic physics, or nuclear medicine and life sciences, are reviewed and prioritized by international Experimental Evaluation Committees (EECs). TRIUMF presently maintains EECs for Nuclear Physics (NP EEC), Particle Physics (PP EEC), and Molecular and Materials Science (MMS EEC), as well as the Life Sciences Expert Committee (LSPEC). These committees meet at least once per year and review proposals to provide advice to TRIUMF management about allocation of time and preparation as well as overall schedule for providing resources to proposed experiments. These committees take into account the overall intellectual merit, technical readiness, and opportunity for impact presented by each proposed experiment. TRIUMF is also represented in an ex-officio role in the Subatomic Physics Long-Range Planning Committee, so that the laboratory is aware of and can provide feedback on the strategic planning of the national subatomic physics community.

3.1 Safety and Control Areas

The following subsections are organized to reflect the ordering of licence requirements for different Safety and Control Areas as specified in the CNSC REGDOC-3.4.1 *Guide for Applicants and Intervenors Writing CNSC Commission Member Documents.*

3.1.2 Management System

Relevance and Management

The intent of a Management System is to provide an overarching set of principles, policies, and processes to govern all aspects of operating the organization in a safe, effective, and consistent manner. It does this by integrating "requirements for health, safety, the environment, security, economics, and quality and directs the organization through the business plan."[4]

The TRIUMF Management System (formerly known as the "Quality Management System) intends to comply with CSA Standard N286-12 *Management System Requirements for Nuclear Facilities*, as specified in the *Quality Manual* (Document-611). The manual is organized to reflect the structure of the N286-12 standard and describes how TRIUMF's organizational structure, policies and processes fulfill the requirements of the standard in each of the management areas outlined in the standard: Safety Culture; Business Planning; Organization and Governance; Resources; Communication; Information management; Work management; Problem identification and resolution; Change; Assessment; Use of experience; Continual improvement.

The framework for the TRIUMF Quality Management System (QMS) was first implemented in 2007 with the formation of the QMS Implementation Panel. The panel had a broad mandate to specify the elements of a QMS applicable to all licensed activities at TRIUMF, oversee its implementation, and provide guidance to TRIUMF staff on how to meet its requirements.

Past Performance

During the 2012-2022 licensing period the TRIUMF QMS both consolidated the programs that had been conceived and developed over the previous licensing period, while expanding their scope and modifying them as needed to meet the changing needs of the organization. Some of the highlights include:

- Implementation of Document Management Training program (2012) to provide lab-wide support for required document management practices.
- Implementation of training in the requirements of the QMS for Division Heads[5] and Project Managers (2015, both programs). This training ensures that requirements and principles of the QMS are integrated into the planning and execution of Divisional activities and project management at all stages of their development.

[4] N286-12 *Management System Requirements for Nuclear Facilities,* CSA Group (2012)

[5] The positions formerly known as "Division Heads" are now referred to as "Associate Laboratory Directors"

- Creation of a new position of QMS Leader (2015) to provide full-time leadership and guidance in the application of the QMS to all activities, and to co-ordinate continual improvement in the QMS processes (e.g. work control; document control; problem resolution, internal assessment, etc.).
- Introduction of the *TRIUMF Strategic Plan for Safety* (Document-121747; 2015), an Action Plan with both immediate and longer-term goals to improve the safety programs at the laboratory, following both internal and external reviews of safety management. The plan includes measures to enhance all aspects of how safety is addressed in all activities, at all levels of the organization, including:
    - Project and experiment planning
    - Operational safety, including Controlled Work processes and Access Control
    - Responsibility and accountability: improve knowledge and communication of safety and QMS requirements
    - Continual improvement of the NCR and Quality Assessment processes, as specified in *TSOP-02 Non-conformity Reporting and Resolution* (Document-4758) and *TSOP-09 Quality Program Assessment* (Document-607), respectively.

  Progress made on implementing the plan is reported each year in the Annual Compliance Report.
- Introduction of a coherent, detailed analysis showing explicitly the linkage between TRIUMF's vision and goals, the Key Performance Indicators (KPIs) that measure progress towards the goals, and the risks that might affect progress, outlined in three new documents (2016):
    - *TRIUMF Logic Model* (Document-129376)
    - *TRIUMF Key Performance Indicators* (Document-126719)
    - *TRIUMF Enterprise Risk Management Program* (Document-134918)
- Improvements to the management of Controlled Work (2017) to require more explicit descriptions of: the work to be done; the procedure to be used to perform the work; and the method of verification of the work. The requirements are detailed in *Work Permit Guidance for Permit Holders, Facility Coordinators, RPG Surveyors, and Operations.* (Document-143163)
- An independent Safety Culture Assessment was made during 2017-2018, and documented in both a detailed final report and a shorter summary report. A plan to implement measures to bolster the identified strengths and make improvements in areas where challenges were identified will be one of the top priorities of the new TRIUMF Chief Safety Officer (hired March, 2021).
- The new position of Chief Operating Officer / Deputy Director, Operations (COO/DDO) was created in 2018 to facilitate the development of a cohesive and responsive structure to provide support services to TRIUMF's science and applied science programs. The areas of responsibility now under this umbrella include EHS, Design and Fabrication, Engineering Services, Human Resources, Facilities, Information Systems & Technology, and Quality.

- A new Director, Human Resources was hired in 2018, reporting to the DDO. A related change has resulted in the Training Manager reporting to the Director, Human Resources.
- An additional OHS ("conventional safety") officer was added to support both operational responsibilities and program development (2018).
- A new Director, Quality was hired in December 2019 to spearhead the continual improvements in this SCA. Initial efforts focused on performing a gap analysis of the TRIUMF MS against the requirements of N286-12, and implementing measures to bring the MS into alignment with N286-12. This was followed by new initiatives to improve the NCR processes (*TSOP-02 Non-conformity Reporting and Resolution*, Document-4758) to make them more systematic, efficient, and effective, and to expand and systematize the assessment processes described in *TSOP-09 Quality Program Assessment* (Document-607).
- A new Director, Facilities position was created in 2020, with the primary mandate to oversee the management of the physical site infrastructure, including space allocation, refurbishment, asset management, and security.
- A new Chief Information Officer joined TRIUMF in December 2020. Among the high-priority tasks are the implementation of a cyber-security policy and the roll-out of the WorkDay software package;
- Quality Council initiated in February, 2021.

Future Plans

Among the functions of the Quality Council will be to ensure that TRIUMF's core documents[6] will be reviewed and updated as part of a regular cycle of three to five years. Additionally, the Council will specify a comprehensive program of internal audits to encompass both independent assessments and self-assessments.

The roll-out of WorkDay, a new Enterprise Resource Planning Package, is scheduled for July, 2021. As well as upgrading the tools for finance and supply chain management, this ERP package will become the primary software package used by Human Resources and will facilitate resource management and project planning for the organization.

Challenges

Led by the Quality Council, TRIUMF Management is implementing an action plan to address findings of the Management System Inspection held in February, 2021 that will bring TRIUMF into compliance with N286-12 by the time of relicensing. In addition to presenting weekly progress updates to Senior Management, TRIUMF will share monthly progress updates to the CNSC.

[6] Documents referenced in the Licence Conditions Handbook

3.1.3 Human Performance Management

Relevance and Management

The safe and reliable operation of TRIUMF depends crucially on a well-trained staff who thoroughly understand both the requirements of their specific job responsibilities, as well as the requirements for completing their work safely with appropriate mitigation of various hazards, both radiological and non-radiological.

The TRIUMF Training Manager oversees a team including a Learning and Development Specialist and a Records Manager. The TRIUMF Learning Management System, which went “live” in 2020 is a versatile, customized commercial software package that provides for all aspects of training management, including:

- Provides record management for all training completed by all staff and visitors;
- Serves as a host / portal for online courses, both in-house and external;
- Provides reports to supervisors to track completion status of courses for employees, as well as automated notifications for employees and supervisors to inform and remind them of impending training expiration and scheduling of upcoming in-person training courses.

All in-house training courses are developed according to the Systematic Approach to Training (SAT) framework described in *TSOP-04 TRIUMF Training Program* (Document-609). The training team provides the following support for all TRIUMF employees:

- Guidance in the creation, development, and implementation of SAT-based, in-house training programs for both site-wide needs (e.g. radiation protection), and group-specific training requirements;
- Technical assistance in the implementation of in-house training, such as visual effects, narration, and recording for online courses;
- Facilitation of the effective delivery of training courses by other staff via “Train the Trainer” sessions, customized for specific situations and groups.

The Training Implementation Panel is chaired by the Training Manager, and the membership includes representation from all Divisions as well as the Deputy Director, Research. In addition to providing guidance in the development of training plans, Panel members also perform audits of training programs, review audit reports performed by non-Panel members, and report to Senior Management and Leadership on the activities of the Panel at both quarterly Safety and Quality Management Review Meetings (Training Manager) as well as Leadership meetings (Deputy Director, Research).

The three major areas of TRIUMF’s training programs are Safety Training, Operator Training, and group-specific / task-specific training.

Training programs are kept up-to-date with respect to changing needs by periodic audits and “training needs assessment” protocols triggered by e.g. new facilities coming online; acquisition of new equipment or software; new responsibilities for individuals or groups.

Safety Training includes four principal areas:

1. Training related to accessing or working in specific areas or facilities. These programs include:
    - Safety Orientation Training and Basic Radiation Protection Training, both required for unescorted site access inside the security fence;
    - Building Access Training, required by all employees and visitors for unescorted access into different buildings, both inside and outside the security fence;
    - Exclusion Area Training, required by all employees and visitors who access areas required to be locked during beam delivery;
    - Facility-specific training requirements for entry to e.g. radioisotope labs operated by the Life Sciences and Accelerator Divisions, or other rooms or areas with significant hazards.
2. Radiation Protection Training includes Basic Radiation Protection Training (BRPT) as described above, and Advanced Radiation Protection Training (ARPT), required to attain Nuclear Energy Worker (NEW) status. The initial ARPT is in-person training, while the refresher course (5-year period) is online, with an in-person, hands-on component. The RPG also provides additional targeted Radiation Protection training for specific groups or tasks, including:
    - Surveying and decontamination skills for Operators who act as surrogates for RPG surveyors during non-standard working hours;
    - Contamination monitoring and control for radioisotope lab personnel;
    - Use and handling of radioactive calibration sources.
3. Conventional Safety Training for all types of hazardous work. Depending on the course, training is delivered by the TRIUMF Occupational Health and Safety Coordinator, subject matter experts from TRIUMF or outside organizations, or via online modules.
4. Supervisor Safety Training, required for all group leaders, department heads, and anyone else required to supervise work at TRIUMF, e.g. Work Permit Holders. This training consists of an initial, one-time online component that describes the legal and regulatory requirements for supervisors, including due diligence, and an ongoing annual requirement to attend one of the bi-monthly in-person sessions delivered by EHS personnel.

Operator Training is implemented for all Operations Groups: Driver (520 MeV Cyclotron and e-linac); Rare Isotope Beams (RIB); TR13; and Applied Technology Group (ATG). The programs are managed by each Operations Group Coordinator, and include classroom, online, and on-the-job training.

Group-specific and job-specific training plans exist for nearly all technical and administrative groups on site, and new training plans are produced and updated as required.

Past Performance

A training plan for Working in Exclusion Areas was released in 2014, with Basic Radiation Protection Training following in 2015.

A systematic program to develop group-specific training plans commenced in 2011 for designated “high-priority” groups, specified for groups where incorrect performance could result in injury, downtime, expense or unnecessary radiation dose. Other groups’ plans were released over the next several years. Not including Operator Training plans, at present there are 40 released group-specific or task-specific training plans, with new plans added as required.

As mentioned earlier, the Training Implementation Panel maintains an audit schedule for all training plans, with a risk-based period of 3 to 5 years. Revisions and new releases of training plans are produced as indicated by audit results.

