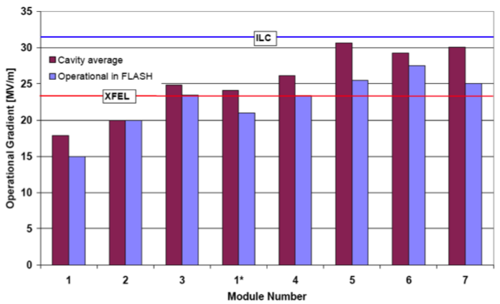
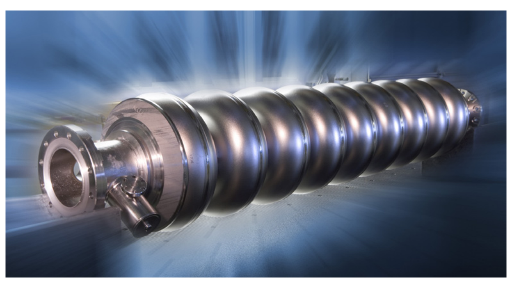
In addition, exploratory research is looking into other materials. Nb_3Sn, the most promising candidate, has the potential of producing 100 MV/m accelerating fields. While copper cavities can produce fields of the order of 50 – 100 MV/m, but only for microseconds, SRF cavities could approach these fields for long pulses and with much lower cooling costs and additionally allow continuous operation at medium fields for many hours.



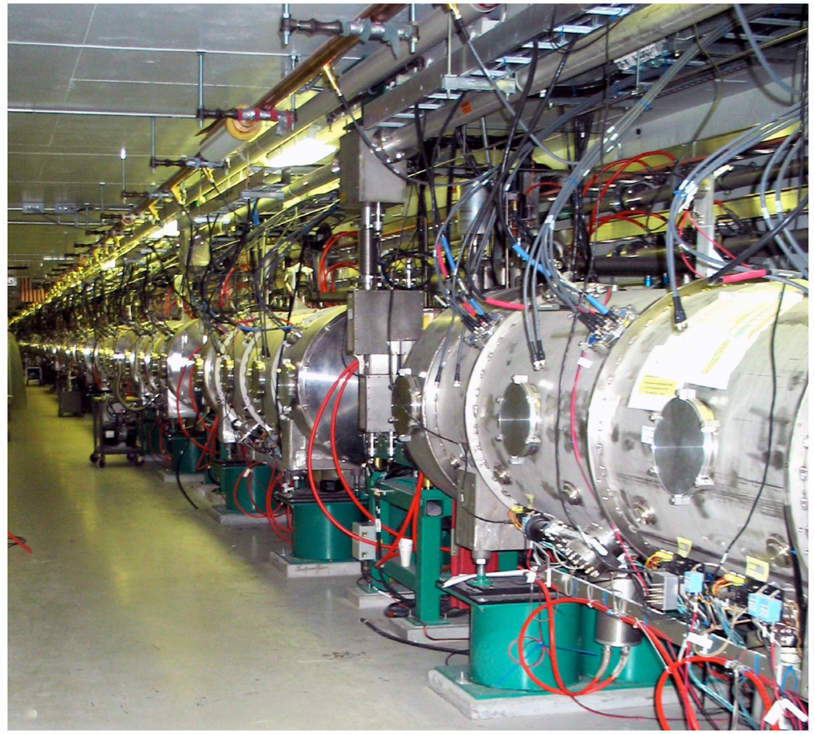
Evolution of cavity fields over the last five years. The bar chart compares bare cavity test results with performance in the accelerator. Each bar is an average field of eight cavities in a cryomodule.

A Promising Future for SRF

SRF systems have already been operating routinely in a variety of accelerators with a range of demanding applications resulting in an annual research investment of more than 1 billion dollars in the US alone. Some exciting future applications will only be possible using this SRF technology. This includes basic research into elementary particles and what gives mass to matter and properties and production of nuclei in supernovae. In addition, very bright and short pulsed x-ray sources will have very important applications in medicine, biology and material sciences. And applied research in accelerator physics could lead to the development of new types of nuclear reactors and in the reduction of the lifetimes of long-lived isotopes in nuclear waste which could make storage a viable option. For more details and further applications, see the accompanying brochure ***RF Superconductivity 2010: Science, Technology, Applications.***



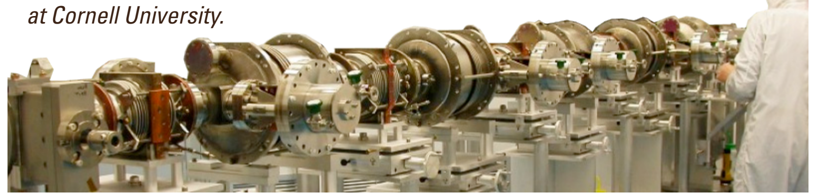
9-cell niobum cavity to be used in European XFEL at DESY and the future ILC.



