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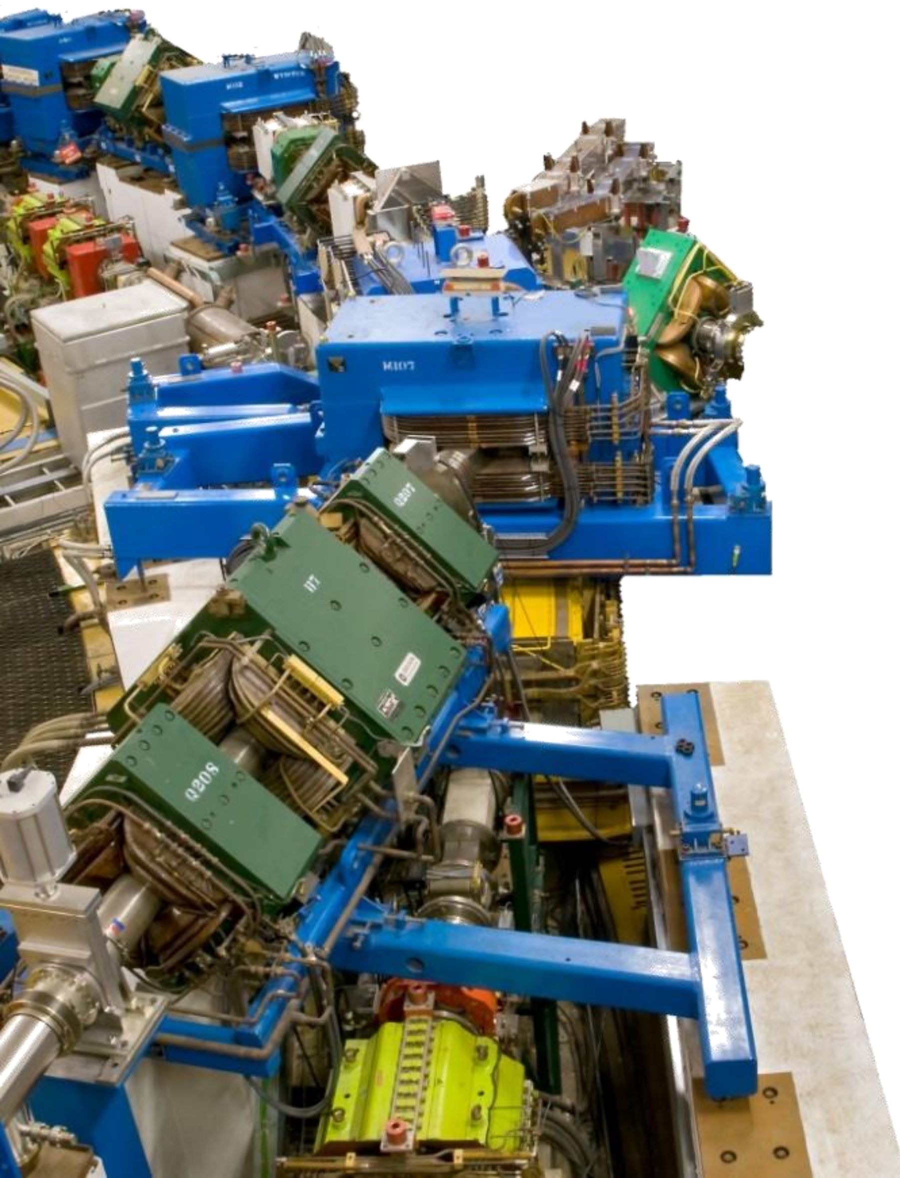
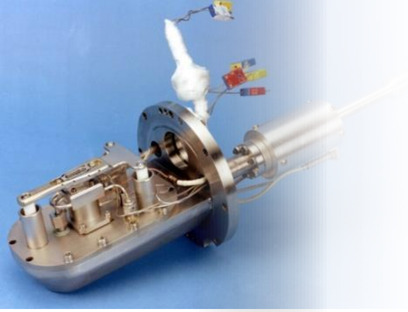
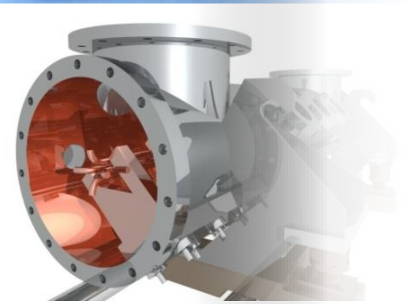
10 Years of Impact and Inspiration

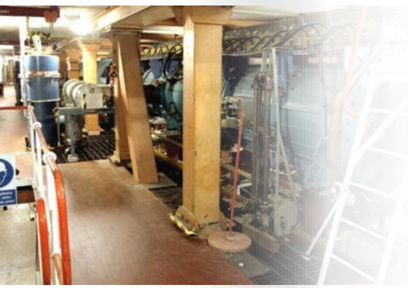


ISIS Update

John Thomason
ISIS Accelerator Division Head

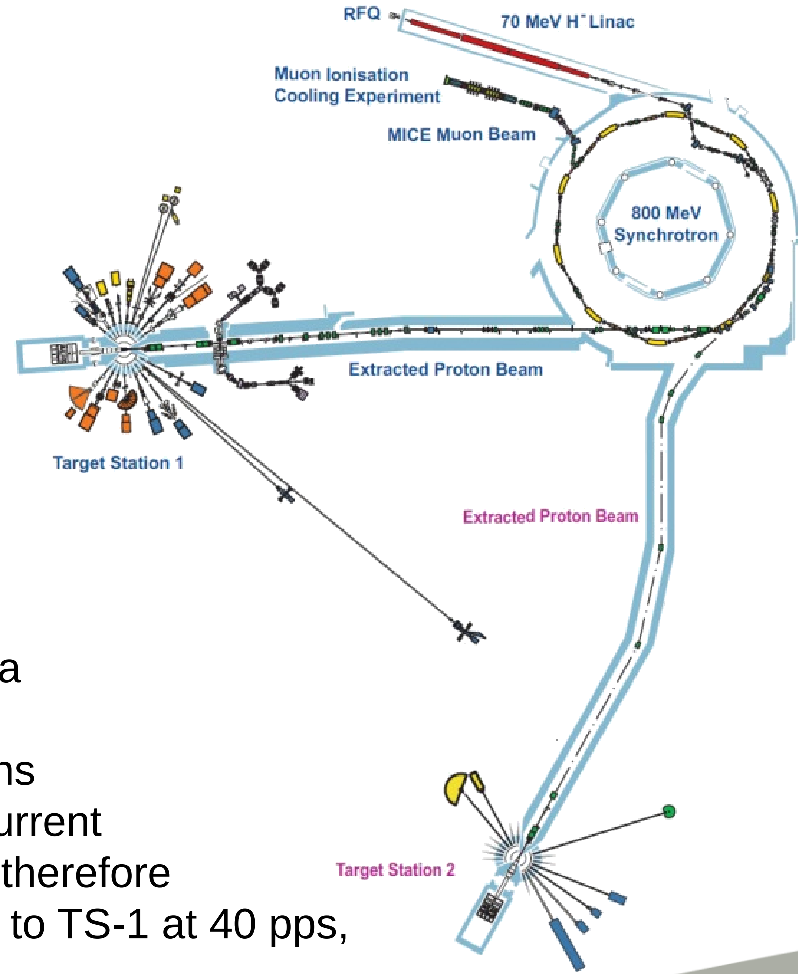






ISIS Accelerators

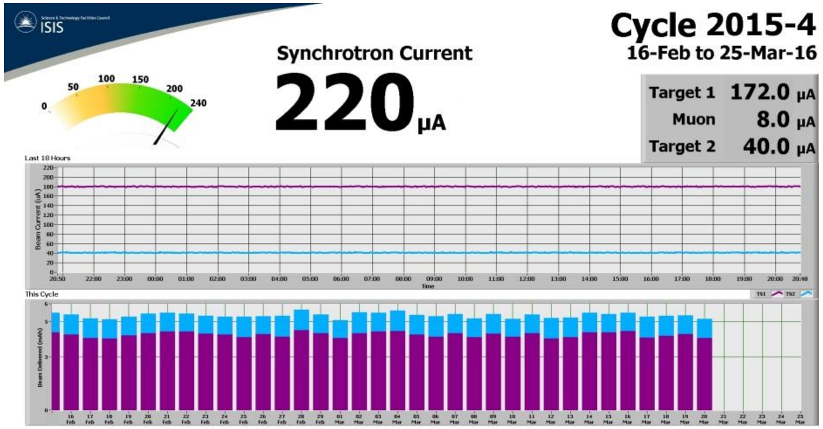
- H^- ion source (17 kV)
- 665 kV H^- RFQ
- 70 MeV H^- linac
- 800 MeV proton synchrotron
- Extracted proton beam lines

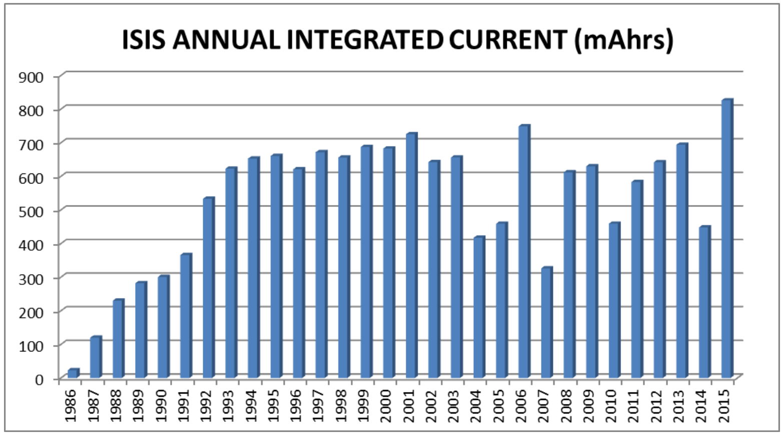


The accelerator produces a pulsed beam of 800 MeV (84% speed of light) protons at 50 Hz, average beam current is 220 μA (2.8×10^{13} ppp) therefore 176 kW on target (140 kW to TS-1 at 40 pps, 36 kW to TS-2 at 10 pps)

