Tour Script – Summer 2016

Lobby Model

Before beginning your tour, take some time in the lobby to talk to your group and show them the models. Depending on your group and on your preferences, you may want to spend more or less time in at the models, but it is important to give visitors an overview of our lab and facilities before getting started.

Cloud Chamber

This device allows us to see background radiation in real time. The large clouds that disappear slowly are alpha particles (helium nuclei), the thin straight ones are protons and muons and the ones that zig-zag are electrons. The length of the cloud is correlated to the mass of the particle.

. You can make one these at home using dry ice and an aquarium.
. The wires on the top are electrically charged and give us a stronger signal
. This is one of the first types of particle detectors used at the beginning of the 20th century
. The liquid used is isopropyl alcohol and is cooled to -27 C

Historic Photos

Lower Sector Magnets (North Pole)

The shape of the magnets is related to its function – particles moving at 75% the speed of light effectively weigh 1.5 times more (due to Einstein's special relativity), thus need a stronger

The six separate magnet sectors produce regions of strong and weak magnetic fields, resulting in a vertical focusing effect that is further reinforced by the spiral shape; the focusing prevents ions from drifting towards the lid or floor of the tank.

The magnets were built by a ship-building company; due to tradition, when delivering the product, it gifted TRIUMF a ship steering wheel (currently located in the Board Room)!

. The tank must support 2,600 tons of atmospheric pressure
. Vacuum inside the tank if 5×10^{-8} Torr (50 trillionths of an atmosphere). This is the same order of magnitude as in the neighborhood of the International Space Station
. About 2,000 trillions particles are accelerated per second
. Construction started in 1970; first beam was extracted in December 1974

Main Control Room

The control room monitors virtually all aspects of the cyclotron and the main injection beamline, including radiation levels. There is an operator here 24/7 throughout the year. The green bar histograms indicate the radiation levels along the proton beamlines. Unlike a nuclear reactor, once a cyclotron is shut off, it stops producing radiation--there's no chain reaction that must wind down. **Of Interest** One of the space shuttle control stations used TRIUMF's main control room as their prototype. **Quick Facts**

- There is an automatic shut down if the radiation levels get too high
- Operating budget for 2010-2015 is about $44M annually, with additional funding for experiments and applied research
- Annual electricity bill is about $4M; the lab has its own electrical substation

- The control room monitors 3,000 devices and 50,000 different information readings.
- There are always 2 people on duty 24 hours a day every day of the year. There must always be at least one person in the room.

Ion Source

Starting with hydrogen gas, a hot filament emits electrons that bombard and break up the hydrogen molecules, forming a gas discharge (as in a neon tube, but more intense). This discharge contains neutral atoms, bare protons, and negative hydrogen ions. A positive voltage at the chamber's exit attracts the negative H- ions out of the box and into the pipe that transports them towards the main injection beamline.

The decommissioned ion source produces polarized ions (proton spins aligned) that were last used for the TRIUMF 221 MeV parity violation experiment in 1995. It has not been needed since. Currently ongoing experiments do not require polarized particles, thus the newer and more efficient unpolarized source is used. There is also a 2nd unpolarized ion source located towards the south, but it is rarely used.

. Ceramic insulators maintain the 300,000 volt potential difference.
. The walls are shielded with aluminium, creating a Faraday Cage, to protect electrical devices outside from the radio frequency voltages used within the room and to ensure a uniform field
. Methods of extracting protons from a proton cyclotron are generally no more than 80-90% efficient and require significant and bulky equipment; by using the H- ions, we can extract the beam simply by stripping the electrons with a 25 micrometer carbon foil, boosting the extraction efficiency to 99.999%.

Main Injection Beamline

. Negative hydrogen ions travel through the stainless steel beamlines towards the cyclotron. The long and straight sections contain electrical plates to steer and focus the beam while the cylindrical objects hanging below are cryogenic vacuum pumps. The collision of a hydrogen ion with an air molecule would cause it to be scattered out of the beam, thus having a vacuum is more efficient. The plastic boxes with springs inside them on the beam are used to measure the shape and size of the beam by measuring the current picked up on two wires as they are passed through it.
. The 'accordions' in the beamline allow for temperature changes that may cause the metal to expand or contract. Black iron cylinders shield the hydrogen ion beams from the magnetic field of the cyclotron.
. • The cyrogenic pumps keep the beamline at 15 K (-258 C). Cryogenic pumps dramatically improve the vacuum by cooling the beamline to the point that air "freezes out"; at this temperature, air condenses out of the pipes.

Top of Cyclotron

The roof on which you're standing is 12 m (40 feet) above the midplane of the cyclotron, the diameter of which (18 m) is indicated by the red line painted on the concrete. There are 3 overlapping layers of concrete beams below you, each 1.6 m deep.

Concrete is good for shielding because it contains hydrogen (in water) to capture neutrons. About 200 special blocks placed directly around the cyclotron also contain metallic aggregate with heavy elements to stop gamma rays.