Other significant developments over the present licensing period include:

- Work Permit training introduced (2012);
- All group training plans reviewed to identify non-routine tasks (2014);
- Building Access Training Plan released (2015);
- Partnership entered with LinkedIn Learning to allow all employees access to more than 6000 online courses (2017);
- Requirements specified for new Learning Management System finalized (2018). The new system was procured in 2019 and launched in January, 2020;
- Leadership Development curriculum introduced, and first cohort trained (2019); additional training provided in 2020. Beginning in 2021 this program will be expanded to include leaders from all organizational levels;
- In 2020 TRIUMF transitioned from the annual employee Performance and Planning Review (PPR) process to the new People, Performance, and Potential (P3) process. This process included a coaching skills workshop for supervisors as well as multiple check-ins between the worker and supervisor throughout the year.

Future Plans

TRIUMF will be transitioning to a new Enterprise Resource Planning (ERP) system in 2021. This system, Workday, will collect all worker related data into a single system. This includes transitioning all training content and records into the Workday Learning module.

Challenges

3.1.4 Operating Performance

Relevance and Management

Conduct of licensed activities for accelerator facilities follows from the high-level provisions of *TSOP-11 Operations Management* (Document-5604) and in *TSOP-12 Configuration Management* (Document-5605), manifested in detailed operating procedures for Operations Groups described in the respective Group Manuals.

A fault reporting system is used extensively by the Operations groups to notify service groups of necessary work. Recurrent malfunctions outside of normal expectations are

escalated to non-conformities and resolved using TSOP-02 *Nonconformity Reporting and Resolution* (Document-4758).

Most major maintenance on the 520 MeV cyclotron and ancillary systems is performed during the annual winter shutdown period which typically extends from the beginning of the calendar year until the end of March. A detailed work schedule is produced by the Systematic Approach to Shutdown (SAS) Committee, which reports to the ALD, Accelerator Div. The SAS Committee's terms of reference (Document-146584) describes the work planning requirements for all tasks undertaken in a given year. Additional guidance is provided by subsidiary documents including the *Systematic Approach to Shutdown Job Grading Tool* (Document-175798) and *Systematic Approach to Shutdown Workflow* (Document-67361).

Other licensed activities include conducting experiments using radioactive materials. Experiments conducted at TRIUMF are managed according to *TSOP-07 Experiment Management Science Division* (Document-599) and *TSOP-14 Approval of Experiments for the Life Sciences Division* (Document-24353), with experimental safety reviews conducted as per provisions of the divisional safety committees' terms of reference, *Physical Sciences Divisional Safety Committee Terms of Reference* (Document-145636))and *Life Sciences Division Safety Committee - Terms of Reference* (Document-146028), respectively.

The nonconformity reporting system applies to all activities on site. Trending of faults and nonconformities is carried out according to the *TSOP-09 Quality Assurance Assessment* (Document-607) process by the Director, Quality who reports to Management at quarterly Safety and Quality Management Review Meetings (SQMRM). The completion status of corrective actions (CAs) is also tracked by the nonconformity reporting system and Director, Quality, with overdue CAs brought to the attention of managers at weekly Senior Management meetings.

Annual Compliance reports are submitted to the CNSC to provide a summary of licensed activities for the year, including a variety of operational performance and other data to demonstrate compliance with regulations and licence conditions. Reporting on Operating Performance includes summaries of reportable and unusual events, as well as results of root cause investigations and specified corrective actions.

Past Performance

Key Performance Indicators are defined for all accelerators that are in a regime of "normal operations", including the 520 MeV cyclotron, ISAC RIB facilities, and small cyclotrons used for isotope production. Operating performance is reviewed weekly at Operations meetings attended by representatives of Operations groups and service groups, and quarterly at Safety and Quality Management Review Meetings.

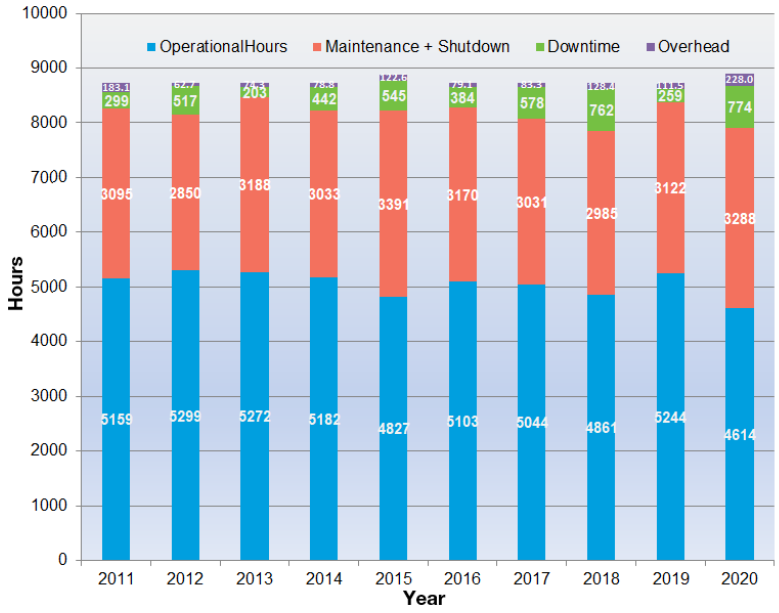

Figure 5 Operating hours for 520 MeV cylotron, 2011-2020

Figure 5 and Figure 6 show annual operating hours and availability, respectively, for the 520 MeV cyclotron from 2011 to 2020. Annual targets for these two KPIs are 5000 operational hours and 90% availability, respectively. Operations during 2020 were somewhat curtailed as a result of site occupancy limitations due to the COVID-19 pandemic.

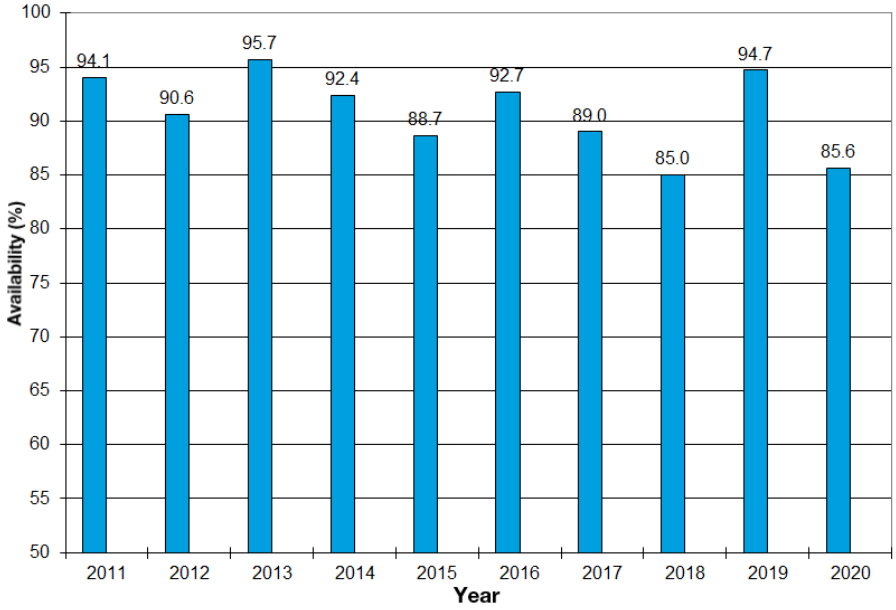

Figure 6 520 MeV Cyclotron availability, 2011 to 2020

Trending of root causes for nonconformities indicates that many of them involve deficiencies in Standards Policies and Administrative Controls (SPAC). The corrective actions for these typically involve improvements to one or more of procedures,

communication, and training, and where warranted, audits of how tasks are performed by the responsible groups.

Since 2012 there have been 27 reportable incidents. Only one of these incidents resulted in a radiation dose that exceeded a regulatory limit or action level: in 2015 a non-NEW exceeded the TRIUMF non-NEW quarterly whole body dose Action Level of 0.5 mSv. The corrective actions from the root cause analysis included: implementing a blanket prohibition on non-NEWs entering high-radiation and contamination control areas without the explicit review and authorization of the Radiation Protection Group; and the introduction of a general requirement for all employees to complete Basic Radiation Protection Training before being allowed unaccompanied access inside the TRIUMF security fence.

In 2014 an employee was missed during a pre-lockup search prior to e-linac operation. The individual responded to start-up alarms and exited through the primary access door using its emergency breakout hardware. Although prompt radiation was not generated while the individual was in the area, the event was immediately recognized to be very serious because of the potential for a significant dose exposure. Further operation of the e-hall was halted pending investigation of the causes and the development of appropriate CAs.

Eleven short-term CAs specific to the e-linac access control systems and training were identified as being necessary to implement prior to allowing e-linac operations to restart almost two months following the incident. Five additional Generic Root Causes generated five longer-term CAs relevant to access control systems across the site and associated training for people working in exclusion areas and performing lockups.

Of the remaining reportable incidents, a total of 15 involved airborne releases of gaseous or volatile radionuclides from failures of radioisotope production targets irradiated for BWXT (8) and processing of radioisotopes in radioisotope labs managed by the Life Sciences Division (7). Of the former, five were rubidium targets irradiated on the Beamline 2C Solid Target Facility (520 MeV cyclotron), and three were xenon gas targets used by BWXT to produce I-123 on low-energy isotope production cyclotrons operated by the TRIUMF Applied Technology Group (ATG).

Based on conservative estimates derived from atmospheric transport modelling codes, the maximum dose to a member of the public from any of these releases was approximately 100 nSv, with most of the others much lower than that.

Corrective actions from investigations into the two major sources of these releases have indicated the need for detailed engineering analyses to understand the failure modes and provide engineered controls and real-time diagnostic data that will reduce the likelihood of future releases. Among the improvements being implemented in the 2021 shutdown period are a higher-capacity cooling system, more accurate cooling water flow measurements, and improved reliability of the mechanism to seat targets in the target chamber.

The other reportable events during the current license period include:

- A stopped “rabbit” in the pneumatic transfer line used to send short-lived radionuclides from TRIUMF to researchers at UBC (2012);
- A malfunctioning nuclear exhaust air monitor detector that resulted in erroneous emissions data being reported in the Annual Compliance Report (2013);

- Acquisition of thorium metal foils without an import license (2016);
- Incorrect weight stated on an import license for graphite obtained for use in the UCN experimental facility from collaborators in Japan (2016);
- A brief excursion above the maximum allowed current for irradiating a metal foil target on an isotope production cyclotron (2017);
- Contamination of the inside of a Type A shipping flask due to damage sustained to the inner package during road transport for disposal to Canadian Nuclear Labs in Chalk River (2018);
- An improperly secured lock ring on the outer package of a Type A container, followed by damage to the same container sustained when it fell from an airport loading ramp. (N.b. the original unsecured lock ring had been properly secured by a TDG-qualified freight handler prior to the package being dropped. These two incidents are considered to be separate “Dangerous Occurrences” under the PTNS regulations, but were reported to the CNSC as a single incident.)

Finally, there were three conventional safety incidents that were reportable to one or more provincial regulators, WorkSafeBC and Technical Safety BC:

- A lock on a breaker panel was cut off without following proper procedure to ensure the safety of the person who had placed it. The investigation into the incident resulted in 13 CAs to improve and communicate procedures, training, and policies as documented in TRIUMF Safety Notes. In addition, “Lock-out” audits were performed for all indicated service groups to ensure that practices are in line with modified requirements.
- An underground 12.5 kV power line from the adjacent BC Hydro substation to the TRIUMF site was struck during collection of soil for required environmental sampling prior to the start of IAMI construction. The principal CA was to introduce a requirement to obtain a “Ground Disturbance Permit” to trigger a review prior to undertaking any drilling. This requirement is documented in an update to *TSN 3.7 Work Permit System*, and includes adherence to a new safe work procedure.
- An employee suffered minor injuries trying to escape from a stuck elevator which had no emergency two-way communication device. The principal CA was to take steps immediate steps to install two-way emergency communications in the three elevators on site that were not equipped. Other CAs included clarification of the expected response from Operations to reports of stuck elevators and communications to staff about what to do if they are in a stopped elevator.

Neither of the electrical incidents resulted in injuries.

