Keeping TRIUMF Cool

TRIUMF has chosen low-temperature superconducting (SC) technologies for the high energy acceleration of radioactive ion beams in ISAC. The key advantages of this choice over room temperature designs are greater energy efficiency and a compact design, allowing TRIUMF to build smaller buildings to house the experimental and support facilities. These benefits allow TRIUMF to reduce its energy consumption and operational costs.

The effect of superconductivity, however, appears only at extremely low temperatures of 9K (-264°C) that are not normally found on Earth. These low temperatures are achieved with cryogenic technology, which relies on helium refrigeration plants and vacuum isolated liquid nitrogen shielded distribution systems.

In 2007, TRIUMF’s Vacuum and Cryogenics Group took on the tasks of planning, installing and preparing for the commissioning of Phase II of the Cryogenic Refrigeration System for ISAC-II and a new helium refrigerator for the main cyclotron. Performing the work in-house rather than contracting it out resulted in substantial cost savings for TRIUMF. The group also undertook to reduce TRIUMF’s costs for liquid helium for experiments by installing a helium recovery system.

TRIUMF’s use of cryogenic technologies and the resulting operational improvements and cost savings are described below.

SC LINAC powered by cryogenic technology
The construction of TRIUMF’s SC facilities has been a significant milestone for TRIUMF and for SC technology in Canada. In 2006 TRIUMF’s team of scientists, engineers and technical staff commissioned the first SC linear accelerator (LINAC) in Canada, using cavities made in Europe. Since then it has transferred the fabrication technology to a local company, PAVAC Industries Inc., now one of only five companies in the world, and the only Canadian company, able to produce SC equipment of this kind. The first phase consisted of 20 medium-beta superconducting cavities in five cryomodules. The Phase-II project presently underway consists of three cryomodules of a different design, containing 20 high-beta or higher velocity cavities.

TRIUMF’s ISAC-II LINAC achieves its SC capabilities through the use of cryogenic technology. When in operation, a radio frequency (RF) electrical current can be transmitted through cavities made from the metal niobium without resistance or heat generation. To create the right conditions for effective operation of superconductivity in the niobium cavities, helium must be compressed and liquefied to 4.2 Kelvin (-269° C), a temperature slightly above absolute zero.

Faster, smaller, and bigger savings
A quick glance around the TRIUMF laboratory shows the ISAC-II building has a substantially different look than other buildings on site. The new building is smaller and more compact because it was specifically designed to take advantage of the smaller footprint of the refrigeration plant and associated cryogenic system. They require much less space than traditional water cooling systems. SC technology brings with it other cost benefits, in particular, lower costs for electrical power as there can be significant savings due to minimal heat losses. Equally important, TRIUMF’s new cryogenic system allows TRIUMF to recover and recirculate helium used in ISAC-II and elsewhere on site. There is a world-wide shortage of liquid helium so this an important benefit in terms of conservation and cost savings.
Using TRIUMF’s talents

To reduce capital costs, TRIUMF played a significant role in the construction of its new refrigeration facility. The scope of the contract with the manufacturer, LINDE Kryotechnik of Switzerland, was limited to the supply of major components. TRIUMF assumed responsibility for the installation of these major components, as well as the room temperature piping, a 114 cubic metre horizontal buffer tank, and a 1000 litre (one cubic metre) helium dewar. The new cold distribution system, specified by TRIUMF, was supplied by DeMaCo of the Netherlands.

The helium distribution system supplies liquid helium to the cryomodules which contain SC cavities and solenoids. The system is designed so that operators can cool each of the modules separately at any given time. This feature provides greater flexibility, an asset for a large research facility.

The supply trunk distributes helium flow in parallel to the cryomodules through remotely controlled supply valves. Helium returns from the cryomodules to the cold return trunk through open/close valves. The lines to and from the cryomodules are connected to the trunks through field joints. During cool-down, when temperatures are warmer than 30K, the returning gas is sent back to the suction side of the compressor through the vaporizers and room temperature return piping located outside of the building. At the end of the trunks’ keep-cold sections, adjustable valves are installed to avoid potential development of thermo-acoustic oscillations.

Valves installed in the middle of the two trunk lines make it possible to run two separate refrigerators, with the linear accelerator divided into two almost-equal loads. There are also two additional helium lines between the cold trunks and the ISAC test/assembly area (clean room).

Keeping costs down

The screening of the distribution system with a liquid nitrogen shield helps to minimize liquid helium losses. As helium is significantly more expensive than nitrogen, TRIUMF engineers have designed the system to use helium only for cooling beyond the temperatures that can be achieved with liquid nitrogen.

Liquid nitrogen removes most of the heat from the cryomodules, while liquid helium cools the system down further. The liquid nitrogen distribution system supplies liquid nitrogen to the thermal shields of the helium distribution lines and the cryomodules. The nitrogen vapour is exhausted outside the building.

