Particle Accelerator Conference

May 9, 2009
Vancouver, British Columbia
Canada

TRIUMF
Tour

TRIUMF Cyclotron

www.triumf.ca/pac09
Dear PAC09 participants,

Welcome to TRIUMF, Canada’s National Laboratory for Particle and Nuclear Physics. It is a pleasure to give you a direct introduction to our laboratory through a walking tour of the facility. At the tour of the experimental buildings you will have an opportunity to see first-hand where TRIUMF experiments are done. Our researchers and machine experts will describe the installations on the spot and will be able to answer your questions.

This booklet is designed to allow you to better visualize what you are being shown relative to the full facility. Because you are accelerator specialists, we have arranged a tour that highlights areas not normally included on our public tours.

Please be careful, obey the signs & remain with your tour group. Refer to your tour guides if you have any questions or concerns.

Enjoy your visit.

Sincerely
Paul Schmor

The TRIUMF model display shows the layout and location of, and facilities within, the main cyclotron building (at 1:96 scale) and the ISAC-I and ISAC-II experimental halls (at 1:48 scale each). All models are brought up to date every few years and show an accurate representation of the site. They are very helpful for visualizing facilities and accelerator components hidden in remote inaccessible locations or under tonnes of concrete shielding. For example, the world’s largest cyclotron is covered by three layers of six-foot thick concrete blocks each weighing 100 tons, the Proton Cancer Therapy centre is covered by 35 ton shielding blocks, and the ISAC isotope production facility lies in a cavern a few stories underground. There is maze of facilities and jungles of equipment on the tour, and the models are useful for appreciating how the various areas work together. The displays were constructed over the years by B&B Scale Models of Vancouver.
Advanced Applied Physics Solutions (AAPS) is a not-for-profit corporation established by TRIUMF, Canada’s National Laboratory for Particle and Nuclear Physics and related research. It received start-up funding in March 2008 from the Government of Canada’s Networks of Centres of Excellence Program (http://www.nce.gc.ca/index.htm) through the Centres of Excellence for Commercialization and Research Initiative.

The mission of AAPS is to research, develop and commercialize innovative technologies from TRIUMF and other advanced physics research with potential for the social and economic benefit of Canada.

The workhorse of the TRIUMF laboratory is the TRIUMF 500 MeV cyclotron. It produces multiple beams of high energy protons that drive a variety of experimental physics programs and a few irradiation facilities. The distinct feature of the TRIUMF cyclotron is a simultaneous extraction of up to 4 beams of variable intensity and at different energies. This is possible because of acceleration of negatively charged hydrogen ions with subsequent stripping of both electrons applied only to a fraction of the circulating beam by insertion of thin carbon foils at required radii, thus producing proton beams of specific energies.

<table>
<thead>
<tr>
<th>Main parameters</th>
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<tbody>
<tr>
<td>Range of extracted energies</td>
<td>70-520 MeV</td>
</tr>
<tr>
<td>Maximum individual beam intensity</td>
<td>150 µA</td>
</tr>
<tr>
<td>Total extracted current</td>
<td>250 µA</td>
</tr>
<tr>
<td>Intensity fluctuation of stabilized beam</td>
<td>±1%</td>
</tr>
<tr>
<td>Ion source</td>
<td>Cusp filament source</td>
</tr>
<tr>
<td>Injection energy</td>
<td>300 keV</td>
</tr>
<tr>
<td>Transmission</td>
<td>60-70%</td>
</tr>
<tr>
<td>Dee gap accelerating voltage</td>
<td>190 kV</td>
</tr>
<tr>
<td>RF system</td>
<td>1 MW, 23 MHz, cw</td>
</tr>
</tbody>
</table>
Meson Hall

TRIUMF’s CMMS (Centre of Molecular and Materials Science) facilitates an international community of chemists, condensed matter physicists and materials scientists to utilize the powerful experimental capabilities bestowed upon the muons in their capacity as atomic scale local probes of matter.