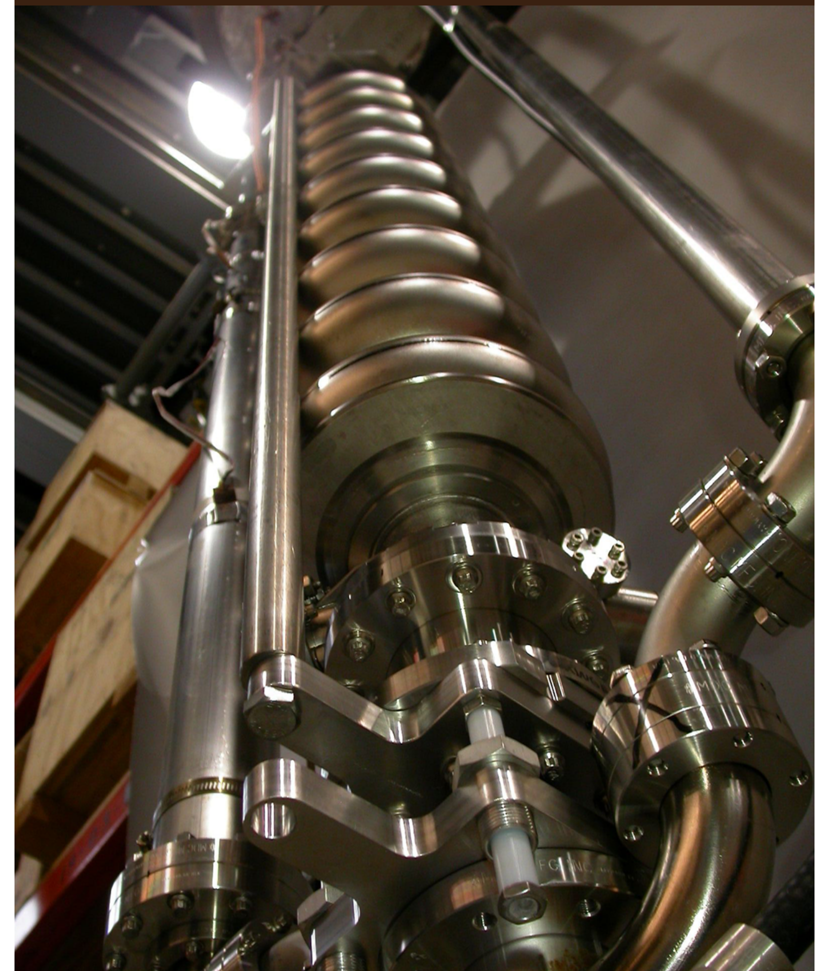
Cryomodules in the SNS tunnel at Oak Ridge National Laboratory.

“SRF technology allows substantional cost savings…”

ERL-injector cavity string assembly at Cornell University.



superconducting radio frequency



A companion guide for
RF Superconductivity
2010

www.lepp.cornell.edu/Research/AP/SRF/

Introduction

The aim of this brochure is to summarize, in a brief and understandable way, the status of the science, technology and applications of Superconducting Radio Frequency (SRF) particle accelerators and to discuss their varied and exciting prospects for the future. It will be stressed that SRF technology allows substantial cost savings compared to more conventional accelerators.

SRF CAVITIES

Today's Particle Accelerators: Very Diverse Tools

Originally, accelerators were developed to do basic research in elementary particle physics: the study of the basic building blocks of matter. Today, their use has expanded to industry in such diverse fields as medical diagnosis and treatment, life sciences, chemistry, material science, and luggage interrogation for homeland security defense applications. Researchers also focus on using accelerators, particularly with SRF technology, for a new type of nuclear reactor and solving the nuclear waste disposal problem.

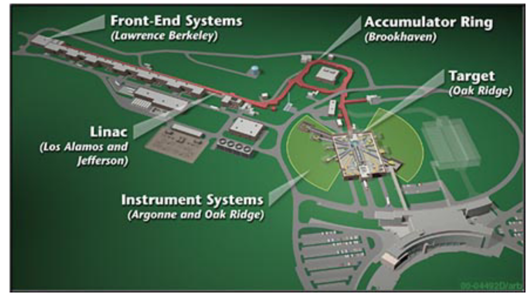
Radio Frequency Cavities and Superconductivity

At the heart of any modern day accelerator is the radio frequency (RF) accelerating cavity where electrons or protons gain energy by riding on an electric field wave, akin to a surfer riding an ocean wave. The federal government supports both the development and use of these accelerators with an annual budget of about $1 billion. Almost all modern day frontier accelerators employ the technology of superconductivity either in the use of magnets or in the RF cavities. For the latter, superconductivity enhances the performance of the cavity structure and reduces the cost of cooling the accelerator by up to 1000 times compared to normal conducting cavities for continuous or long pulse operation.