A phase separator in the refrigerator room accepts the two-phase (liquid and gas) nitrogen supplied from the main supply tank (34 sq metres) through a 60 metre long transfer line. The phase separator utilizes a 240 litre nitrogen Dewar, which is equipped with a pressure-differential level-monitor controlling the solenoid supply valve, a pressure switch at 69 kPa (10 pounds per sq in) controlling a vent solenoid valve, and a manual supply valve. The vent valve and the vent lines are oversized to reduce pressure fluctuations during Dewar refills.

How the system works

The Phase-II refrigerator for the high beta section of the SC LINAC was commissioned in June 2008. This refrigerator is identical to the one used in Phase-I, and the refrigerator’s performance was tested with the Phase-I section of the
LINAC. The early addition of the new system allows for greater flexibility in constructing the Phase-II LINAC. While Phase-I is in operation, the Phase-II refrigerator will be used for Phase-II LINAC development, including the single cavity test cryostat for new cavity performance qualification and newly assembled high beta cryomodules.

The two 114 square metre helium buffer tanks are treated independently for Phase-I and Phase-II inventory because the development section has a higher probability of contaminating the helium inventory with impurities. Phase-I and Phase-II have a single helium recovery compressor, which is capable of looking after the helium gas load of the complete system. The compressor was installed and commissioned with the Phase-I refrigerator.

In case of emergencies (i.e. total power outage) the control valve system will ensure the helium recovery from both systems, guiding the flow to the Phase-I buffer tank first, and then, when the pressure reaches 800kPa, to the Phase-II buffer tank.

Cyclotron
A solution to costly maintenance
TRIUMF’s new helium refrigerator for the main cyclotron cryogenic pumping system replaces a thirty-year old refrigerator previously used on the cyclotron. In addition to increased reliability, the new refrigerator is capable of liquefying helium gas.

The old system was becoming unreliable, and a factory reconditioning of the old unit or replacement with a new cryogenerator of the same type would not significantly improve performance. The Cryogenics Group proposed to replacing the old system with a new LINDE-1630 helium refrigerator.

Installation goes smoothly
The new refrigerator system, including the helium buffer tank, compressor, room temperature piping, helium transfer lines, and the refrigerator were installed and commissioned. This system has successfully maintained the vacuum for beam production since September 2007.

The new system possesses numerous technical and cost-saving advantages. For example, the new system is able to produce liquefied helium and send it through the cryopanels inside the cyclotron. This feature boosts the performance of the cryopanels and improves pumping speed by lowering temperature.

A world-wide shortage of helium
A world-wide shortage of liquid helium is putting a strain on physics laboratories, manufacturers, and other businesses that depend on a secure and constant supply of liquid helium. The demand for liquid helium is fueled by growing high-tech manufacturing in China, Japan, Taiwan, and South Korea. The gravity of the situation has led the National Research Council (US) to establish a committee to study and make recommendations on the likely effects of the helium shortage. Igor Sekachev, TRIUMF’s Vacuum and Cryogenics Group Leader, has been asked by the US Government to sit as a member of this committee.

Helium liquefaction at TRIUMF
TRIUMF uses about 30,000 litres of liquid helium per year for experiments. Liquid helium users at the nearby University of British Columbia require another 10,000 litres of liquid helium each year.

Despite a pricing agreement with its main supplier of liquid helium, TRIUMF is feeling the effects of shortages and rising prices. Due to the loss of two major crude helium sources, the supplier is able to provide TRIUMF with only 60% of its normal supply, and further interruptions in the supply of liquid helium can be expected, along with price increases.
The issue of helium retention and recycling has become a critical issue for TRIUMF.

Plans made by the Vacuum and Cryogenics Group to address the helium supply problem include maintaining TRIUMF’s liquid helium and helium gas suppliers, but with the ability to substitute these suppliers if required. During the short term, from September 2007 to March 2008, an existing helium recovery system, which had been decommissioned, was restored to capture and recycle the helium gas exhaust from experiments.

For the intermediate term, April 2008 to January 2010, TRIUMF will use the new Linde TCF50 helium liquefier in ISAC-II Phase-II. In the long term, after January 2010, a helium liquefier of about 100 liquid litres per hour, similar to the Linde L140, will be purchased, installed and commissioned and is expected to meet TRIUMF’s needs for the foreseeable future.

Seeking new and innovative solutions

The goal of the TRIUMF Vacuum and Cryogenics Group is to seek new and innovative solutions to improve the support provided to Canadian and international scientific experimental groups, increase the overall efficiency of TRIUMF’s operation, reduce operating costs, and reduce dependence on outside suppliers of liquid helium.

The Group continues to meet its goals by developing and implementing innovative ways to address each problem encountered. This combination of science, engineering, and attention to costs are examples of the responsible practices that have made TRIUMF one of the leading laboratories in the field of cryogenics and superconducting technologies.

Igor Sekachev is the Group Leader of TRIUMF’s Vacuum and Cryogenics Group.