Performance

- 220 µA to two target stations
- Synchrotron efficiency = 93-95 %
- Beam availability = 90±5 %





- ~£50M/year operating budget (£8M/year for accelerator operation/sustainability)
- ~400 staff - 120 in accelerator division
- 160 - 200 operating days per year split into 4 or 5 cycles
- Long (6-9 month) shutdown every ~3 years for upgrades

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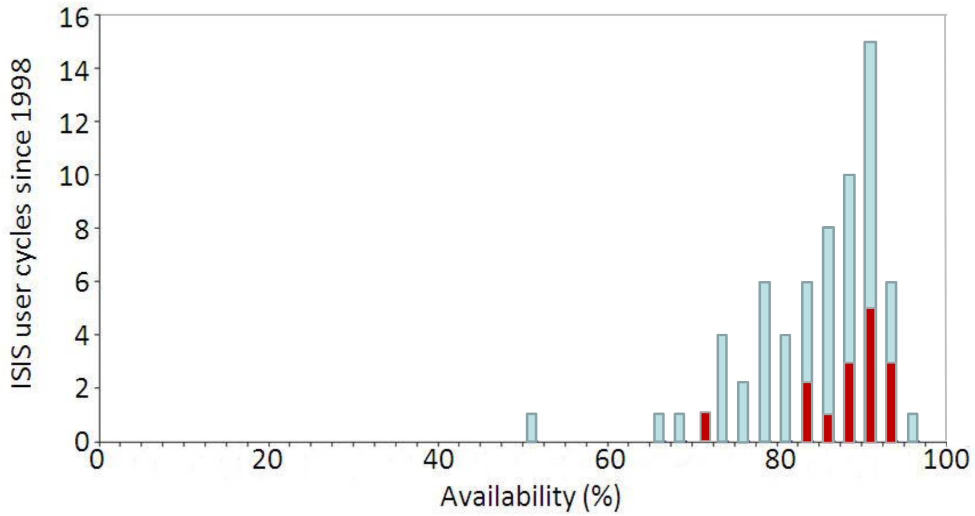
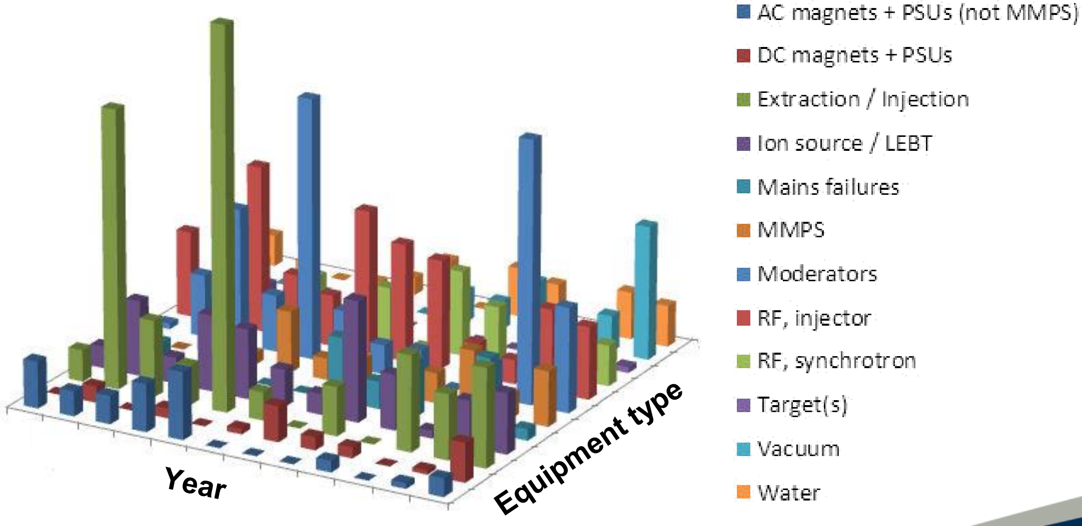
Availability

- It is vital that we maintain the confidence of our user community
- Need to target available effort and resource at improving (variability of) availability



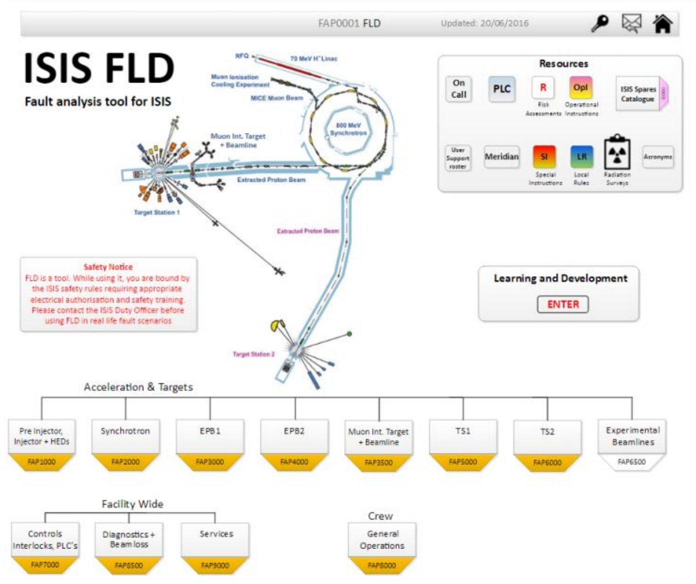


- Analysing trends and predicting problems is non-trivial

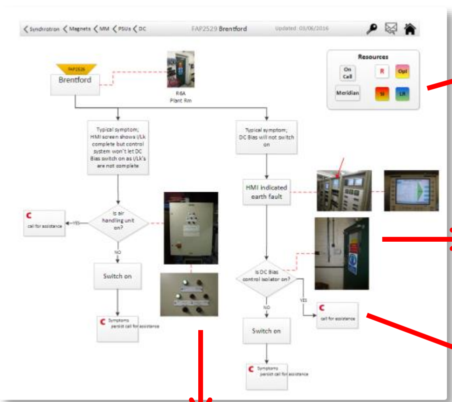
Achieving > 90% availability: short term, immediate response

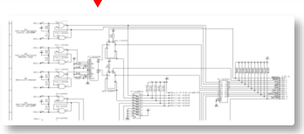
- Maintaining 32 years of skill & knowledge
- ISIS breaks down and needs fixing
- Always unforeseen circumstances
- Fault-finding required just to stand still
- A limit of crew specialist knowledge
- Skilled engineers at a premium
- Recruitment and retention ongoing process
- Training constantly required

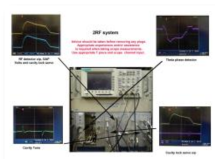
FLD: part of the solution

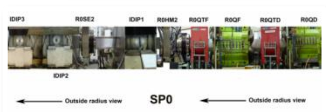


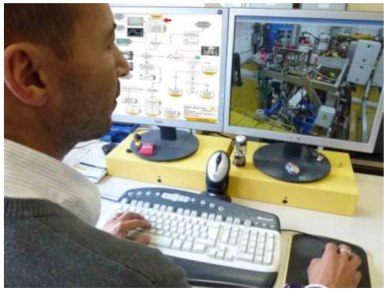
- Fault analysis software tool
- Available to crew site wide 24/7
- Content supplied by equipment owners
- Fault pathways for analysing faults
- Access to specialist information
- Helps increase availability











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Achieving > 90% availability: medium term maintenance

