



ISIS Main Ring Dipole Coil Failures

S Jago

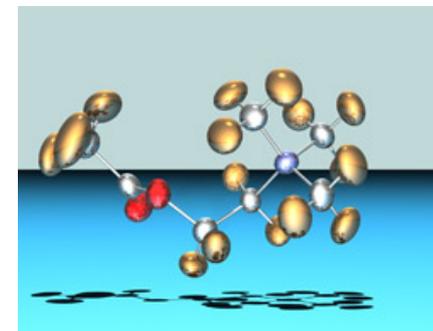
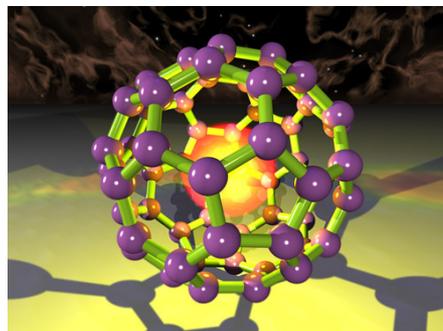
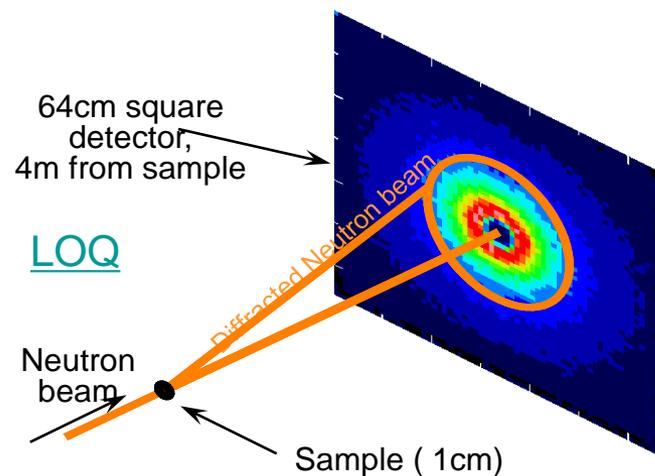
T Mouille, M Hughes, S West, A McFarland, S Kellard

30th April 2015

Accelerator Reliability Workshop
Knoxville

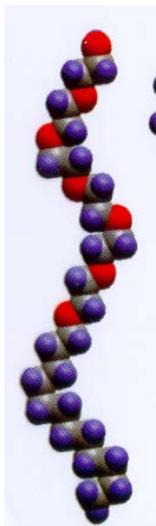
ISIS Pulsed Neutron & Muon Source

- Used to Probe into Atomic Structure of Materials
- Non-destructive & highly Penetrating
- “Where atoms are and what they are doing...”



ISIS - Applications

Establishing the link between surface adsorption properties and detergency



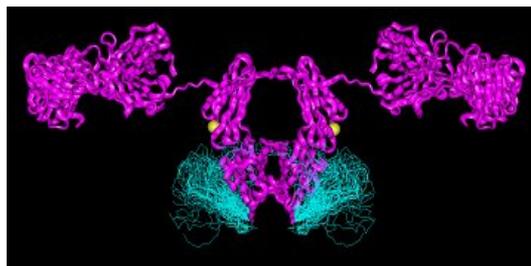
Residual stress
analysis of an Airbus
wing component



Metallurgy of a 2700
year old Greek Helmet



High capacity magnetic
data storage for IBM



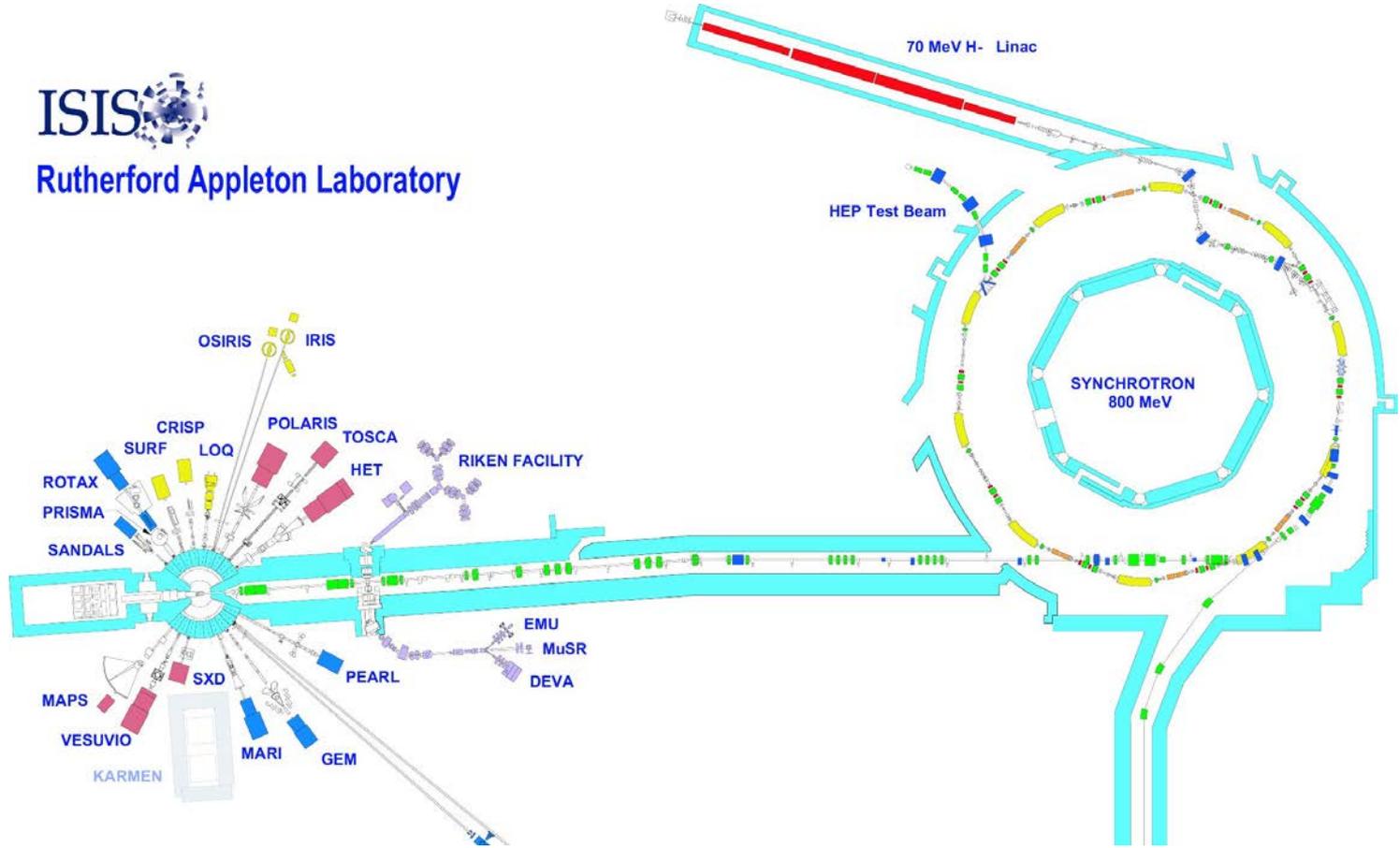
Human
Immunoglobulin,
IgA1,
Antibody involved in
immune
protection at
mucosal surfaces
and in blood



