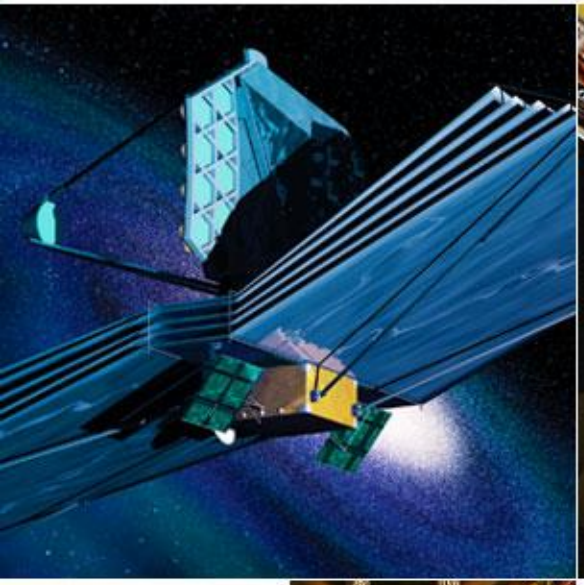
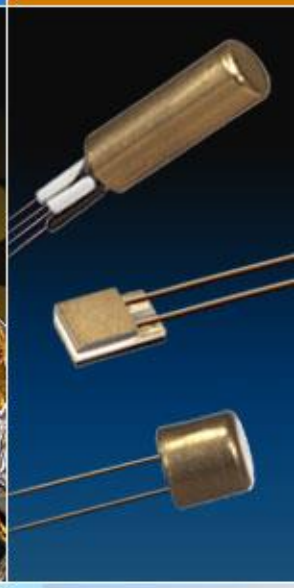
Lake Shore CRYOTRONICS





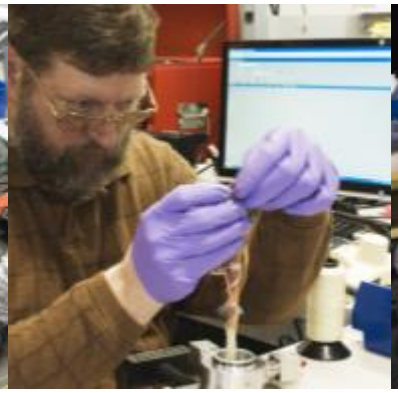
What is your favorite cryogenic temperature sensor for high energy physics? And why is it Cernox?

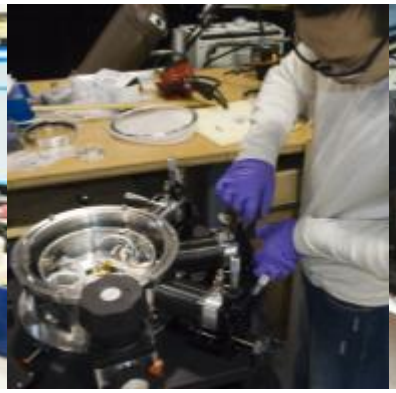
Dr. Scott Courts

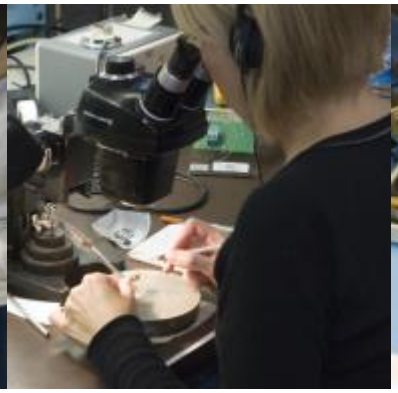
Advancing Science

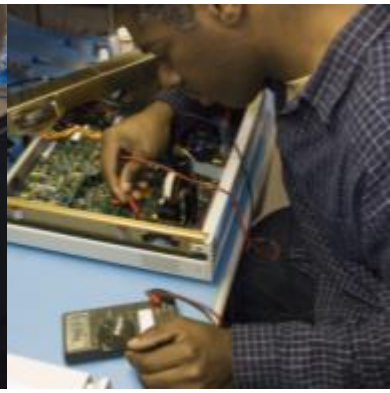
Established and dependable

- Over 50 years in operation
- Located in Ohio, USA
- ISO 9001 quality system
- Approx. 150 employees, over half with degrees in physics, engineering or material science



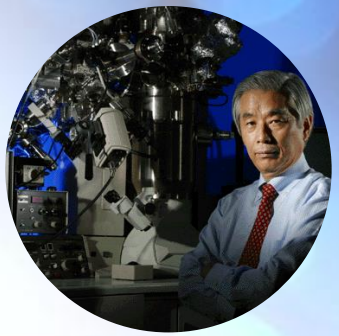






Lake Shore CRYOTRONICS

Supporting Significant Scientific Accomplishments



Dr. Sumio Iijima
Inventor of the carbon nanotube

CERN LHC
Particle Accelerator

National Ignition Facility

NASA James Webb
Space Telescope

Alex Mueller & Georg Bednorz
Nobel Prize in Physics in 1987 for work in high temperature superconductivity

Lake Shore CRYOTRONICS

Temperature Sensing

High Energy Physics Applications

- Cryogen liquefaction and distribution
- Thermal radiation shielding
- Superconducting radiofrequency cavities
- Superconducting magnets

Purpose

- Control of cool down and warm up processes
- Temperature limit setting
- Diagnostics
- Monitor safety margins