ISIS Maintenance Period Work-list

1st – 28th* August 2016

INJECTOR

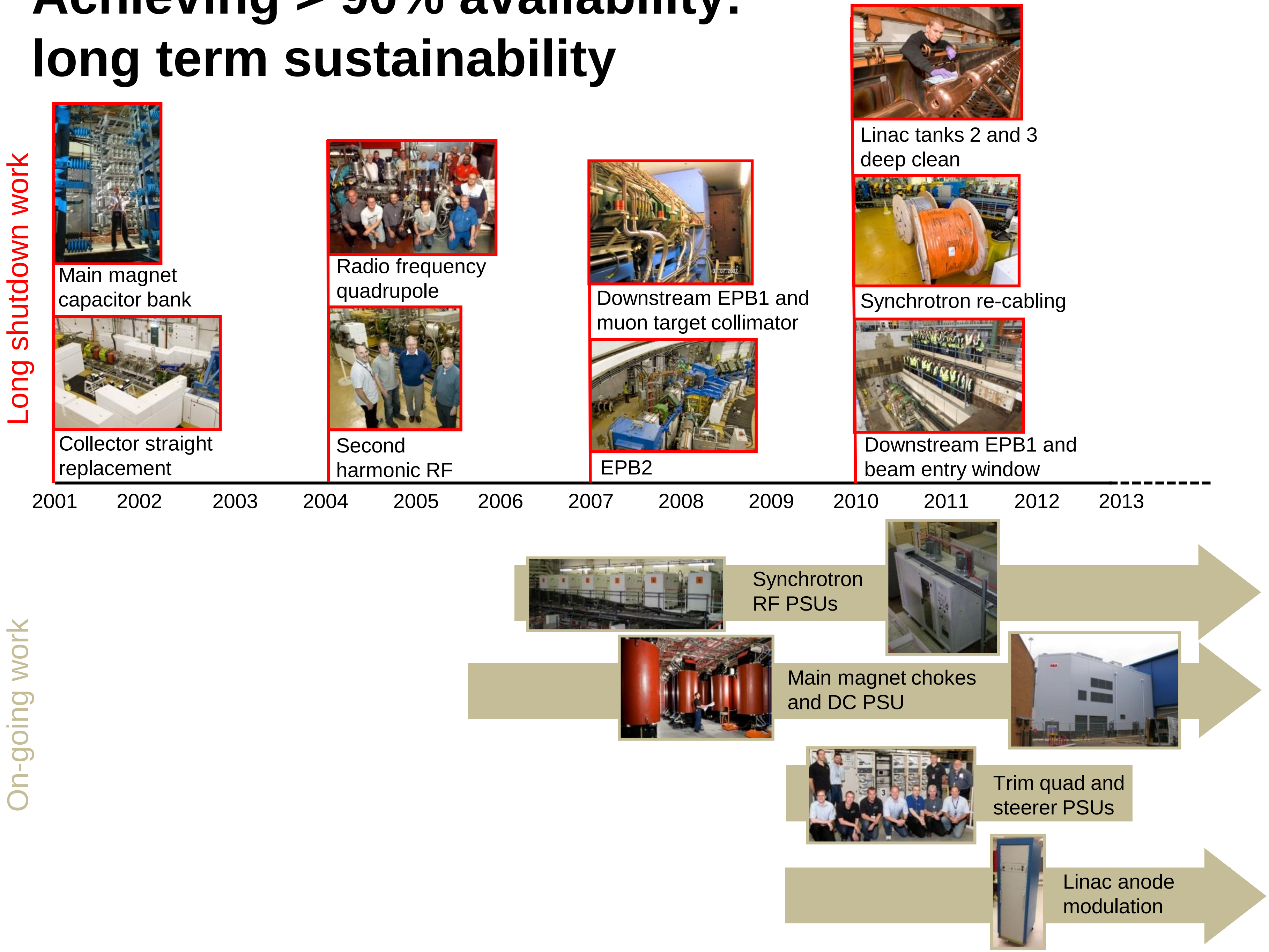
Task/Title of work	Proposed dates	Responsible person	Comments
Debuncher Feedline investigate window	4th Aug	JL	
Tank 2 o ring vacuum leak repair	2nd Aug	JL/GM	
Tank 4 Vac check (recent blip)		GM	
Mod 4 timing crate		PAH/SRS	
Mod 1 & 2 enclosure modification	1st →	SRS & Sect.	Contract & electrical support
Mod 4 303 maintenance		Linac Sect	
Mod 1 tune up / 4616 change		Linac Sect	
RFQ Tune up		Linac Sect	
Mod 3 cleaning		Linac Sect	
Remove cathode modulator water from M1		Linac Sect	
Fit 40kV volt meters		Linac Sect	
Interlock checking	28th August	Mark A.	Requires ion source operational please !
Install new heat exchanger for Mod 4	1st - 5th	S. Morse	No RF water to Mod 4
New PM9 installation.	17th Aug	Alex Pertica / Tony Kershaw	Pre-alignment required against the rails system frame.
Work on Injector BLM Argon system	2nd – 12th	Tony Kershaw	
Check oil level/condition on injector rotary and all roughing pump	3 Aug	SP	
Test operation Tank 3 roughing pump	3 Aug	SP	
Test RGA operation all Tanks	3-5 Aug	SP	
Test HEDS pump 1 operation	4 Aug	SP	

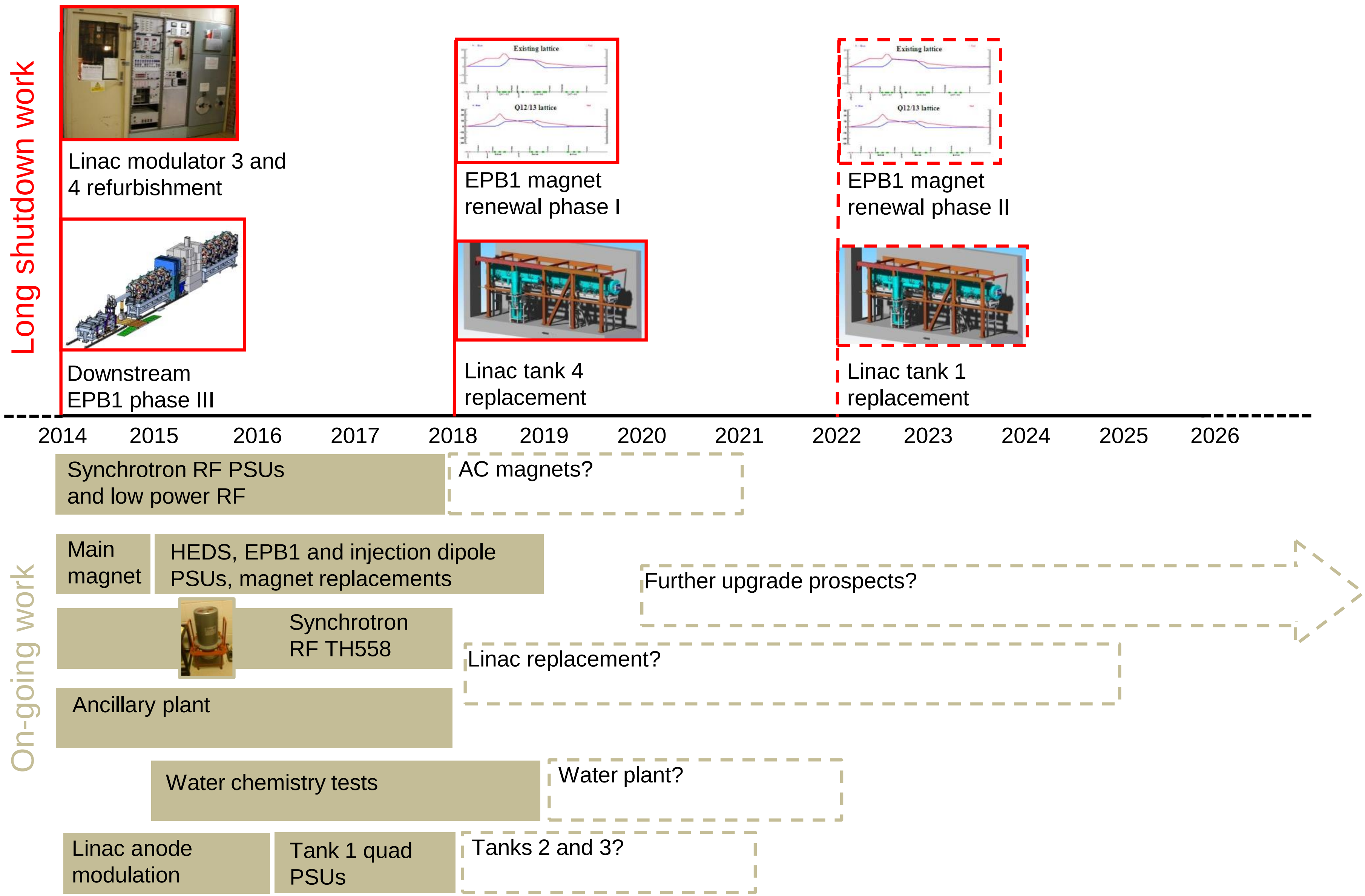
SYNCHROTRON / EPB1 & 2

Task/Title of work	Proposed dates	Responsible person	Comments
Run RF systems/LOI HPD in synch	15th – 28th	A Seville	Water and all necessary ILKS required!
JEMA connection to system 2	1st	NF/DG	all necessary ILKS required
Liquid Resistor tests	1st Aug	AS/RM	Access to cavities & running them up/down
HPD servicing – 1RF2, 1RF8, 1RF9, 2RF5, 2RF6 drain down, 1RFHPD5 service, 1RF8 inspection	WC 8th	DG	
HPD servicing – 1RFHPD6 service, 1RF9 inspection, IRFHPD7 service, 1RF2 inspection	WC 15th	DG	
HPD servicing – 2RFHPD2 service, run up all RF equipment	WC 22nd	DG	
Hall 2 patch panel connections			
Replace the egg flow meters on the bat cave panel	15th – 26th	P Masterson	
Break into the main magnet circuit to install the tee pieces and valves for the adiabatic upgrade	1st – 14th	D Couchman	Must be finished on the 14th to allow RF work!!
Replace SP7 flow panel	1st – 14th	S.Lees	No water supply to SP7
Replace SP8 flow panel	15th – 26th	P.Masterson	No water supply to SP8
Flush extract septum 1	16th – 18th	P.Masterson	Septum 1 water off
Install water supply for new steering magnet SP3	17th – 18th	P.Masterson	No trim quad/ steering magnet water SP3
Install Vacuum port in shutter void ventilation	17th Aug	G.Field / P.Masterson	Shutter void ventilation off
R80 process water glycol fill	22nd – 25th	P.Masterson	R6 link plant off, not EPB2 magnet / PS water
Upgrade E1Q1 power supply from 200A to 300A including new supply cable	Flexible (1 week)	A Black	
Install new Musr power supply including new supply cables	1st – 5th	A Black	
Choke oil top up, clean & inspection	25th & 26th August	S Reeves	Dependant on new DC bias switch on / testing date
Coil Clamp checks	24th Aug	Jim Loughrey	
Air sampling equipment set up	8th Aug	Jim Loughrey	
EPB Position monitor install	15th Aug	Jim Loughrey	
Check vibration on K2 magnet	15th Aug	Jim Loughrey	
Commission EPB1 MOLs	1st - 28th Aug	Tim Carter / Andy Sanders	Requires access to EPB1 & EPB1 PSUs to be switched off/on.
Upgrade inner sync water panel interlocks SP7 (possibly SP8)	1st - 28th Aug	P Masterson / Tim Carter	Cannot run / test MMPS during this time.
Confirm correct operation of North Tunnel EPB1 water panels during devicenet fault.	1st - 28th Aug	Tim Carter / Andy Sanders	Will require EPB1 PSUs to be switched off.
Measure injection dipole magnet temperatures, resistance and inductance	1st and 4th	J Ranner	
Measure trim quad currents	15th	J Ranner	Needs water
Modify MMPS control system for new DC Bias PSU	8th and 9th	J Ranner	
Trim Quad Power Supplies. Maintenance & Calibration	1st – 28th Aug	M Julian / B Orton	
Extract Kickers Maintenance	1st – 28th Aug	M Julian/ J Tydeman	
EC Muon Kicker Installation	1st – 28th Aug	M Julian	
HEDS Chopper Install	1st – 28th Aug	M Julian/ B Orton	
MMPS Danfysik DC Bias Commission	23rd- 28th Aug	S West	
New double position monitor installation next to EPM26 or EPM26A.	18th Aug	Alex Pertica	
Replace Scintillators in Dipole 2	15th – 26th	Tony Kershaw / Alex Pertica	Being done at end of shutdown when Rad levels lowest

*Should aim to be finished by 16:30 on Friday 26th Aug

Achieving > 90% availability: long term sustainability





Long shutdown work
Linac modulator 3 and 4 refurbishment
Downstream EPB1 phase III
EPB1 magnet renewal phase I
Linac tank 4 replacement
EPB1 magnet renewal phase II
Linac tank 1 replacement
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
On-going work
Synchrotron RF PSUs and low power RF
AC magnets?
Main magnet
HEDS, EPB1 and injection dipole PSUs, magnet replacements
Further upgrade prospects?
Synchrotron RF TH558
Linac replacement?
Ancillary plant
Water chemistry tests
Water plant?
Linac anode modulation
Tank 1 quad PSUs
Tanks 2 and 3?

