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TEST RESULTS OF HTS COILS AND AN R&D MAGNET FOR RIA*

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Rare Isotope Accelerator (RIA)
RIA: CONNECTING NUCLEI with the UNIVERSE

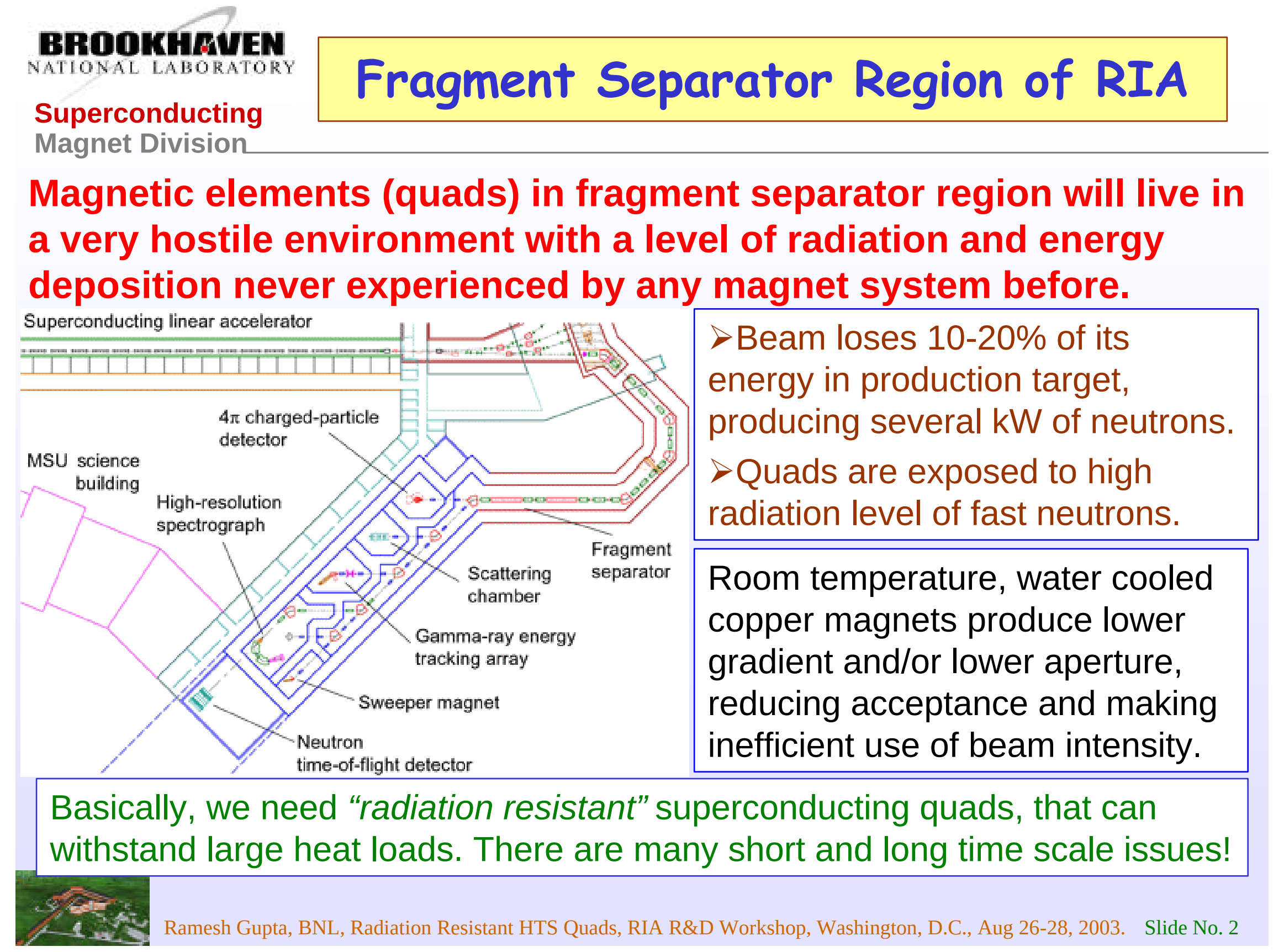
Abstract

- Development of the radiation resistant HTS magnet is a crucial part of the R&D for the Fragment Separator region of Rare Isotope Accelerator (RIA).
- Major progress is reported here through the construction & test results of :
  - ➢ 13 HTS coils each made with ~220 meter of commercially available BSCCO2223 tape
  - ➢ A "big" HTS model magnet with cost effective magnetic mirror configuration

Introduction

Quadrupoles in the 400 kW end of RIA's Fragment Separator are subjected to several orders of magnitude more radiation and energy deposition than typical accelerator magnets receive during their entire lifetime

- ➢ HTS magnets are proposed for this extremely high radiation region of the Fragment Separator
- ➢ Warm iron design reduces the heat load from ~15 kW to ~130 W in the first quadrupole alone
- ➢ HTS, with ~30 K operation, offers a factor of 10 savings in cooling cost for removing this enormous amount of heat energy



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Fragment Separator Region of RIA

Magnetic elements (quads) in fragment separator region will live in a very hostile environment with a level of radiation and energy deposition never experienced by any magnet system before.