> *"Almost all modern day frontier accelerators employ the technology of superconductivity either in the use of magnets or in the RF cavities."*

An Example: The SNS

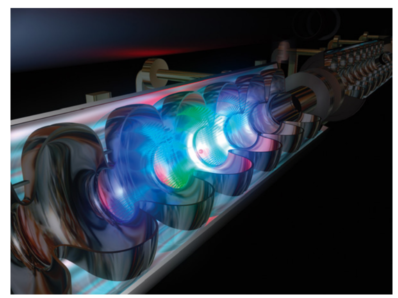
As an example of a new application of SRF, the first very high intensity proton accelerator is operating for the billion dollar Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. Neutron scattering is an important tool for material science, chemistry and the life sciences. SNS will provide 1.4 megawatt of beam power on target to produce the world's highest intensity neutron flux for science and technology research and development.



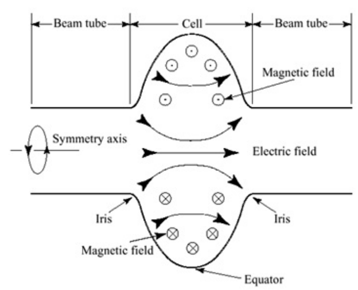
SNS Facility layout at Oak Ridge National Laboratory.

The Need for Large Accelerating Fields and Associated SRF Benefits

In order to produce the required accelerating field (millions of volts per meter), mega amps of surface currents flow in the metal walls of the cavity structure. In a normal conducting metal such as copper, this produces an enormous amount of heat which is costly to cool. In addition, the presence of the cavity structure near the particle beam has disruptive effects on the particle beam, limiting its density and therefore limiting the accelerator's use for many modern day applications. The good news is that these detrimental effects can be overcome by the use of superconducting cavities.



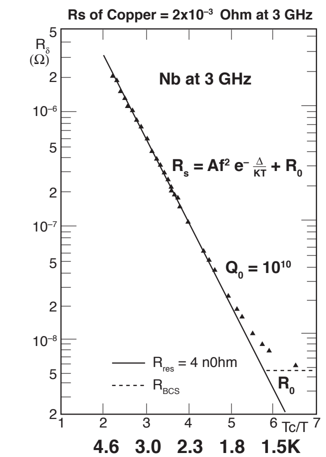
Cutaway view of a superconducting cavity accelerating a beam.



Single cell cavity with electric and magnetic field lines.

What is Superconductivity?

Superconductivity was first discovered by Dutch physicist H.K. Onnes in 1911 when he cooled mercury to the temperature of liquid helium (4 degrees Kelvin (K), -452F or -269C) and observed that its electrical resistance suddenly vanished. The theoretical understanding (known as the BCS Theory) was first advanced in 1957 by U.S. physicists Bardeen, Cooper and Schrieffer for which they were awarded the Nobel Prize in 1972. In a normal conductor, resistivity is due to a frictional or resistive force experienced by a current of moving electrons. In a superconducting metal such as niobium, the resistance to RF current flow decreases sharply below what is known as the critical temperature, T_C. The figure shows the rapid decrease in resistance vs. temperature for niobium. Note that for RF currents that reverse direction with very high frequency (3GHz), there is a finite residual resistance which is lower than that of copper, strongly reducing the cooling cost during accelerator operations.



The resistance of Niobium as a function of temperature. Note that the vertical axis is equally spaced in powers of 10(logarithmic). A straight line on such a graph indicates an exponential dependence. R_0 is the finite residual resistance.

> "In a superconducting metal such as niobium, the resistance to RF current flow decreases sharply below the critical temperature, T_C."

SUPERCONDUCTING RF (SRF)

The Development of Higher Cavity Voltages

Achieving higher accelerating fields is a continuing goal. For a given energy, the higher the accelerating field, the smaller and cheaper the accelerator. Typical SRF fields for operating accelerators installed some years ago are in the range of 5 – 20 MV/m (MegaVolts/meter). Today, fields of 25 – 50 MV/m are being demonstrated in laboratory tests of SRF niobium cavities, and research continues to push performance towards the theoretical limit of 60 MV/m.