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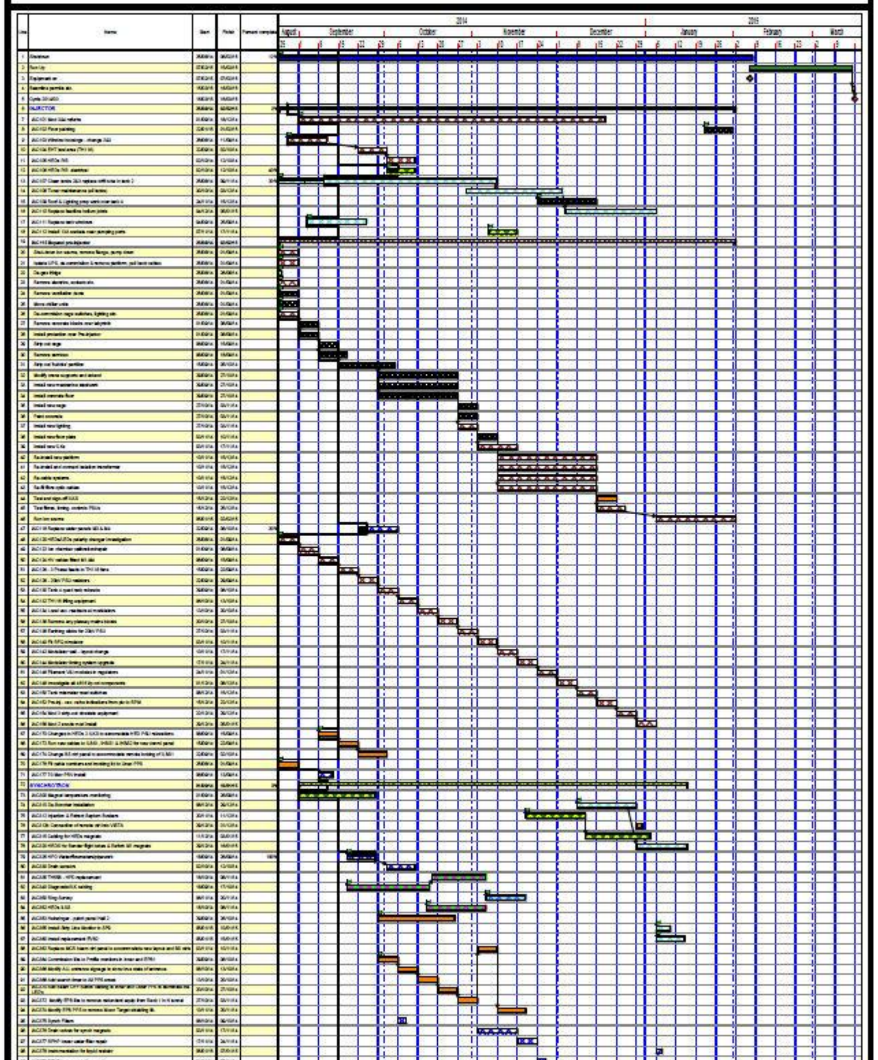
2014 Long Shutdown

ISIS



Drawn by: Mike Krendler | Programme Number: Progress 1 | Comment: | Date : 16/09/2014

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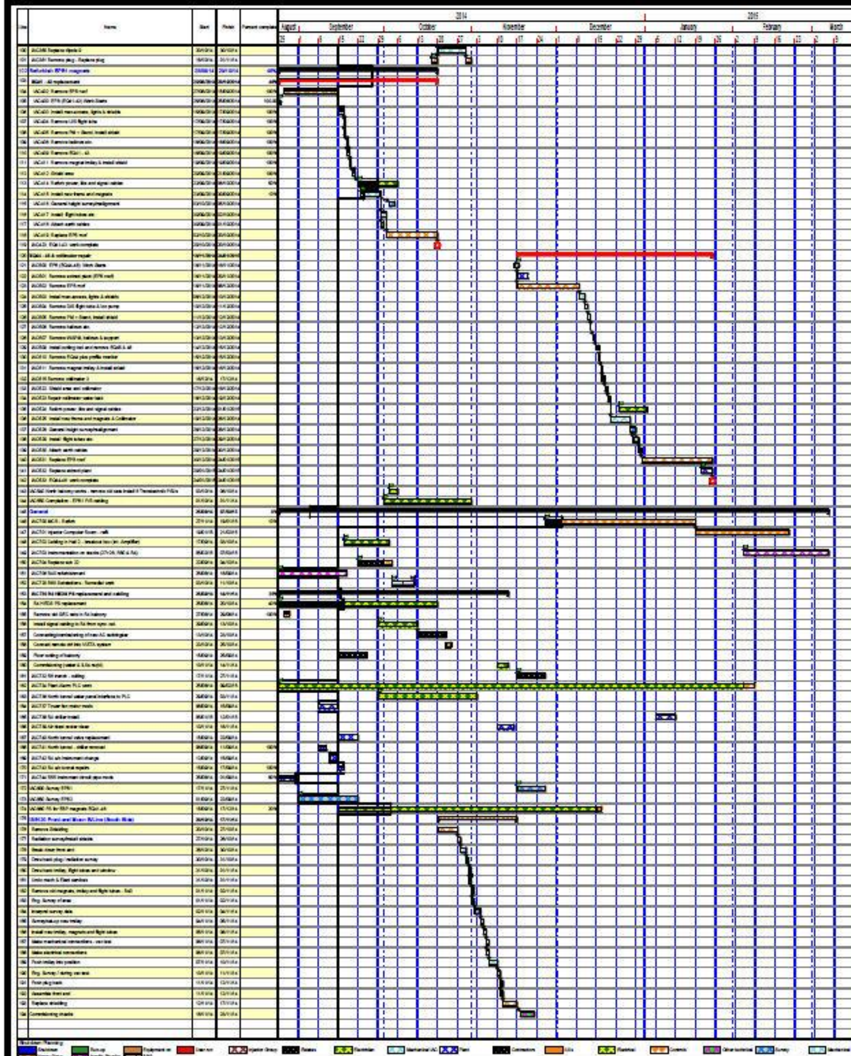
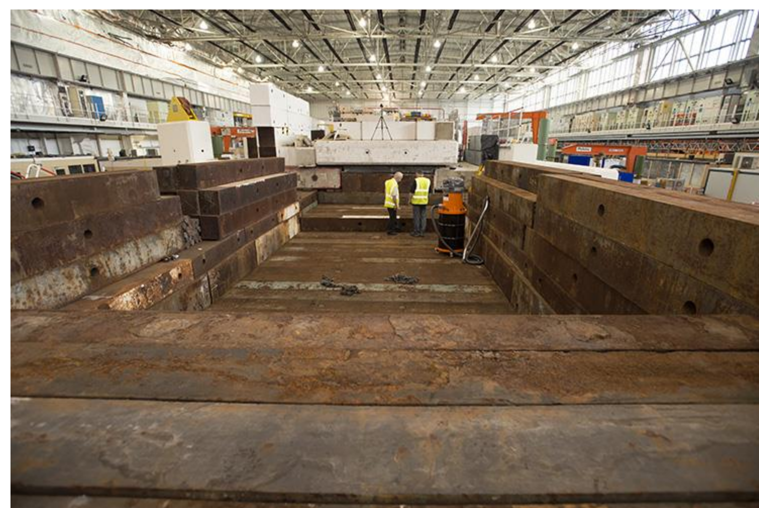
2014 Long Shutdown

