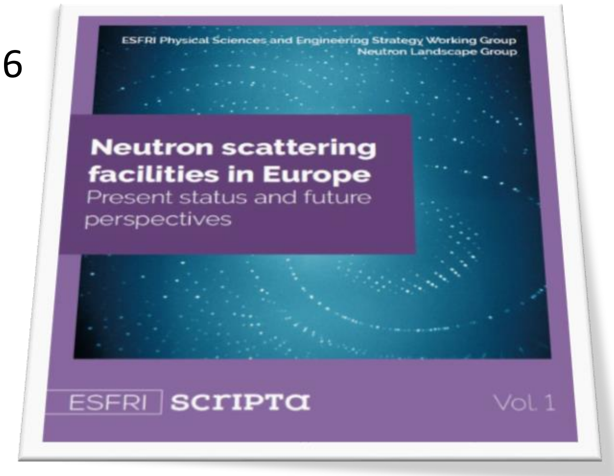
Overview of ISIS-II Roadmap

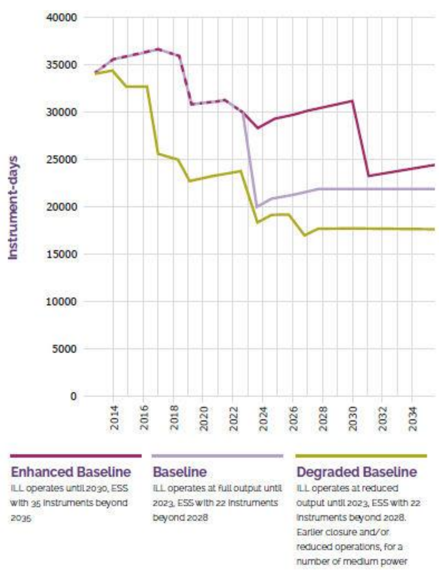
John Thomason
ISIS Accelerator Division Head

Recent Neutron Reviews

June 2016



September 2017



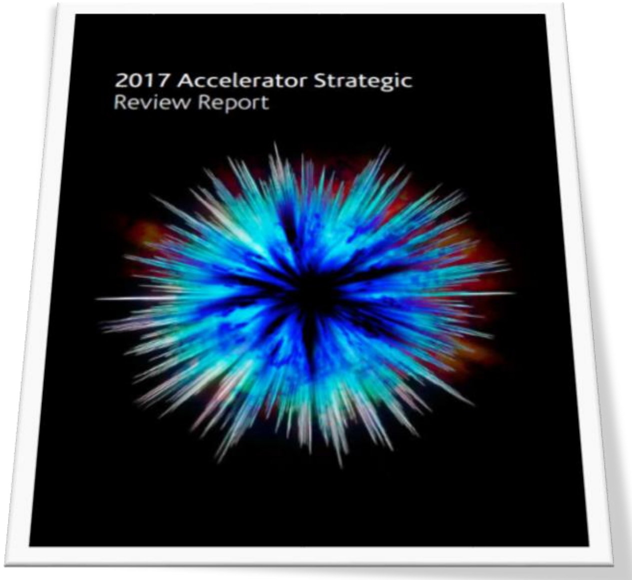
Scenarios for neutron provision in Europe from 2015 to 2035 (ESFRI report p.76)

From the Executive Summary:

- Central to all of the options is the need to maintain the UK's internationally competitive ISIS facility.
- In light of the significant changes over the coming years as sources close and the ESS comes on line, there should be a further detailed evaluation of the UK's neutron needs in the mid-2020s.

STFC Accelerator Strategic Review

April 2018



Recommendations:

- The UK national laboratories should be charged with the co-ordination of research and development activities across stakeholders in development of future neutron and x-ray sources.