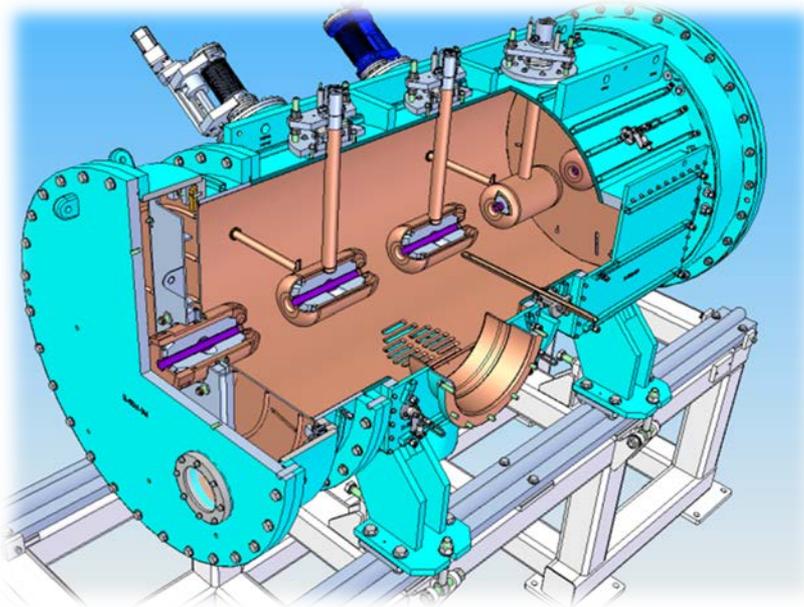
ISIS Accelerator



Rutherford Appleton Laboratory



Tank 4

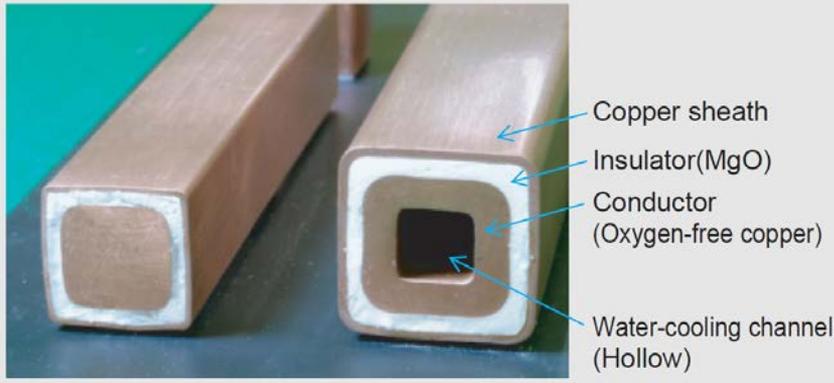


- Replacement for one of the four tanks in the 70 MeV DTL
- Redesigned in 6 x 2m sections
- Copper plated steel