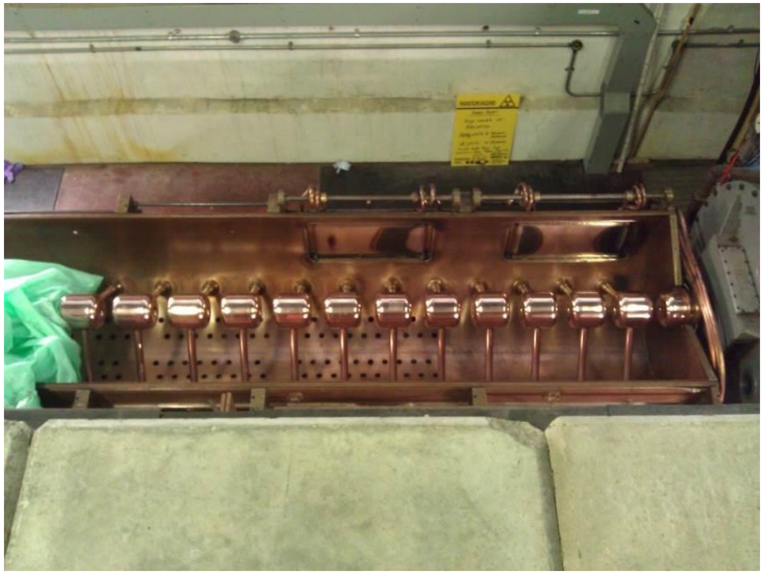
ISIS



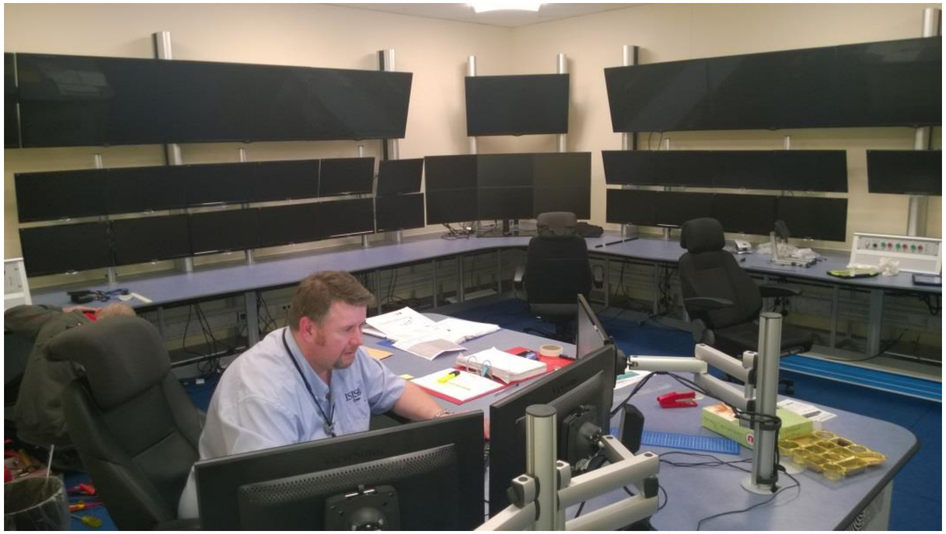
Drawn by: Mike Krendler | Programme Number: Progress 1 | Comment: | Date : 16/09/2014



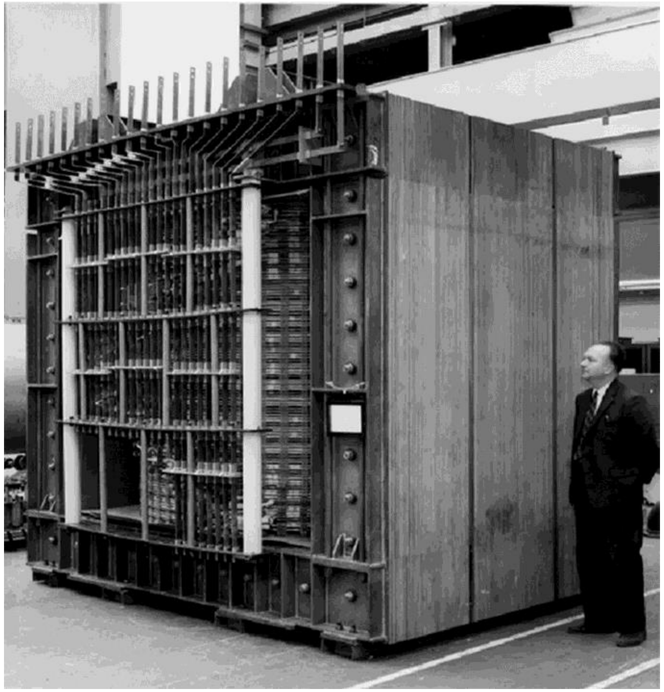

WT.17 TON
QC2-3



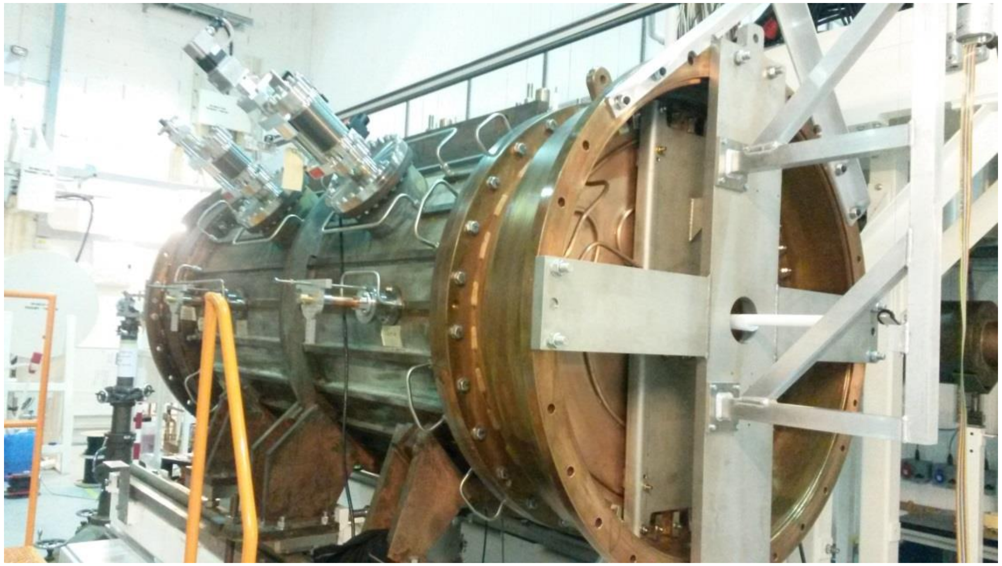

THE VAUGHAN CRANE



Main Magnet Power Supply

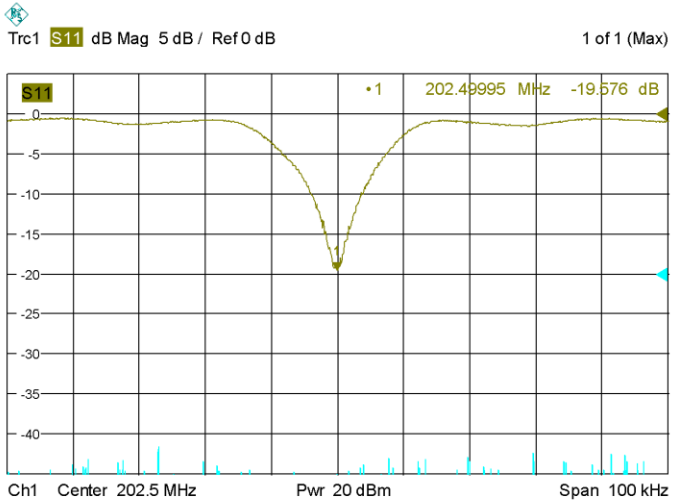


Tank IV replacement



The 1/6 length Tank IV test vessel is complete and the first RF measurements have been made.

The un-tuned frequency was correct to 2 parts in 100,000.



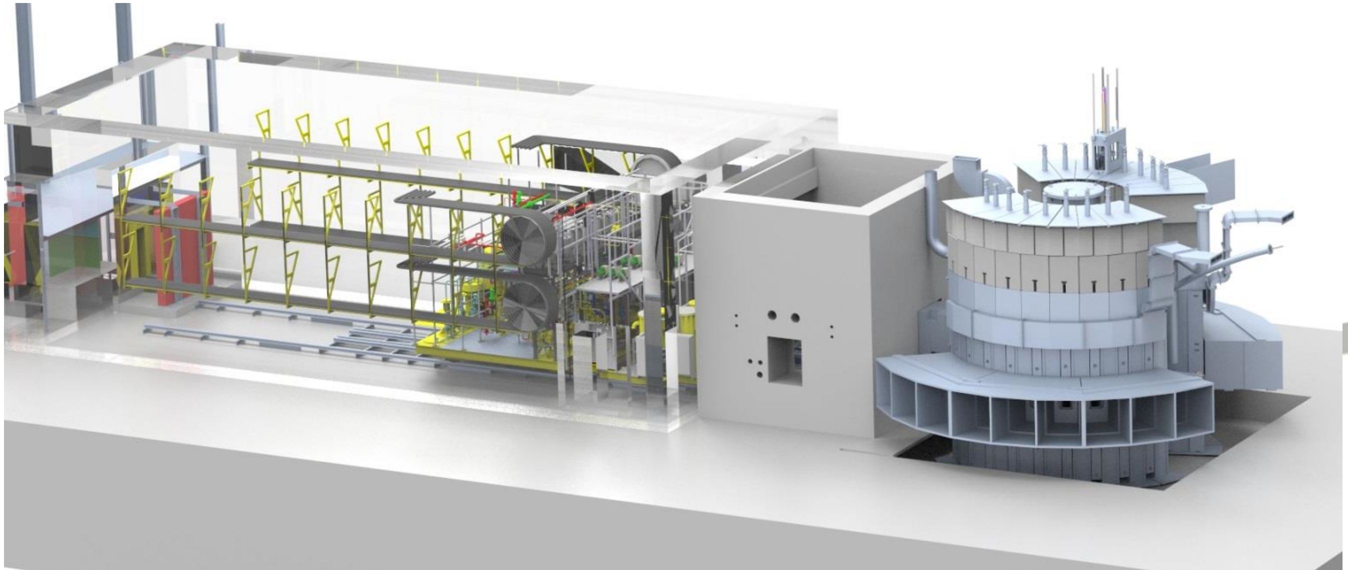
The tuning mechanisms operated exactly as designed and brought the vessel on tune at 202.5 MHz.