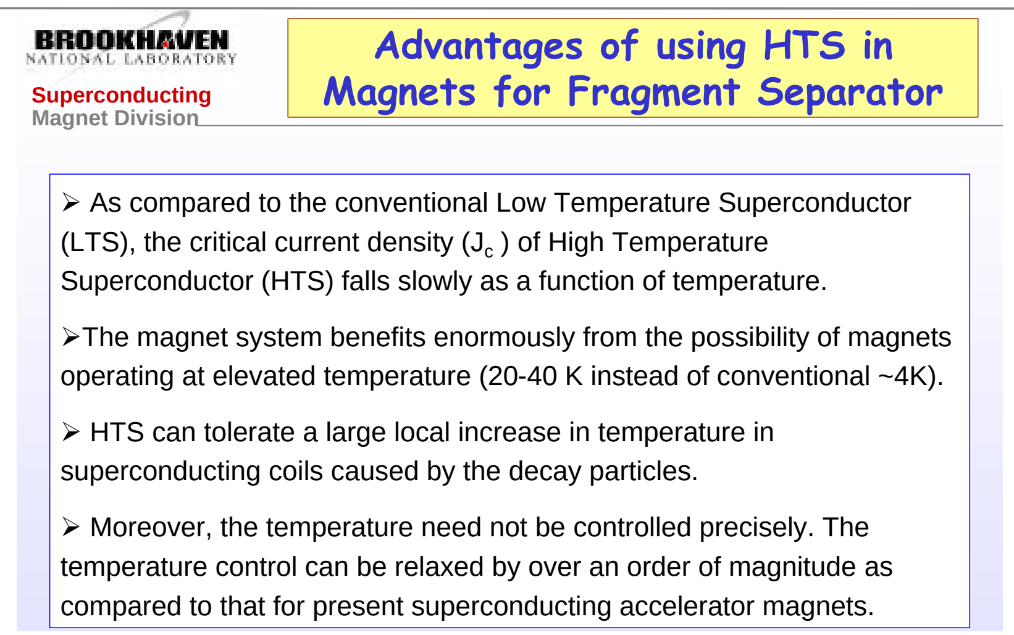
- ➢Beam loses 10-20% of its energy in production target, producing several kW of neutrons.
- ➢Quads are exposed to high radiation level of fast neutrons.

Room temperature, water cooled copper magnets produce lower gradient and/or lower aperture, reducing acceptance and making inefficient use of beam intensity.

Basically, we need *"radiation resistant"* superconducting quads, that can withstand large heat loads. There are many short and long time scale issues!

Ramesh Gupta, BNL, Radiation Resistant HTS Quads, RIA R&D Workshop, Washington, D.C., Aug 26-28, 2003. Slide No. 2

*Work supported by U.S. Department of Energy.



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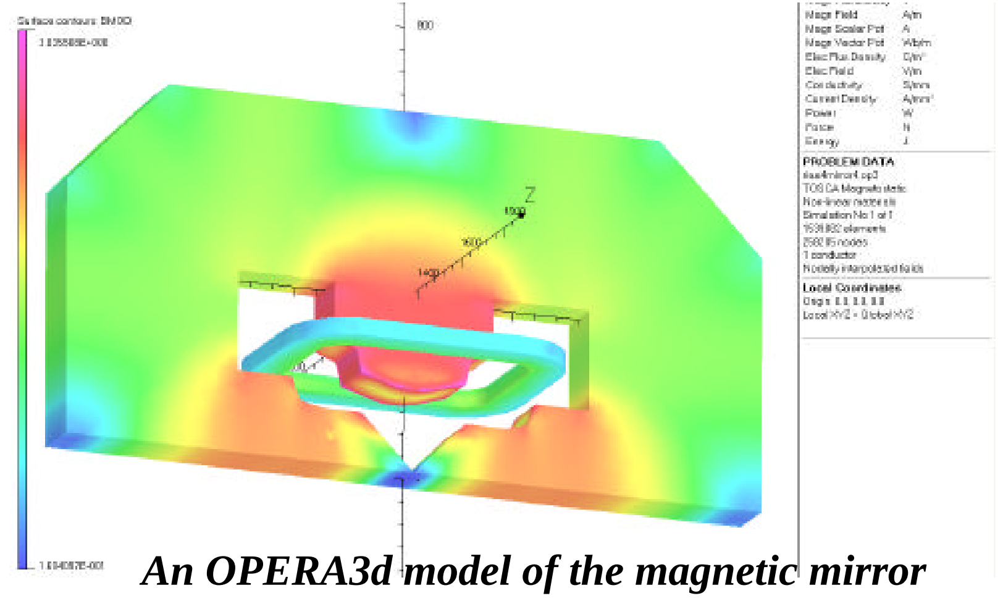
Advantages of using HTS in Magnets for Fragment Separator

- ➢ As compared to the conventional Low Temperature Superconductor (LTS), the critical current density (J_c) of High Temperature Superconductor (HTS) falls slowly as a function of temperature.
- ➢The magnet system benefits enormously from the possibility of magnets operating at elevated temperature (20-40 K instead of conventional ~4K).
- ➢ HTS can tolerate a large local increase in temperature in superconducting coils caused by the decay particles.
- ➢ Moreover, the temperature need not be controlled precisely. The temperature control can be relaxed by over an order of magnitude as compared to that for present superconducting accelerator magnets.