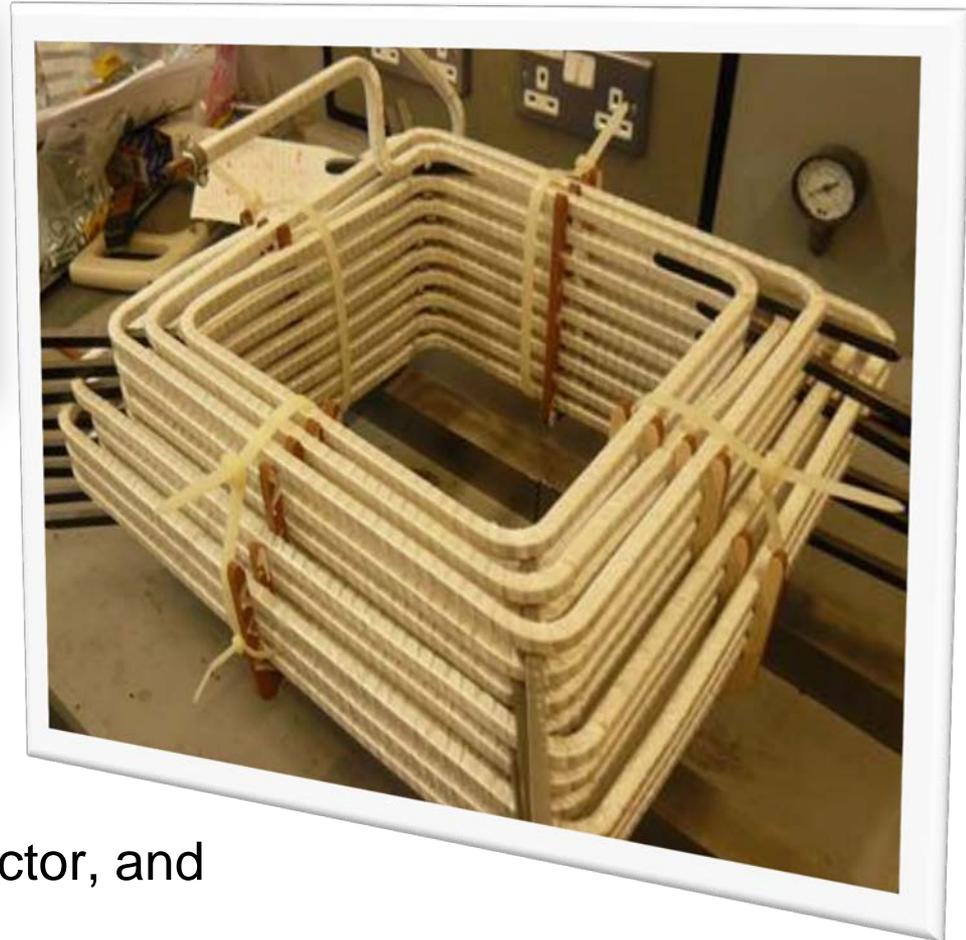


- New test facility needed, including new RF drivers; transmission lines; water system; vacuum system; interlocks; shielding; controls; and testing equipment.

Concrete Magnets

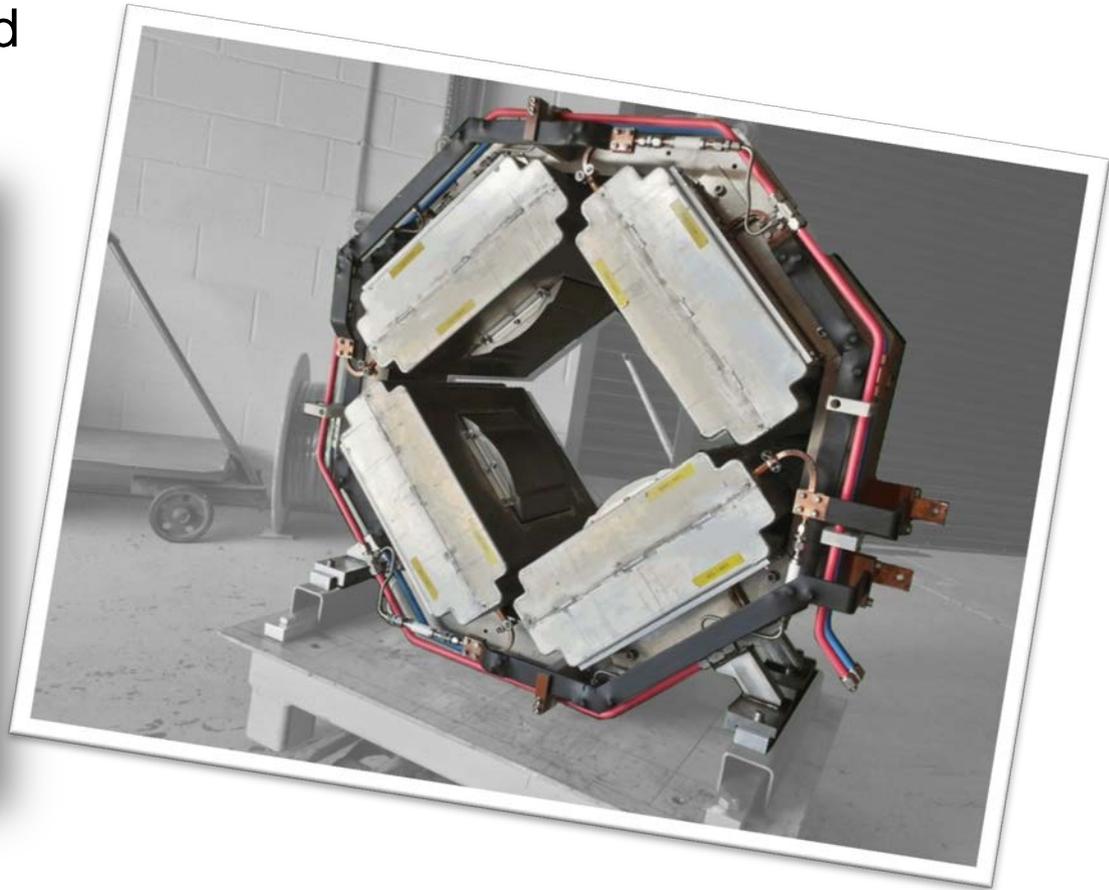
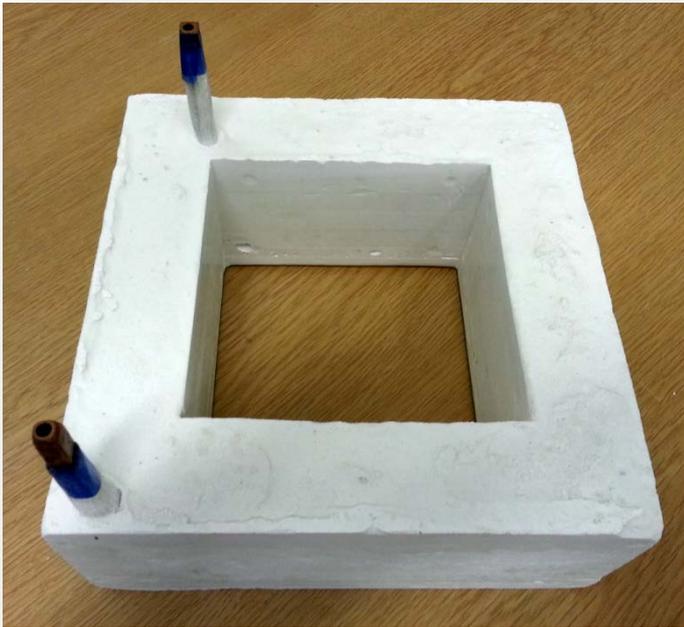