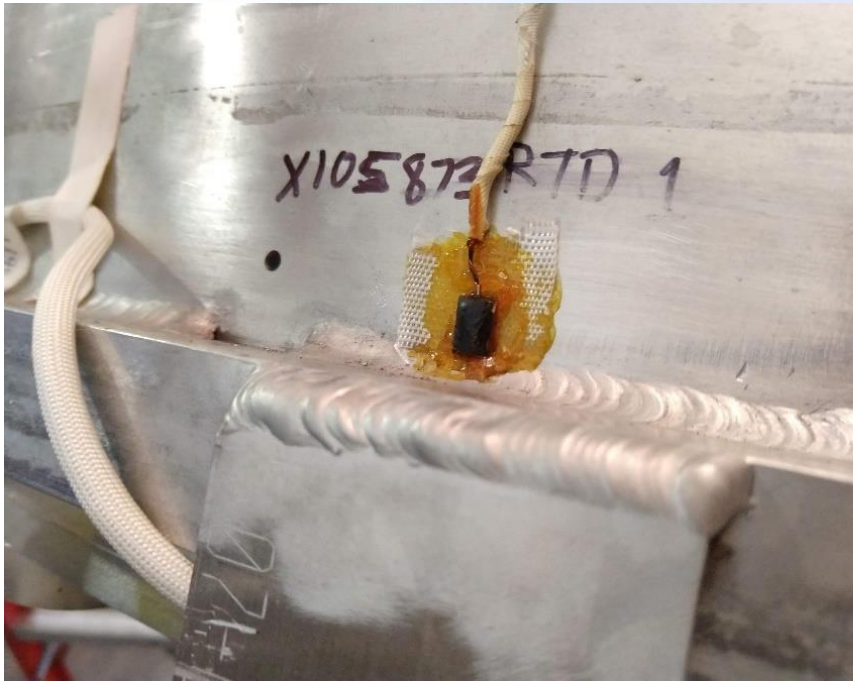


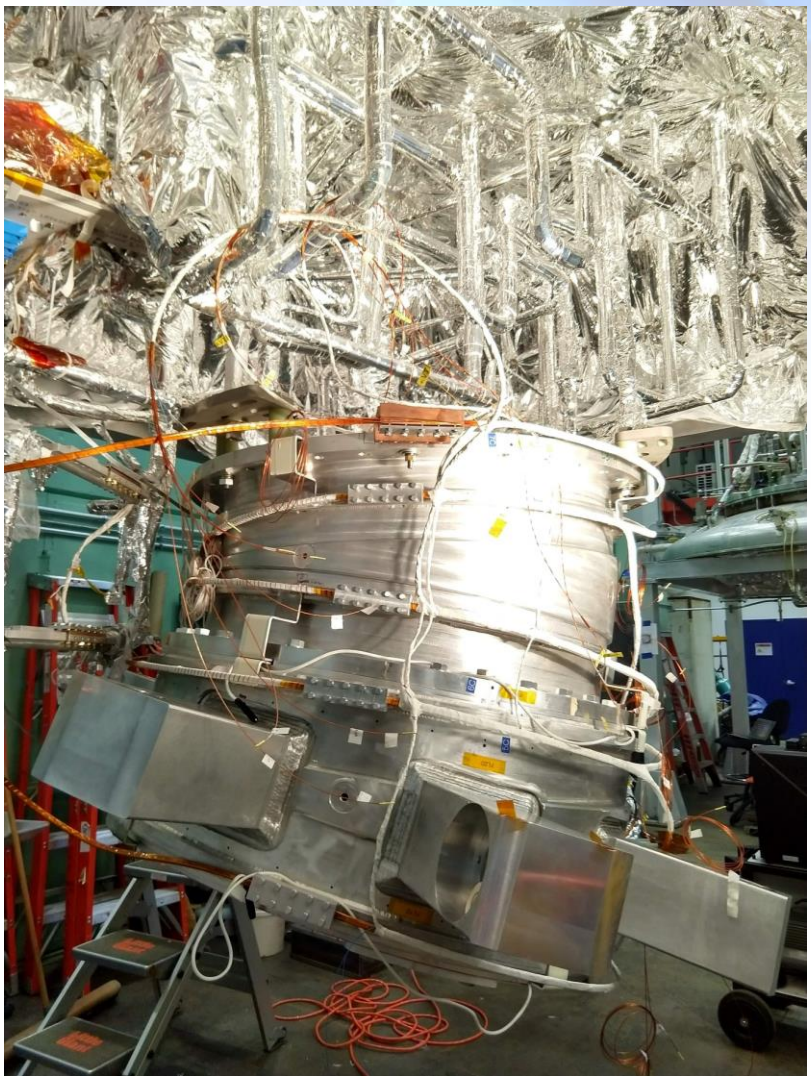
Photo credit: Karie Badgley, mu2e project

Lake Shore CRYOTRONICS

Remote Sensing

Photo credit: SLAC

Photo credit: Karie Badgley, mu2e project



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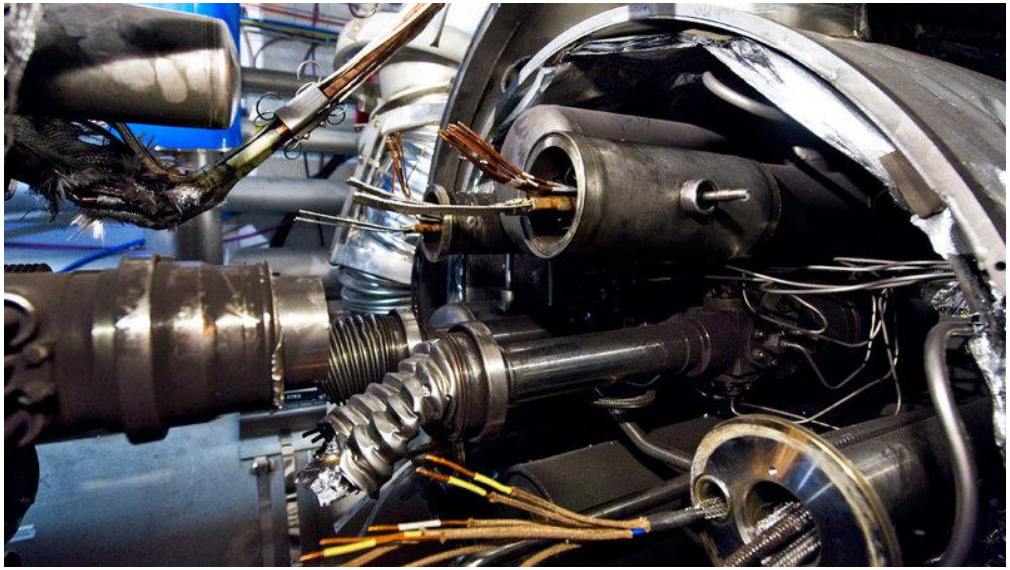
Remote Temperature Sensing

- Temperature sensors are often buried and difficult to replace
- In large scale applications, a failed temperature sensor can result in
  - High replacement cost
  - Extended, expensive downtime
  - Equipment damage

Temperature sensor selection and reliability is essential!



https://www.npr.org/templates/story/story.php?storyId=121352948

Lake Shore CRYOTRONICS

A Brief Accelerator Facility History

Mid- to late-1980s

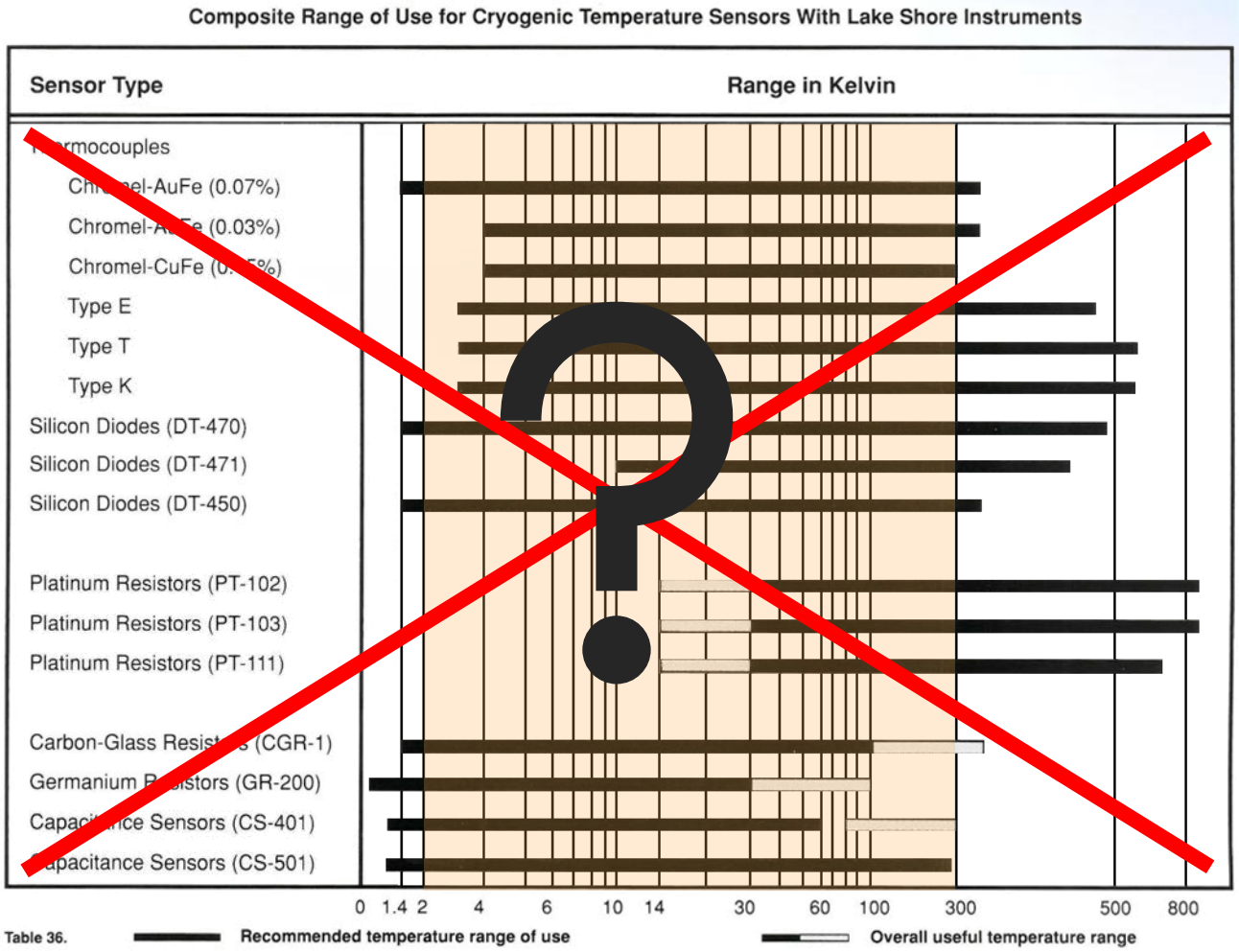
Operating	Under Construction	Under Study
KEK (Japan)	UNK I (USSR)	UNK II
AGS (BNL)	SSC (USA)	LHC (CERN)
PS (CERN)	LEP II (CERN)	CLIC (CERN)
CESR (Cornell)	RHIC (BNL)	SC (Stanford)
Tevetron I & II (FNAL)		VLEPP (USSR)
SPS and LEP I (CERN)		JLC (Japan)
SLC SLAC (Stanford)		
TRISTAN (Japan)		
HERA DESY		