Each yellow concrete block weighs 100 tons and requires both 50-ton cranes to lift.

Cyclotron Model

Some key features of the cyclotron are visible on the 1/20th scale model. The over 300 thin steel tie rods coming through the top of the magnet serve as an anchor for the vacuum tank, keeping it from collapsing in on itself due to atmospheric pressure. Each rod supports a load of 8 tons. It takes about 30 minutes for the twelve electric jacks to raise the top half of the cyclotron

1.2m for maintenance.

The magnet sectors within the model reflect realistic colour schemes – a reference guide for workers inside the vault during the maintenance periods. The colour scheme was chosen by an artist by request of the first director. The significance of the colours has been lost in time.

- 18,000 amps run at 75 volts through coils around the outside of the poles, magnetizing the steel and producing a field ranging from about 0.3 Tesla (3,000 Gauss) near the center to 0.45 Tesla near the outside.
- The cyclotron draws 2,000,000 watts of power
- Cumulative weight of the magnets is 4,000 tons

Vacuum Tank Model

The 1/10 scale model is a working model that was used to test the resonator set-up; it is equipped with a pair of alternating radio frequency electrodes, separated by a narrow gap. The electrodes are excited with opposing electric potentials. As hydrogen ions are injected in the centre, they are repelled from the negative side and attracted to the positive, gaining energy and speed every time they cross the gap between the electrodes. The charges are continuously alternated to continue the acceleration process.

As the ions accelerate, they move out to a larger radius. Once at full speed, the ions pass through a carbon foil (1 cm^2 and only 25 micrometers thick; much thinner than aluminum foil), which strips the loosely attached electrons from the ions, leaving a beam of protons.

Charged particles travel in curved paths in a magnetic field. The negative hydrogen ions travel in a counter-clockwise direction whilst the positive protons travel clockwise, enabling the proton beam to be directed out of the cyclotron and into the different experimental areas.

Accelerating H^- ions rather than protons requires limiting the magnetic field strength to about 1/3 of that available for protons of the same energy. This is because using stronger magnets would cause the H- ions to fly apart. Limiting the field results in larger circles which makes TRIUMF's cyclotron the largest in the world.

- A radio transmitter set at 23 megahertz switches the electrode 23 million times a second
- Up to four foils can be placed in different positions inside the tank and arranged such that each extracts a beam of a different energy and intensity
- Ions go through 1,500 revolutions in 1/3,000th of a second before extraction

Meson Hall – Proton Therapy

Proton cancer therapy is used to treat a rare type of cancerous growth on the back of the eye called ocular melanoma. A low energy proton beam from the cyclotron is directed into the patient's eye, irradiating the tumour. The means in which protons interact with matter is what makes proton therapy superior to conventional x-ray therapy. With x-rays, most of the energy is deposited immediately upon entering the skin followed by a gradual decrease that lacks a definitive endpoint, which means that the brain immediately behind the eyeball has the possibility of being irradiated. With protons, most of the energy is deposited right before the beam stops, having penetrated a certain depth into the tissue.

Treatment process consists of several stages. First, tiny tantalum clips are attached to the eye to define the contour of the tumour, followed by an ultrasound to define the dimensions of the eye and an x-ray photograph taken while in the treatment position. The clips show up in the x-ray and the image is digitized to create a computer model of the eye. An ophthalmologist and radiation oncologist, together with the medical physicist determine the best treatment position and beam intensity. A copper plate has a hole cut in it, in the shape of the tumor. A bite block and solid mesh face mask are used to immobilize the patient during treatment while they also watch a flashing light to prevent eye movement.

- The facility treats about 12-15 patients per year
- The four painless treatments are spread out over 4 days, each lasting approximately 50-90 seconds

- Local tumour control with protons is better than 95% and some vision may even be preserved in the affected eye.
- The cost of the treatment is $25,000 but is covered by healthcare. The equivalent treatment in the US costs about $75,000.
- There are only a few dozen places in the whole world that can do this treatment

PET Scan

PET functional imaging is used for studying neurodegenerative diseases such as Alzheimer's, Parkinson's, epilepsy, etc., as well studying the metabolism of different chemicals within the body. Initially, a specific isotope is attached to a biological molecule and injected into the patient. Near the site of where the molecule is metabolized, the isotope will decay, emitting a positron that annihilates with an electron in the surrounding tissue. Two photons (gamma rays) are produced as a result of the annihilation and travel outwards from the point of interaction in opposite directions. A ring of detectors in the PET scanner senses these coincident events from one slice of tissue. Then, from the accumulated data from many decays, a 2D map can be constructed showing the regions where the biological molecule was metabolized and the decay occurred. Repeating this process for several neighboring slices enables a 3D map to be built up.