- Epoxy is damaged by radiation
- The “normal” solution is to use Mineral Insulated Conductor
- MIC is expensive, hard to get hold of and difficult to work with.
- Use normal hollow copper conductor, and wind with 10mm space.



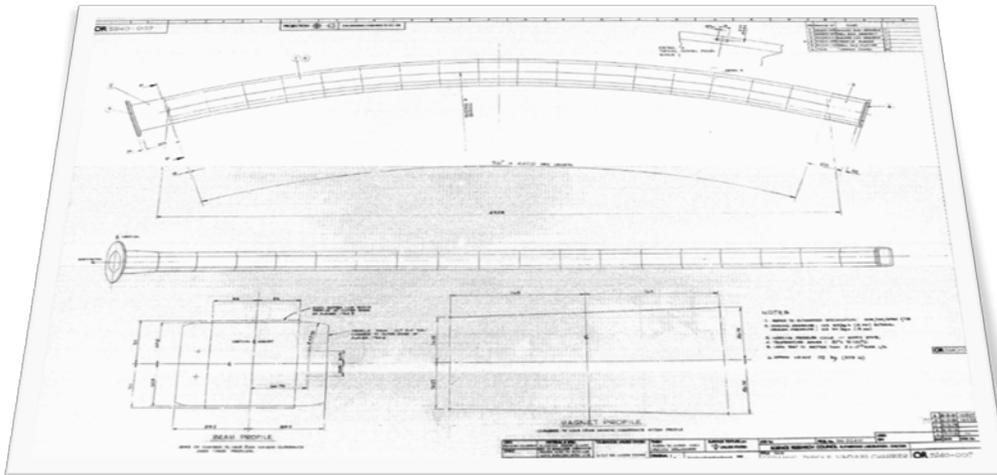
Concrete Magnets

- Add concrete to mechanically support and constrain conductors



Ceramic Vessels

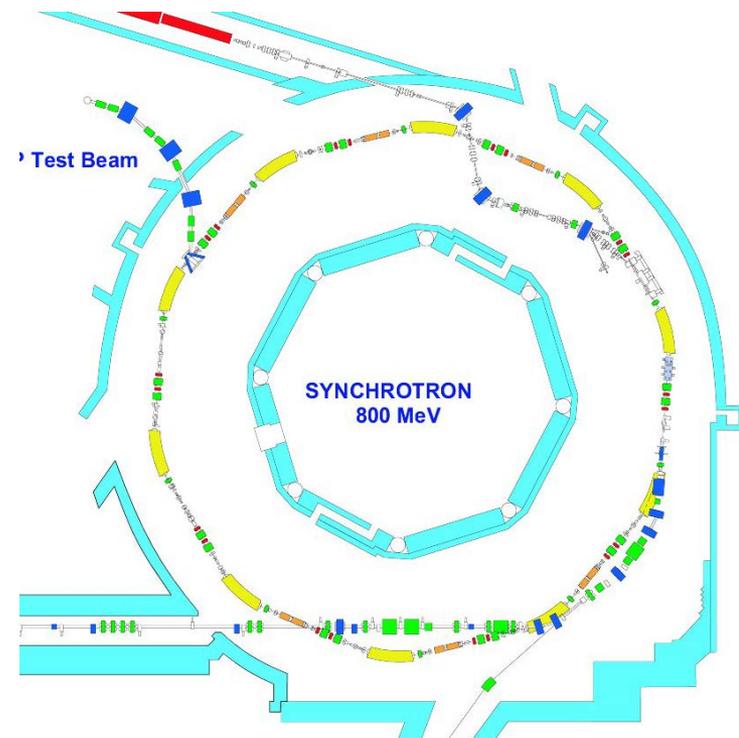
- Components made by industry and assembled (joined) at RAL
- Need a ~1300 Degree C Furnace
- Original furnace not been used for ~20 years
- More financially viable to buy a new one...



Dipole Coils



- 20 x Dipole Coils in the Ring
- Current varies from 269 to 1067 A on a 50 Hz Sine wave
- 14.7 kV rms (max Vpp in coil = 16.5 kV)
- ~4.5 m long