Increasing energies resulting in:

- *Higher radiation levels*
- *Adoption of superconducting magnets, requiring cryogen*

Lake Shore CRYOTRONICS

Cryogenic Temperature Sensors — Circa 1990



2 K to 300 K range

Stable/ repeatable

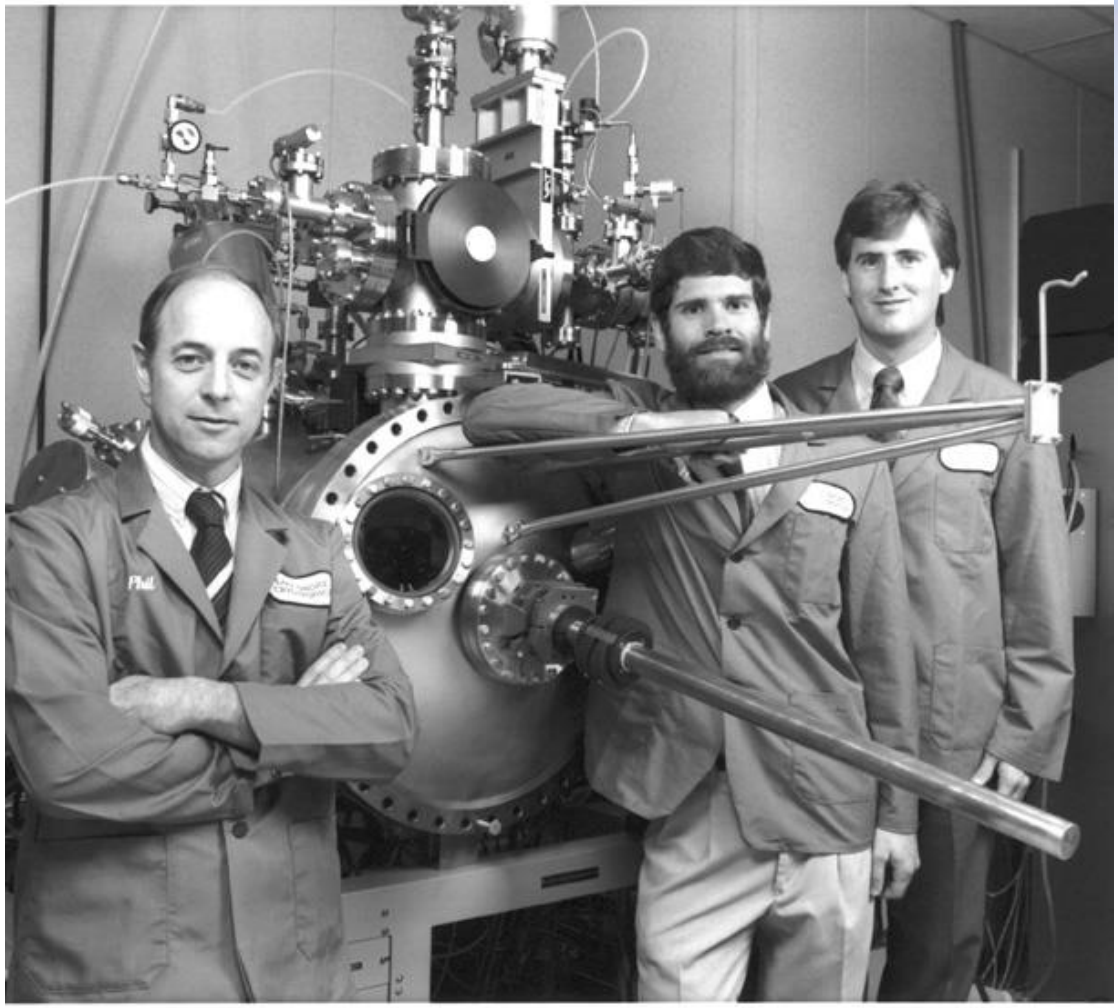
Low magnetic offset

Radiation hard

Sensor Development — 1990

- Research in Japan uncovered a material that looked promising
- Conducting ZrN phase embedded in an insulating ZrO phase
- Could tailor the ratio of conducting to nonconducting phase to adjust the resistance range and sensitivity
- Demonstrated low magneto-resistance
- Expected radiation resistant

But needed to confirm



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Cernox® Development — 1990

- Developed for Superconducting Super Collider under a Department of Energy SBIR grant

SBIR·STTR
America's Seed Fund™
POWERED BY SBA

SBA

A RADIATION RESISTANT CRYOGENIC TEMPERATURE SENSOR FOR THE 4K TO 80K RANGE

Award Information

Agency:
Department of Energy

Branch:
N/A

Contract:
N/A

Agency Tracking Number:
10846

Amount:
$499,454.00

Phase:
Phase II

Program:
SBIR

Small Business Information

Lake Shore Cryotronics, Inc.
64 E Walnut St, Westerville, OH, 43081

Principal Investigator	Business Contact	Research Institution
Name: Dr Philip R Swinehart Title: Principal Investigator Phone: (614) 891-2243	Phone: () -	N/A