DESIGN PARAMETERS

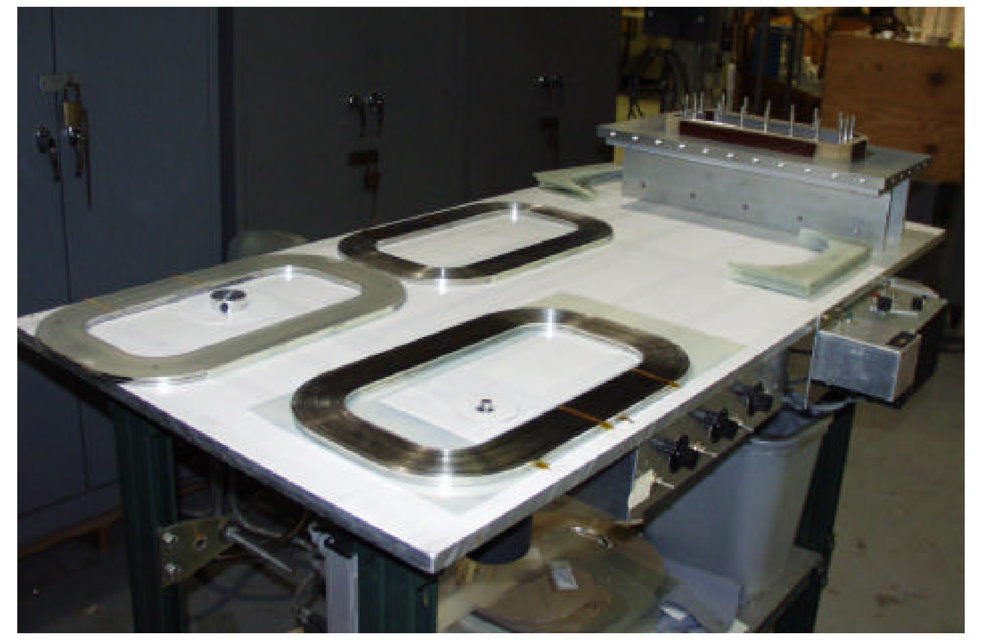
- Aperture: 300 mm
- Gradient: 10 T/m
- Magnetic Length: 1 meter
- Coil Width: 500 mm
- Coil Length: 1125 mm
  (300 mm in model magnet)
- Coil Cross-section: 62 mm X 62 mm
- No. of Layers: 12
- No. of turns per layer: 175
- Conductor Size: 4.2 mm X 0.3 mm
- Minimum Bend Radius: 50.8 mm
- S.S. Insulation: 4.4 mm X 0.038 mm
- Yoke Cross-section: 1.3 m X 1.3 m



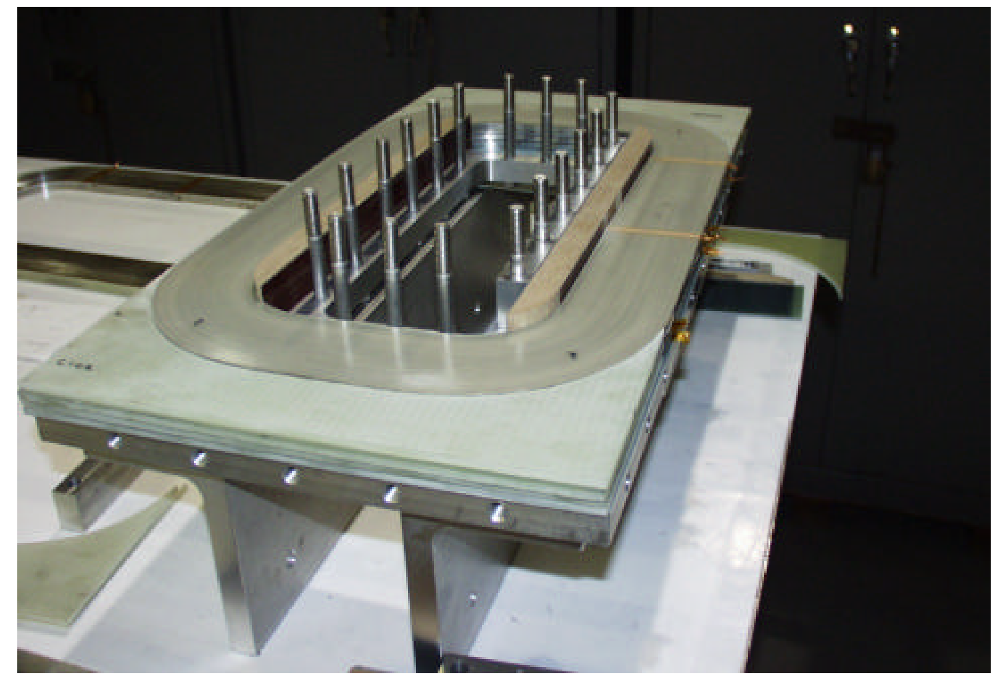
An OPERA3d model of the magnetic mirror design. Color indicates the field intensity on the surface of coil and iron regions.