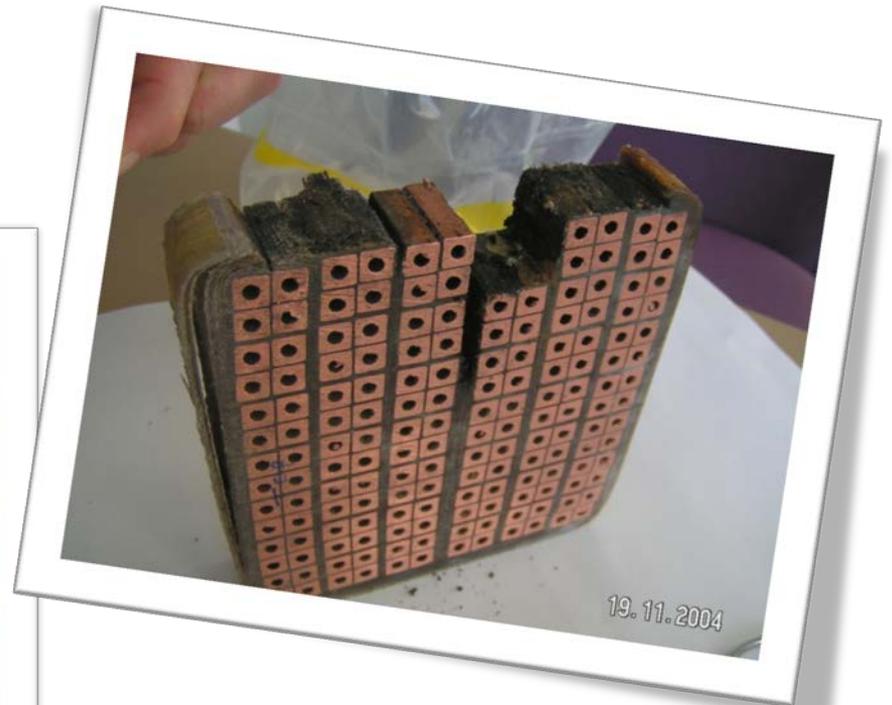
Dipole Coils



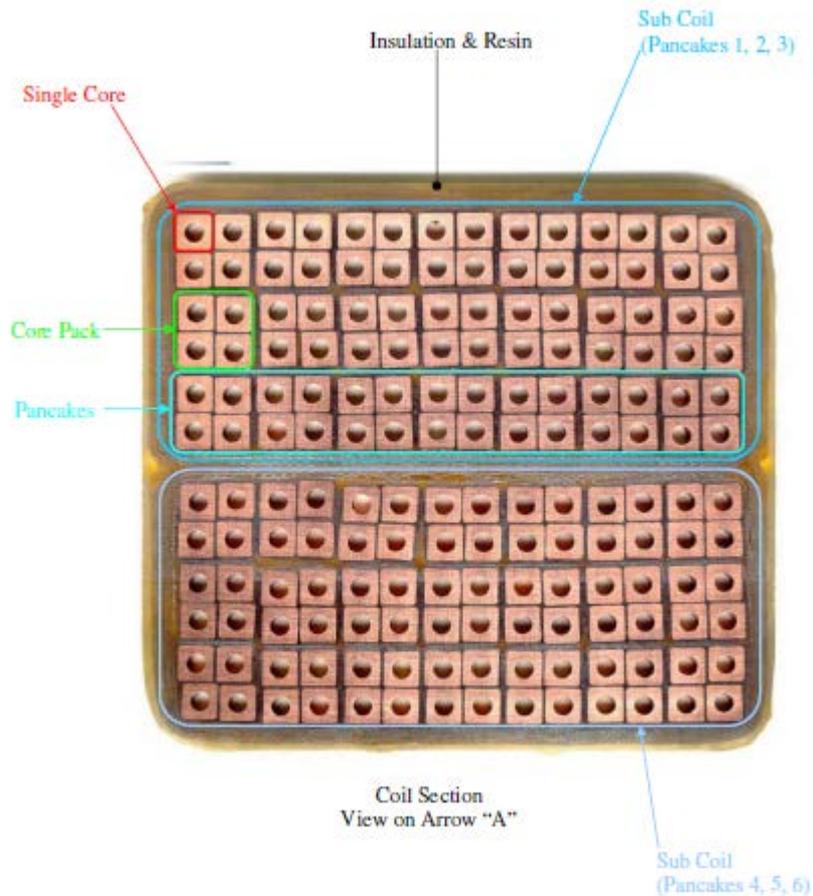
- Original coils made by Tesla Engineering in early 1980's
- Constructed using a Mica / Glass tape then vacuum impregnated
- Original coils in service since then (some are still going...)
- Started to see failures in 2002

Dipole Coils

- Further failures in March 2003 and October 2004
- We have a problem!



Dipole Coils



- Anatomy of a coil
- Specification and drawings of original coil dusted off and sent out to tender
- New coils made without Mica

ISIS FACILITY



Science & Technology Facilities Council
ISIS

TECHNICAL SPECIFICATION FOR
MANUFACTURE, SUPPLY AND TESTING OF
SYNCHROTRON DIPOLES COILS FOR ISIS.

APPROVAL

Title	Name	Signature / Date
AUTHOR	Matt Kearsley	
SECTION LEADER	Eddie McCarron	
GROUP LEADER	Harry Jones	

REVISION HISTORY

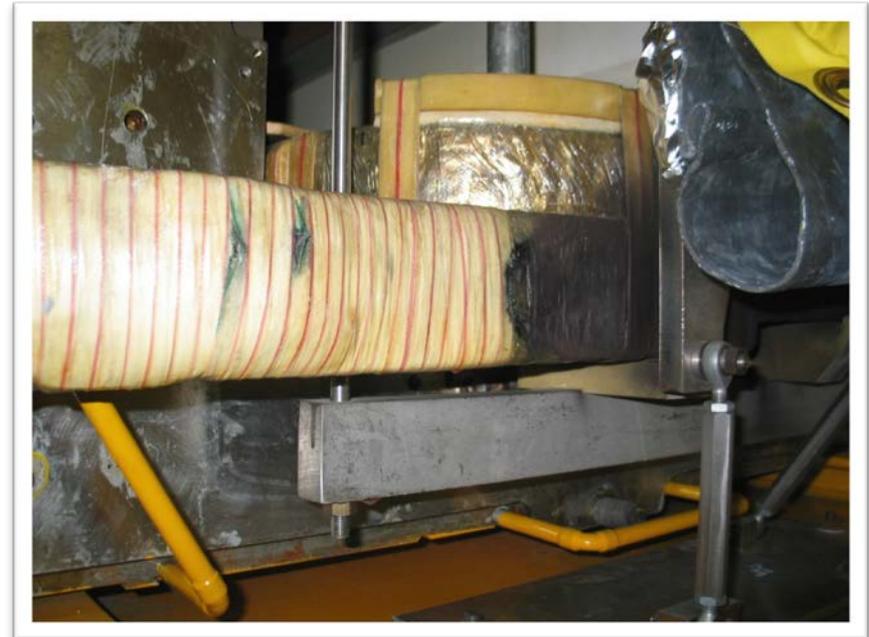
Issue	Date	Author	Revision Comments
3	02/10/78	Original Tender Document
4	12/11/04	M.J.Kearsley	Re-typed, Revised Insulation & Coil Specs.
.....	HA1-Hakim	Electrical Tests updated
5	17/09/07	M.J.Kearsley	Up date Manufacturing Specs & Corporate ID.