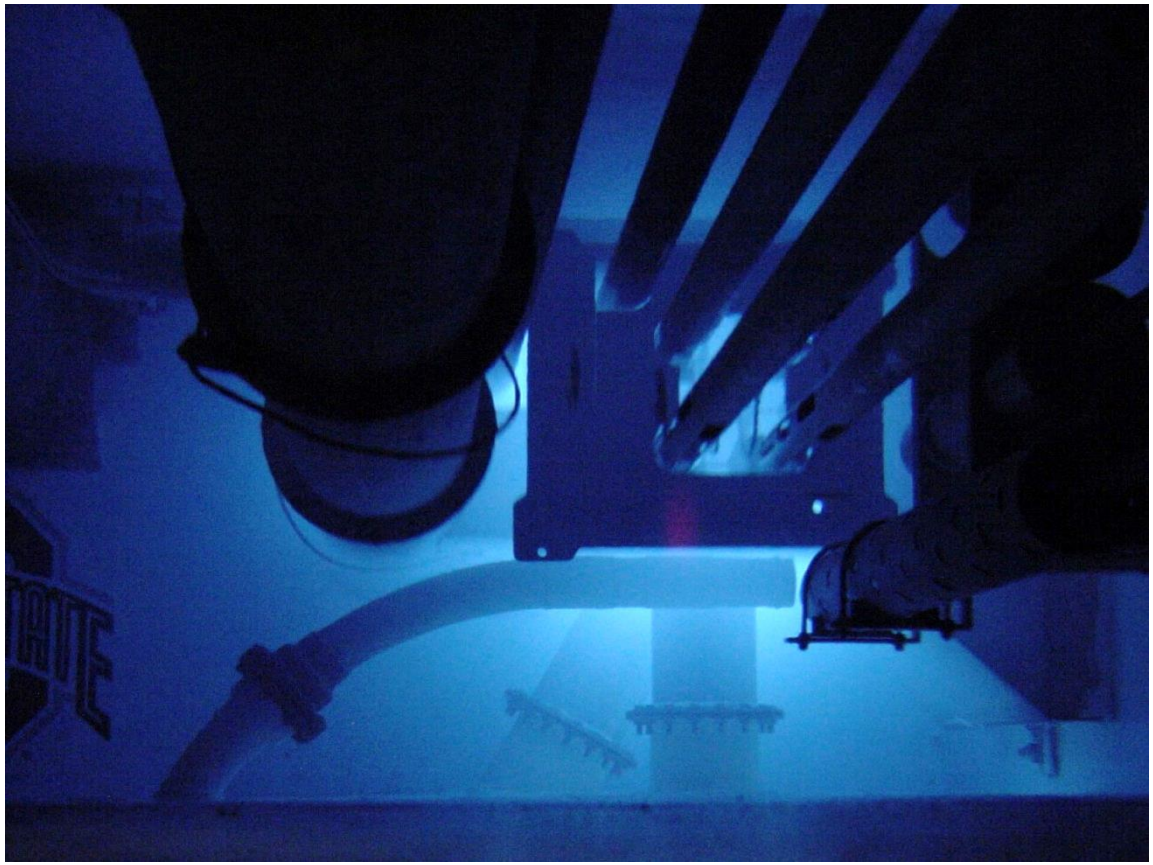
Abstract

THE SEVERE ENVIRONMENT OF HIGH ENERGY PHYSICS FREQUENTLY COMBINES CRYOGENICS, HIGH TEMPERATURES, HIGH VACUUM, AND HIGH RADIATION FLUENCES. A SENSITIVE, STABLE, ACCURATE, ANDEASY-TO-USE THERMOMETER FOR THE TEMPERATURE RANGE TO 80 K (-269 DEGREES CENTIGRADE TO -193 DEGREES CENTIGRADE) ALSO RESISTANT TO IONIZING RADIATION IS NOT COMMERCIALLY AVAILABLE. THIN FILM ZIRCONIUM NITRIDE IS A CONDUCTING CERAMIC WITH GOOD POTENTIAL FOR PROVIDING SMALL, ROBUST, THERMALLY FAST RESISTANCE SENSORS NOT ONLY FOR THE TEMPERATURE RANGE OF IMMEDIATE INTEREST, BUT BEYOND IT AS WELL. IN PHASE I ZIRCONIUM NITRIDE WILL BE REACTIVELY SPUTTERED IN A RESISTANCE THERMOMETER CONFIGURATION. THE PROJECT ALSO WILL TEST THE DEVICE'S THERMOMETRY CHARACTERISTICS AND ITS RESISTANCE TO GAMMA AND FAST NEUTRONRADIATION.

Lake Shore CRYOTRONICS

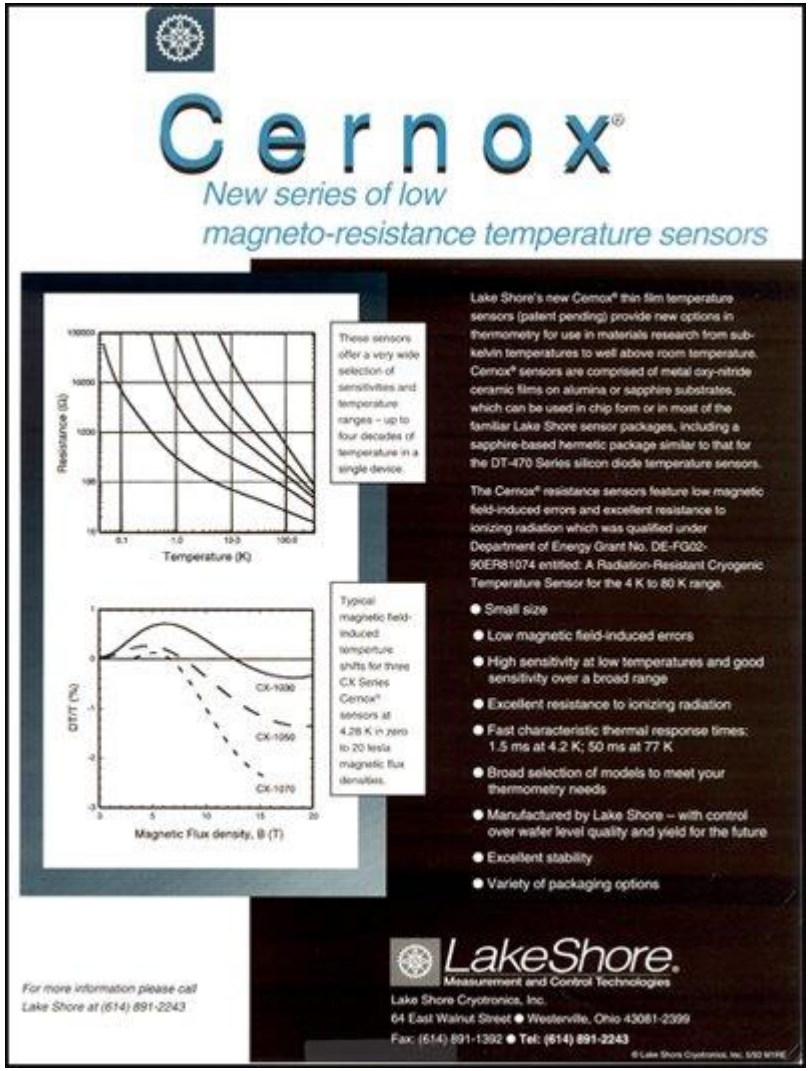
Cernox® Development — 1990 to 1992

- In-situ cryogenic irradiation capability designed and implemented at The Ohio State University Nuclear Reactor Lab for both gamma and neutron studies



Lake Shore CRYOTRONICS

Cernox® Release! – 1993



Cernox®

New series of low magneto-resistance temperature sensors

Lake Shore's new Cernox® thin film temperature sensors (patent pending) provide new options in thermometry for use in materials research from sub-kelvin temperatures to well above room temperature. Cernox® sensors are comprised of metal oxy-nitride ceramic films on alumina or sapphire substrates, which can be used in chip form or in most of the familiar Lake Shore sensor packages, including a sapphire-based hermetic package similar to that for the DT-470 Series silicon diode temperature sensors.

The Cernox® resistance sensors feature low magnetic field-induced errors and excellent resistance to ionizing radiation which was qualified under Department of Energy Grant No. DE-FG02-90ER81074 entitled: A Radiation-Resistant Cryogenic Temperature Sensor for the 4 K to 80 K range.

- Small size
- Low magnetic field-induced errors
- High sensitivity at low temperatures and good sensitivity over a broad range
- Excellent resistance to ionizing radiation
- Fast characteristic thermal response times: 1.5 ms at 4.2 K; 50 ms at 77 K
- Broad selection of models to meet your thermometry needs
- Manufactured by Lake Shore – with control over wafer level quality and yield for the future
- Excellent stability
- Variety of packaging options

These sensors offer a very wide selection of sensitivities and temperature ranges – up to four decades of temperature in a single device.

Resistance (Ω)

Temperature (K)

Typical magnetic field-induced temperture shifts for three CX Series Cernox® sensors at 4.28 K in zero to 20 tesla magnetic flux densities.