- A high radiation dose: 10^{19} n/cm^2.
- Organic insulation used in present accelerator magnets won't survive.
- We plan to use stainless steel tape – being a metal, it offers a robust radiation resistant insulation.
- Radiation damage properties of HTS to be measured by NSCL.

A coil being wound on the new computer controlled winding machine.

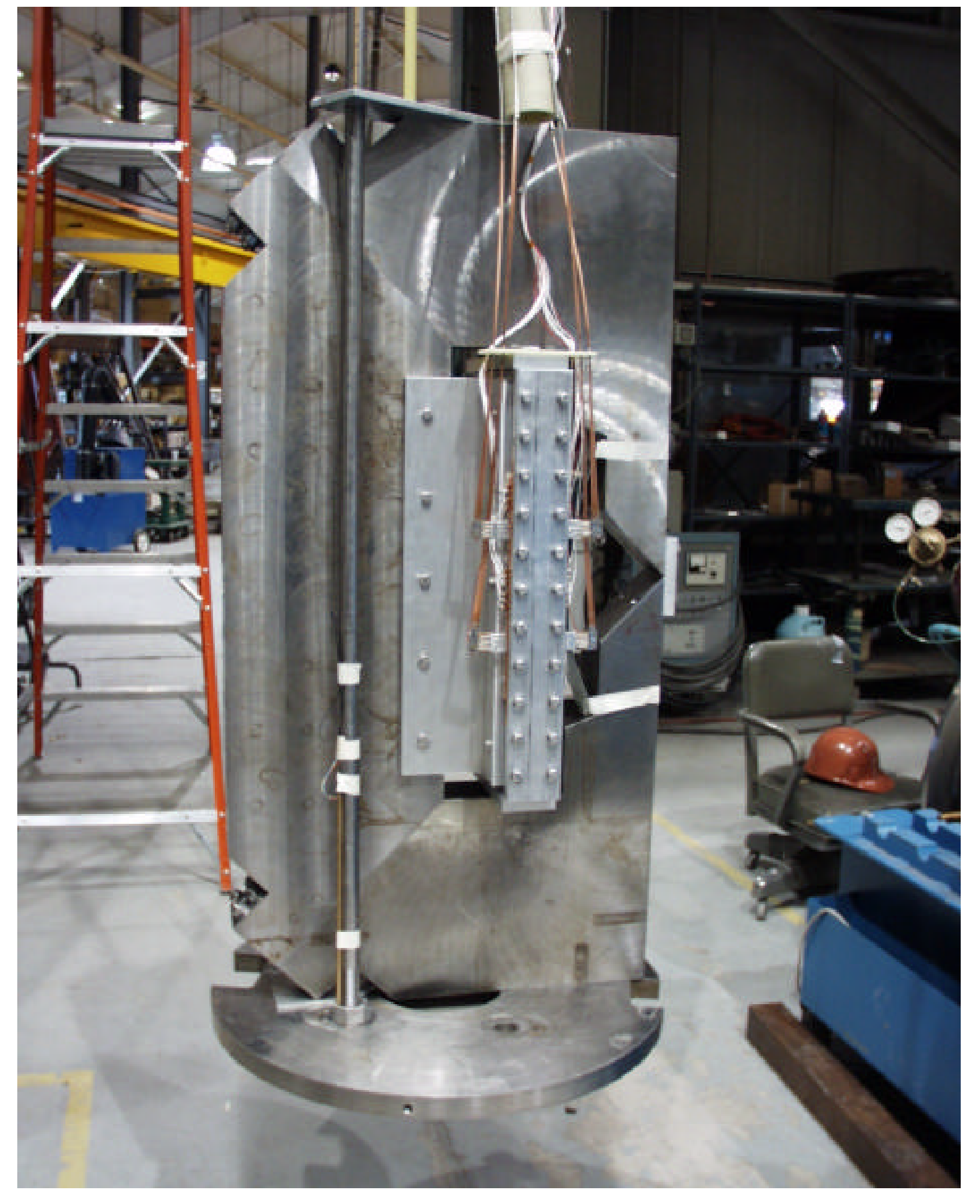


Three pairs of coils (six coils). These coils are made with HTS tape (nominal 4.2 mm wide and 0.3 mm thick) and insulating stainless steel tape (nominal 4.6 mm wide and 0.04 mm thick).