Depending on the condition being looked at, the isotope is attached to a specific molecule: *Glucose* – for studying glucose metabolism *Dopamine* – neurotransmitters involved in Parkinson's *Chemotherapy drug* – for studying drug resistance in cancer cells

Whereas CAT and MRI scans look at body structures (i.e. bones and organs), PET scans look at body function at the molecular level (i.e. activity within regions of the brain).

We hope to eventually use this technology to detect Alzheimer's

- The three cyclotrons at MDS Nordion can produce enough radioisotopes to treat up to 45,000 patients a week
- The PET scanner on display was the first ever built in British Columbia and the 6th in the world

TR – 13

The blue structure is the shielding around a low-energy cyclotron used to produce medical isotopes for the well-established PET research program at TRIUMF and UBC. The isotopes are transported from TRIUMF to UBC via the rabbit line – an underground air pressure tube.

The TR13 was actually built as a TR19 but due to shielding requirements it has been locked to 13 MeV so that it is easier to access without lots of concrete in the way.

Similar technology is crucial in staving off the nuclear isotope crisis that looms for Canada when the Chalk River nuclear reactor permanently shuts down in 2018. Chalk River produces 40% of the world radioisotopes for medicine. However, it is old and has broken many times in the past few years. TRIUMF has developed technology that lets us create these medical isotopes without a reactor, with almost no nuclear waste, and do it locally. This can be done using cyclotrons similar to the TR-13. TRIUMF hopes to create a network across Canada with these small accelerators to supply Canada and then the world with the isotopes that it needs to save lives.

Lower energies are sufficient for the production of specific isotopes (i.e. ^{18}F and ^{11}C), including those that are needed for medical use

Radioactive isotopes can also be used for studying nitrogen uptake in plants (^{13}N) and for research in the pulp and paper industry

The TR in TR-13 stands for TRIUMF. It was designed by TRIUMF and built by EbCo in Richmond (now Advanced Accelerator Systems

It takes 2 minutes for isotope samples to travel the 2.5 km to the hospital in the pneumatic rabbit line; both efficient and necessary for short-lived isotopes

- TR13 reaches energies of 13 MeV, the main cyclotron can attain energies of up to 520 MeV
- About 500 transfers are made per year

GRIFFIN

Low energy experiment used to study the radioactive decay of exotic isotopes. The isotopes are implanted into a piece of special tape within the black ball at the centre of the spectrometer. The implantation point is surrounded by detectors which measure the beta particles and gamma rays emitted as the isotopes decay. These radiations help scientists understand the interactions between the protons and neutrons inside the nucleus.

Spectrometers measure the position and energy of particles. The black tubing is there to supply the detector crystals with liquid nitrogen, which need to be kept cool in order to function properly.

- Aluminized Mylar tape is used to trap the isotopes within the black ball
- Each of the 16 detectors contains $350,000 worth of hyper-pure germanium crystals

TITAN

- Measures the mass of unstable exotic isotopes ions by trapping them in combined magnetic and electric fields. The process is complicated by the short half-life of the atoms studied. **Of Interest** The ions orbit in the combined fields in a complicated 3D motion, but with distinct frequencies for their horizontal and vertical motion. From observations of their motion we can figure out their mass. **Quick Facts**

Measures the mass of unstable atoms to 1 part per 100 million accuracy; equivalent to measuring a 100 ton jet to the accuracy of the smallest 1 g screw

TITAN is the fastest reacting apparatus of its kind in the world: one of the exotic isotopes studied, lithium-11, has a half-life of just 8.6 milliseconds.

DRAGON

DRAGON recreates the nuclear reactions occurring in novae, supernovae, and x-ray bursts to study the various processes by which the heavier elements were created from the hydrogen, helium, and fraction of lithium formed in the Big Bang. The fusion reactions in stable stars cannot create anything heavier than iron, but a massive star explodes, in an event called supernova, the conditions inside the star are hot and dense enough to allow for the production of the heavy elements, usually through nuclear reactions involving exotic isotopes. Supernovae are also an important source of the elements magnesium and nickel.

DRAGON investigates these processes by firing an exotic isotope beam at a hydrogen or helium gas target and studying the reaction products

After collision, the reaction products are filtered by mass using electric and magnetic fields; unwanted products are stopped when they strike collimators while desired products are transported to the end of the beamline, where they can be studied. DRAGON measures the gamma rays that are emitted by these isotopes. When fusion occurs the atoms are in an excited state and when they de-excite they emit a photon at a specific wavelength which is directly correlated to the isotope produced. Once we know what this gamma ray “signature” looks like we can look for this signature in space and know that it comes from this isotope. We can even create a map of the entire galaxy showing us where different isotopes are.

- About one ‘event’ (desired reaction) per second per day
- Different isotopes are used, most in the sodium-magnesium-aluminium cycle; short-lived radioactive isotopes of particular interest because the ability to measure them is quite recent
- Rather than make discoveries, DRAGON makes measurements of things that theorists cannot predict, i.e. the probability of the fusion reaction