ΔT/T (%)

CX-1030

CX-1050

CX-1070

Magnetic Flux density, B (T)

LakeShore
Measurement and Control Technologies

Lake Shore Cryotronics, Inc.
64 East Walnut Street ● Westerville, Ohio 43081-2399
Fax: (614) 891-1392 ● Tel: (614) 891-2243

For more information please call Lake Shore at (614) 891-2243

Neutron and gamma radiation effects on cryogenic temperature sensors

S. Scott Courts, D. Scott Holmes, and Philip R. Swinehart

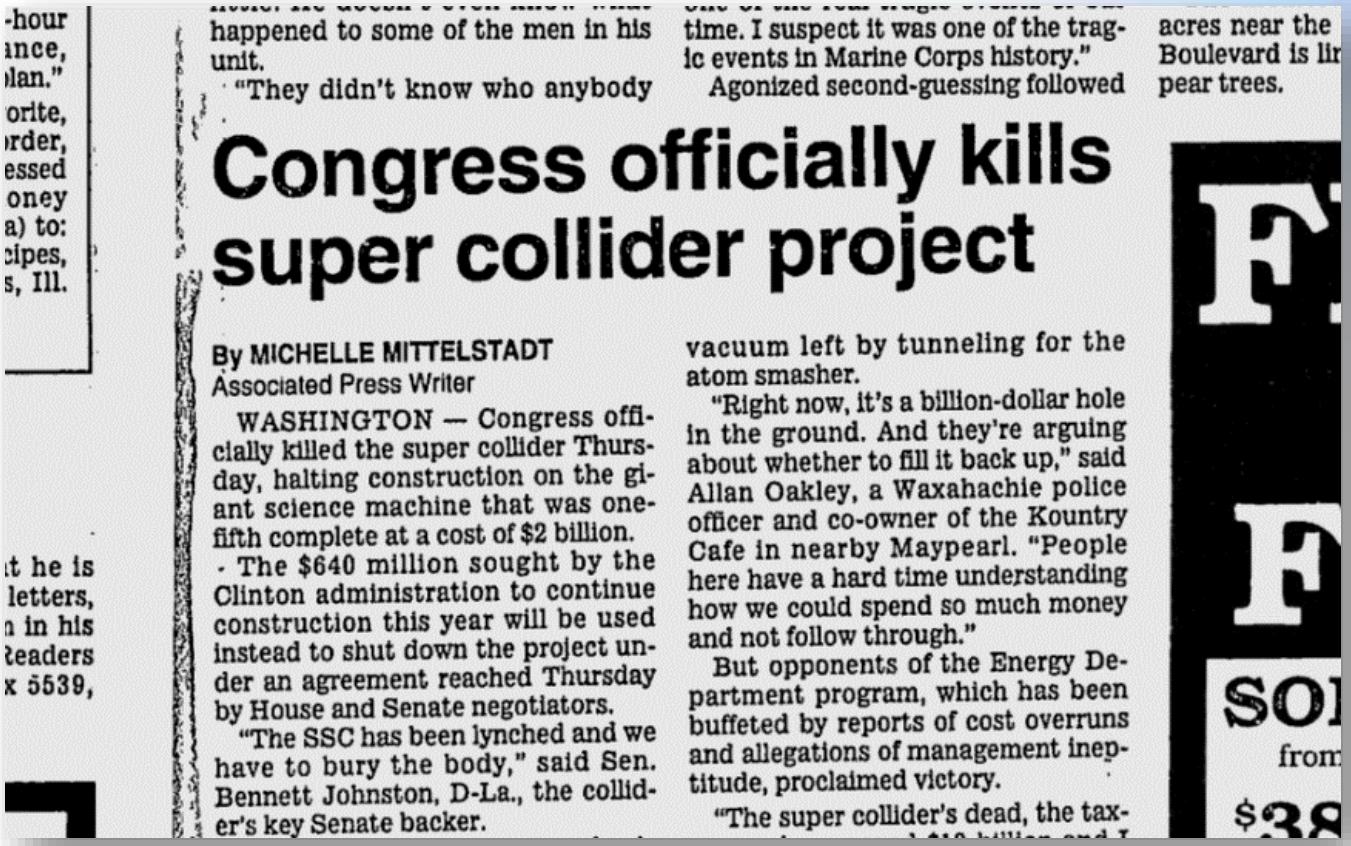
Lake Shore Cryotronics, Inc., Westerville, Ohio 43081

ABSTRACT

Several types of commercially available cryogenic temperature sensors were calibrated, irradiated at room temperature by a gamma source or neutron + gamma source, and recalibrated as a first step in determining their suitability for use in radiation environments. Comparisons were made between the pre- and post-irradiation calibrations and the equivalent temperature shift was calculated for each sensor at various temperatures. Temperature sensors which were gamma irradiated were irradiated to a level of 10,000 Gy. Temperature sensors which were neutron+gamma irradiated were irradiated to a fluence of 8.6×10^{13} n/cm². In general, diodes are unsuitable for use in either type of radiation environment. For gamma radiation, both carbon-glass and germanium resistance sensors performed well at lower temperatures while the rhodium-iron resistance sensors performed well over the range 1.4K to 300K. Of the three device types tested with neutron + gamma radiation, the carbon-glass sensors performed best at lower temperatures while the platinum sensors performed best at higher temperatures.

Lake Shore CRYOTRONICS

, October 22, 1993



happened to some of the men in his unit.

"They didn't know who anybody

time. I suspect it was one of the tragic events in Marine Corps history."

Agonized second-guessing followed

acres near the Boulevard is lir pear trees.

Congress officially kills super collider project

By MICHELLE MITTELSTADT
Associated Press Writer

WASHINGTON — Congress officially killed the super collider Thursday, halting construction on the giant science machine that was one-fifth complete at a cost of $2 billion.

The $640 million sought by the Clinton administration to continue construction this year will be used instead to shut down the project under an agreement reached Thursday by House and Senate negotiators.

"The SSC has been lynched and we have to bury the body," said Sen. Bennett Johnston, D-La., the collider's key Senate backer.

vacuum left by tunneling for the atom smasher.

"Right now, it's a billion-dollar hole in the ground. And they're arguing about whether to fill it back up," said Allan Oakley, a Waxahachie police officer and co-owner of the Kountry Cafe in nearby Maypearl. "People here have a hard time understanding how we could spend so much money and not follow through."

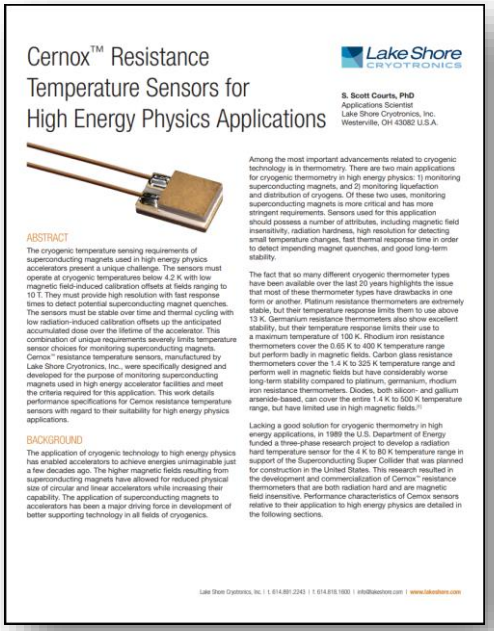
But opponents of the Energy Department program, which has been buffeted by reports of cost overruns and allegations of management ineptitude, proclaimed victory.

"The super collider's dead, the tax-

Cernox®

The world missed out on this accelerator, but gained a sensor for future ones

- Excellent resistance to ionizing radiation
  (Tested to 5 MGy / 500 Mrad)
- Low magnetic field induced errors
- Excellent long-term stability (over decades!)
- High sensitivity at low temperatures
- Small size
- Fast thermal response
- Variety of packaging options



Cernox™ Resistance Temperature Sensors for High Energy Physics Applications

Lake Shore CRYOTRONICS

S. Scott Courts, PhD
Applications Scientist
Lake Shore Cryotronics, Inc.
Westerville, OH 43082 U.S.A.

ABSTRACT

The cryogenic temperature sensing requirements of superconducting magnets used in high energy physics accelerators present a unique challenge. The sensors must operate at cryogenic temperatures below 4.2 K with low magnetic field-induced calibration offsets at fields ranging to 10 T. They must provide high resolution with fast response times to detect potential superconducting magnet quenches. The sensors must be stable over time and thermal cycling with low radiation-induced calibration offsets up the anticipated accumulated dose over the lifetime of the accelerator. This combination of unique requirements severely limits temperature sensor choices for monitoring superconducting magnets. Cernox™ resistance temperature sensors, manufactured by Lake Shore Cryotronics, Inc., were specifically designed and developed for the purpose of monitoring superconducting magnets used in high energy accelerator facilities and meet the criteria required for this application. This work details performance specifications for Cernox resistance temperature sensors with regard to their suitability for high energy physics applications.