The ISIS First Target Station Project

What will actually be done during the project

- Complete refurbishment of the internals of the target station, including:
  - Design of the target; target cooling systems
  - Moderators and reflector, and all their cooling systems and services which sit behind the target station

- The project does not include any significant changes to the TS1 neutron or muon instrument suite
- Development of instruments will carry on in parallel to the TS1 project
- Some instruments will see a gain in neutron flux as a result of the project
- The baseline aim is for no instrument's capabilities to be reduced by the project



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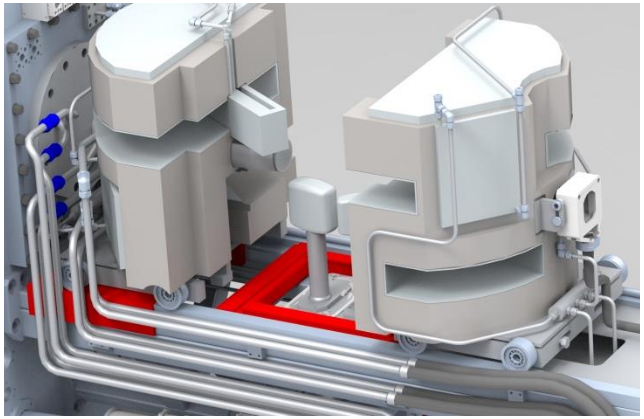
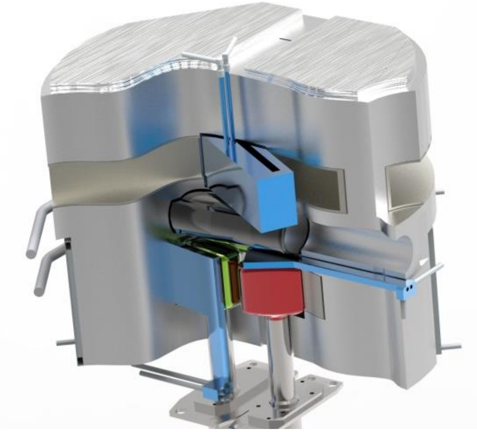
The ISIS First Target Station Project

Why are we doing the TS1 Project, and why now?

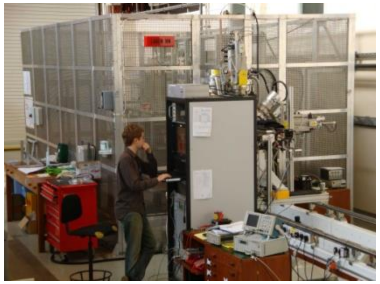
- To secure the future of TS1 and enable it to operate for many more years
- To provide improved flexibility for future target or moderator changes
- To make operation of the target station easier, e.g. improving the time for methane moderator changes
- To provide a neutron performance increase, of up to a factor of 2, on some instruments
- To provide confidence in the ongoing operation of TS1 to enable future instrument upgrades
- To further improve our knowledge of target station design for future projects and further develop our staff in this area





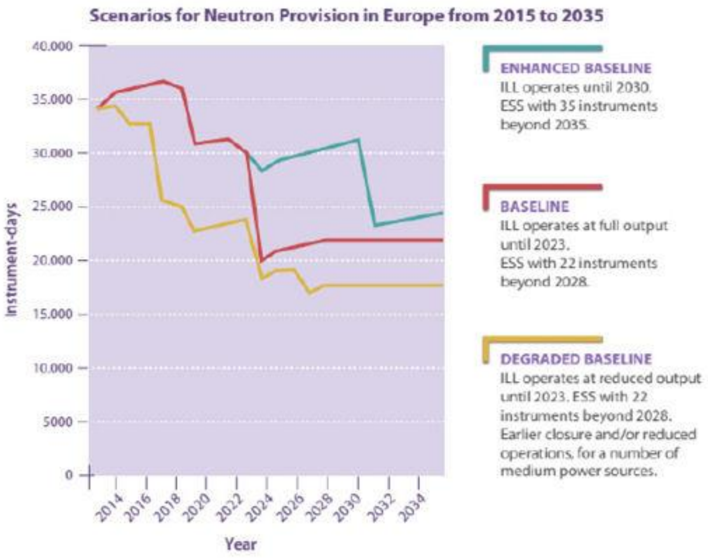
Test facilities

- Whenever possible ISIS downtime from commissioning new equipment should be minimised by using suitable off-line test rigs
- Direct effect on availability




ISIS-II

- We have been looking at upgrades to ISIS for many years, but now is a good time to refocus given the advent of ESS, but impending 'neutron drought' in Europe



- ESFRI Physical Sciences and Engineering Strategy Working Group Neutron Landscape Group - Neutron scattering facilities in Europe: Present status and future perspectives

- ISIS-II Working Group has been set up, and consists of experts from accelerator, target, neutronics, instrument science, detector and engineering. *Important to stress that this must be envisaged as a facility upgrade, not simply an accelerator upgrade*

ISIS-II Working Group

Accelerator
Alan Letchford
Shinji Machida
John Thomason (Chair)
Chris Warsop

Target
David Jenkins

Neutronics
Steve Lilley

Instruments
Rob Bewley
Rob Dalgliesh
Mario Campana (Secretary)
Adrian Hillier
Ron Smith

Detectors
Davide Raspino

Engineering
Steve Jago

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ISIS-II Working Group

- Looking primarily at 'short-pulse' (< 1 μs proton pulse) options for:

    1) Stand alone facility
    2) Re-use of ISIS infrastructure
    3) Compact neutron sources

- Ten meetings have been held, working from 'ideal instrument suite' backwards looking at all aspects of the facility

- Multiple day-one target stations, variety of repetition rates, FFAG options and muon production all important topics of discussion

1) Stand alone facility

- Assume a green field site, full funding and two target stations from day one

- Unanimous that the most attractive option is something similar to what SNS will look like after the proposed Second Target Station (STS) upgrade

  - 1.3 GeV proton beam at ~2.5 MW after Proton Power Upgrade (PPU)
  - First Target Station (FTS) at 50 Hz (nominal frame length 16.7 ms), ~2 MW
  - STS at 10 Hz (nominal frame length 100 ms) , ~0.5 MW

- However, 40 Hz (nominal frame length 20 ms) is felt to be better optimised for ISIS-II

- Maximum facility power will probably be determined by target capability, operability and useful neutron output rather than accelerator design and could be scaled up/down depending on operational experience running SNS FTS at 2 MW post PPU and/or overall cost envelope

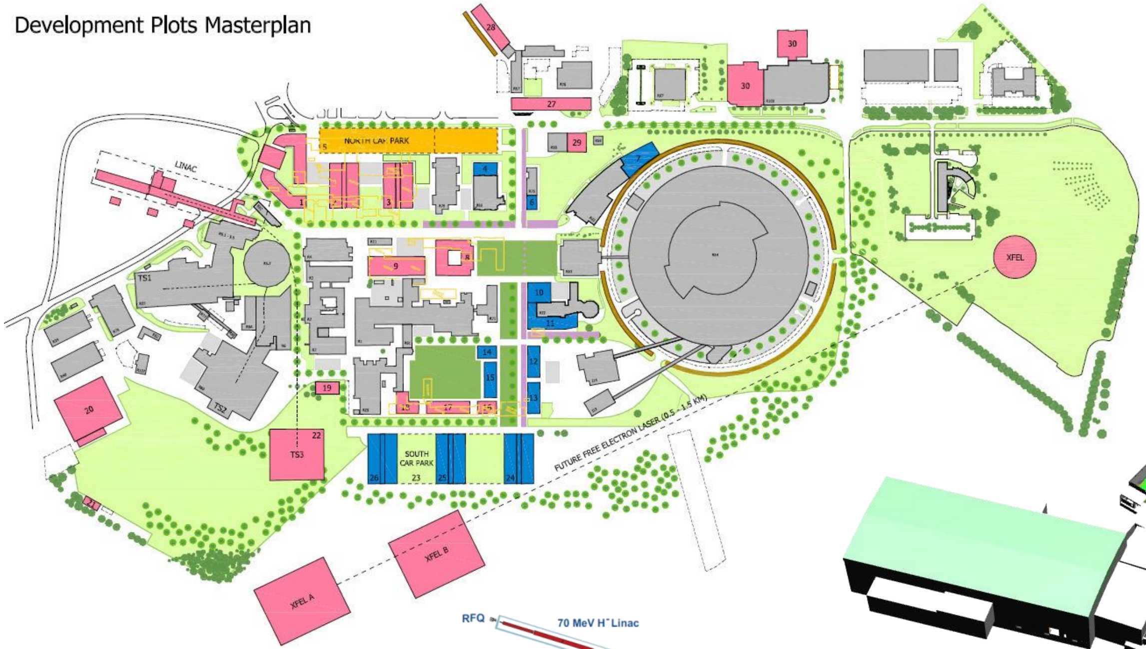
Recommendations

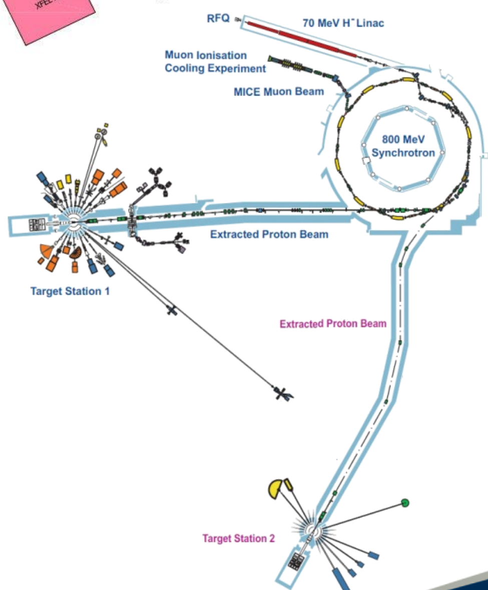
1. Keep accelerator design on ‘back burner’ as most of the issues and design choices are the same as those for ‘re-use of ISIS infrastructure’ scenarios