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<http://www.isis.rl.ac.uk/>

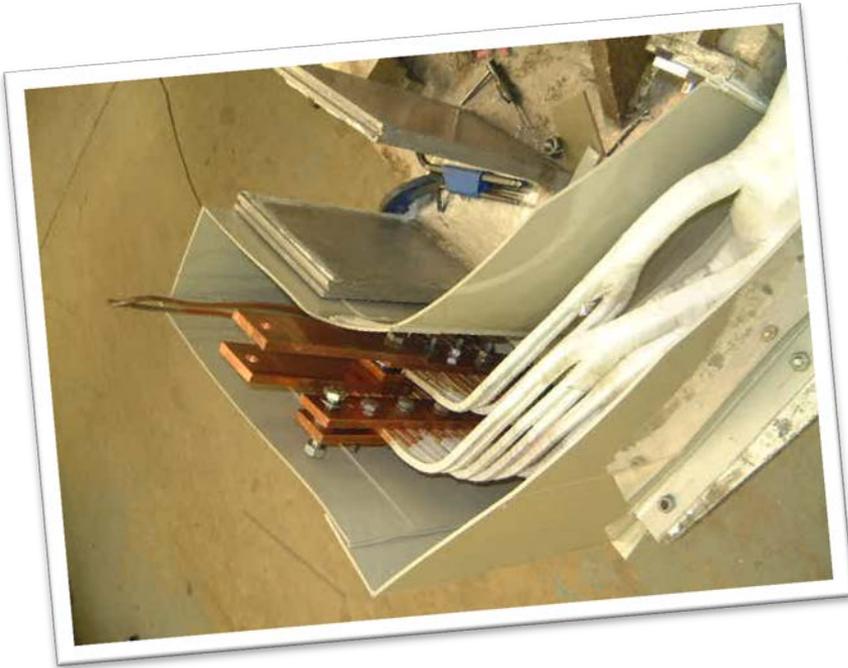
Dipole Coils

- Further failures in Dec 2006 and Sept 2007
- More coils procured with a new manufacturer
- Some new coils now being installed in machine

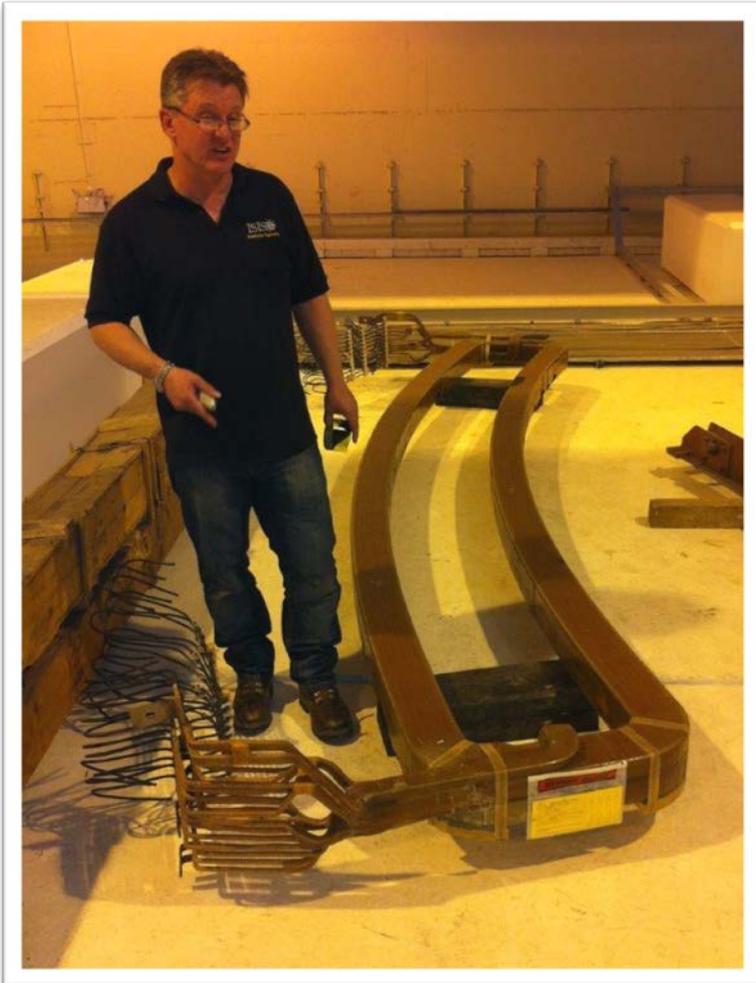


Dipole Coils

- Many failures on original magnets are in the same area
- Insulation on new coils is strengthened in this area



Dipole Coils



- Failures continue in May 2011, May 2012 and Sept 2012
- More fail in 2013
- First new coil fails in Nov 2013
- Now believe we have a serious problem
- Further failures of new coils in Feb, May and Aug 2014