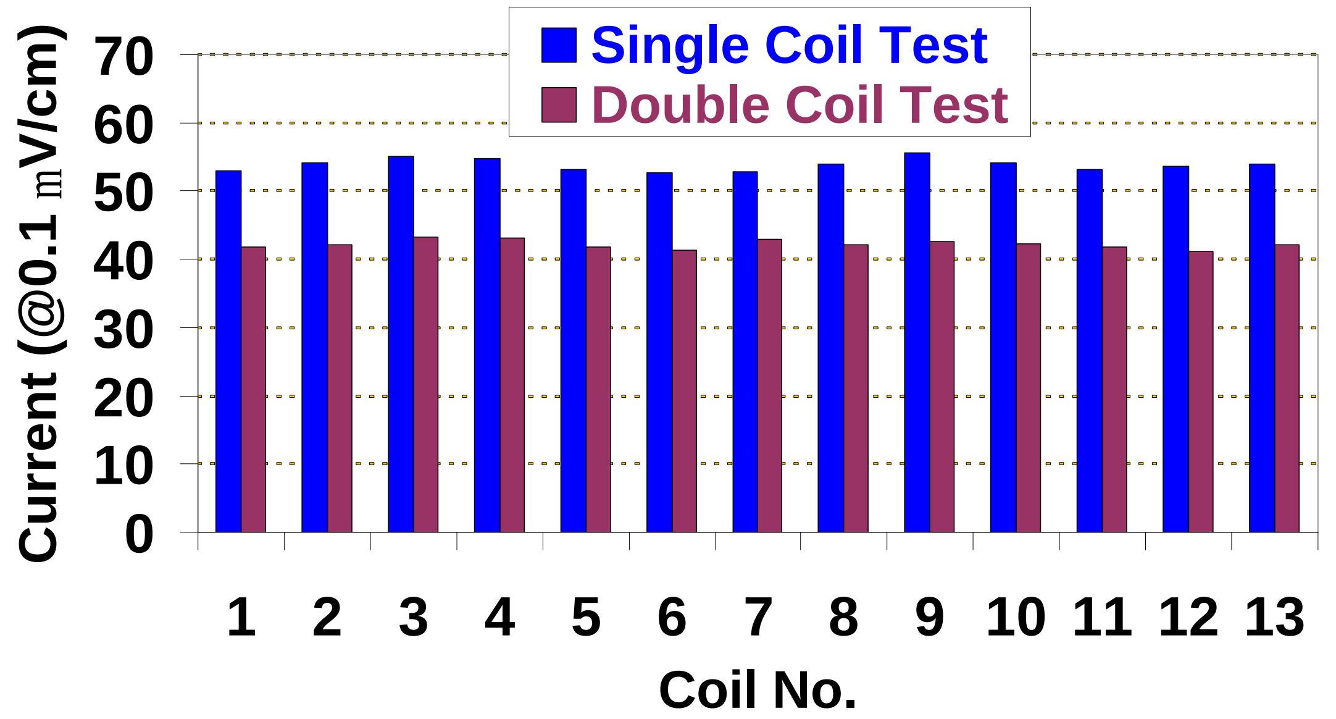


Three pairs of coils during their assembly a support structure.

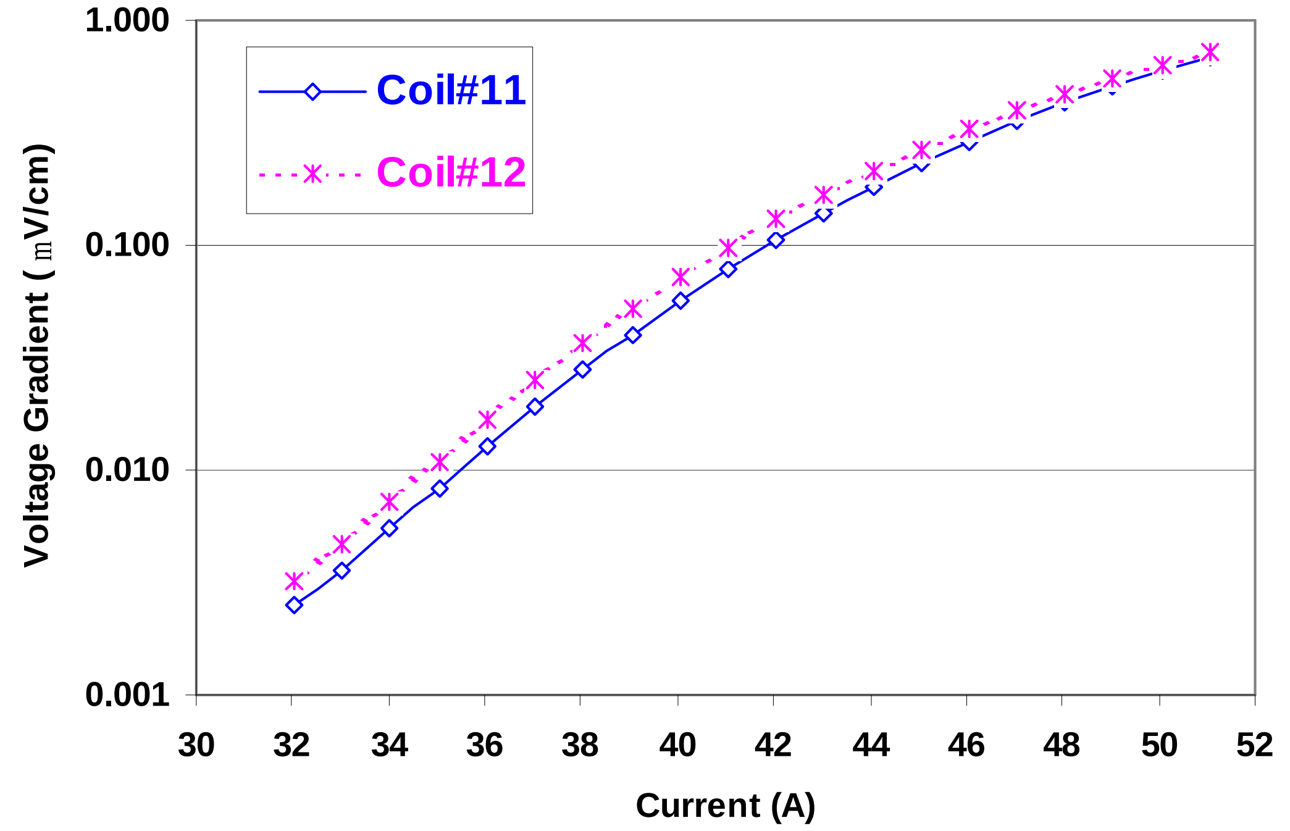
Coils in their bolted support structure, with the pole iron (in the middle, inside the structure), magnetic mirrors (two on the upper side with 45 degree angles on either side of the vertical axis) and iron return yoke.