Future Plans

TRIUMF is committed to continuous improvement of processes related to problem-solving, including fault reporting and correction, nonconformity resolution, internal assessment, as well as ensuring that indicated corrective actions are tracked and completed in a timely manner.

Detailed planning for the consolidation of control rooms for all three accelerator facilities—520 MeV Cyclotron; e-linac; ISAC/ARIEL RIB facilities—is underway, with the initial design review occurring in February 2021. The TRIUMF Control Centre (TTC) is

expected to improve both operational efficiency and communications between the Operators of the different facilities.

Challenges

TRIUMF intends to make further significant upgrades of the Beamline 2C Solid Target Facility to improve diagnostics for monitoring the target temperature and performance of the cooling system. Early detection of overheating is considered to be the key element in reducing the incidence of target failures.

3.1.5 Safety Analysis & Physical Design

Relevance and Management

Safety Analysis Reports (SARs) for the different TRIUMF facilities continue to be the established format for documenting hazard analyses and mitigation measures for both engineered and administrative controls. Safety Analysis Reports for all the different facilities at TRIUMF are included in the Table in Appendix A.

Prompt radiation associated with the acceleration of the primary beam constitutes the most significant hazard for the TRIUMF accelerators. Typically, the safety envelope for an accelerator is composed of a thick shielding enclosure with radiation monitors positioned on the outside of shielding. In addition, there is an Access Control System which is designed to keep personnel out of areas where beam is being delivered, and to keep beam from being delivered to areas where personnel may be present. The Radiation Monitoring System and the Access Control System are the central elements in the Safety System for the different accelerator facilities.

A description of the physical design of the different accelerator facilities at TRIUMF is included in the respective SARs. This includes a description of the accelerator ancillary systems, systems that are important for ensuring safe operation within regulatory requirements. These systems include:

- Cooling water systems for components in high activation areas;
- Nuclear ventilation systems for beamline and target enclosures;
- Nuclear ventilation for hot cells where irradiated targets are serviced;
- Vacuum exhaust systems.

Each facility Safety Report examines the associated hazards with these systems and documents the worst-case scenarios that can arise from potential failures associated with each facility. In all cases, controls for containment have been engineered to ensure that single point and compound failures would result in doses to staff, personnel and members of the public that are well within the regulatory limits for operation of a nuclear facility. For facilities or processes expected to generate significant quantities of radioactive waste, considerations for its handling, storage, and ultimate disposal are also required to be documented in the SAR.

Any modification undertaken to a facility or significant changes in its operating regime requires a revision to the SAR.

Past Performance

The nature of TRIUMF as a laboratory for cutting-edge pure and applied science results in a nearly constant need to perform safety analyses for accelerator facilities that are

either entirely new to TRIUMF—most recently ARIEL and IAMI—as well as for existing facilities where advancement of the science program requires the development of enhanced capabilities to achieve the desired successes. Recent examples of the latter include the development of production targets for ISAC with new materials or new operating principles, and the construction of the UCN facility in the Main Accelerator Building Meson Hall.

The safety analysis performed for all of these facilities takes into account all radiological and non-radiological hazards and their mitigations; the expected environmental impact of the new facility (or modified facility or operations), including emissions and radioactive waste; the requirements for safety systems, access control systems, and any other engineered safety measures indicated by hazard analyses.

The process for overall planning and project management adhere to *TSOP-15 Project Governance* (Document-22889) which includes requirements for hazard analyses and a holistic consideration of requirements relevant to all phases of the project from its initial conception to its decommissioning. Processes related to design and construction follow *TSOP-06 Engineering Design, Manufacture, and Assembly* (Document-597).

Releases of Safety Analysis Reports for new (ARIEL; UCN; IAMI) or modified facilities and operations occurring during the present licensing period include:

- *ISAC-II Safety Analysis Report* (Document-561; 2013);
- *Design Note TRI-DN-13-17 BL1A Shield Plug Modifications for UCN* (Document-93063; 2013);
- *Actinide Target SAR Addendum for Thorium Oxide* (Document-110961; 2014);
- *Beamline 2C4 Solid Target Facility Safety Report* (Document-30071; 2012; 2016; 2017);
- *ARIEL Facility Safety Report* (Document-51332; 2014; 2015)
- *TRI-DN-16-34 - Safety Analysis for UCN Commissioning to 1 Microampere* (Document-136684; 2017);
- *ARIEL-II Phase 3/CANREB Safety Analysis Report* (Document-158171; 2018)
- *TR13 Safety Report* (Document-5359; 2018; 2018; 2020);
- *TRIUMF to ACU, CCM, CBH Pipelines for PET Radiopharmaceuticals Safety Analysis Report* (Document-9605; 2014; 2017; 2020);
- *IAMI Safety Analysis Report* (Document-189013; 2020);
- *Actinide SAR Addendum for a proton-to-neutron converter target at ISAC* (Document-188621; 2020).

In 2015 a new document, *Worst Case Emissions Analysis Report* (Document-55017) was produced that consolidated the worst-case emissions scenarios from all relevant SARs into a single location.

Design principles for all access control systems follow the ANSI N43.1 Standard. Safety System design and assembly follows *TSOP-06 Engineering Design, Manufacture, and Assembly* (Document-597), while processes for maintenance and repairs adhere to *TSOP-12 Configuration Management* (Document-5605). Significant installations of new or modified safety systems include:

- M20 experimental area Service Cave Area Safety Unit and lock-up completed and commissioned (2012);

- Oxygen Deficiency Monitoring System (ODMS) installed and commissioned for the ISAC Facility (2012); the Electron Hall and Compressor Building (2014); and the Main Accelerator Building (2015);
- Electron Hall maze constructed and interfaced to the 520 MeV Central Safety System. The interlocks prevent exposure to prompt radiation hazards for people working in one facility while the other is in operation. (2013);
- Implementation of Corrective Actions related to access control systems required as a result of the e-hall lock-up incident described in Section 3.0.4 (2014-2016);
- Expansion of the e-linac/ARIEL Radiation Monitoring and Access Control systems into the ARIEL building to provide the basis for lock-up of the ARIEL tunnel (initial phase 2015; ongoing).

In 2018 the EHS Scientific Computing Analyst position, which had been in existence since 2011 as a renewable contract position, was made into a permanent position in recognition of the importance of high-level technical expertise in shielding design and analysis.

Future Plans

TRIUMF's plans for the near future include updating and re-organizing many of the facility safety analysis reports to consolidate their content, and align it with recently built or modified facilities. This includes the *TRIUMF Safety Report* (Document-563)*, ISAC I Safety Report* (Document-565)*, ISAC II Safety Report* (Document-561)*, and the ARIEL-II Phase 3/CANREB Safety Analysis Report* (Document-158171)*.* Modifications to SARs for facilities under construction or partially completed (ARIEL, IAMI, UCN) will be updated as needed as the facilities enter different phases of commissioning or are brought into full operation.

It is also planned to update *Worst Case Emissions Analysis Report* (Document-55017) with standardized methods to predict worst-case dose impacts for both on-site and off-site scenarios for worst-case airborne emissions releases. The analysis for off-site doses will include a change of the formalism to one based on methods used to calculate TRIUMF's Derived Release Limits as described in *TSN 2.4 Derived Release Limits for Radioactive Emissions from the TRIUMF Site* (Document-8506), which have been in use since 2017 following an update to comply with CSA N288.1-14.[7]

Over the next licensing period the SSG will continue to complete and commission new elements of the e-linac/ARIEL Safety System as the project progresses in phases towards its completion. Once the construction of the IAMI building is completed in 2022, installation of the safety systems will occur. The completion of the TRIUMF Control Centre (TCC), presently in the design stage will require the re-routing of cables for safety system signals from their present destination (RIB Control Room in the ISAC II building) to the TCC.

[7] There is sufficient conservatism built into this model to suggest that the results will be similar to those presently in use.

CNSC REGDOC-2.5.1 General Design Considerations: Human Factors

TRIUMF expects to be fully compliant with this REGDOC within two years of relicensing. Planned revisions to TSOP-06 presently in draft form include explicit reference to human factors as a necessary design consideration.

Challenges

3.1.6 Fitness for Service

Relevance and Management

Fulfilment of TRIUMF's regulatory obligation to operate safely requires a reliable and systematic program to test, calibrate and maintain equipment and systems crucial to monitoring hazards and enforcing operational requirements to prevent undue harm to staff, the public, and the environment.

These requirements encompass mitigation of all significant hazards, both radiological and non-radiological. Radiological hazards include both prompt and residual radiation, of which prompt radiation has by far the more severe hazards.

With respect to monitoring and protection from prompt radiation hazards the TRIUMF Safety Systems Group (SSG) has overall responsibility for designing, installing, commissioning, testing, and maintaining the safety systems that ensure reliable safe operations of the accelerators.

The SSG is also responsible for maintaining and calibrating all hand-held, standalone, and special-purpose radiation monitors used at TRIUMF, including monitors for airborne emissions. Calibrations for some types of monitors are performed in the SSG's on-site calibration facility, while others are sent off-site to either the manufacturer or an independent commercial service provider. Air monitor calibrations undergo an additional calibration and signal continuity verification check performed by the Radiation Protection Group to ensure the validity of reported emissions monitoring results.

Calibrations for all radiation monitors are performed as required by regulation, following *TSOP-08 Calibration and Inspection* (Document-595); calibration records are stored on Docushare and accessed via the Calibration & Inspection Index, a purpose-built web-based facility.

Fire prevention and protection programs at TRIUMF comply with CSA N393-13 requirements. Testing and inspection for fire safety equipment and systems including emergency lighting is performed by a combination of TRIUMF staff, external service providers, and UBC technicians, with inspection records stored on Docushare and accessible via the Calibration & Inspection Index.

Similar calibration / inspection / testing regimes, including record management provisions exist for: oxygen deficiency monitors (for areas where cryogenic fluids are used); flammable gas monitors; differential pressure gauges (regulation of nuclear ventilation systems); HEPA and charcoal filtration "challenge" tests.

Past Performance

Over the present licensing period most of the non-routine activities have been in the planning, design, installation, and commissioning of safety systems for new or modified facilities, including:

- Implementation of supplementary source-based calibration and signal continuity checks for all air monitors, performed annually by RPG technicians (Document-109449; 2014);
- Regular calibration of Oxygen Deficiency Hazard monitors by the Mechanical Services (Document-117682; 2015);
- Changes to the 520 MeV Radiation Monitoring System to add a single channel analyzer narrow window air monitoring of Kr-79 of the STF Hot Cell from an already existing air monitor sampling line (2019);
- Installation and commissioning of a Lucas cell on the sampling line of the nuclear exhaust of the RCR1 lab required for the detection and quantification of alpha-emitting nuclides in the nuclear exhaust systems for hot cells and fume hoods (2019).

Future Plans

Safety systems including access control systems, radiation monitoring systems, and ODH monitors for new facilities will be commissioned or re-commissioned as they are built or modified to accommodate the requirements for new facilities coming online for commissioning and eventually, regular operations.

Challenges

3.1.7 Radiation Protection

Relevance and Management

The Radiation Protection Program is administered by the Radiation Protection Group (RPG), consisting of two health physicists, a radioactive materials co-ordinator, and four technicians. The Safety Systems Group maintains and calibrates all fixed and portable radiation and contamination meters, as well as a suite of more sophisticated instruments used for quantifying emissions, assaying waste, and monitoring ambient air for alpha emitters. The group consists of two engineers and two technicians. Both groups are supported by a radiation safety officer and a radiation physicist that provide additional accelerator health physics analysis particularly when the program needs to be expanded to new facilities being brought online.

Sources of radiation at TRIUMF can be either prompt radiation fields present outside shielding during machine operation, or residual radiation fields inside shielding when the machine is off for personnel access. The former are effectively controlled with the Radiation Monitoring System using monitors located outside shielding. When the trip level is exceeded, the accelerated beam is interrupted using redundant devices activated by the Central Safety System. Residual radiation fields are affected by lower-level beam losses that are controlled with beam loss monitors during operation. Dose for TRIUMF personnel is almost exclusively from exposure to residual radiation fields when performing maintenance and repair work on activated components. Work in high radiation areas is work-permit controlled and requires a radiation survey before the work can begin.