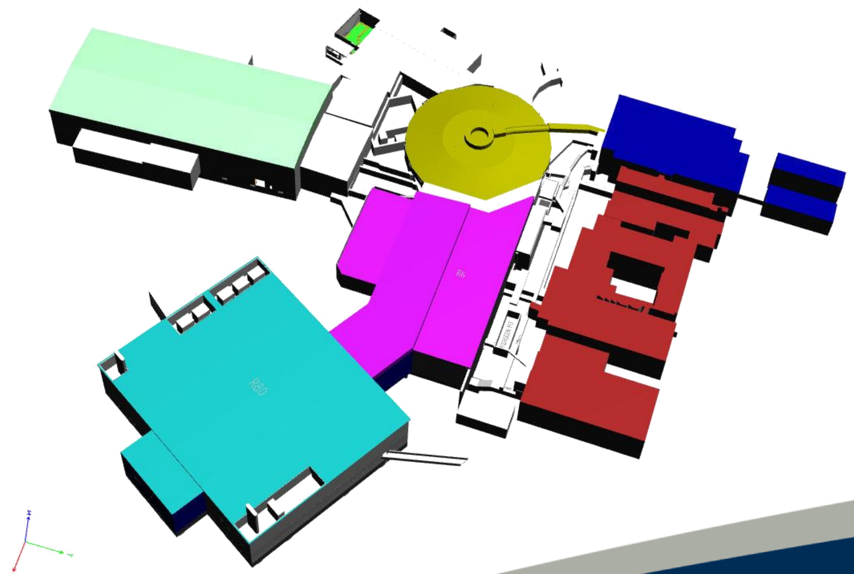
2. Keep a watching brief on SNS FTS mercury target performance post PPU and STS ‘rotating wheel’ target development

2) Re-use of ISIS infrastructure

Development Plots Masterplan

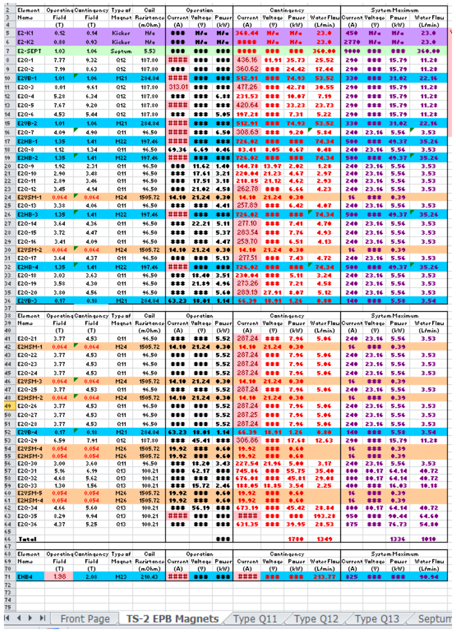






What we 'know' post WG meetings (1)

- It should be possible to upgrade ISIS TS-2 (still at 10 Hz) to ~0.25 MW with a plate target similar to that proposed for the TS-1 upgrade which is planned to go ahead in ~2020. All flight lines would remain the same



- A new TS-3 at 40 Hz (eventually replacing TS-1) with a compact Target Reflector and Moderator (TRAM) could operate effectively as a high resolution target station and complement an upgraded TS-2. If the nominal 1 MW proves to be too much power for a TRAM fully optimised for useful neutron output we could operate at lower frequency or reduced proton pulse intensity – we should design for operability rather than raw power

- 1.2 GeV is the maximum beam energy that would allow re-use of the majority of the components in the present EPB1 and EPB2

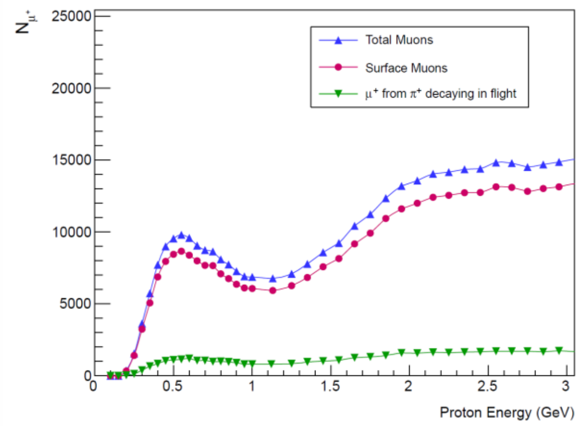
What we 'know' post WG meetings (2)

- It should be possible to fit a suitable 1.2 GeV accelerator running at ~1.25 MW in the present synchrotron hall, based on either a rapid cycling synchrotron, an accumulator ring or an FFAG

- A staged approach should allow us to keep the ISIS science programme running as much as possible during ISIS-II build and minimises beam off time to any one target

- Highly optimised muon production should be possible at ~500 MeV directly from the linac (but at a cost)

- Need to consider at what point we would choose to switch off TS-1, depending on critical mass of instruments on TS-3. May be advantage in running accelerator to produce 40Hz:10Hz:40Hz beam in the interim



(a). Raw muon yield per 10^9 protons.

Muon production (1)

- 'Parasitic' muon production from the 40 Hz, 1.2 GeV proton beam before the TS-3 neutron production target (similar to the scheme used at present on ISIS) does not provide the ideal repetition rate or pulse length for muon experiments (irrespective of any increase in pulse intensity)

- Muon production at the end of the linac has been proposed as a possibility for PIP-II at Fermilab, and a similar concept could be applied to ISIS-II, by interleaving muon production pulses with the neutron production pulses

Table 2: Comparison of ISIS low energy muon program with a similar configuration of the PIP-II linac beam.

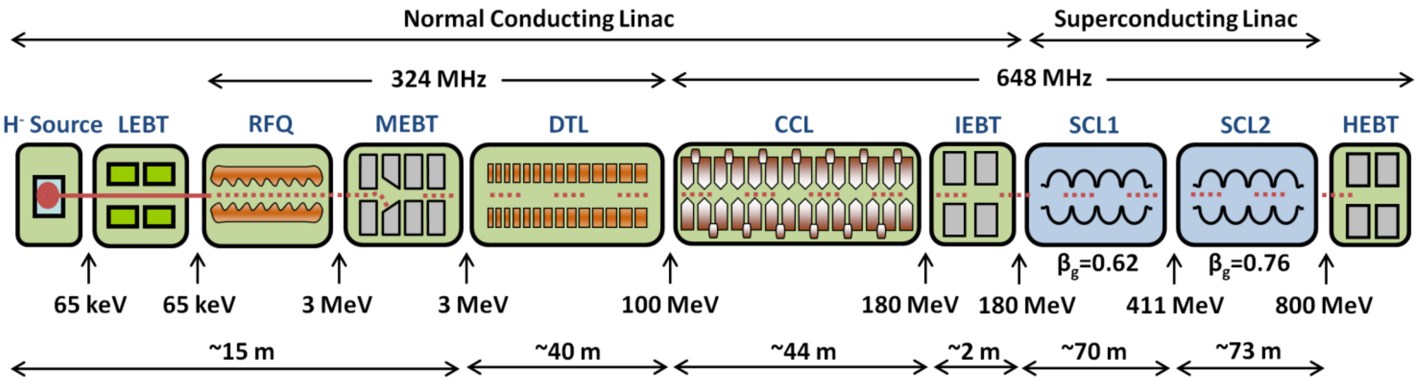
Parameter	ISIS	PIP-II	Comments
Kinetic Energy [MeV]	800	800	
Circumference [m]	163	N/A	
f_{RF} [MHz]	3.099	40.625	
Protons per Bunch	1.4×10^{13}	1.5×10^{8}	
Bunches per Cycle	2	5	ISIS bunches sent to two sub-lines
Bunch Length [ns]	100	98.5	
Bunch Spacing [μsec]	20000	32	
I [μA]	224	3.9	
Total Power [kW]	180	3.1	
Target Station 1 Power [kW]	143	N/A	4 out of 5 ISIS cycles
Muon Production Power [kW]	3.4	3.1	1 cm Carbon target in ISIS beam line

Muon production (2)

- This provides the opportunity to tailor the beam for optimal muon production at ~50 kHz and pulse length <10 ns (and would also allow the neutron production pulses to be optimised independently)
- Would need to consider the additional cost of having to run the linac close to CW rather than at ~10% duty cycle (and the capital cost of providing more RF power in the first place)
- Would also need a muon target and beam dump arrangement that could handle the linac beam power and to find space for muon instruments, probably in a dedicated building

Accelerator options (1)

- Proposed accelerator specification is 1.2 GeV, ~1.25 MW, 50 Hz (but flexible frequency may present some advantages), < 1 µs pulse train



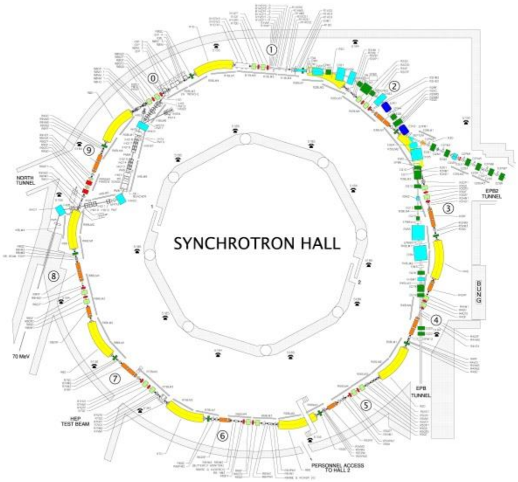
- Linac front end to 3 MeV would be based on Front End Test Stand frequency and architecture

- Design to 180 MeV has been shown to be compatible with present ISIS synchrotron to produce 0.5 MW with relatively little change needed except for the injection straight