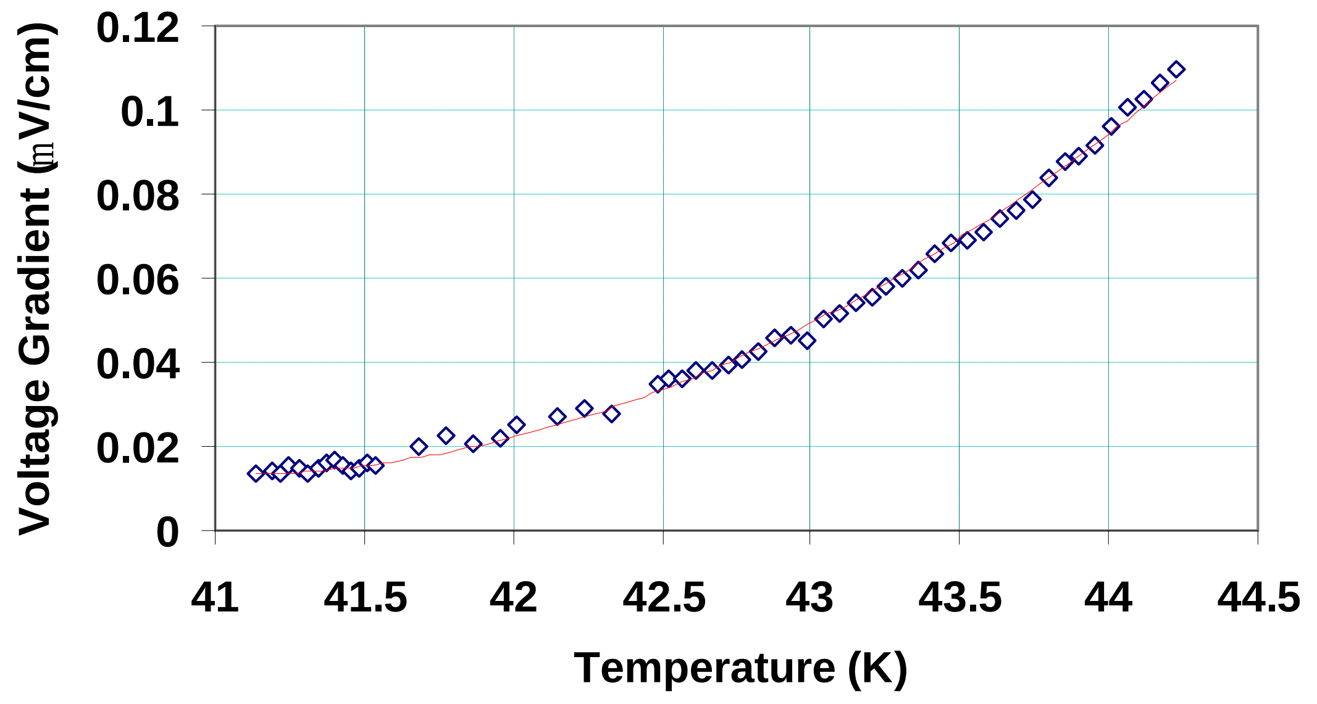
Magnetic mirror model magnet, just before the test. At the test facility, the magnet can be tested in a wide range of temperature (4.2 K to 80 K). A higher operating temperature translates in to a significant reduction in operating cost.