TRIUMF Safety Note 1.2 TRIUMF Policy on Radiation Exposure (Document-545) defines TRIUMF administrative levels used to control dose to personnel, and the procedures when these administrative levels are exceeded. TRIUMF's administrative levels for Nuclear Energy Workers are set at approximately half of the regulatory limits.

In order to achieve the objectives of the TRIUMF policy on radiation exposure daily records of dose are available to workers, their supervisors and senior management. Administrative control levels for accrued dose are in place and if exceeded require a review of the work by the supervisor and the head of the Radiation Protection Group to ensure adequate mitigation measures have been taken before work can resume.

For major projects involving significant radiation exposures, the project leader prepares a detailed work plan and dose study, including an analysis of tasks, the duration of the tasks, the expected radiation fields and a dose estimate. Dose records from similar tasks are used as well as the extensive records of radiation fields kept by the Radiation Protection Group.

Dosimetry in the form of Landauer OSL badges is required for all persons entering the TRIUMF security zone. Dosimetry results are reviewed by the RPG Health Physicist and reported to Management quarterly at Safety and Quality Management Review Meetings. Additional Direct Reading Dosimeters (DRDs) are required for all work with the potential for non-negligible dose accrual, with the results logged daily by workers in the dosimetry database, which automatically informs workers, their supervisors, and the Health Physicist when doses approach or exceed any internal guideline or limit.

The RPG Health Physics Lab is equipped with a thyroid monitoring system that can be used in the event of a suspected exposure to radioiodines, re-certified annually by Health Canada-administered challenge tests. To date, no non-zero doses to TRIUMF staff have been measured.[8]

Past Performance

TRIUMF has made a concerted effort to manage dose since the mid-1990s as evidenced in Figure 7 showing the trend for the collective dose since the start of machine operation at TRIUMF. The reduction in dose starting in the mid 1990s was achieved with better dose planning for maintenance work and with 520 MeV cyclotron upgrades such as the RF Booster that resulted in a significant reduction in the cyclotron residual radiation fields.

Studies have demonstrated that operation at the extraction energy of 480 MeV rather than 500 MeV does not adversely impact the scientific goals of the laboratory and results in a reduction in activation of cyclotron components and consequently a reduction in the residual radiation fields. With this reduction in the dominant contribution to personnel dose, TRIUMF has been able to increase the cyclotron operating current without adversely affecting the collective dose.

[8] TRIUMF also provides thyroid monitoring BWXT employees.

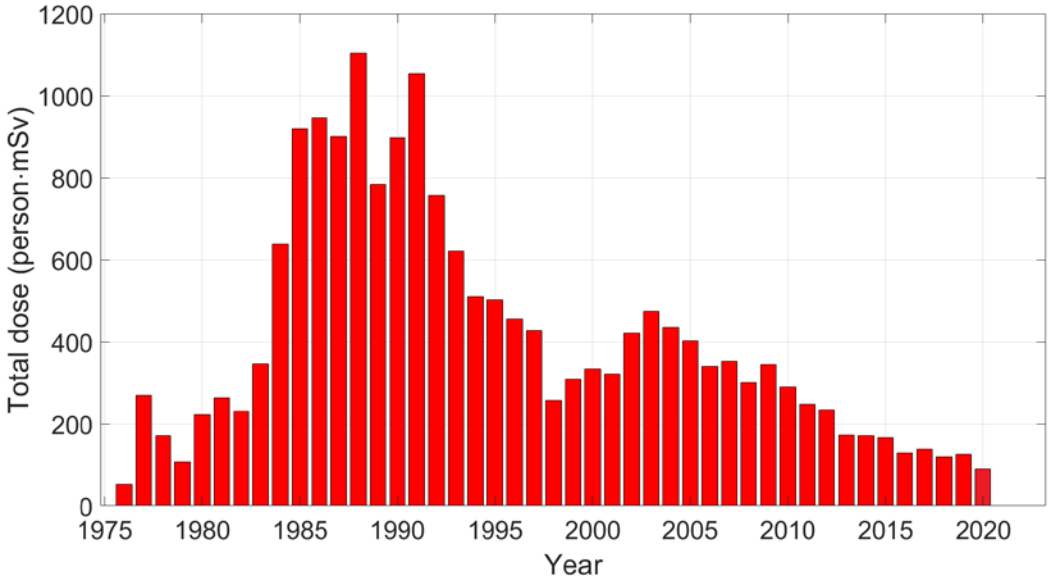

Figure 7 Collective dose accrual v. year

Table 2 shows doses for all badged persons from 2012 to 2020 and separated into NEWs and non-NEWs. In most recent years the highest average NEW whole-body doses for service groups working in high-radiation areas are ~1.5 mSv, with maximum doses of ~8-9 mSv. The TRIUMF administrative whole-body annual dose limit of 10 mSv has not been exceeded in the present licensing period. The non-NEW whole-body quarterly Action Level of 0.5 mSv was exceed once in 2015. Following this incident, the RPG immediately implemented corrective actions intended to prevent a recurrence, including: a blanket prohibition on non-NEWs accessing high-radiation areas without explicit review and authorization by the RPG; and a site-wide requirement to complete Basic Radiation Protection Training for non-NEWs to have unescorted access inside the security fence.

Table 2 Personnel dose accrual since 2012. All doses are in mSv.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Whole Body (NEW)									
Average	0.75	0.77	0.52 (0.72)	0.49 (0.69)	0.33 (0.54)	0.29 (0.47)	0.29 (0.6)	0.30 (0.62)	0.26 (0.53)
Max.	7.5	6.49	6.32	5.87	8.62	7.85	8.3	9.18	7.93
#Persons	259	183	275 (197)	280 (200)	356 (218)	390 (240)	405 (186)	433 (208)	405 (202)
Whole Body (non-NEW)									
Average	0.02	0.02	0.004 (0.02)	0.01 (0.03)	0.008 (0.028)	0.009 (0.025)	0.002 (0.013)	0.003 (0.03)	0.004 (0.02)
Max.	0.22	0.18	0.16	0.67	0.15	0.11	0.07	0.18	0.09
#Persons	603	206	1146 (224)	1137 (433)	976 (274)	960 (333)	907 (98)	1092 (108)	701 (139)
Shallow									

Average	N/A		0.46	0.29	0.29	0.24	0.48	0.47	0.28
Max.			6.36	5.65	9.37	7.92	8.37	8.71	7.81
#Persons			324	507	429	501	249	284	398
Extremity									
Average	6.6	6.03	4.42	5	2.96	3.27	3.94	4.24	3.28
Max.	59.8	52.2	46.2	27.5	19.1	14.5	28.3	42.9	50.0
#Persons	57	34	65	35	43	38	55	64	55
Lens									
Average	N/A		0.34	0.24	0.25	0.21	0.37	0.41	0.32
Max.			6.38	5.9	9.09	7.92	8.37	9.17	7.97
#Persons			441	645	517	581	298	327	344

Notes:

1. **2012 and 2013 results are for persons with non-zero doses only. Starting in 2014 average whole body doses are calculated for both "all monitored persons", and those with non-zero doses only; the latter appear in parentheses.**
2. **Starting in 2014 shallow doses and lens doses are shown for all monitored persons with non-zero doses.**

Future Plans

TRIUMF does not anticipate an increase in the collective personnel dose with the eventual onset of operation of the Electron Linear Accelerator (e-linac) and ARIEL. Residual fields for the e-linac will be several orders of magnitude less than for the 520 MeV cyclotron, and the design of the production targets at ARIEL is planned to include more remote handling for high dose tasks such as the connection of services to the target station.

Starting in 2017 and continuing through to the present, TRIUMF has increased the use of programmable electronic DRDs (eDRDs) in place of pencil dosimeters for work performed in high-radiation areas, with the ultimate intention being to phase out the use pencil dosimeters. This development coupled with the favourable trends of generally low and decreasing doses has resulted in the initiation of a project to remove the global requirement for dosimetry inside the security fence, resulting in non-NEWs no longer being required to be badged. Non-NEWs would then be required to wear eDRDs for work in areas with a non-negligible possibility of dose accrual.

Challenges

The anticipated high-volume production of Tc-99m in radioisotope labs at IAMI is expected to result in extremity doses for lab technicians that are much higher than those presently seen at TRIUMF. The RPG will work with IAMI management to implement controls and procedural measures to minimize this expected development. Best industry practices will be used to keep doses ALARA.

3.1.8 Conventional Health and Safety

Relevance and Management

Relevant conventional safety hazards are addressed in facility Safety Reports, and include electrical, mechanical, chemical, compressed gases (including flammable), and cryogenic. Of these, electrical hazards are the most prevalent owing to the large assortment of high-voltage and/or high-current devices needed for accelerator and ancillary systems, and for experimental facilities. As many electrical hazards as possible are mitigated through engineered controls (which are specified during the design phases for new facilities). When this is not practical, administrative controls are used.

The TRIUMF Occupational Health & Safety (OHS) group consists of two OHS specialists who administer a suite of different programs as mandates by the British Columbia provincial authority WorkSafeBC. An ongoing program of regular Supervisor Safety Training sessions is required for all group leaders in addition to any other employees who supervise work.

A summary of programs and procedures is maintained in the *TRIUMF Occupational Health & Safety Handbook* (Document-840). Detailed guidance for mitigation of specific hazards is available in the form of *TRIUMF Safety Notes*, of which 11 are devoted exclusively to different conventional hazards and mitigations.

The Joint Health and Safety Committee[9] (JHSC) is mandated by WorkSafeBC regulation with co-Chairs and members representing both management and employees. Committee membership includes representatives from all Divisions who meet monthly. The TRIUMF OHS Officer acts as an *ex-officio* advisor to the committee and attends all meetings. Members are required to receive training specified by WorkSafeBC, and between them conduct regular inspections across the entire site, including radiation areas.

Both the OHS Officer and one of the JHSC co-Chairs attend the quarterly Safety and Quality Management Review Meetings and present summary reports to Management for their respective areas of responsibility. Detailed statistics on all reported injuries, categorized by hazard type, are reported. Injuries to hands typically dominate, consistently accounting for roughly half of the total.

Past Performance

One of the principal metrics used to monitor conventional safety performance is “Lost Time Injuries” (LTI), for which both the number of LTIs and the number of lost working days are considered. To facilitate meaningful comparisons with similar organizations, the number of injuries each year is normalized by a factor proportional to the total number of insured workers at each organization. For TRIUMF, WorkSafeBC compares these data as injury rates with the designated Classification Unit of “Advanced Education” in units of “# LTI per 100 person*years of employment (Figure 8). The other LTI statistic is the average number of lost days per LTI, a measure of the seriousness of the

[9] Formerly known as “TRIUMF Accident Prevention Committee” (TAPC)

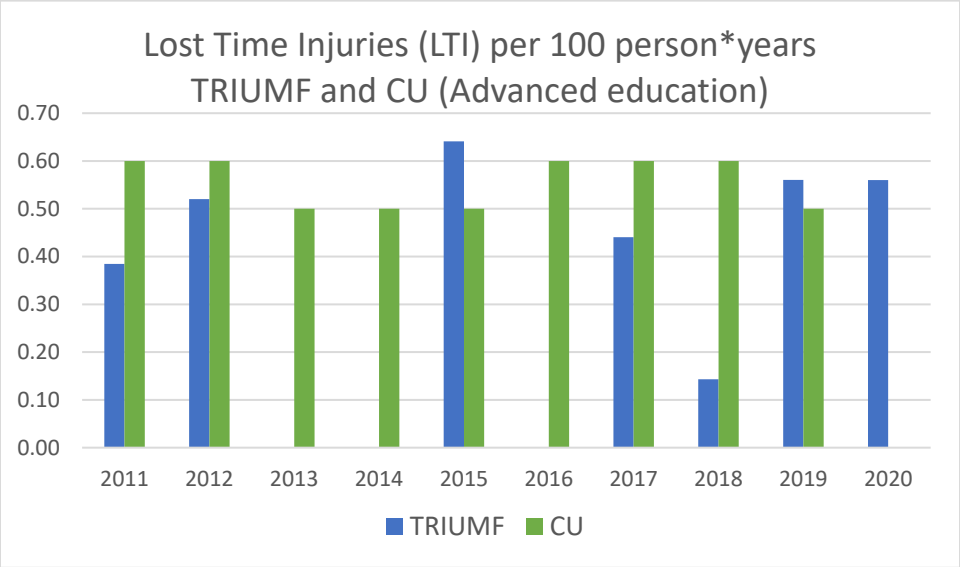

Figure 8 Lost time injury rates, TRIUMF and WorkSafeBC Classification Unit

LTIs. The number of LTIs during this period has never exceeded 4 per year. For 2020 (4 LTIs) the person*years normalization is assumed to be what it was in 2019. The total lost time of 47 days from 4 LTIs is comparable with other years of the licensing period.