- Enable implementation of a range of ISIS II upgrade options. A programme of continued investment in developing advanced technology for high-intensity accelerators should be pursued. In particular, focus on cost effective accelerator technology options for MW-scale beams applicable to other fields such as:
  - Superconducting RF accelerating structures
  - High intensity H^- beam front end test stand
  - High power target development
  - High intensity H^- ion sources

ISIS-II Working Group

- We have been looking at upgrades to ISIS for many years, but 2016 was deemed to be good time to refocus given the advent of ESS, but impending 'neutron drought' in Europe.
- ISIS-II Working Group was been set up, consisting of experts from accelerator, target, neutronics, instrument science, detector and engineering. *Important to stress that ISIS-II must be envisaged as a facility upgrade, not simply an accelerator upgrade.*

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

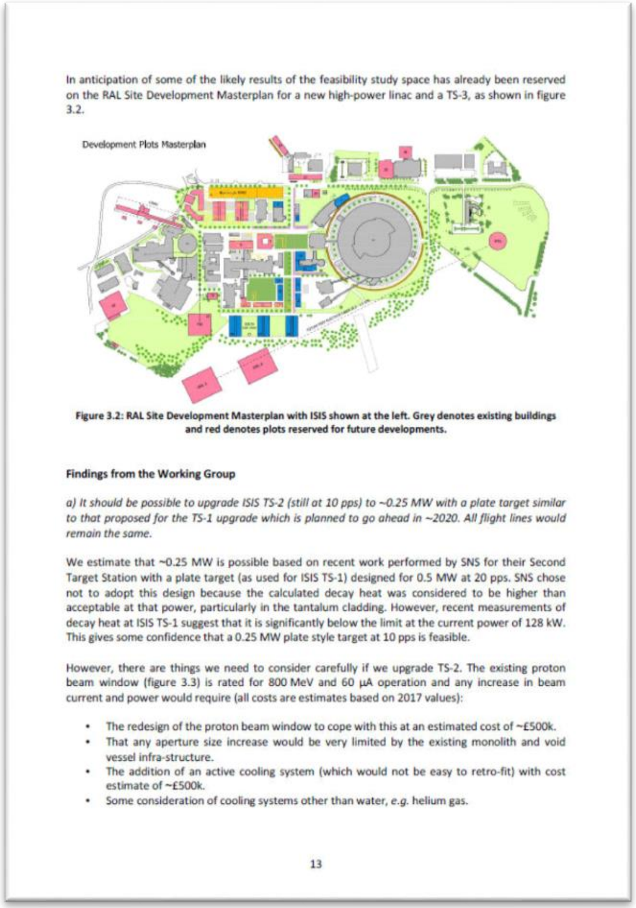
Engineering
Steve Jago

ISIS-II Working Group

- Ten meetings were held, working from an 'ideal instrument suite' backwards looking at all aspects of the facility.
- Multiple day-one target stations, variety of repetition rates, FFA* options and muon production all important topics of discussion.
- 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
     (see Alain Menelle's talk)

- Working Group Report was produced in early 2017.



In anticipation of some of the likely results of the feasibility study space has already been reserved on the RAL Site Development Masterplan for a new high-power linac and a TS-3, as shown in figure 3.2.

Figure 3.2: RAL Site Development Masterplan with ISIS shown at the left. Grey denotes existing buildings and red denotes plots reserved for future developments.

Findings from the Working Group

a) It should be possible to upgrade ISIS TS-2 (still at 10 pps) 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.

We estimate that ~0.25 MW is possible based on recent work performed by SNS for their Second Target Station with a plate target (as used for ISIS TS-1) designed for 0.5 MW at 20 pps. SNS chose not to adopt this design because the calculated decay heat was considered to be higher than acceptable at that power, particularly in the tantalum cladding. However, recent measurements of decay heat at ISIS TS-1 suggest that it is significantly below the limit at the current power of 128 kW. This gives some confidence that a 0.25 MW plate style target at 10 pps is feasible.

However, there are things we need to consider carefully if we upgrade TS-2. The existing proton beam window (figure 3.3) is rated for 800 MeV and 60 μA operation and any increase in beam current and power would require (all costs are estimates based on 2017 values):

- The redesign of the proton beam window to cope with this at an estimated cost of ~£500k.
- That any aperture size increase would be very limited by the existing monolith and void vessel infra-structure.
- The addition of an active cooling system (which would not be easy to retro-fit) with cost estimate of ~£500k.
- Some consideration of cooling systems other than water, *e.g.* helium gas.

