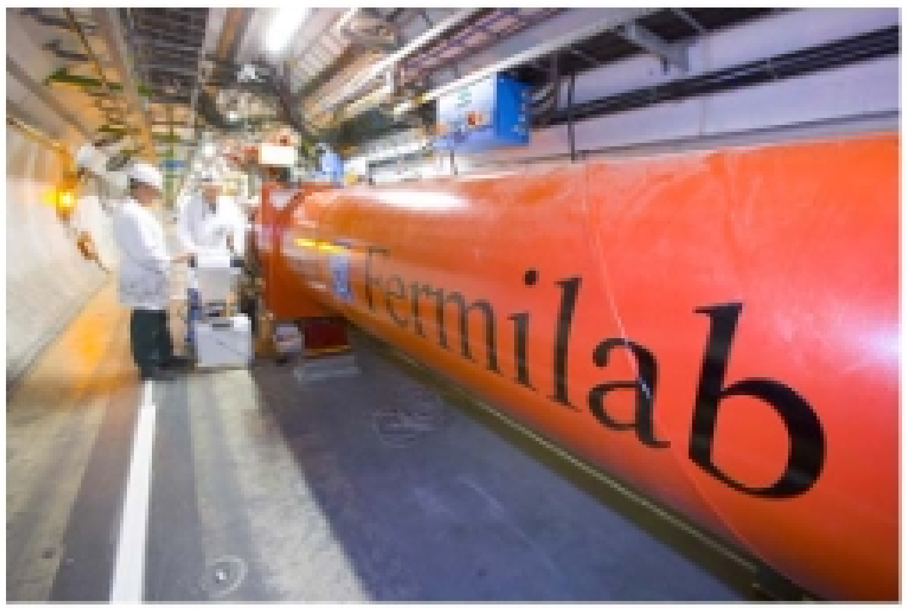
Insulation--FermiLab Failure at CERN

On Tuesday, March 27,2007 there was a serious failure in a high-pressure test at CERN of a Fermilab-built "inner-triplet" series of three quadrupole magnets in the tunnel of the Large Hadron Collider. The magnets focus the particle beams prior to collision at each of four interaction points around the accelerator.

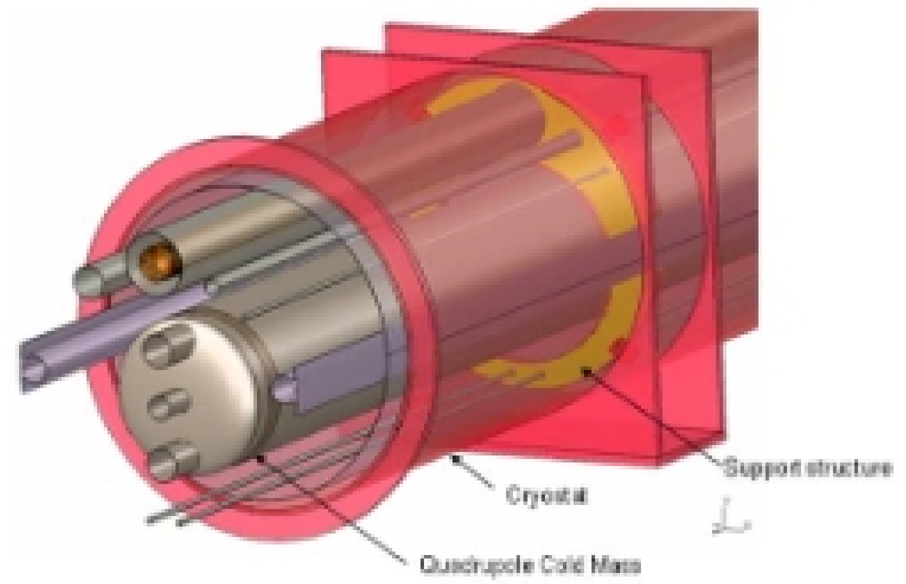
Preliminary indications are that structures supporting the inner "cold mass" of one of the three magnets within its enclosing cryostat broke at a pressure of 20 atmospheres, in response to asymmetric forces.

Failure to account for the asymmetric loads in the engineering design of the magnet appears to be a likely cause. The test configuration corresponds to conditions that occur during a magnet quench, when a superconducting magnet suddenly "goes normal," releasing large amounts of energy.