Figure 9 shows the average lost time per LTI for TRIUMF and its advanced education classification unit.

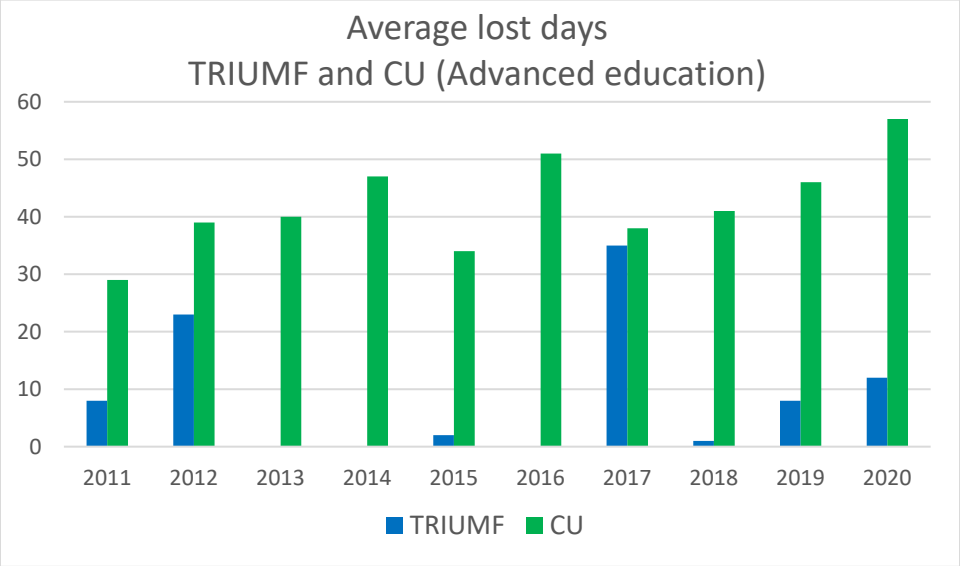

Figure 9 Average days lost per LTI, TRIUMF and WorkSafeBC Classification Unit

Among the causes of injuries since 2018, several resulted from improper use of power tools, including one in 2020 that resulted in 39 of the 47 total lost days where a worker's hand was cut when a table saw blade kicked out a piece of sheet metal being cut.

In 2018 a report of a possible uptake of lead by a worker lead to a site-wide investigation of the prevalence of lead on surfaces in experimental halls. Although the areal densities of lead on most surfaces in most of the areas were found to be below the allowed regulatory levels, some measurements were above threshold.

The sources of lead in these areas were a combination of unpainted lead bricks and sheets used for radiation shielding, along with the paint that had been historically used for painting large concrete shielding blocks. For the latter source, the paint tends to become pulverized over time as the shielding blocks are removed and replaced regularly to perform maintenance work.

Measurements made to determine whether individual workers might be exposed to airborne lead dust did not show any evidence that the dust found on surfaces was also airborne. Similarly, bioassays performed on workers whose jobs require them to handle lead did not indicate any uptake from performing these tasks regularly.

Following the discovery of above-threshold lead dust concentrations, a major remedial program was put into place. The elements of this program included:

- All unpainted lead from the site was cataloged and either painted if still required for use, or sequestered and moved to a storage area, where they were required to be wrapped in plastic sheeting;
- A iterative remediation program was enacted consisting of extensive sampling, followed by cleaning where warranted, followed by re-assessment by third-party contractor;
- A training program to make workers aware of the nature of lead hazards and the mitigation measures;
- Requirements for Personal Protective equipment to be worn for workers spending significant time in affected areas.

The remediation program was completed in mid-2020 when the final areas that were measured levels above-threshold were assessed to be below threshold following cleaning. TRIUMF has produced a *Lead Exposure Control Plan* (Document-183709) that documents the ongoing monitoring and mitigation measures and whose acceptance by WorkSafeBC was the final requirement for them to close the item.

Requirements for obtaining a “ground disturbance permit” prior to undertaking drilling or digging on the TRIUMF site were released in 2019, along with a safe work procedure for performing the work. Please see Section 3.0.4 for more details.

From 2018 to 2020 TRIUMF OHS has been developing measures to strengthen the requirements for hazard assessment and pre-job briefings. A new TRIUMF Safety Note, *TSN 3.9 Hazard Assessment & Pre-Job Briefing* (Document-178912) was released in 2020 and is now required site-wide after an initial roll-out of the requirements that applied to work by contractors.

Other recent improvements include the roll-out of a confined space safety program (2020) which includes:

- A new TRIUMF Safety Note, *TSN 5.13 Confined Space Entry Program* (Document-155698);
- A site-wide catalog of confined spaces categorized on a multi-level scale depending on the hazard level;

- Training requirements for anyone required to enter confined spaces;
- Training requirements for anyone supervising work in confined spaces;
- A requirement for specific safe work procedures for all confined spaces.

Future Plans

Implementation of measures to address improvements in safety culture will bring a focus on the goal of reducing loss time injuries. In addition, TRIUMF OHS will continue its efforts to reduce injuries through a multi-pronged program of ensuring all workers are adequately trained to mitigate hazards specific to their work, ensuring that adequate hazard assessments pre-job briefings are performed prior to work commencing, and ensuring that workers and supervisors have access to guidance on hazard mitigation from TRIUMF Safety Notes, safe work procedures, and ready access to knowledgeable safety experts.

Among the initiatives presently underway at the time of writing are:

- A comprehensive cryogenics safety program;
- A comprehensive set of safe work procedures for the use of power tools;
- A new TRIUMF Safety Note, *TSN 1.9 TRIUMF Arc Flash Policy and Procedures.*

Challenges

Monitoring safety culture will continue to receive focus at the CSO level to ensure improvements in behavioural safety and a reduction in lost-time incidents. Tools will be implemented to address gaps such as communication of lessons learned and review and coaching of workers in job-hazard assessments and pre-job briefing and review.

CNSC REGDOC-2.8.1 Conventional Health and Safety

TRIUMF is presently in compliance with this REGDOC.

3.1.9 Environmental Protection

Relevance and Management

TRIUMF has an established Environmental Protection program consistent with the requirements of CNSC REGDOC-2.9.1 *Environmental Protection: Policies, Programs and Procedures*, whose principles and requirements are laid out in *Environmental Management System* (Document-15678). The program elements include detailed requirements for both emissions monitoring and environmental monitoring as described in *Monitoring Emissions for the TRIUMF Site* and *Environmental Monitoring for the TRIUMF Site.*

All non-negligible radioactive airborne emissions and waterborne effluent are monitored, characterized, and reported at quarterly Safety and Quality Management Review Meetings against established KPIs. Impacts of the emissions and effluent on the public are modeled via the formalism of *TSN 2.4 Derived Release Limits for Radioactive Emissions from the TRIUMF Site* (Document-8506) according to CSA N288.1-14.

Design of new facilities and experimental safety reviews take into account expected environmental impacts of operations, including “worst case” release scenarios; where applicable, engineered mitigation measures are specified.

Past Performance

TRIUMF's emissions as reported in Annual Compliance Reports from 2012 through to 2019 are shown in Figure 9 on a logarithmic scale. The line labelled "Regulatory Limit" corresponds to 50 μSv which is 5% of the Derived Release Limit reference dose of 1 mSv. The decrease in 2020 relative to 2019 is from reduced operations due to the COVID-19 pandemic.

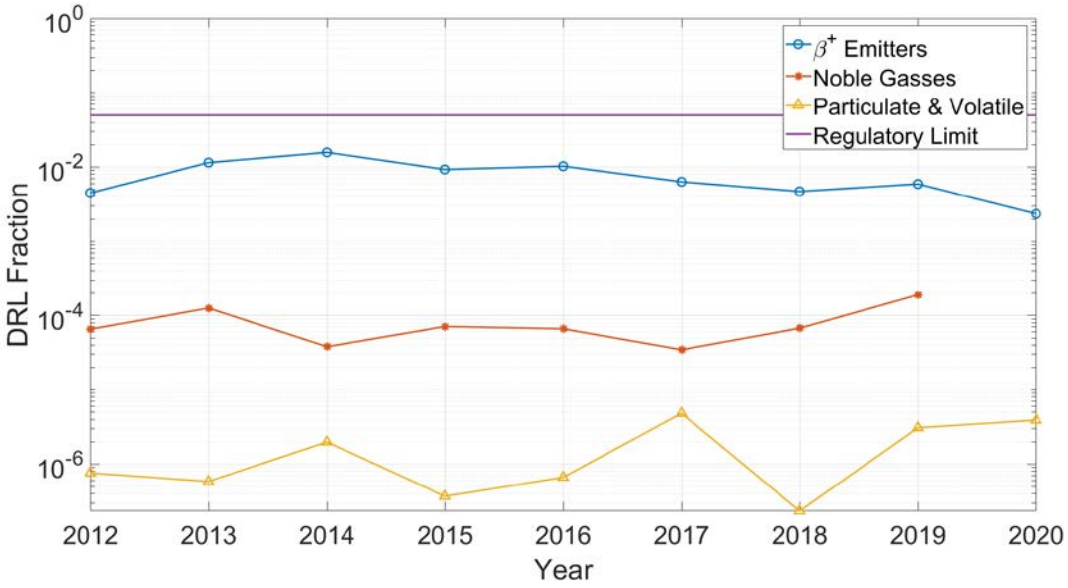

Figure 10 TRIUMF airborne emissions, 2012 to 2020.

The principal emissions are short-lived nuclides due to neutron activation of air produced in spaces immediately adjacent to accelerators and production targets. Releases of noble gases, principally due to releases from BWXT medical radioisotope production processes, are approximately two orders of magnitude below the air activation products, with particulate and volatile releases four orders of magnitude less. Total annual releases of liquid effluent are at the level of 10^{-8} of the DRL.

Over the present licensing period TRIUMF has fully developed processes to fully characterize and monitor the downstream impact of its principal emissions, which consist mainly of short-lived β^+ emitters (C-11; N-13; O-15) and Ar-41. This characterization included the following elements:

- Calibration of the responses of active stack monitors with C-11 radiomethane;
- Measurements of the relative fractions of each of the dominant β^+ emitters and Ar-41 in the nuclear ventilation exhaust of the principal stacks;
- Calculation of new Derived Release Limits based on CSA N288.1-14;
- Annual comparisons of the predictions of the DRL model to downstream doses measured with data from a Health Canada detector located approximately one-half way between the TRIUMF site and the "critical population" in the Wesbrook Village area of the UBC South Campus Development.

The comparison between the results predicted by the DRL model and the Health Canada measured doses for the years 2014 to 2019 is shown in Table 3.