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*The Accelerator Formerly Known as FFAG

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 (see Mike Plum's talk):

  - 1.3 GeV proton beam at ~2.5 MW after Proton Power Upgrade (PPU)
  - First Target Station (FTS) at 45 Hz (nominal frame length 16.7 ms), ~2 MW
  - STS at 15 Hz (nominal frame length 66.6 ms) , ~0.5 MW

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

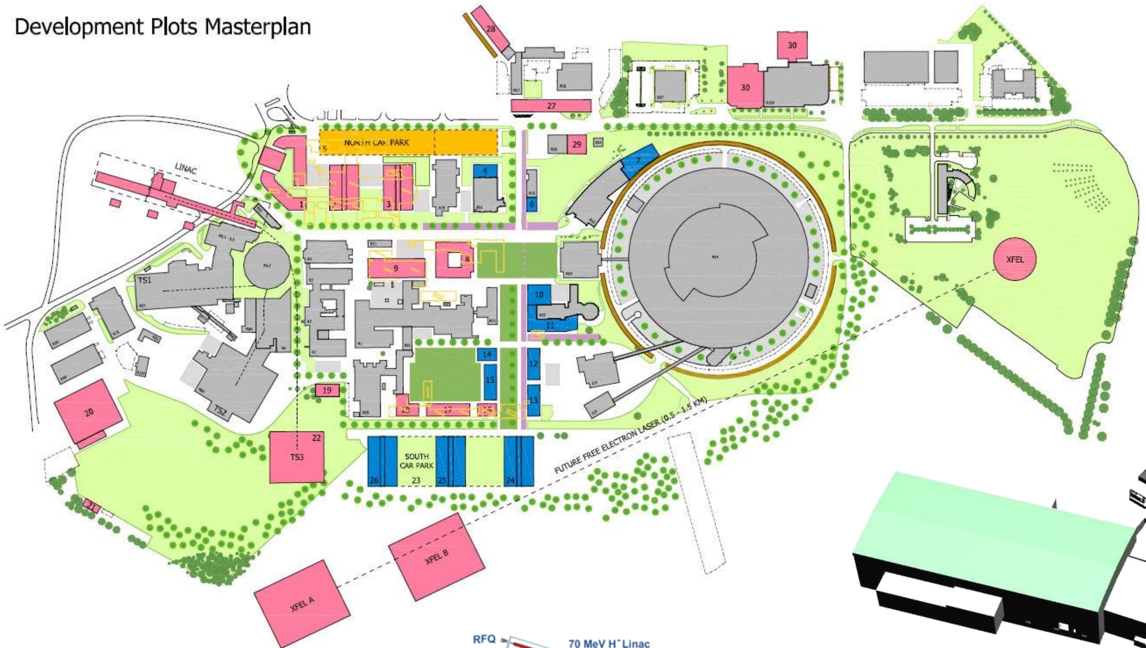
- Maximum facility power will probably be determined by target capability, operability and useful neutron output rather than accelerator design and could be scaled up/down depending on operational experience running SNS FTS at 2 MW post PPU and/or overall cost envelope.