- The $\mu$SR research at TRIUMF is focused on the areas of:
  - High Temperature Superconductors
  - Physical, Green and Materials Design Chemistry, including hydrothermal reactions in Nuclear Power Reactor
  - Exotic Magnetism, Strongly Correlated Systems, Quantum Phase Transitions
  - Industrial Basic Research for Automobile Technology, i.e. Batteries
  - Nuclear Quantum Electrodynamics: $\mu$ captured onto heavy nuclei

$\mu$SR infrastructure facilities at TRIUMF are currently undergoing a significant upgrade. A new channel (M9A) is currently being built, and a second channel (M20) will be significantly upgraded.

The TR13 is a low energy cyclotron intended for Positron Emission Tomography (PET) isotope production. The cyclotron is capable of accelerating up to 100 mA of ions to 19 MeV and extracting two beams of variable current. Machine energy is limited to 13 MeV in order to minimize the shielding. It is a 4 sector isochronous cyclotron with a deep valley magnet. The accelerating structure consists of 2 dees and operates at 73.3 MHz. The orbital plane is vertical with an external cusp ion source feeding up to 1.5mA of dc H ions. Beam extraction is accomplished with two radial stripping probes each holding a diamond-like carbon foil. The cyclotron is used to produce the short-lived positron emitters $^{18}\text{F}$ (110mins), $^{11}\text{C}$ (20mins), & $^{13}\text{N}$ (10mins). Target materials are irradiated as either gas or liquid. Special chemistry systems allow the radionuclides to be attached to molecules with a known function in living systems (e.g. neurotransmitters in the brain). PET is a technique of producing a cross-sectional image of the distribution of these molecules and makes use of the fact that decay by positron emission results in annihilation radiation of two gamma rays that can be detected outside the body. A PET image shows function in a body whereas an MRI or a CT scan shows the structure of a body.
The facility is used by MDS Nordion for manufacturing Radiopharmaceuticals for clinical trials. In these glove boxes MDS Nordion manufactures 2 radiopharmaceuticals:

1. **ZEMIVA** - which is an $^{123}$I labeled fatty acid which is used in emergency departments to determine if someone has had a heart attack.
2. **ALTROPANE** - which is an $^{123}$I labeled molecule for diagnosis of Parkinson’s disease.

Over 250 doses per day can be manufactured on-site and shipped to various hospitals and research facilities across Canada and the US. Because of the short half-life of $^{123}$I (13.2 hrs) radiopharmaceuticals labeled with $^{123}$I have to be manufactured and shipped within a very tight timeline. MDS Nordion also makes a variety of isotopes on their 3 commercial cyclotrons located on site. These include:

- $^{123}$I for use in making capsules for Thyroid scans.
- **Thallium-201 (Tl)** used for scanning and diagnosing heart disease.
- **Gallium -67 (Ga)** used for finding chronic infections, bronchogenic carcinoma, and abscesses.
- **Indium-111 (In)** used for finding acute infections as well as labeling to antibodies to diagnosing different forms of cancer.
- **Palladium-103 (Pd)** used in Brachytherapy to treat prostate cancer.
- **Strontium-82 (Sr)** used in PET centres to determine heart function.
- **Copper-64 (Cu)** used for new novel PET drugs.

MDS Nordion has 3 radioisotope production cyclotrons (CP-42 and two TR-30’s) located on TRIUMF site. TR-30 machine is based on a TRIUMF design. A new state-of-the-art commercial cyclotron (TR-30) was put in operation in 2003. New machine has allowed additional products for up to one million nuclear medicine procedures around the world each year. TRIUMF staff operates all three Nordion cyclotrons from a single control room. The cyclotron operator technicians control beam from the cyclotrons through various magnets to MDS Nordion’s 6 solid target stations and 3 gas target stations. At the target stations the beam is deposited on a target with enriched material to make the radio-isotopes. The operators also control target transfers between target stations and hotcells as well as controlling and monitoring of the nuclear ventilation system, fire control, and facility temperature. The control room is staffed 24hrs/day, 365 days/year and at least one of the 3 cyclotrons is always producing beam.
**DRAGON**