Table 3 Measured v. predicted dose at Health Canada detector location

Year	Measured Dose (nSv)			Predicted Dose (nSv)	Ratio
	511 keV	1294 keV	Total		
2014	3.17E+03	1.85E+02	3.35E+03	8.89E+03	2.65
2015	2.61E+03	1.28E+02	2.73E+03	7.50E+03	2.74
2016	2.37E+03	1.10E+02	2.48E+03	7.86E+03	3.17
2017	2.63E+03	1.17E+02	2.75E+03	8.32E+03	3.02
2018	2.55E+03	1.00E+02	2.65E+03	6.28E+03	2.37
2019	3.01E+03	1.20E+02	3.12E+03	6.14E+03	1.97

In 2017 *TRIUMF Screening Level Environmental Risk Assessment* (Document-148250), was released as a retrospective risk assessment to substantiate the identification and quantification of contaminants and physical stressors associated with TRIUMF operation which may pose a risk to the environment, and to establish which of these need further monitoring and analysis. The assessment confirmed that TRIUMF's environmental protection programs were adequate.

Following an assessment of procedures and practices, the RPG documented a detailed set of procedural requirements, *Environmental Protection Program Requirements* (Document-142043) covering all aspects of the emissions and environmental monitoring (2017). The intent was to identify and remedy potential weak points in the program, as well to provide a basis for future internal environmental audits. The first two of these audits were performed in 2019. (The schedule was disrupted in 2020 due to the COVID-19 pandemic.)

In 2020 the Safety Systems Group installed a Lucas cell as part of the stack monitoring equipment for the Life Sciences research labs in the basement of the Meson Hall Extension Service Annex. The function of this device is to detect and quantify airborne alpha emitting nuclides used in experiments.

Future Plans

The Office of EH&S will continue to provide guidance on environmental protection requirements to designers of new facilities like ARIEL and IAMI.

TRIUMF is considering installing another detector to the south of the site that will provide similar monitoring capability to the Health Canada detector provides on the north side. This in turn will provide an additional data point to validate the DRL model used to predict doses to the public.

Challenges

3.1.10 Emergency Management and Fire Protection

Relevance and Management

TRIUMF has a well-established Emergency Program consisting of an Emergency Preparedness Plan (EPP; Document-4952) that outlines roles and responsibilities for implementing the overall program, and an Emergency Response Plan (ERP; Document-5856) with a complete spectrum of graded emergencies and corresponding responses.

The program and all supporting documents were reviewed and updated in 2019 to align with REGDOC 2.10.1 – Nuclear Emergency Preparedness and Response.

The Emergency Response Manager plans and coordinates regular exercises and drills. Outside observers have been involved in the drill assessment and a debriefing is carried out after the event. Corrective Actions is implemented to address deficiencies.

The TRIUMF site has four Emergency Assembly Areas (EAAs). The ERP specifies each EAA to be attended by an RPG Surveyor, a Communications person with a two-way radio, and a Level 2 FAA.

Elements of the First Aid Program are described in TSN 2.1 (Document-857). TRIUMF continues to have more than the required full complement of Level 2 First Aid Attendants for regular working hours. After regular hours, the required Level I coverage as specified based on the staffing levels is provided by security guards hired on contract.

The TRIUMF site and Fire Protection Program is reviewed annually against the requirements of CSA N393-13.

Past Performance

A 2014 internal training audit specified the need for training for TRIUMF staff who have designated roles. The training is provided in the form of a pre-drill session presentation and "question and answer" session prior to each emergency response drill.

Emergency response drills were held at the following times over the present licensing period:

- October, 2014: Attended by Vancouver Fire and Rescue Services and BC Ambulance representatives who provided feedback. Corrective actions were completed and report sent to the CNSC.
- June, 2016: Included a compound Radiation Protection and First Aid Exercise. Attended by Vancouver Fire and Rescue Services. Overall, the EPP was found to comply with licence condition handbook and regulatory requirements. Ten recommendations were issued and addressed as part of continual improvement. CNSC personnel also observed the exercise and provided feedback to TRIUMF Emergency Preparedness personnel.
- September, 2019: A site-wide emergency evacuation drill was held to verify that all buildings on site could be safely evacuated simultaneously. A table-top emergency response exercise with a chemical spill as the emergency scenario was conducted immediately after the evacuation exercise. Based on observations made during the exercises, a total of 8 corrective actions were indicated.

With the onset of COVID-19 in 2020, TRIUMF struck a task force to coordinate the response site wide. A systematic approach was taken coordinated by the Chief Operating Officer with input from the Emergency Response Manager and other key stake holders. HR and EHS policies were put in place to provide personnel with guidance on reporting absence due to COVID, a protocol for managing the potential incidence on site and guidance for personnel on mitigation requirements. In addition, specific safe work procedures and facility controls were enacted to provide a safe work environment for personnel.

The Fire Protection Program continued to meet the requirements of NFPA 801 with an intent to transition to regulatory compliance with CSA N393-13 over the licensing period. Site FHAs were updated and new FHAs were completed for the ARIEL and IAMI facilities. Major upgrades to the fire prevention system, site condition inspection, Third Party Reviews (TPRs) for inspection testing and maintenance (ITM), as well as fire protection program reviews were conducted as follows over the present licensing period:

- Site Condition Inspection 2013
- TPR for ITM: 2013 (for years 2011 and 2012)
- Site Condition Inspection 2015
- TPR for ITM: 2015 (for years 2013 and 2014)
- Replacement of fire alarm system: 2013 to 2016
- Fire Protection Program Review (2016)
- In 2017, TRIUMF engaged outside expertise in industrial safety to implement a site-wide 5S program that resulted in significant reduction of accumulated surplus equipment and generally improved site organization as well as optimizing work space across the laboratory. A direct benefit of this industry best practice was a significant reduction in combustible load resulting in improved fire safety.
- “Mock-emergency” exercises conducted October, 2018 in the ARIEL Building ground floor beamlines “switch-yard” to verify the efficacy the proposed emergency egress routes. The exercises involved the transport of a spine-board through the proposed routes. One area was identified as being inaccessible in this manner. Administrative controls were developed to mitigate the hazards of this limitation, including: a specific pre-job briefing requirement to notify workers of the impaired rescue zone; a safe work procedure; and a requirement for two persons to be present when work is performed in this area.
- Site FHA updated to CSA-N393 (2019)
- Site Condition Inspection 2019
- TPR for ITM: 2019 (for years 2017 and 2018)
- The PLC Fire Safety Solutions audit of the TRIUMF Fire Protection Program documented the state of compliance with the requirements of CSA N393-13, the National Fire Code of Canada (NFCC-2015) and other applicable codes and standards. A task group led by the Fire Protection Program manager was formed to address the findings from the audit and the site FHA and bring TRIUMF into complete compliance.
- In 2020, TRIUMF entered a six-year contract with PLC Fire Safety Solutions to provide ongoing mandated assessments and inspections of the TRIUMF FPP, and to provide training to TRIUMF personnel to perform annual facility inspections in the intervening years between the three year audit.

Future Plans

The FHA updated in 2019 evaluated worst case internal and external fire scenarios and their impact on fire, life, and nuclear safety objectives for TRIUMF facilities. The FHA concluded that fire hazards are being controlled and that impacts of a fire event would not exceed loss-limiting criteria including regulatory dose limits for member of the public or TRIUMF personnel, nor result in unacceptable releases to the environment. There were deviations from accepted codes and standards identified and these are in

the process of being addressed to enhance site fire safety. The most challenging areas concern fire suppression in the ISAC experimental halls, a separate testable emergency generator for the forced air in the stairwells at ISAC and ARIEL, and a fire wall or safety interlock upgrade for the main cyclotron magnet transformer.

CSA N393-13 Fire protection for facilities that process, handle, or store nuclear substances

The 2019 FHA was conducted on the basis of assessing compliance with this standard. Most of the identified deficiencies are expected to be resolved within a year of the date of this document. Any remaining actions will be completed within one more year.

Challenges

3.1.11 Waste Management & Decommissioning

Waste Management

Relevance and Management

The TRIUMF waste management program for hazardous non-radioactive waste is managed by the OH&S Officer and provides for safe secure storage of waste away from the main work areas, in the stand-alone Hazardous Materials Building for eventual off-site disposal with a third party facility. JHSC inspections and management site walkthroughs include monitoring the handling of hazardous materials across the site.

The TRIUMF Radioactive Waste Management Program is managed and implemented by the Radiation Protection Group. High-level waste in the form of BL1A and ISAC irradiated targets is allowed to decay in a dedicated Spent Target Storage Facility and is subsequently shipped off-site after a 2-3 year decay period to Canadian Nuclear Laboratories (CNL) for storage in the Intrusion Resistant Underground Storage Facility. Typically, there are two such shipments a year and the activity inventories are reported in the Annual Compliance Report.

Low-level radioactive waste consisting largely of personal protective clothing and decontamination waste is sorted at the source and segregated to allow for optimum decay and eventual disposal to local landfill sites when radioactivity levels drop below the clearance level. Waste that is not clear is stored and re-assessed periodically.

Contaminated oil from vacuum pumps is assayed for both beta/gamma emitters and tritium and disposed of as non-radioactive in the regular hazardous waste stream after being cleared based on the assay results. The assay results are all stored in a purpose-built database. For oil that does not clear immediately, the database projects an expected clearance date based on the measured radioactive inventory.

Low-level metal waste is disposed of to local recyclers as non-radioactive after being cleared.

The disposal status of the different radioactive waste streams is reported by the RPG at quarterly Safety and Quality Management Review meetings.

Past Performance

After the restrictions placed on waste disposal at CNL in late 1990s, and prior to the establishment of the present radioactive waste management program in 2012 TRIUMF

had amassed a backlog of compactible waste, ion exchange resin, HEPA filters, and pump oil, accumulated over 10-15 years of operations. Since then, almost all of the backlog of all of these waste types[10] except metals and concrete has been cleared and released as “non-radioactive” under the provisions of the program.

Clearance of historic backlogs of low-level metals, composed almost exclusively of activated components of decommissioned beamlines and ancillary systems, commenced in 2019 and is ongoing.

In 2014 a Transport Canada inspection found workers whose job included preparing hazardous waste for transport who did not have TDG training. The deficiency was promptly corrected.

Future Plans

The RPG is investigating methods to reliably place upper bounds on the bulk activity concentrations in activated concrete blocks based on the assessment of surface properties. Once finalized, his will potentially allow their disposal via pulverization and subsequent use as a component of road-building aggregates.

A mechanism for tracking hazardous materials from purchase to disposal will be developed and implemented on a site-wide basis in Workday to better manage all aspects of procurement, use, and storage.

CSA N292.0-19 General principles for the management of radioactive waste
CSA N292.3-14 Management of low and intermediate-level radioactive waste

TRIUMF expects to be in compliance with both standard within one year of relicensing.

Challenges

Planned refurbishment of Beam Line 1A in the Meson Hall over the next licensing period will result in the removal of large radioactive components that will need to be stored on the TRIUMF site for decay prior to its ultimate off-site disposal. This in turn will require a significant effort to investigate and implement safe removal and disposal of older physically large waste/surplus accelerator components that presently occupy most of the available space in shielded storage.

In recognition of the need to address requirements for shielded storage over the next several decades, a radioactive waste (RAW) working group was struck in 2019 to develop plans for establishing infrastructure required for storing, assessing, preparing and packaging RAW taking into account refurbishment projects and ramping up of ARIEL and IAMI facility operations. An initial report (July 2020; Docment-183041) identifies the preparatory tasks to be completed and the resources required to develop a fully costed plan.

[10] Ion exchange resin and HEPA filters are included in the “compactable” waste stream owing to the disposal endpoint being the local landfill.

Decommissioning

Relevance and Management

The TRIUMF Preliminary Decommissioning Plan addresses the activities that will need to be undertaken for a full decommissioning of the facility to a Greenfield site. The plan is based on a thorough study and analysis of the activation levels in the infrastructure, particularly for the heavily shielded areas. Identification of the long-lived activation products indicate an optimum decommissioning time frame that allows bulk materials and large accelerator components to decay below clearance levels. The plan is staged over three phases: the first 2-3 years when all ancillary buildings and any removable radioactive material are removed leaving the site in a safe; after 25 years when the low energy cyclotrons are decommissioned; and after 45 years when the remaining 520 MeV facility is decommissioned. At each stage of the plan the footprint for the site is reduced so that for the last phase from 20 – 45 years only the accelerator vault and a much smaller service annex remain.