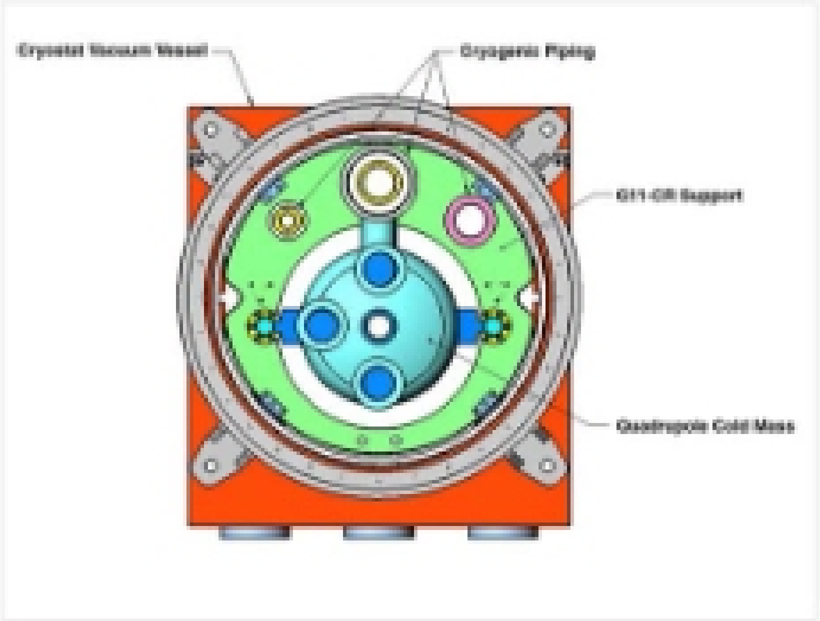
Inner-Triplet Quadrupole Magnet



Inner Support Structure



Cross Section at One Support Point



Fermi-Lab/CERN Follow-up

From The Sunday Times April 8, 2007

Big Bang at the atomic lab after scientists get their maths wrong Jonathan Leake, Science Editor

A £2 billion project to answer some of the biggest mysteries of the universe has been delayed by months after scientists building it made basic errors in their mathematical calculations.

The mistakes led to an explosion deep in the tunnel at the Cern particle accelerator complex near Geneva in Switzerland. It lifted a 20-ton magnet off its mountings, filling a tunnel with helium gas and forcing an evacuation.

It means that 24 magnets located all around the 17-mile circular accelerator must now be stripped down and repaired or upgraded. The failure is a huge embarrassment for Fermilab, the American national physics laboratory that built the magnets and the anchor system that secured them to the machine.

It appears Fermilab made elementary mistakes in the design of the magnets and their anchors that made them insecure once the system was operational.

Dr Lyn Evans, who leads the accelerator construction project at CERN, the European organization for nuclear research, said the explosion had been potentially very dangerous.

"There was a hell of a bang, the tunnel housing the machine filled with helium and dust and we had to call in the fire brigade to evacuate the place," he said. "The people working on the test were frightened to death but they were all in a safe place so no-one was hurt." An investigation by CERN researchers found "fundamental" flaws that caused the explosion, close to the CMS detector, one of the LHC's most important experiments.

Coincidentally, Fermilab stands to gain most from delays at CERN. Its researchers also operate a rival but less powerful particle accelerator, the Tevatron.

Name the main source of heat input to the cold end of a cryostat:

A. Conduction through structural supports
B. Gas conduction and convection
C. Radiant heat transfer
D. All of the above
E. Depends on the design and situation

There are many sources of heat to the cold end of any cryostat. Here we ask for the main source without giving any details. Often most of the heat comes thru supports, because the cold end is massive (a magnet), but if, for example, the dewar is not designed properly, the main source can easily be radiation. In space applications, it is often convection. So the answer does depend on the particular case being considered.

Thermal Insulation-Chapter 7
read it!