BACKGROUND

The application of cryogenic technology to high energy physics has enabled accelerators to achieve energies unimaginable just a few decades ago. The higher magnetic fields resulting from superconducting magnets have allowed for reduced physical size of circular and linear accelerators while increasing their capability. The application of superconducting magnets to accelerators has been a major driving force in development of better supporting technology in all fields of cryogenics.

Among the most important advancements related to cryogenic technology is in thermometry. There are two main applications for cryogenic thermometry in high energy physics: 1) monitoring superconducting magnets, and 2) monitoring liquefaction and distribution of cryogens. Of these two uses, monitoring superconducting magnets is more critical and has more stringent requirements. Sensors used for this application should possess a number of attributes, including magnetic field insensitivity, radiation hardness, high resolution for detecting small temperature changes, fast thermal response time in order to detect impending magnet quenches, and good long-term stability.

The fact that so many different cryogenic thermometer types have been available over the last 20 years highlights the issue that most of these thermometer types have drawbacks in one form or another. Platinum resistance thermometers are extremely stable, but their temperature response limits them to use above 13 K. Germanium resistance thermometers also show excellent stability, but their temperature response limits their use to a maximum temperature of 100 K. Rhodium iron resistance thermometers cover the 0.65 K to 400 K temperature range but perform badly in magnetic fields. Carbon glass resistance thermometers cover the 1.4 K to 325 K temperature range and perform well in magnetic fields but have considerably worse long-term stability compared to platinum, germanium, rhodium iron resistance thermometers. Diodes, both silicon- and gallium arsenide-based, can cover the entire 1.4 K to 500 K temperature range, but have limited use in high magnetic fields.[1]

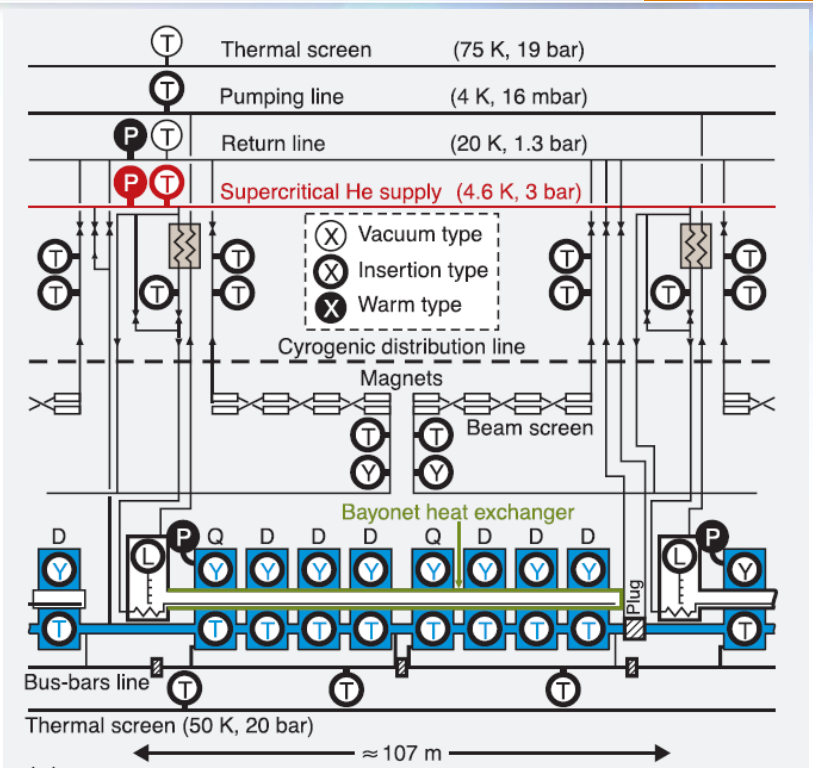
Lacking a good solution for cryogenic thermometry in high energy applications, in 1989 the U.S. Department of Energy funded a three-phase research project to develop a radiation hard temperature sensor for the 4 K to 80 K temperature range in support of the Superconducting Super Collider that was planned for construction in the United States. This research resulted in the development and commercialization of Cernox™ resistance thermometers that are both radiation hard and are magnetic field insensitive. Performance characteristics of Cernox sensors relative to their application to high energy physics are detailed in the following sections.

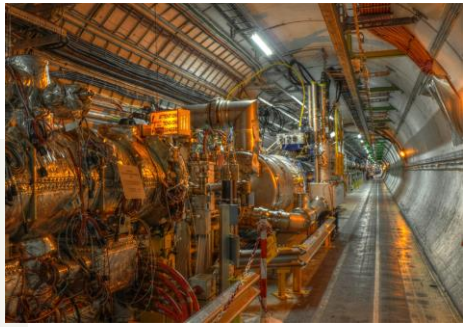
Lake Shore Cryotronics, Inc. | t. 614.891.2243 | f. 614.818.1600 | info@lakeshore.com | www.lakeshore.com

Lake Shore CRYOTRONICS

Cernox in big physics

- Accelerators
  - Mu2e and others at Fermilab
  - SLAC LCLS II at Stanford University
  - FRIB at Michigan State University
  - CEBAF Linac at Thomas Jefferson National Lab
  - Advanced Photon Source at Argonne National Lab
  - SNS at Oakridge National Lab
  - LHC at CERN — Switzerland
- Fusion Reactors
  - NIF at Lawrence Livermore National Lab — U.S.
- Other
  - Dozens of unmanned research satellites (NASA, ESA, JAXA, etc.)
  - Many other international high energy facilities

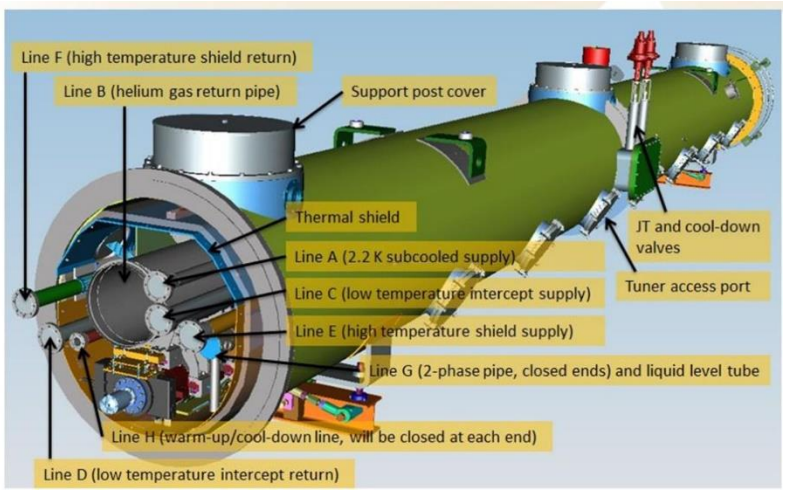


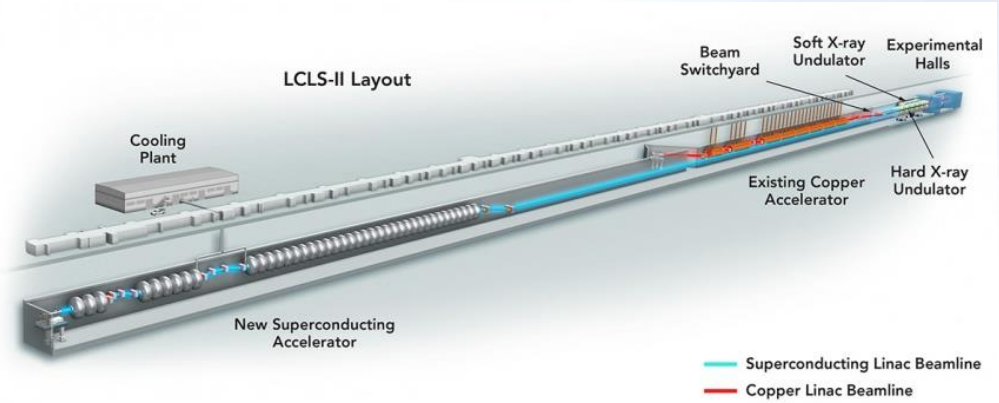


Lake Shore CRYOTRONICS

LCLS-II Cryomodule and Cryogenic Distribution Control

K. Mattison #, M. Boyes, M. Cyterski, D. Fairley, C. Hovater, J. Kaluzny, B. Lam, A. Martinez
SLAC National Accelerator Laboratory, Menlo Park, CA 94025 USA