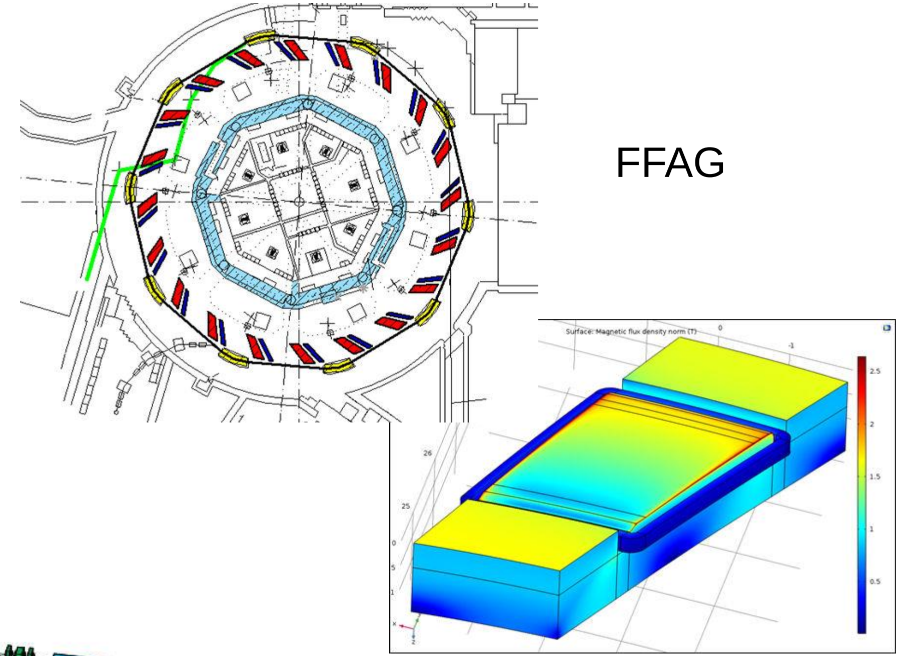
- 800 MeV SCL design shown here could be curtailed at ~500 MeV for injection to an FFAG or extended to 1.2 GeV for injection into an accumulator ring

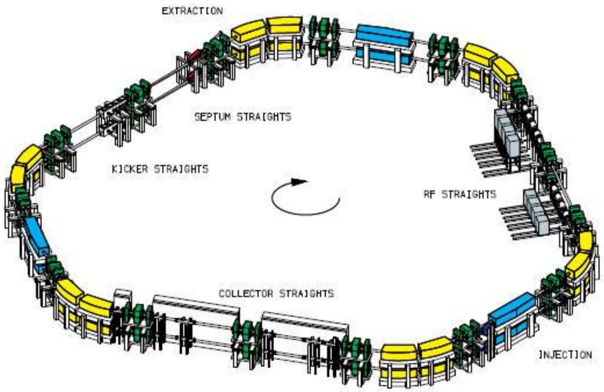
Accelerator options (2)

RCS



FFAG





Accumulator ring

Accelerator options (3)

	FFAG	RCS	Accumulator ring
Extraction energy (GeV)	1.2	1.2	1.2
Injection energy (MeV)	~500	~800	1200
Pros	• Fixed field magnets (could be permanent or superconducting?) – higher reliability and availability • Flexible pulse repetition rates possible (up to 100 Hz?) • ‘Pulse stacking’ possible • Optimal energy for ‘linac’ muon production	• Most conservative option, technology familiar to ISIS • More chance to re-use present ISIS PSUs • Possible to replace the current ring piecemeal rather than as one big job could minimise downtime	• Fixed field magnets (could be permanent or superconducting?) – higher reliability and availability • Relatively simple magnet design • Could run at different frequencies (up to 100 Hz?) • Fixed frequency RF
Cons	• Least conservative design – would need significant R&D to convince ourselves (and funding bodies!) to pursue • Complicated magnet and RF design • Individual magnets are relatively large, exceeding current crane capacity	• Fixed frequency (probably no more than 50 Hz) • AC magnets - less reliability and availability • Would probably need stacked rings to get above 1 MW • Most susceptible to changes in linac energy if retuning in event of cavity failure	• May require additional achromat between linac and ring • Largest linac – largest footprint

- In the absence of detailed costings at this stage it is assumed that by the time size of linac vs. size of ring and capital vs. operational cost are taken into account each option will cost the same to a first approximation

Possible staged upgrade scenario (1)

E.g. ‘optimised’ to reduce cost at each stage

1. Upgrade TS-2 to be capable of taking 0.25 MW

2. Install 180 MeV linac in new hall (partly re-using MICE hall?) with enough space for later upgrade to full energy linac and upgrade present RCS to take beam at 180 MeV to give 0.5 MW capability, running TS-1 at 160 kW (with reduced pulse intensity), TS-2 at 100 kW

3. Install linac to full energy, but continue to inject at 180 MeV

4. Replace current RCS to give 1.25 MW capability running TS-1 at 40 Hz, 160 kW (with reduced pulse intensity), TS-2 at 0.25 MW

5. Build new muon target hall taking 500 MeV beam from the linac

6. Build TS-3 to replace TS-1, but still running TS-1 and TS-3 in parallel until a critical mass of instruments is available on TS-3

7. Shut down TS-1 and run TS-3 at 1 MW, TS-2 at 0.25 MW

Possible staged upgrade scenario (2)

E.g. 'optimised' to reduce downtime at each stage

1. Upgrade TS-2 to be capable of taking 0.25 MW

2. Install full energy linac in new hall (partly re-using MICE hall?) , but only run at 180 MeV and upgrade present RCS to take beam at 180 MeV to give 0.5 MW capability, running TS-1 at 160 kW (with reduced pulse intensity), TS-2 at 100 kW

3. Replace current RCS to give 1.25 MW capability running TS-1 at 40 Hz, 160 kW (with reduced pulse intensity), TS-2 at 0.25 MW

4. Build new muon target hall taking 500 MeV beam from the linac

5. Build TS-3 to replace TS-1, but running TS-1 and TS-3 in parallel until a critical mass of instruments is available on TS-3

6. Shut down TS-1 and run TS-3 at 1 MW, TS-2 at 0.25 MW

Recommendations

1. Keep development of RCS, accumulator ring and FFAG based designs active to the point where we can make a well informed decision on which option to pursue based on technical merit and lifetime cost

2. The FFAG option will require R&D, with the initial proposal being the development of a prototype magnet (and later an RF system). If this is successful then we will aim to incorporate these as part of a small FFAG on the end of FETS in order to explore the beam dynamics fully

3. Ensure that the upgrade is optimised for neutron production, but with careful consideration of muon production as well

4. Pursue an appropriate development programme for a compact TRAM for TS-3, including definition of suitable figures of merit for moderator output

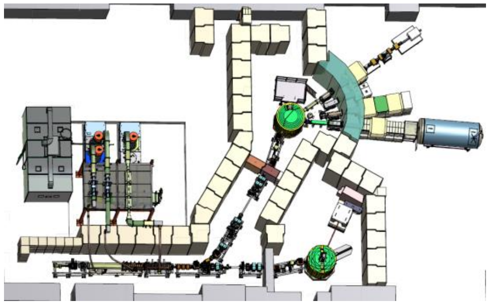
5. Continue to reserve the space on the RAL site for a new linac, TS-3 and possibly a new muon target/instrument building

6. Continue to explore staged upgrade scenarios in order to minimise cost and downtime at each stage, feeding this information into the technical decision making process

3) Compact neutron source

- There is already quite a large community in Europe and Japan under the umbrella of UCANS (Union for Compact Accelerator-driven Neutron Sources), which held its sixth annual meeting in Xian 25-28 October 2016

UCANS

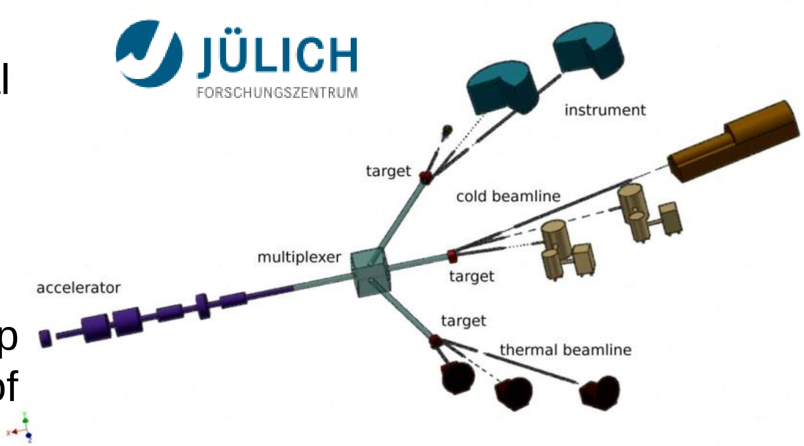


- Sources typically involving a proton or deuteron RFQ, linac to ~10 MeV and low Z target (but with some also using cyclotrons) produce neutron pulses in the > ms range. Pulse compression to produce a ‘short-pulse’ source would be very difficult at such low energies

- Currently ‘short-pulse’ compact sources are typically driven by electron linacs, but produce relatively low neutron fluxes

- Laser driven sources (being developed at the Central Laser Facility at RAL and elsewhere) produce short pulses, but currently repetition rates are very low and the quality of the neutron pulses is nowhere near good enough to do useful science

- The proposed Jülich High Brilliance Neutron Source has an RFQ and normal conducting linac producing a deuteron beam at 25 MeV, 100 mA 4% duty cycle which delivers 100 kW to multiple beryllium targets, each with one optimised moderator. This will support up to 20 instruments and have a price tag of at least €200M



Recommendations

1. If ISIS has serious ambitions to become involved in the development of CANS a small working group should be set up to investigate current worldwide capability and demand in order to determine how best to participate. Attendance at the next UCANS meeting and other relevant conferences and workshops should be ensured at an appropriate level.

2. Keep a watching brief on developments in laser driven neutron production in case of anything game-changing

Summary

- ISIS availability of >90% is generally achieved and satisfies the expectations of our user community, but we need to paddle very hard just to stay still, with concentration on short, medium and long term strategies and enough resource to back them up
- ISIS availability is limited by the age of some components and the design of others, but engineering and design solutions cannot remove every possibility for unscheduled downtime
- Good people and good training are essential
- Future plans are essential to continued neutron provision in Europe beyond 2030

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