Minimize heat leaks
- Structural Supports
- Gas conduction and convection
- Radiant heat transfer

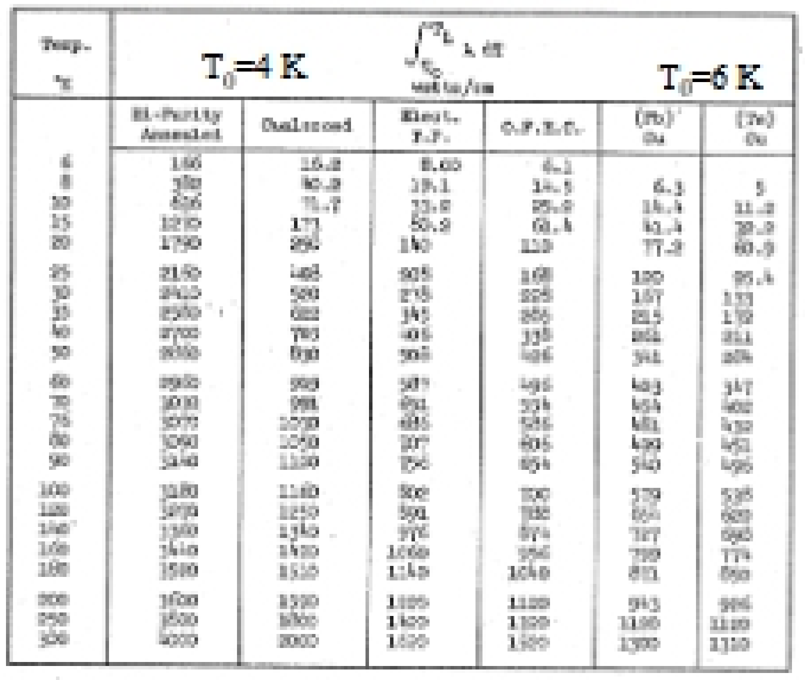
Insulating Supports

Conduction dominates heat leak-usually 1-d between 2 reservoirs
Use integrated thermal conductivity

$$Q = \frac{A}{L} \int_{T_0}^{T_L} \lambda \, dT; \qquad Q\,\frac{L}{A} = \int_{T_0}^{T_L} \lambda \, dT$$

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_0 = initial temperature (6°K for [Pb]Cu and [Te]Cu; 4°K for all other Coppers)

Conductivity Integrals



Power Law Conductivities

$\lambda \sim T^n$ n=1 for metals and
n=3 for insulators

Q dominated by T_{hot}--most of support is warm

Strength–Conductivity Comparison of Materials for Support Members[1813,*]

Material	S_y/k_m	Material	S_y/k_m
Teflon	3,350	347 stainless (cold drawn)	17,500
Nylon	11,930	1100-H16 aluminum	140
Mylar	70,700	2024-0 aluminum	210
Dacron fibers	155,000	5056-0 aluminum	300
Glass fibers	45,300	K Monel (45%, cold drawn)	8,500
304 stainless (cold drawn)	12,500	Hastelloy C (annealed)	7,500
316 stainless (cold drawn)	16,300	Inconel (cold drawn)	5,700

* S_y in lb/in.²; k_m in Btu/hr-ft-°R; k_m is mean thermal conductivity between 300 and 90 K.

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TABLE 2-1

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Insulating Materials

- Bulk Fill
- Foams
- Layered
- Basic Design Factors
- Definitions: k-value and CVP

Bulk Fill

New materials

- Cabot, aerogel beads (Nanogel®)
- Aspen Aerogels, aerogel blankets (Pyrogel®and Spaceloft®)
- Sordal, polyimide foams (SOLREX®)
- InspecFoams, polyimide foams (SOLIMIDE®)
- TAI, pipe insulation panels
- NASA, Layered Composite Insulation (LCI)