Cryomodules (~×37)

Instruments	Controllers	He Vessel	Magnet	He Lines	Total
Cernox	Lakeshore 240	4	2	2	8

Cryogen distribution system

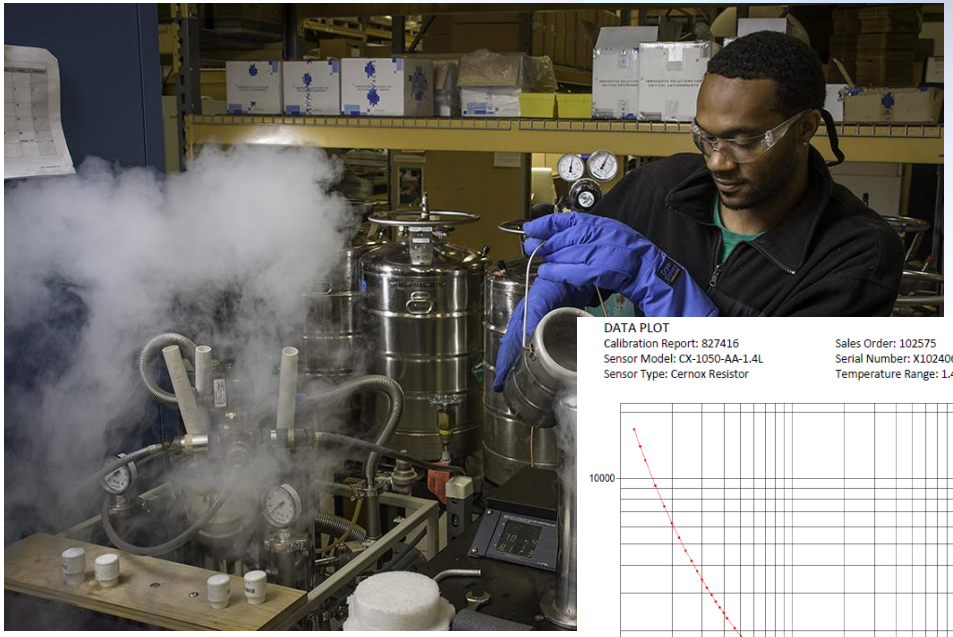
Instruments	Controllers	US DB	DS DB	FC1	FC2	FC3	FC4	FC5	FC6	US EC	DS EC	Total
Cernox	Lakeshore 240	19	19	10	9	9	9	9	9	8	9	110

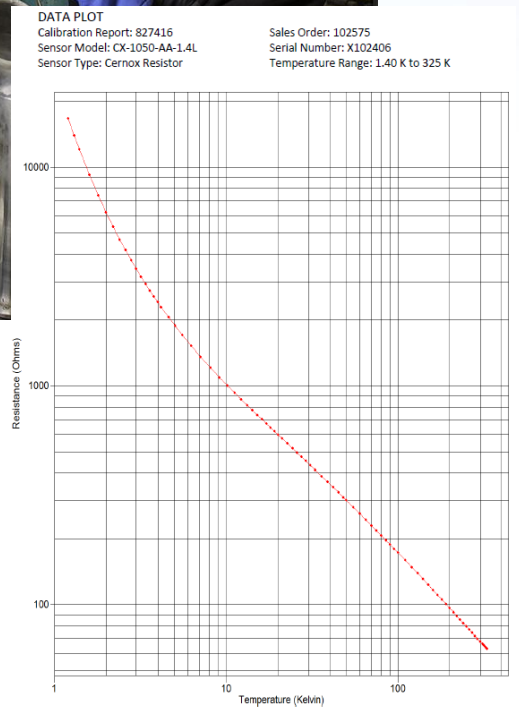
400+ Cernox sensors total

Calibration Services

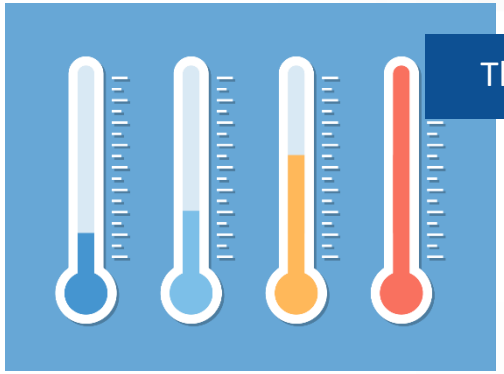
Lake Shore operates one of the most advanced temperature sensor calibration facilities in the world

- Traceable
  - Over 50 standards referenced to NIST, NPL, & PTB
  - Nuclear orientation thermometers also used for temperatures less than 50 mK
  - Adherence ITS-90 and PLTS-2000 temperature scales
- Scalable
  - Capable of calibrating tens of thousands of sensors per year
  - Different levels of calibration to suit a given project





Continued Investment in Sensor Characterization



Thermal Cycling

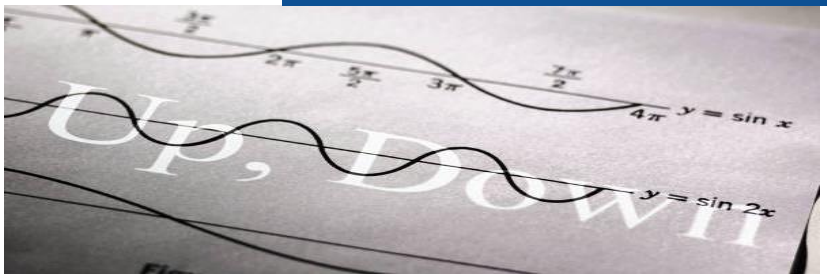
Project requirements drive our sensor research

