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TRIUMF 500 MeV Cyclotron: The next 40 years

I am delivering these words with a great sense of pride and immense responsibility.

We feel the responsibility entrusted upon us to ensure that the TRIUMF 500 MeV cyclotron, a world-class accelerator with unmatched capabilities, continue to remain relevant and vibrant and to drive excellence in science and applications, for 40 more years to come, just as you, the original cyclotron builders succeeded.

You have handed the research community of Canada and indeed the world, a tremendous asset which for 40 years has been the engine of discovery, innovation, and important societal and economic benefits.

It is worth remembering that for its day, this cyclotron was a very daring machine: Use of H-minus and the extremely good vacuum that it necessitated, high extraction energy in spite of low injection energy, extreme spiral angle magnets,… And all this design was based on calculations made with computers that had a 1000 times less computing power than today's throwaway laptops.

These features of the design resulted in versatility that allowed 4 simultaneous extracted proton beams at energies ranging from 70 to 520 MeV, with a broad range of beam intensities, from nA to >100 uA, and a total current of up to 300 uA (in the past polarised beam capability). These design attributes coupled with robust and reliable engineering, have enabled first rate discovery science in nuclear physics, materials science, and nuclear medicine, the treatment of patients, the production of medical isotopes, and proton and neutron irradiation capabilities.

Despite its 40 years of continuous operation, the TRIUMF 500 MeV cyclotron has been performing with outstanding reliability, delivering >5000 hours/yr exceeding 90% availability, at times reaching spectacular performance at > 95% availability. [slides]

Over the years the maximum annual integrated charge has been steadily increasing [slide].

During the last decade 220-250μA extracted current was routine operation, and in recent years a total of up to 300 uA has been achieved: roughly 100uA in each of BL1A, BL2A (ISAC) and BL2C.

Despite the increased performance, the dose to personnel during shutdowns is going down steadily over the years. [slide!]

This spectacular and continuously improving cyclotron performance is the result of a multipronged effort:

1. Going back to the beginning of the cyclotron: outstanding design, engineering, and manufacturing
2. Cyclotron upgrade program: an ongoing program of improvements to maintain the reliability and availability goals, and upgrade the cyclotron performance through targeted investments and developments
3. A number of strategic initiatives to increase availability, and maximize scientific productivity of the entire facility, such as:

    - Maintenance if required: transition from compulsory one shift per week to maintenance as required

    - Systematic Approach to Shutdown (SAS), where planning and execution of shutdown is done within a "project" framework.

Going forward, the laboratory is expanding its flagship onsite rare isotope beam program with the new Advanced Rare Isotope Laboratory, ARIEL. [slide]

ARIEL will deliver unprecedented intensities of rare, short-lived isotopes for simultaneous and multiple experiments for Science and Medicine. ARIEL will triple TRIUMF's capabilities for producing beams of rare isotopes and will expand the range of isotopes produced.

One of ARIEL's cornerstones is a new proton beamline BL4N from the 500 MeV cyclotron, which will provide a second independent proton driver for RIB production, and together with the existing BL2A, and the newly build electron linac driver, will triple the RIB production. BL4N is specified for 500 MeV and up to 100 uA beam current, and opens up possibilities for Fundamental symmetries experiments that require long running times and are presently impractical. In fact, the science that is enabled by BL4N is so compelling and urgent that is driving the early implementation of BL4N in advance of the completion of the e-linac. It is evident that in the ARIEL era, the cyclotron continues to play a central role by providing 2 of the 3 driver beams for the RIB science, while continuing to deliver beams for all the other programs. When BL4N is implemented, the total extracted current will have to be up to 400 uA.

To maintain the cyclotron's present level of performance, and enhance its capabilities to meet the future demands of 400 uA operation, a comprehensive upgrade program has been implemented, under the able leadership of Yuri Bylinski. The program has two major elements:

1. Upgrade machine components
2. Develop new capabilities

The program also addresses high risk vulnerabilities.

As part of this program:

Starting 2003, a comprehensive refurbishment effort was invested into the RF system. Almost every stone was turned over and all known issues addressed. Old-timers may recall persistent sidewide announcement: "Beam off, RF". Today we eliminated it from our lexicon.