Post Mortem

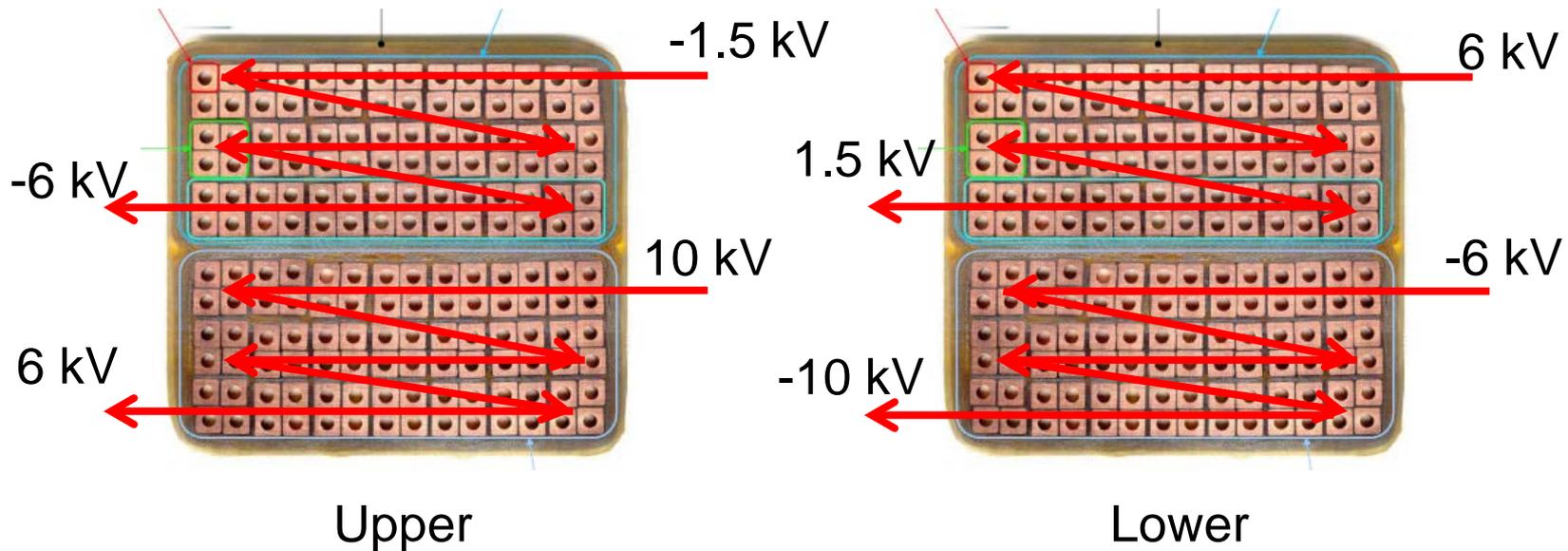


- Pull failed coils apart –
What can we learn?
- Failures often sub-coil to
sub-coil



Upper vs Lower

- More upper coils had failed than lower
- Look at the design in detail ... there could be a good reason!
- Pancake termination sequence different



Analyse

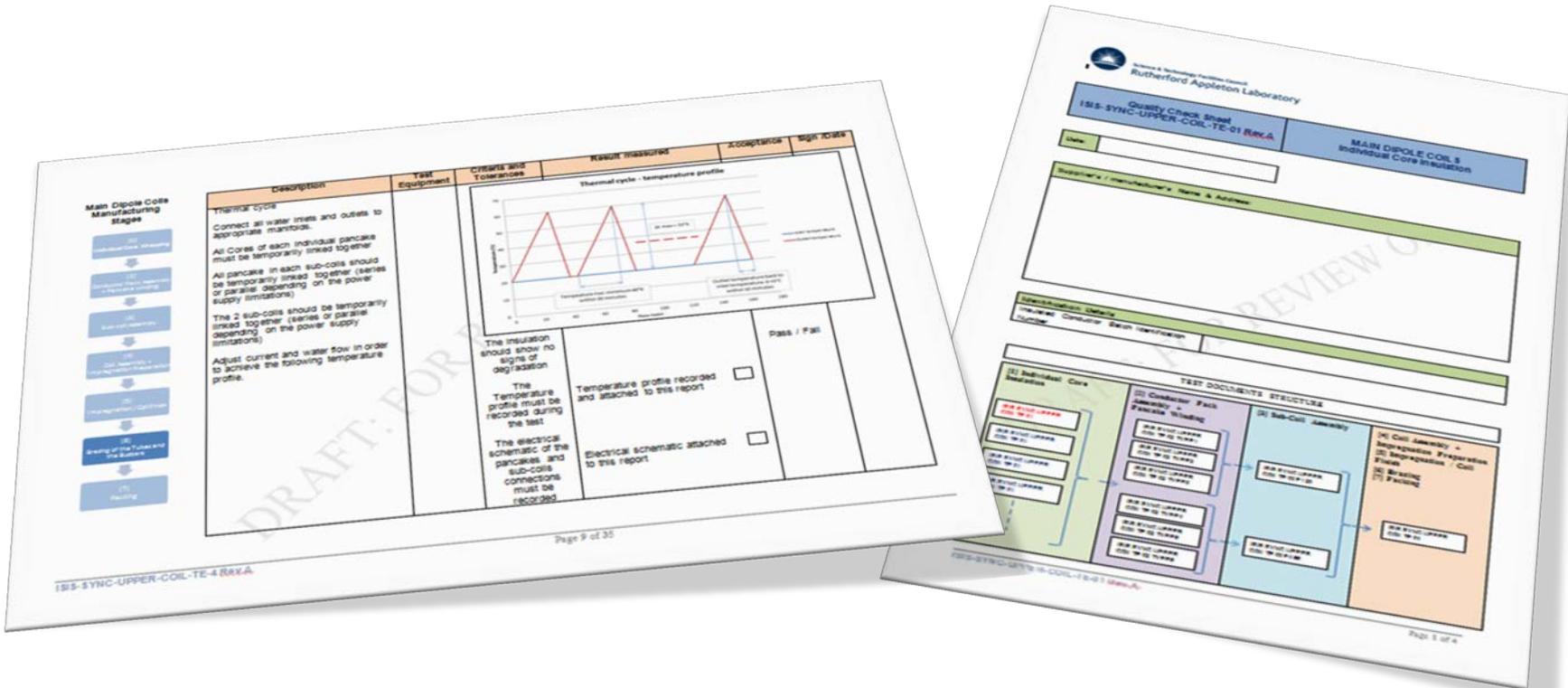
- We have had 17 coils fail in total
- 11 out of 17 have been Upper coils – Thanks, but we knew that already by looking at our spares stock levels!
- 10 out of 17 failures since 2011