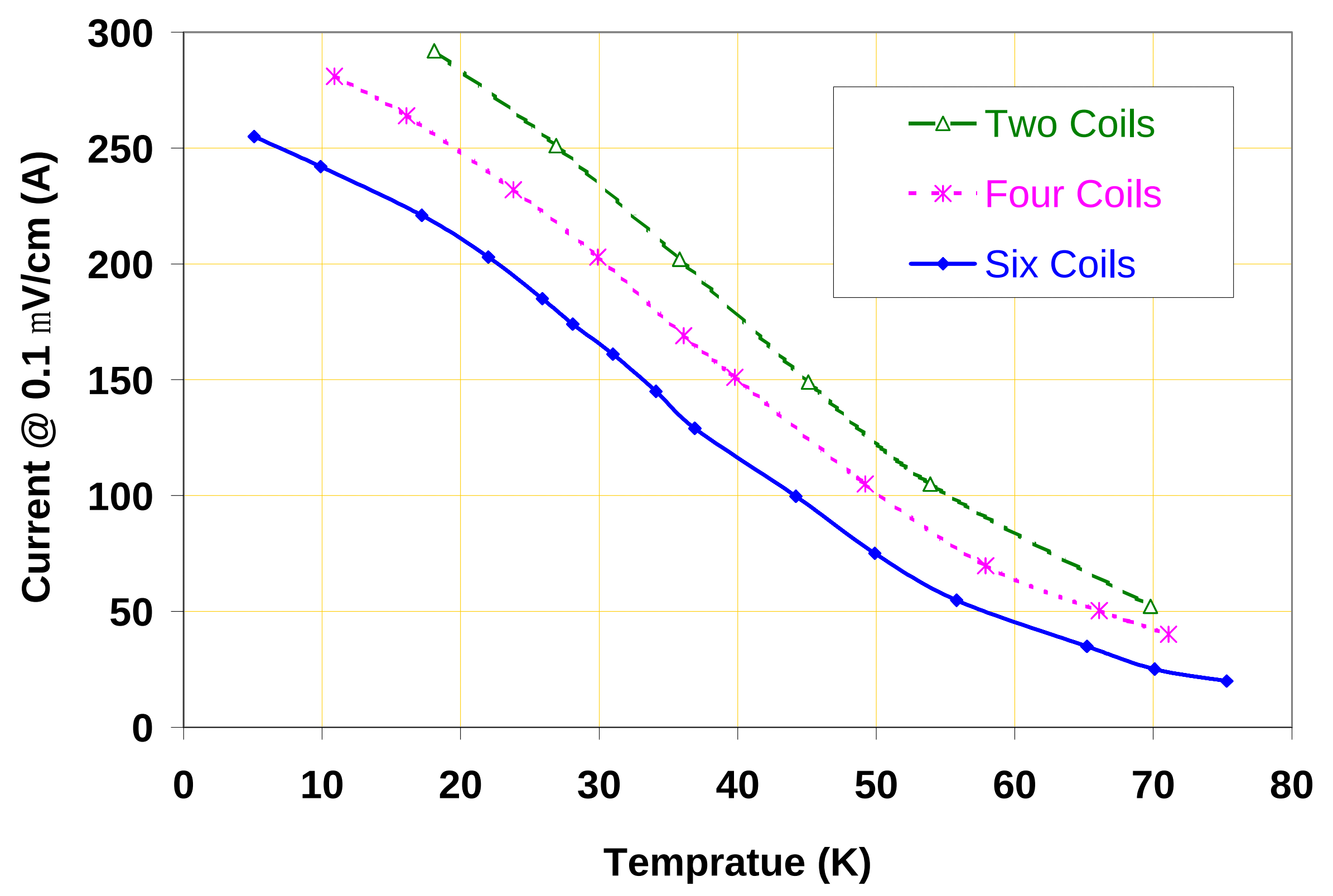
The current at a voltage gradient of 0.1 m V/cm (10 m V/meter) over the total length of the coils at 77 K.



Typical voltage gradient vs. current curves for a pair of coils operated in series in liquid nitrogen bath.



Voltage gradient as a function of temperature for the magnetic mirror model at a constant current of 100 A.



A summary of the temperature dependence of the current in two, four and six coils in the magnetic mirror model. In each case voltage appears on the coil is closest to the pole tip. Magnetic field is approximately three times as great for six coils as it is for four coils.

SUMMARY

A magnetic mirror model built with commercially available high temperature superconductor has achieved the desired performance (~150 A at ~30 K). It meets the RIA requirements with a margin. Stainless steel tape between the turns has provided the necessary insulation. The successful test of this magnet is the first significant step towards demonstrating that HTS-based magnets can provide a good technical solution for one of the most critical items of the RIA proposal.

At present, no magnet made with HTS is in use in any accelerator. The result presented here proves that despite its brittle nature, the technology to build magnets with HTS can be developed. HTS based accelerator magnets offer several unique advantages.

HTS used in this work was purchased from American Superconductor Corp.

http://www.nscl.msu.edu/ria/
http://www.phy.anl.gov/ria/
http://www.orau.org/ria/

What is RIA?

A schematic of the RIA facility is shown in Figure 1. The key to the scientific discovery potential of the facility is its ability to provide the highest-intensity beams of stable heavy ions for the production of rare isotopes. This concept builds on developments in superconducting technology in the U.S. and Europe over the past two decades. RIA's driver accelerator will be a flexible device capable of providing beams from protons to uranium at energies of at least 400 MeV per nucleon, with beam power in excess of 100 kW. With this flexibility, the production reaction can be chosen to optimize the yield of a desired isotope. In comparison to the two main competing in-flight facilities, the Radioactive Ion Beam Factory at RIKEN and the GSI upgrade, RIA has two advantages. First, RIA's capability for post acceleration (not included in either of the other two projects) will allow a wider range of studies and will include the measurement of nuclear reactions at astrophysical energies and the search for new heavy elements with long lifetimes. Second, the acceleration scheme of RIA's primary-beam linac is planned to be 20-fold more efficient than either of the other facilities and, hence, able to deliver significantly more primary-beam power. In comparison to the main ISOL competition, ISAC at TRIUMF, RIA has higher primary-beam power and a more flexible combination of ion sources, which will provide higher intensities and a wider variety of rare isotopes.