In 2011, a new Vertical Injection Line was installed. [slide]

The new 12 m electrostatic beamline employs low-maintenance robust optics compatible with future intensity increase by factor ~5, improved vacuum, dramatically extended diagnostics and tuning capabilities, greatly expanding beam characterization and tuning.

45 optics elements and 5 types of19 diagnostics devices were fabricated in house and installed in the winter of 2011. Although conditions were harsh, and work was arduous, the team was motivated and inspired and did a fabulous job. The results were amply rewarding. As my colleague Rick Baartman said: "The Theoretical tune worked right out of the box. Amazing few teething problems. This new line has given us the benefits we anticipated (reliability and tunability) and some we

hardly dared hope for (improved cyclotron transmission) and prepares us up for all possible envisaged high intensity upgrades."

[slide] In SDs 2012-2013: We replaced 106 +30 years old Trim & Harmonic coil power supplies with multiple benefits include: Improve Harmonic Coils capabilities, Reduce power consumption, Reduce heat load to B2 Level, Reduce down time, Reduce maintenance overhead.

[slide] Wiring in the vault is exposed to harsh conditions of radiation, humidity and temperature. This leads to premature failures and damage. Starting in 2010 we embarked on replacement of all the cables (~1500 units) ending in the cyclotron vault, and the cable tray infrastructure. The goal is to have all replaced by 2016.

[slide] In 2013, mindful of the safety of our workers who maintain the Cyclotron Elevating System Upper Bearing, a new, improved and WorkSafe BC compliant Fall Protection System was installed at station 9, and 5 more will be installed in this coming SD.

Many more other projects were completed, that I don't have time to go through here.

[slide] In parallel, a systematic beam development program has been carried out by the Beam Physics group, under the leadership of Rick Baartman and Yuri, with great impact on operations:

1. In 2009, the extraction energy was reduced from 500 MeV to 480 MeV. This has led to ~30% reduction in activation and dose to personnel, for the same beam intensity. Alternatively, it allows an equivalent intensity boost within the traditional activation dose budget.
2. The BL2A beam intensity was stabilized to ±1% by introducing a feedback loop between the electron current caught on the stripper and the pulser at injection.
3. [slide] Stabilizing the BL2A intensity however magnified intensity fluctuation in the other primary beam lines. The root cause of the instability was traced to the cyclotron's ν_r = 3/2 resonance leading to a radial beam intensity variation at energies above 450 MeV. To suppress this resonance a delicate machine tune was developed employing two sets of harmonic coils

near the extraction radii (HC12 & HC13). This reduced the intensity instability in the unregulated beam lines (BL1A & BL2C) from **±10% to ±1%,** and dramatically improved stability in 2 beamlines simultaneously.

[These coils were never intended to generate the needed third harmonic to correct the resonance. We could change amplitude but not phase. But we (Thomas) found a clever way to run HC12 and HC13 together to give us a phase knob.]

Going forward into the next 5YP, one of the overarching objectives of the Accelerator Division strategic plan: is to maintain and strengthen our world-leading expertise in cyclotron physics and engineering.

Main thrust areas towards this objective are:

1) Stable and reliable operation at 300 μA

2) Address highest risk vulnerabilities:

[slide] Main Magnet power supply replacement, PLC-based Controls subsystems upgrade, Vault recabling, plan to have a new ion source as a prime injector and convert I1 to hot spare.

3). Work towards 400 μA intensity upgrade:

Upgrade Centre region diagnostics, Space charge limit studies, Replace the Injection line horizontal section.

4. Work towards reducing/eliminating lid-up maintenance

It's an ambitious but necessary program. But we are up to the task, and the results will be worth it:

An engine of discovery and innovation, that will continue to fuel leading edge scientific research, for at least another 40 years, for the advancement of our understanding of the universe, for enabling advanced treatments of disease, and for making the world a better place to live in.

In Ancient Sparta it was the obligation of the younger generations to surpass the elders in bravery and achievements both in times of war and peace. In order not to forget, in major ceremonies, the Spartan youth would pledge to their elders:

"άμμες δε γ' εσόμεθα πολλώ κάρρονες": we shall become much better (than you).

Similarly, we have the obligation to surpass you, so today we pledge: "άμμες δε γ' εσόμεθα πολλώ κάρρονες."

Thank you.