DRAGON is a high-performance recoil separator for the measurement of astrophysical fusion reactions in inverse kinematics. Using radioactive and stable beams in the range 150-1800 keV/u provided by the ISAC accelerator, DRAGON studies the radiative capture of these beams on hydrogen and helium relevant to nucleosynthesis for scenarios such as supernovae, classical novae, and X-ray bursts. The hydrogen or helium is circulated within a windowless gas target capable of holding up to $4 \times 10^{18}$ atoms/cm$^2$. Fusion reactions that occur within the gas target produce excited recoiling nuclei in a forward-focused cone that quickly de-excite with gamma rays emission. An array of 30 BGO crystals surrounds the thin-walled gas target, enabling the gamma rays detection. Finally, the recoiling reaction products are detected at the end of the 21m-long separator using a variety of detection techniques. DRAGON has, over the last eight years, studied some of the most important proton- and alpha-capture reactions to astrophysics, including the $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}$, $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$, $^{26}\text{Al}(p,\gamma)^{27}\text{Si}$, $^{40}\text{Ca}(\alpha,\gamma)^{44}\text{Ti}$ and $^{23}\text{Mg}(p,\gamma)^{24}\text{Al}$ reactions.

**Radioactive beams**, produced by ISOL method, as well as stable beams from an off line ion source (OLIS) are accelerated in the ISAC facility.

The first stage of acceleration in ISAC-I happens in the Radio Frequency Quadrupole (RFQ). The ISAC RFQ accelerates particles of mass to charge ratio up to 30 from 2 KeV/u to 150 keV/u. RFQ is based on a Split-ring structure operating at 35.36 MHz in cw mode. RFQ maximum inter-electrode voltage is 75 kV with power consumption of up to 80 kV. After the RFQ the beam charge state is increased by stripping at a carbon foil and then the beam matched in the MEBT to the downstream linac.

The second stage of acceleration is accomplished with a drift tube linac (DTL). The DTL accepts ions with mass to charge ratio between 2 and 6 and accelerates them from 150 keV/u up to 1.8 MeV/u. The ISAC DTL operates at 106.08 MHz and is divided into eight modules (five Interdigital-H accelerating structures and 3 Splitring bunchers with focusing quadrupoles installed downstream of accelerating cavities). This scheme allows great flexibility of the machine final energy.
TITAN, TRIUMF’s Ion Trap for Atomic and Nuclear science, allows scientists to measure the mass of nuclei very precisely and helps them to understand the fundamental forces that keep atoms stable. The difficulty of precision mass measurements is that the radioactive isotopes often have half-lives around or below one second. It is far from trivial to obtain a very precise measurement when you don’t have much time to get it! Heisenberg’s uncertainty principle couples the obtained energy (or mass) uncertainty directly to the observation time. TITAN aims to a precision of one part in 100 million.

The mass is measured by storing the charged exotic particles in a Penning Trap, which uses a strong magnetic field and a weak electric field to store the particles. The particles revolve in the magnetic field with co-called cyclotron frequency, which is directly proportional to their mass. From the cyclotron frequency the binding energy of the nucleons can be deduced. By following this procedure with a variety of isotopes, the TITAN scientists gain important and forefront information about nature’s radioactive decay and stability, the nuclear synthesis of elements in the Universe and life and death of stars.

The ATLAS experiment at the Large Hadron Collider (LHC) complex, located in Geneva (Switzerland), will collect an enormous amount of data at an unprecedented scale. The experiment will essentially operate around the clock and will produce several petabytes (millions of gigabytes) of data each year. For efficient access to the data, the ATLAS Computing model is based on a set of tiered computing centres which are connected via high performance and dedicated networks: the so called Worldwide LHC Computing Grid (WLCG). The primary data will be initially stored at the Tier-0 centre at CERN, and then distributed to ten Tier-1 centres around the world. Each Tier-1 centre has custody of a share of the data. TRIUMF is hosting the Canadian Tier-1 data centre. The data centre uses state of the art cooling infrastructure and computing technologies. The current computing and storage capacity consists of about 650 processor cores, one petabyte of disk storage and half petabyte of tape storage. This capacity will double in the summer of 2009.
Gamma rays emitted from nuclei reveal what they look like and how they work in much the same way that infrared and optical spectroscopy reveals the composition and structure of atoms and molecules. The TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer, or TIGRESS, was specifically designed for experiments with the high-energy, above-Coulomb-barrier, exotic radioactive ions that are produced at ISAC-II. TIGRESS uses high purity germanium (HPGe) crystals to measure the position of gamma-ray interactions and derive the gamma-ray energy emitted from the nucleus. TIGRESS scintillator escape suppressors are designed so that the apparatus can easily be reconfigured from a “high efficiency” mode for the rarest, most exotic beams, to “high signal-to-noise” mode for detailed experiments with more intense beams. With TIGRESS and ISAC-II we have begun to address key questions about how nuclei work. One such question is where or if the “magic numbers” – the nuclear equivalent of noble gases in chemistry – persist in the heaviest, most exotic isotopes. The “neutron-rich” nuclei exist for only milliseconds in supernova explosions, yet they contribute to the formation of elements such as niobium, tungsten and gold – all elements heavier than iron.