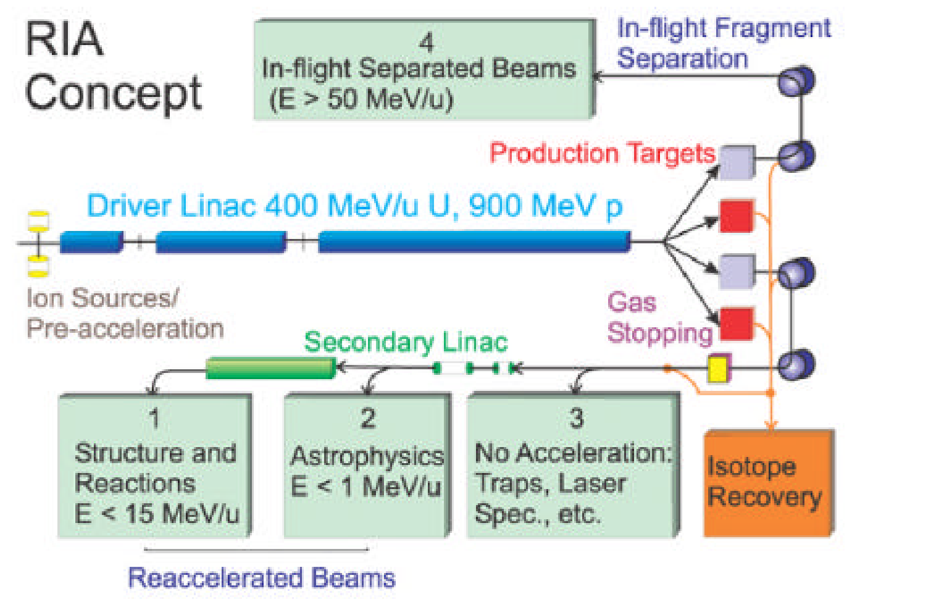


Figure 1.
The heart of the facility is composed of a driver accelerator capable of accelerating every element of the periodic table up to at least 400 MeV/nucleon. Rare isotopes will be produced in a number of dedicated production targets. Upon extraction from the targets, these isotopes can be used at rest for experiments in Area 3, or they can be accelerated to energies below or near the Coulomb barrier and used in Areas 2 and 1, respectively. Isotopes will also be harvested for applications (Isotope recovery). Fast beams of rare isotopes can also be used directly after separation in a high-resolution fragment separator (Area 4). RIA brings together the most powerful known techniques for rare isotope production in a single facility.

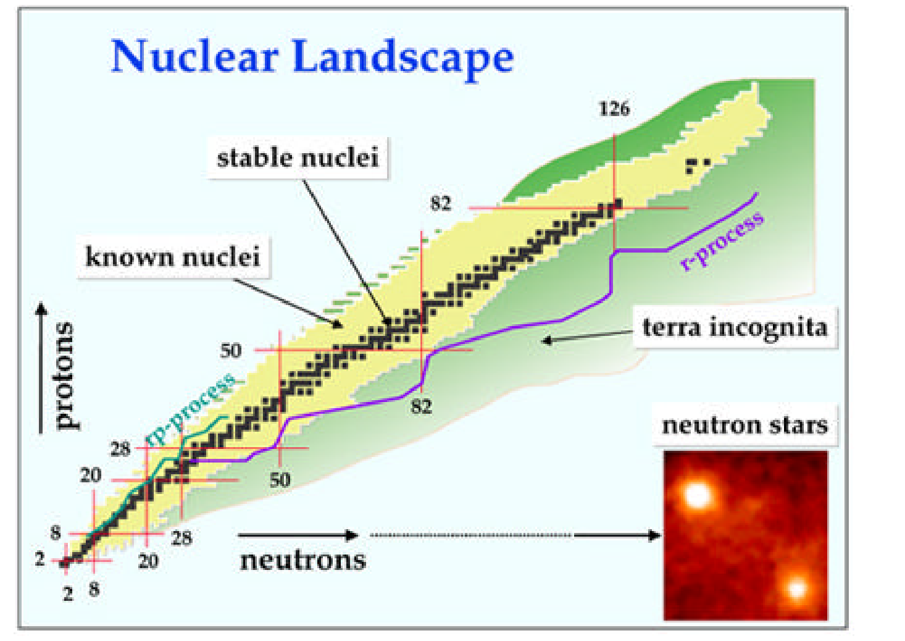


Figure: On this chart of the nuclides, black squares represent stable nuclei and the yellow squares indicate unstable nuclei that have been produced and studied in the laboratory. The many thousands of these unstable nuclei yet to be explored are indicated in green (Terra incognita). The red vertical and horizontal lines show the magic numbers, reflecting regions where nuclei are expected to be more tightly bound and have longer half-lives. The anticipated paths of astrophysical processes for nucleosynthesis (r-process, purple line; rp-process, turquoise line) are also shown.