- MTBF Original Coils ~ 10,000 Hours
- MTBF New Coils ~ 2,000 Hours
- Two Different Suppliers of new coils
 - Supplier 1 MTBF ~ 3,500 h
 - Supplier 2 MTBF ~ 1,400 h – but not much data for either

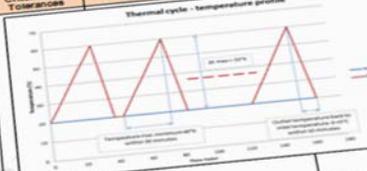
- Are we seeing wear out of original coils on top of infant mortality of new coils?
- Was there infant mortality in the original coils...?

Quality of Manufacture

- Obvious potential issue
- Get deeper into understanding technical aspects of manufacturing methods
- Produce more detailed QA documentation...



Main Dipole Coils Manufacturing Stages

Description	Test Equipment	Criteria and Tolerances	Result measured	Acceptance	Significance
<p>Thermal cycle</p> <p>Connect all water inlets and outlets to appropriate manifolds.</p> <p>All Cores of each individual pancake must be temporarily linked together.</p> <p>All pancake in each sub-coils should be temporarily linked together (series or parallel depending on the power supply limitations).</p> <p>The 2 sub-coils should be temporarily linked together (series or parallel depending on the power supply limitations).</p> <p>Adjust current and water flow in order to achieve the following temperature profile.</p>			<p>Thermal cycle - temperature profile</p> 	<input type="checkbox"/> Pass / Fail	
		<p>The insulation should show no signs of degradation</p> <p>The Temperature profile must be recorded during the test</p> <p>The electrical schematic of the pancakes and sub-coils connections must be recorded</p>	<p>Temperature profile recorded and attached to this report</p> <p>Electrical schematic attached to this report</p>	<input type="checkbox"/> <input type="checkbox"/>	

TEST DOCUMENTS STRUCTURE

```

graph LR
    A[1] --> B[2]
    B --> C[3]
    C --> D[4]
    
```

ISIS-SYNC-UPPER-COIL-TE-4 Rev.A

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Quality Check Sheet
ISIS-SYNC-UPPER-COIL-TE-01 Rev.A

NAME: _____

SUPPLIER / MANUFACTURER'S NAME & ADDRESS: _____

TESTER'S NAME: _____

TESTER'S SIGNATURE: _____

TESTER'S DATE: _____

TEST DOCUMENTS STRUCTURE

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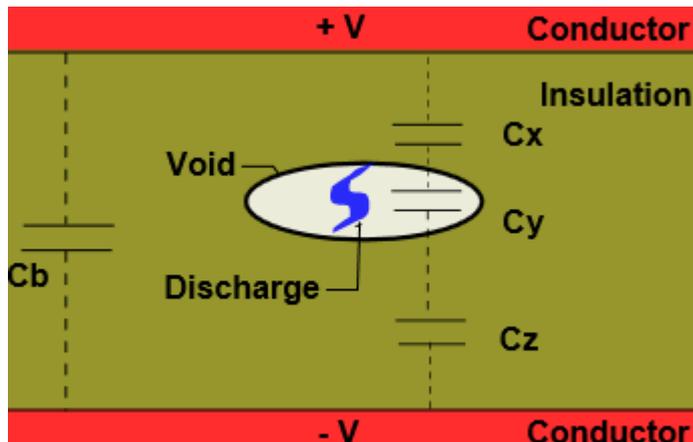
graph LR
    A[1] --> B[2]
    B --> C[3]
    C --> D[4]
    
```

ISIS-SYNC-UPPER-COIL-TE-01 Rev.A

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Insulation Design

- In 2004 were made without Mica in the insulation system
- There is a good chance that the failure mode (in new coils) is via partial discharge...



"Partial discharge" by Wtshymanski at English Wikipedia. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Partial_discharge.svg#/media/File:Partial_discharge.svg

"Electron tree" by Lauren - originally posted to Flickr as Electron tree. Licensed under CC BY-SA 2.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Electron_tree.jpg#/media/File:Electron_tree.jpg



And More...

Soft Pedalling

- 10 out of 17 failures happen during start-up (not in cycle)
- Maybe should expect that (light bulbs...), but doing what we can to soften the start-up

Power Supply

- Attempt to plot changes to whole system (e.g. PSU upgrades) alongside failures, to see if there is any correlation...
- Simulate power supply in SPICE to see any possible transients etc...

Current Situation

- Procuring more coils – delivery due soon
- Increasing knowledge of procedures and upping QA requirements
- Investigating difference in insulation designs / systems using PD measurements to get a better understanding and confidence
- Soft Pedalling on start-up
- Simulations of PSU
- Considering what monitoring can be added
- Running ISIS accelerator in a mode to reduce electrical stress to coils



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