The ISAC high beta linac extension (SCC section) will consist of 3 cryomodules with a total of 20 quarter wave bulk niobium cavities. Two of the cryomodules have six cavities, and the third has eight. Each cryomodule will also house a superconducting solenoid. This area is used for ‘dirty’ assembly. The cryomodule mechanical components, less cavities, are fully assembled here to check for fit and match and to allow for a final metal work. Liquid nitrogen cooled heat shield made of nickel plated copper sheets and high magnetic permeability mu-metal shield are both housed inside big rectangular stainless steel vacuum tank. The cavities and solenoid are supported from a rigid strongback that is in turn supported from the tank lid by stainless steel rods with a four point system to reduce the freedom in the movement of the cold mass. The tank lid also contains all technological penetrations for vacuum, cryogenic, alignment, diagnostic, and rf interfaces. During assembly phase the tank lid is supported by a dedicated assembly frame, which allows easy access to all the components and also provides alignment reference for cavities and solenoid with respect to the beam axis. After compatibility of all the components is checked, they are disassembled and proceed for cleaning in the ultrasonic bath and reassembly in a clean room.
SC Linac

The superconducting (SC) linac can be considered as a third acceleration stage of the ISAC facility. The ion beam at 1.5 MeV/u coming from the DTL is injected into the ISAC II linac. The present installation is composed of five in-house designed cryomodules. Each cryomodule contains four quarter wave bulk niobium superconducting cavities and one superconducting solenoid that provides transverse focusing. The cavities operate at 106.08 MHz in cw mode demonstrating SC heavy ion linac world record accelerating gradients averaging at 7 MV/m which corresponds to a 35 MV/m peak surface field. The accelerating gradient of 7 MV/m is achieved at 7 W of helium consumption per cavity, which is above the design specification of 6 MV/m at 7 W. We have seen very little evidence of degradation in cavity performance over the first two years of operation even after repeated thermal and venting cycles. Each cavity is driven by independent RF amplifier and provides an accelerating voltage of ~1 MV, totalling to 20 MV across the linac. This design provides great flexibility allowing any beam energy between 1.5 MeV/u and 10.5 MeV/u for the ions with mass to charge ratio of 2. By the end of 2009 the linac will be upgraded with twenty more cavities increasing the total accelerating voltage to 40 MV. New cavities feature an improved design and operate at 141.44 MHz.

Clean / Etching Room

The ISAC Clean Room and Chemical Etching lab are two fundamental parts of the TRIUMF superconducting radio frequency (SRF) infrastructure. Clean room includes a test area with x-rays shielded pit designed to hide SC linac cryomodules and single cavity cryostat during high field rf testing, and clean areas (Class 100) for cryomodule assembly and cavities high pressure water rinsing. The etching facility allows the safe handing of the chemical acids used to treat the niobium both during cavity fabrication and after completion of the finished cavity. The acid mixture used is the standard buffered chemical polish (BCP) recipe with the ratio 1:1:2 of HF(48%), HNO3(65%) and H3PO4(85%). During fabrication the niobium parts are etched in preparation for welding. After cavity fabrication the complete rf surface is etched prior to final high pressure water rinsing and cold testing for RF characterization.
Beam Lines and Experimental Facilities

ISAC - I & ISAC - II
Experimental Halls

1. Model
2. AAPS
3. Cyclotron
4. Meson Hall
5. TR 13
6. MDS Nordion CA
7. MDS Nordion CR
8. DRAGON
9. RFQ/DTL
10. TITAN
11. Tier-1
12. TIGRESS
13. SCC Assembly
14. SC Linac
15. Clean/Etching Room