Past Performance

TRIUMF's preliminary decommissioning plan was revised in 2013 and 2018 (with costing in 2012 and 2017 dollars). The last revision included an independent analysis by a quantity surveyor for demolition and disposal costs with separate costing for handling and disposal of hazardous materials such as asbestos tile and leaded paint in pre-1990 buildings. In addition, the time period for decay between the first and second phase had to be extended from twenty to twenty-five years to provide sufficient time for the activity inventory in the isotope production cyclotrons concrete to decay below the unconditional clearance level. Although this shifted the time for the phase 2 work, it did not change the overall 45-year time scale for phase 3 as that is dependent on the 520 MeV accelerator.

Costing for the plan in 2022 dollars includes contingency (15% for Phase 1 and 30% for Phase 2 and 3) and a five year forecast using 2% annual inflation rate with a resultant total projected greenfield cost of $69.87M. Information on TRIUMF's Financial Guarantee for decommissioning is provided in Section 3.0.15 below.

Future Plans

The revision of the preliminary decommissioning plan in 2023 will include the decommissioning costs for IAMI, a cost estimate for which was provided with the construction licence application.

CSA N294-19 Decommissioning of facilities containing nuclear substances

The *TRIUMF Preliminary Decommissioning Plan* (Document-8810) was revised in April, 2020 to incorporate CNSC commentary on the previous version (May, 2019) and is presently in compliance with N294-19.

Challenges

3.1.12 Security

Relevance and Management

The *TRIUMF Security Plan* (Document-29843) describes the measures to ensure compliance with the Nuclear Security regulations, the Radiation Protection regulations

for safeguarding radioactive material, and regulatory requirements for site access control. It is reviewed annually and updated as required. TSOP-10 captures the processes in place for site access for all personnel and visitors. The Radiation Protection Group Radioactive Materials Co-ordinator keeps records of the inventory of all nuclear substances on site. A training plan for TRIUMF Security Guards has also been implemented.

3.1.13 Safeguards

Relevance and Management

TRIUMF continues to participate in the IAEA Integrated Safeguards Approach as a CNZ laboratory. The program is managed by the Radioactive Materials Co-ordinator in the Radiation Protection Group (RPG).

TRIUMF continues to file all required submissions for the inventory of fissile and fertile substances. Most of this material consists of small calibration sources or samples used by experimenters in the subatomic physics program, hundred gram quantities of depleted uranium being used for fabricating actinide targets for creation of rare-isotope beams at ISAC, and thorium metal targets irradiated primarily on the end of BL1A at the Isotope Production Facility (IPF). New materials are declared with an Inventory Change Document and if required an Import Licence is obtained from the SATD Licensing Administrator. The Physical Inventory Taking and Verification is completed and reported annually, as well as submitting "Additional Protocol and Operational Programme" documentation as required.

Past Performance

TRIUMF has had on-site IAEA inspections several times over the present licensing period, including:

- September, 2014: "Complementary Access Inspection". No findings requiring actions by TRIUMF.
- October, 2016: Verification of physical inventory and Design Information Questionnaire. Both verifications reports were satisfactory and no further actions were required.
- February, 2019: Inspection for Safeguarded Materials. Two old containers containing small quantities of thorium nitrate powder ($Th(NO_3)_4$; 0.018 kg Th) and uranium oxide powder (UO_2; 0.044 kg uranium) were discovered in a chemistry cold lab. The issue was resolved with the submission of two ICDs for "accidental gain" of the material, which were immediately removed from the lab to the required secure storage location.
- October, 2020: Verification of physical inventory. No findings requiring actions by TRIUMF. A report of the inspection was submitted to the CNSC by TRIUMF.[11]

[11] Due to COVID-19 travel restrictions, there was no on-site presence of CNSC personnel as is the usual practice.

In 2016 following a review of the requirements of CNSC RD-336, the requirement to submit monthly statements of the General Ledger was rescinded for months in which no inventory changes occur.

In 2018 TRIUMF released a Safeguards program document to consolidate the program information and ongoing requirements, and to document that the requirements of CNSC REGDOC-2.13.1 are being met.

Future Plans

TRIUMF does not foresee any changes in the Safeguards program for the next licensing period, although the quantities of materials handled are expected to increase as a result of the initiation and ramp-up of ARIEL operations, and the intended commercial production of Ac-225 at the IPF. The ARIEL program will include the irradiation of actinide “physics targets” for the nuclear physics research program as well as the irradiation of thorium metal “medical targets” at a dedicated facility downstream of the physics target station but upstream of the beam dump.

Challenges

3.1.14 Packaging and Transport

Relevance and Management

Overall responsibility and management for shipping radioactive materials lies with the RPG Radioactive Materials Co-ordinator (RMC). Authorization to make a shipment requires a permit signed by both an Associate Lab Director and the RMC, who verifies that all regulatory requirements are met for each shipment.

The vast majority of Class 7 shipments from TRIUMF are undertaken by or on behalf of the Life Sciences Division. Other regular shipments include the disposal of spent ISAC targets to CNL in Chalk River, Ontario; few if any shipments fall outside of these two categories in any given year. Almost shipments are made in Type A packaging.

Routine Life Sciences shipments are prepared by TDG-qualified Life Sciences personnel following requirements specified by RMC-owned procedures, with guidance and assistance provided by the RMC for other shipments as required.

Logistics personnel releasing Class 7 packages to carriers are TDG-qualified and receive training in TRIUMF-specific requirements from the RMC.

Past Performance

In 2014 a Transport Canada inspection noted these deficiencies:

1. No record of training could be produced for a Life Sciences Division worker who prepared radioactive shipments;
2. Packages were shipped without a validly displayed 24 hour emergency phone number.

Both deficiencies were corrected promptly.

In 2018 contamination was found the inside of a Type A shipping flask due to damage sustained to the inner package during road transport for disposal to Canadian Nuclear Labs in Chalk River. The resulting investigation found that the cause was due to metal

fatigue of the inner pail resulting from movement of the contents during transport. The principal corrective action was to source a heavier-gauge inner pail.

In 2019 an improperly secured lock ring on the outer package of a Type A container caused the lid to become separated from the rest of the outer package. After the unsecured lock ring had been properly secured by a TDG-qualified freight handler, the outer package sustained significant damage when it fell from an airport loading ramp. Corrective actions included a revision of the TRIUMF shipping protocols to require documentation of instructions for use and certification of any Type A containers.

Future Plans

Shipments of spent targets to CNL in Chalk River are expected to increase by a factor of three or more when ARIEL operations reach their full level during the next licensing period.

Challenges

3.1.15 Site Specific

Public Information Program, Outreach, and Connections to the Local Community

TRIUMF places a high priority on efforts to enhance relations with both the local community and public at large. Through the TRIUMF Communications Office (CO), TRIUMF has undertaken a variety of initiatives to encourage public connection and invite the local community to the laboratory.

These initiatives have included:

- Regular participation in community events held by the local civic association, the University Neighbourhoods Association (UNA), most recently in May, 2020;
- Joining with a local art and design university to develop a program, including an Artist in Residence initiative, which helps contextualize the scientific research and offer new perspectives on it;
- Organizing science lectures and Q&A sessions in the community, including the popular Saturday Morning Lecture series;
- Holding open houses and TRIUMF-related exhibitions both locally and across the country;
- Offering regular public tours where the public is welcomed into the facility;
- Launch of a new online public outreach portal that enables virtual access to the laboratory. (http://www.discoverourlab.triumf.ca)

TRIUMF has developed strong connections with leaders of the local community, such as business owners, journalists, and residents. Among the outreach and public relations activities that have occurred over the present licensing period are:

- Hosting a diverse array of young talent through TRIUMF's own High School Fellowship program, as well as participation in UBC's Emerging Indigenous Scholars Summer School – both initiatives that bring talented high school students to the lab for a summer work experience program (Ongoing);
- Leading a Q&A session with particle physicists following a showing of the CERN-produced film about the Large Hadron Collider at the Vancouver International Film Festival (2014);

- Launching the Unveiling the Universe public lecture series, in partnership with Science World which hosted the lectures, that has attracted several hundreds members of the public for each of its dozen events (2013 onwards);
- Attracting and hosting large international science conferences, including the Annual Meeting of American Association for the Advancement of Science (AAAS) in 2012 and the 9th International Particle Accelerator Conference (IPAC) in 2018 (Ongoing);
- Carrying out a year-long schedule of programs that celebrated the lab's 50th anniversary (2018);
- Condcuting outreach to Ottawa, where TRIUMF community members held meetings with Members of Parliament to discuss topics related to science, technology, and innovation in Canada, as well as hosted a public lecture at the Canadian Museum of Science and Technology (2018);
- Embarking on a new partnership with the RBC Foundation that is expected to significantly increase the scope and scale of TRIUMF's student programs over the next five years (2019).

In 2018, TRIUMF initiated the development of the lab's *Public Information and Disclosure program* (PIDP; Document-156040). This program presents a framework for policies and practices for how the lab discloses, disseminates, and shares information about lab activities with the public and other stakeholders. The program intends to increase the level of public understanding about TRIUMF and ensure key information related to the health, safety, and environment is effectively communicated to the public. The web site includes a statement on the research impact of TRIUMF, a description of the environmental risk assessment and environmental monitoring processes, along with event reporting to ensure transparency of informing the public of both routine and non-routine occurrences at the laboratory.

The TRIUMF Communications Office will continue to explore new and exciting ways of sharing the excitement and value to society of scientific discovery with a particular focus on leveraging new tools and platforms to make the laboratory more accessible to those across the country.

Financial Guarantees

Relevance and Management

The financial instrument for funding decommissioning as described in the preliminary decommissioning plan (PDP) is governed by the Financial Security and Access Agreement, the Escrow Agreement and Fund Contribution Gap Agreement. The main objective of the PDP is to ensure the site is brought to a safe state of closure in the event of decommissioning. The financial component of the plan demonstrates the funding measures and provides assurance that adequate resources will be available to fund decommissioning activities. These are agreements between TRIUMF INC., CNSC and Royal Trust Corporation of Canada, where the latter is the escrow agent.

Past Performance

At the end of Fiscal Year March 31, 2019 the balance in the decommissioning fund was $11.534M. The projected decommissioning fund balance as of March 31, 2023 and as captured in Schedule A of the Financial Security and Access Agreement is

$14.788M. This sum will fund Phase 1 decommissioning costs of $12.656M plus the cost of preparing a detailed plan ($1.5M) for a total of 14.179M, and place TRIUMF in a safe shutdown state.

The next decommissioning phases will be funded by the remaining balance from the decommissioning fund (Schedule A), sale of TRIUMF's assets and interest earned on the investment of monies derived from these sales. While TRIUMF projects all decommissioning costs to be funded from these sources, Financial Guarantees are in place ensuring the decommissioning plan remains fully funded by TRIUMF's university partners under the Fund Contribution Gap Agreement.

Future Plans

The financial instrument will be updated for the next revision of the PDP in 2023 that will include IAMI. Additional decommissioning costs for IAMI have been estimated using the costing for the existing medical isotope production accelerators at TRIUMF. There will be an additional cost of $1.0M for Phase 1 and $0.9M for Phase 2.

4.1 Other Matters of Regulatory Interest

Aboriginal Engagement

TRIUMF is situated on the south campus of the University of British Columbia. The UBC land is leased from the province and the approval requires consultation with the xʷməθkʷəy̓əm (Musqueam) First Nation, on whose unceded land the university is located. The university has a close partnership with the Musqueam First Nation (Memorandum of Understanding-2006) and there is a 99-year land lease in place for the 13.5 acre site that was signed in 2008. Land-use management is bound by the Municipalities Enabling and Validating Act with a requirement for aboriginal engagement when updating land-use plans. The most recent UBC land-use plan received provincial approval in 2010, and it includes a lease specific to TRIUMF for use as academic land.