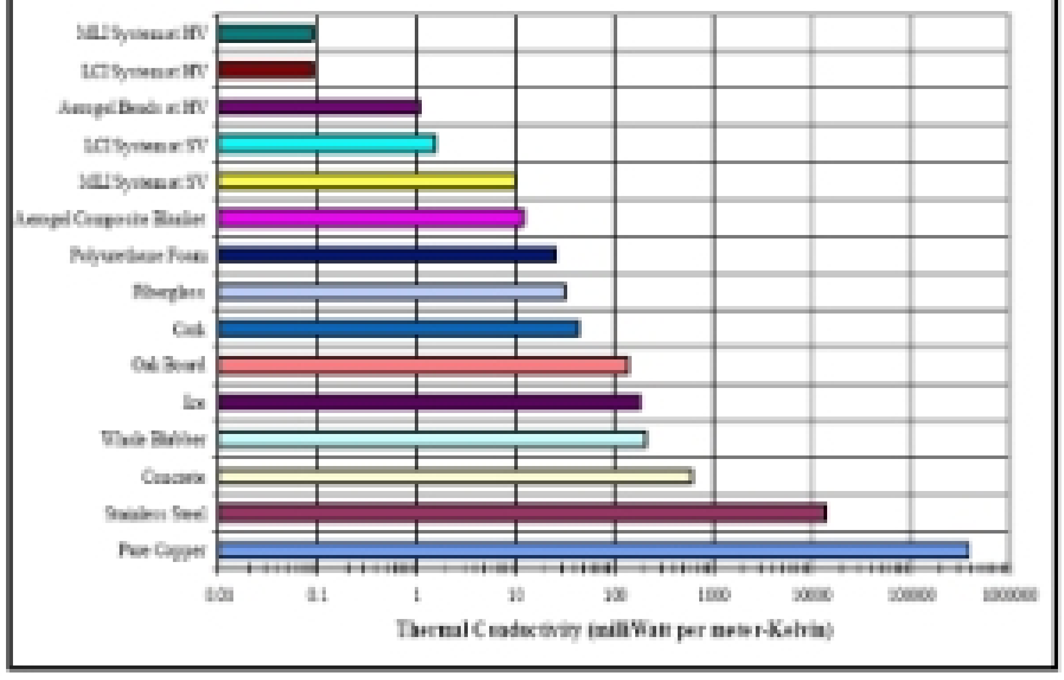
Thermal Conductivity

Material thermal conductivity

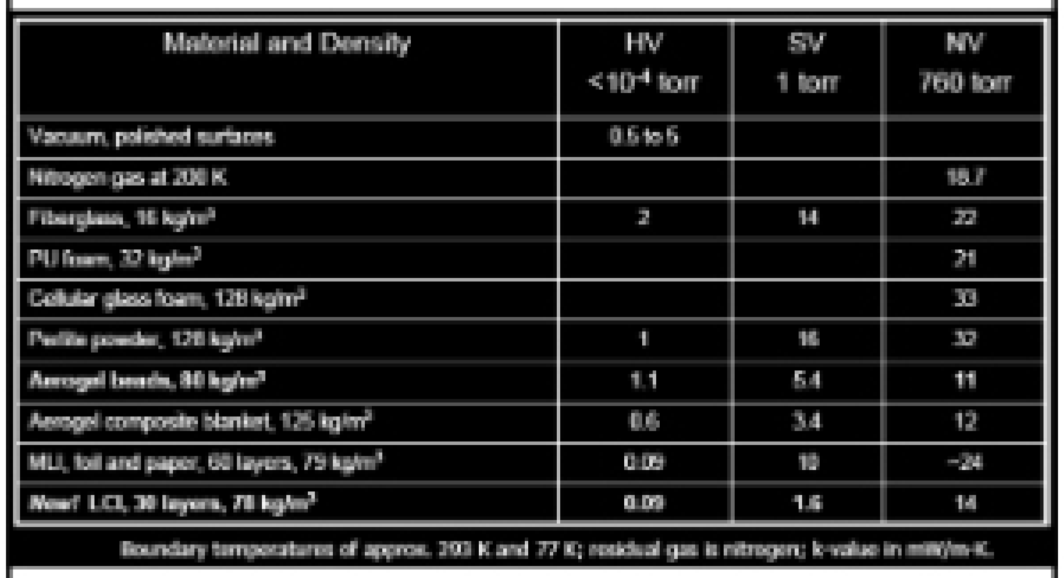
- milliWatt per meter-Kelvin [mW/m-K]
- R-value per inch [hr-ft2-degF/Btu-in]

1 mW/m-K = R144

Thermal Insulating Quality of Various Materials



Representative k-Values



Material and Density	HV $<10^{-4}$ torr	SV 1 torr	NV 760 torr
Vacuum, polished surfaces	0.5 to 5		
Nitrogen gas at 200 K			18.7
Fiberglass, 16 kg/m^3	2	14	22
PU foam, 32 kg/m^3			21
Cellular glass foam, 128 kg/m^3			33
Perlite powder, 128 kg/m^3	1	16	32
Aerogel beads, 80 kg/m^3	1.1	5.4	11
Aerogel composite blanket, 125 kg/m^3	0.6	3.4	12
MLI, foil and paper, 60 layers, 79 kg/m^3	0.09	10	~24
New! LCI, 30 layers, 78 kg/m^3	0.09	1.6	14

Boundary temperatures of approx. 293 K and 77 K; residual gas is nitrogen; k-value in mW/m-K.