Long Term Stability

Ionizing Radiation

Magnetic Fields

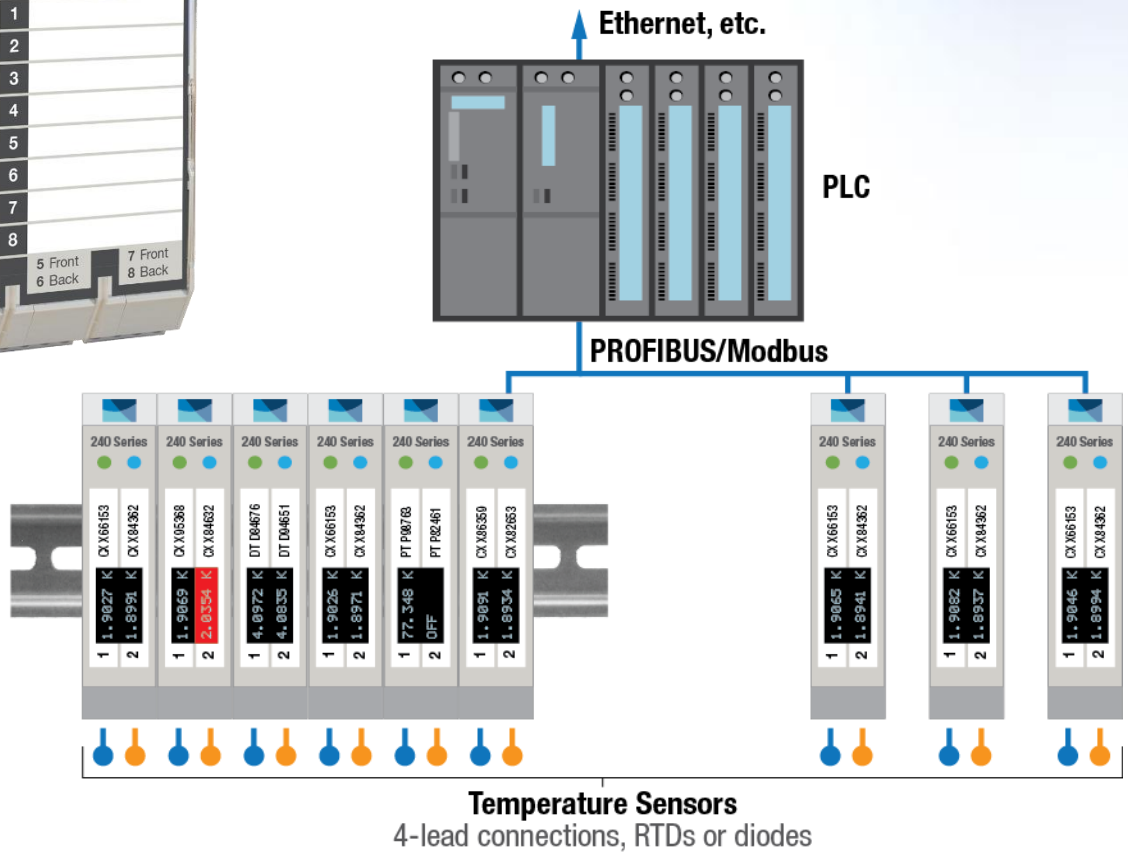
Mechanical Shock and Vibration



Lake Shore CRYOTRONICS

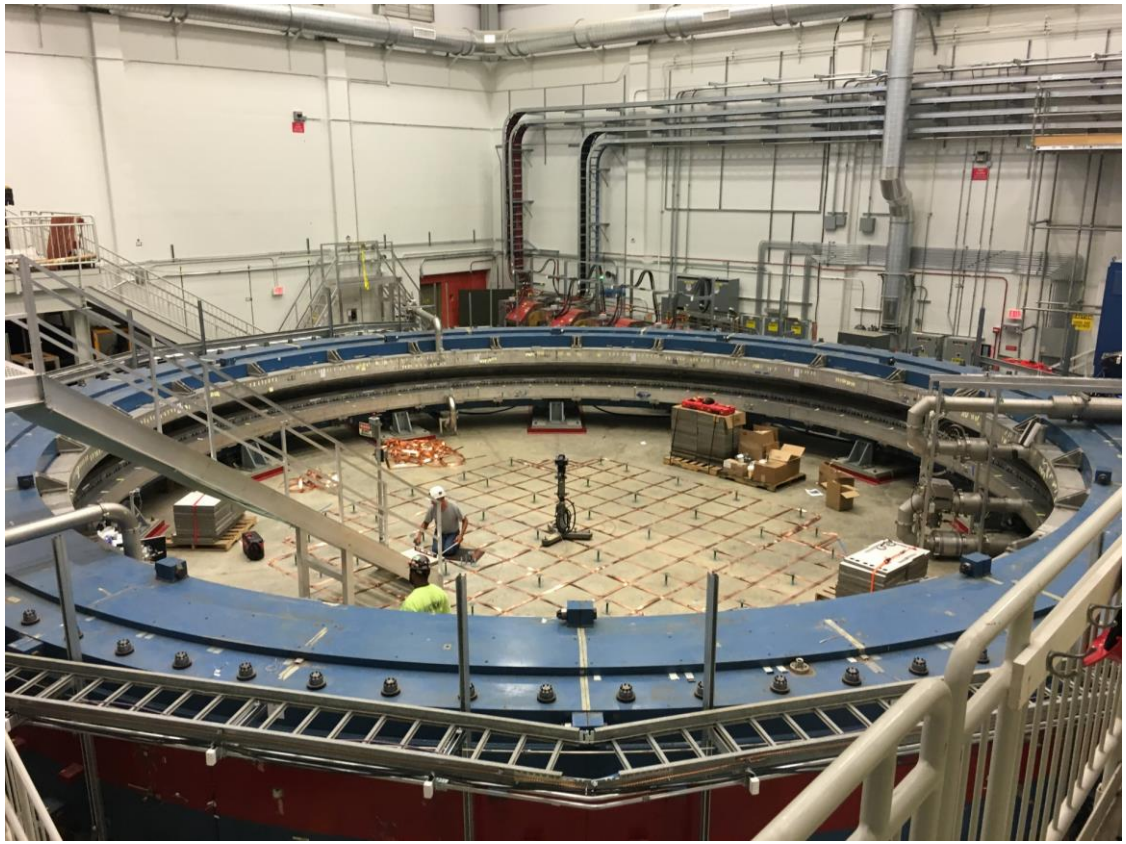
Cryogenic Sensor Input Modules

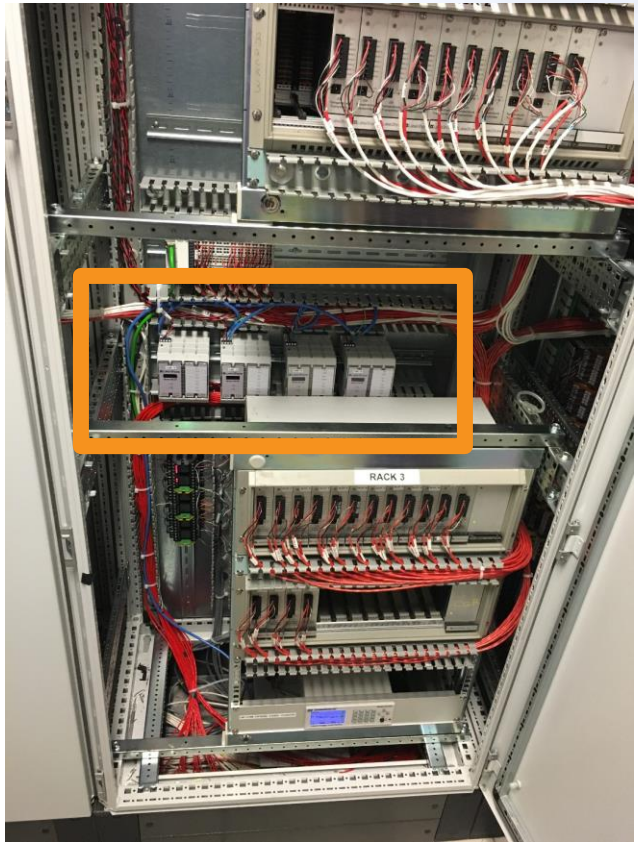
Distributed temperature measurement for large applications



Cryogenic Sensor Input Modules

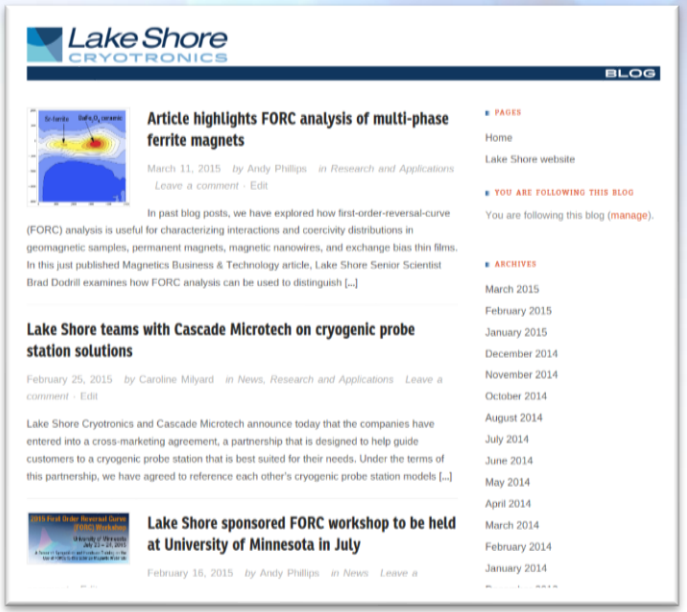
- First placed into service to support Muon g-2 experiment at Fermilab, USA





Contact Us

- www.lakeshore.com
  - Detailed product and application information
  - Local contacts



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- 2019 conferences
  - All of the major cryogenics, magnetics, and physics conferences—check our website for upcoming events

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