Engagement with the Musqueam First Nation occurs on a monthly basis with UBC providing updates on progress with the land-use plan and any changes that will have impact. All construction on the TRIUMF site requires prior approval through the UBC Campus + Community Planning. In addition, with significant changes such as the construction of IAMI, TRIUMF is required to have an open house with specific outreach to the Musqueam community to invite their attendance and input. This engagement is aligned with TRIUMF's Public information and Disclosure Protocol, where the Musqueam First Nation are one of our target audiences.

TRIUMF, with UBC coordination, has disclosed to the Musqueam First Nation our plans for submission to CNSC of an application to renew the TRIUMF operating licence.

Outstanding CNSC Action Notices (March, 2021)

Action Notice	Requirement Summary	TRIUMF Response	Responsible	Due Date
EDAD-TRIUMF-2015-AN1	*Complete revisions to Site Fire Hazard Analysis Report* *And TPR for FP systems ITM & Site Condition Audit*	Request for quotation are due April 30, 2019. Expect to proceed in May with FHA process. All data tables have been revised in preparation. Third Party Review (TPR) for Fire Protection Systems and TRIUMF Action Plan submitted to CNSC Revised site Fire Hazard Assessment submitted to CNSC	EHS/OHS/Eng	COMPLETED TPR &Plan sent November 2019 FHA sent Dec. 2019
MS-TRIUMF-2019-AN5	*Establish a program to ensure that the safety systems of the hotcells are verified and calibrated*	Add fixed-in-place monitors for RCR1 Lab 1. Complete installation of monitors 2. Revise RCR1 SAR 3. Release Lab 005 SAR	LS / RPG/SSG	COMPLETED COMPLETED COMPLETED Sep. 30 (Late)

References

Ref.	Document Title	Document Number	Rev. No.	Effective Date
Executive Summary				
1.	PA1OL-01.00/2022	Document-578		2012-07-01
Business Plan				
2.	TRIUMF Quality Manual	Document-611	7	2020 -06-09
3.	TRIUMF Logic Model	Document-129376	3	2020-07-31
4.	National Research Council of Canada Evaluation of TRIUMF	Evaluation of TRIUMF	-	2019-03-24
SCA Management System				
5.	TRIUMF Strategic Plan for Safety	Document-121747	2	2016-07-07
6.	TSOP-02 Non-conformity Reporting and Resolution	Document-4758	7	2021-02-05
7.	TSOP-09 Quality Program Assessment	Document-607	7	2021-02-05
8.	TRIUMF Key Performance Indicators	Document-126719	2	2016-06-20
9.	TRIUMF Enterprise Risk Management Program	Document-134918	2	2021-01-08
10.	Work Permit Guidance for Permit Holders, Facility Coordinators, RPG Surveyors, and Operations	Document-143163	5	2019-04-05
11.	Safety and Quality Management Review Meeting - Terms of Reference	Document-24195	2	2018-01-15
12.	TRIUMF Policy on Safety in the Workplace (TSN 1.0)	Document-537	2	2011-06-09
13.	TRIUMF Joint Health & Safety Committee Terms of Reference	Document-18121	5	2017-10-23
14.	TRIUMF Annual Compliance Report 2019	Document-179092	1	2020-06-30
15.	TRIUMF Organizational Chart	TRIUMF web site	-	2020-12-15
SCA – Human Performance Management				
16.	TSOP-04TRIUMF Training Program	Document-609	5	2019-04-01
17.	Training Implementation Panel – Terms of Reference	Document-131932	2	2017-10-24
18.	TSN 1.1 TRIUMF Radiation Protection Training Program	Document-538	5	2017-03-07
SCA – Operating Performance				
19.	TSOP-11 Operations Management	Document-5604	2	2008-10-15
20.	TSOP-12 Configuration Management	Document-5605	3	2015-12-04

Ref.	Document Title	Document Number	Rev. No.	Effective Date
21.	Systematic Approach to Shutdown (SAS) Committee - Terms of Reference	Document-146584	2	2019-11-08
22.	Systematic Approach to Shutdown Job Grading Tool	Document-175798	1	2019-11-08
23.	Systematic Approach to Shutdown Workflow	Document-67361	4	2020-12-16
24.	TSOP-07 Experiment Management Science Division	Document-599	4	2015-07-02
25.	TSOP-14 Approval of Experiments for the Life Sciences Division	Document-24353	1	2019-03-11
26.	Physical Sciences Divisional Safety Committee Terms of Reference	Document-145636	1	2017-08-11
27.	Life Sciences Division Safety Committee - Terms of Reference	Document-146028	1	2020-07-16
SCA – Safety Analysis & Physical Design				
28.	TSOP-15 Project Governance	Document-22889	5	2019-03-26
29.	TSOP-06 Engineering Design, Manufacture and Assembly	Document-597	2	2008-10-15
30.	ISAC II Safety Report	Document-561	4	2013-07-22
31.	Design Note TRI-DN-13-17 BL1A Shield Plug Modifications for UCN	Document-93063	2	2013-10-28
32.	Actinide Target SAR Addendum for Thorium Oxide	Document-110961	1	2014-07-30
33.	Beamline 2C4 Solid Target Facility Safety Report	Document-30071	5	2017-08-29
34.	ARIEL Facility Safety Report	Document-51332	3	2015-07-06
35.	Safety Analysis for UCN Commissioning to 1 Microampere	Document-136684	2	2017-04-24
36.	ARIEL-II Phase 3/CANREB Safety Analysis Report	Document-158171	1	2018-09-06
37.	TRIUMF TR13 Safety Report	Document-5359	2	2005-08-25
38.	TRIUMF to ACU, CCM, CBH Pipelines for PET Radiopharmaceuticals Safety Analysis Report	Document-9605	9	2019-11-12
39.	IAMI Safety Analysis Report	Document-189013	1	2020-10-06
40.	Actinide SAR Addendum for a proton-to-neutron converter target at ISAC	Document-188621	1	2020-09-28
41.	Worst Case Emissions Analysis Report	Document-55017	1	2015-01-31

Ref.	Document Title	Document Number	Rev. No.	Effective Date
42.	TRIUMF Safety Report	Document-563	3	2006-01-26
43.	ISAC Extension Safety Report	Document-565	2	2000-10-01
44.	TSN 2.4 Derived Release Limits for Radioactive Emissions from the TRIUMF Site	Document-8506	9	2019-04-12
45.	TRIUMF CP42 Safety Report	Document-7114	3	2006-08-08
46.	TRIUMF TR30-1 Safety Report	Document-3794	3	2005-06-06
47.	TRIUMF TR30-2 Safety Report	Document-562	8	2003-03-01
48.	Functional Requirements and Design of the e-Hall Maze Area Safety Unit	Document-57727	1	2013-01-31
49.	Area Safety Units and the Emergency Trip Pushbutton System for Secondary Beam Exclusion Areas	Document-27748	7	2015-10-01
50.	Accelerator Access Control Interlock Systems: Functional Requirements and Design of Area Safety Units and the Emergency Trip Pushbutton System for Primary Beam and ISAC Exclusion Areas	Document-27775	7	2015-10-01
SCA – Fitness for Service				
51.	TSOP-08 Calibration & Inspection	Document-595	4	2016-12-12
52.	TSOP-12 Configuration Management	Document-5605	3	2015-12-04
53.	Verification of Effluent Air Monitor Calibration	Document-109449	1	2014-05-09
54.	'Air-Check' O2 Deficiency Monitor Calibration Procedure	Document-117682	1	2015-02-10
55.	TSN 1.5 Policy & Procedures for the Defeat of Safety Interlocks and for Device Disables	Document-541	3	2018-11-23
56.	TSN 1.6 Availability Requirements for TRIUMF Radiation Safety Systems	Document-542	1	2011-06-09
57.	TSN 1.3 TRIUMF Lock-out Policy and Procedures	Document-539	6	2018-06-14
SCA – Radiation Protection				
58.	TSN 1.2 Policy on Radiation Exposure	Document-545	3	2010-01-25
59.	TSN 1.1 TRIUMF Radiation Protection Training Program	Document-538	5	2017-03-27
60.	TSN 3.6 Designation of Nuclear Energy Workers	Document-850	2	2012-12-05
SCA – Conventional Health & Safety				

Ref.	Document Title	Document Number	Rev. No.	Effective Date
61.	TRIUMF Occupational Health & Safety Handbook	Document-840	6	2017-09-07
62.	WorkSafeBC OHS Regulations	OHSRegulation	--	
63.	Lead Exposure Control Plan	Document-183709	1	2020-08-28
64.	TSN 3.9 Job Hazard Assessment & Pre-Job Briefing	Document-178912	1	2020-08-18
65.	TSN 5.13 Confined Space Entry Program	Document-155698	1	2020-10-16
SCA – Environmental Protection				
66.	Environmental Management System	Document-15678	2	2016-12-14
67.	Monitoring Emissions for the TRIUMF site	Document-5328	3	2015-11-27
68.	Environmental Monitoring for the TRIUMF site	Document-5329	3	2015-11-27
69.	TRIUMF Screening Level Environmental Risk Assessment	Document-148250	3	2020-10-29
70.	Environmental Protection Program Requirements	Document-142043	1	2017-04-07
71.	TRIUMF Safety Report (Section 4.4.10 – Action Levels)	Document-563	3	2006-01-26
72.	GVSDD Bylaw #299 on Waste Sewage (2007) and amendments	MetroVancouver-Bylaws	-	2018-10-26
73.	GVRD Air Quality Management Bylaw No. 1082 (2008) and amendments	MetroVancouver-Bylaws	-	2020-05-29
74.	BC Environmental Management Act – Waste Discharge Regulations and amendments	EnvManagement-WDR	-	2019-09-15
SCA – Emergency Management & Fire Protection				
75.	TRIUMF Emergency Preparedness Plan	Document-4952	6	2019-11-28
76.	TRIUMF Emergency Response Plan	Document-5856	6	2019-11-29
77.	TSN 2.1 TRIUMF First Aid Program	Document-857	3	2013-12-02
78.	TRIUMF Fire Protection Program	Document-29313	2	2010-10-12
79.	TSN 5.9 Fire Protection and Prevention	Document-868	3	2010-09-03
SCA – Waste Management & Decommissioning				
80.	Radioactive Waste Management Infrastructure Plan - Phase 1	Docment-183041	1	2020-07-31
81.	Radioactive Waste Management for the TRIUMF site (EHS-RPG-06-10)	Document-5330	5	2016-12-23

Ref.	Document Title	Document Number	Rev. No.	Effective Date
82.	Sorting Radioactive Waste at the Source (EHS-RPG-06-01)	Document-5816	2	2012-03-23
83.	Assaying Radioactive Waste (EHS-RPG-06-02)	Document-8000	2	2012-03-23
84.	Assaying Pump Oil Samples (EHS-RPG-06-03)	Document-5817	2	2016-09-01
85.	Characterization of Radioactive Waste (EHS-RPG-06-04)	Document-5815	2	2012-03-29
86.	TRIUMF Preliminary Decommissioning Plan	Document-8810	6	2020-04-30
87.	CNSC Financial Security and Access Agreement	Document-30101	1	2008-01-07
88.	TRIUMF Fund Contribution Gap Agreement	Document-30102	1	2008-01-07
89.	TRIUMF Escrow Agreement	Document-30103	1	2008-01-07
SCA –Security				
90.	TRIUMF Security Plan	Document-29843	5	2015-08-15
91.	TSOP-10 TRIUMF Site Access	Document-1733	6	2018-05-14
92.	TRIUMF Safety Report section 4.1	Document-563	3	2006-01-26
SCA –Safeguards				
93.	TRIUMF Safeguards Program	Document-154117	1	2018-12-17
SCA – Packaging and Transport				
94.	Package Handling and Transport Protocols for Radioactive Shipments	Document-62648	5	2019-10-21
95.	Procurement and Shipping Radioactive Materials Procedure	Document-76036	3	2017-02-09
SCA – Site Specific				
96.	TRIUMF Virtual Lab Tours web site	discoverourlab	-	2020
97.	TRIUMF Public Information and Disclosure Program web site	PIDP	-	2018
98.	TRIUMF Public Information and Disclosure Program	Document-156040	4	2020-12-22