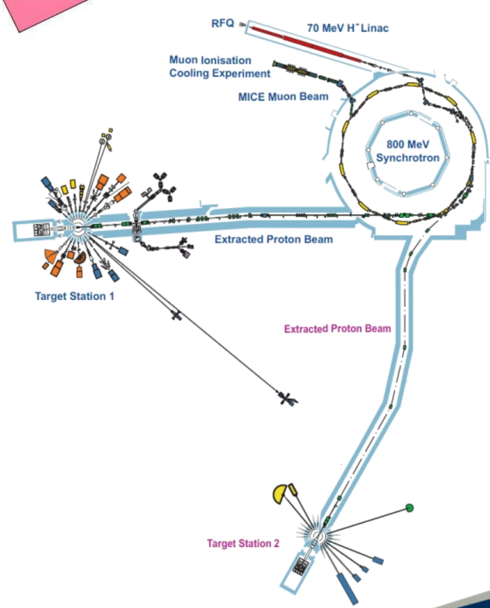
Recommendations

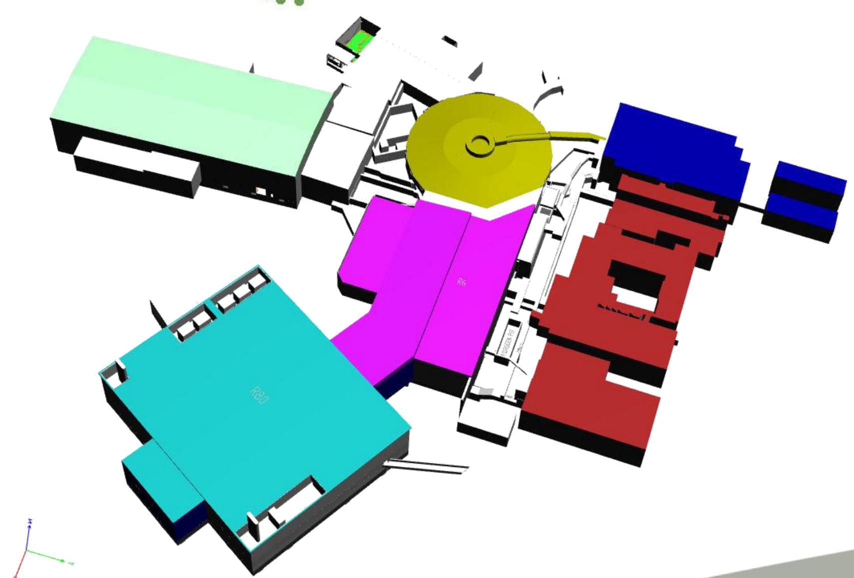
1. Keep accelerator design on 'back burner' as most of the issues and design choices are the same as those for 're-use of ISIS infrastructure' scenarios.

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

1) Re-use of ISIS infrastructure

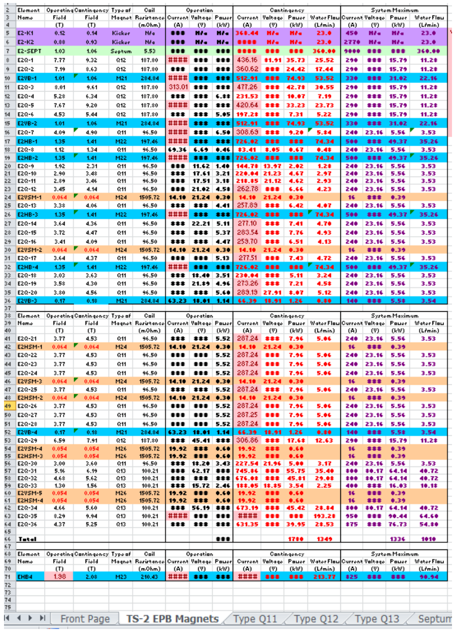






What we 'know' post WG meetings (1)

- 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.

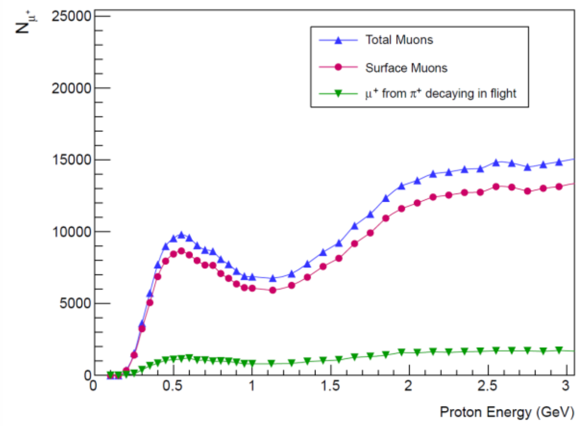
What we 'know' post WG meetings (2)

- 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 FFA.

- 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, but could prove very challenging.

- 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

- '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).

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 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.

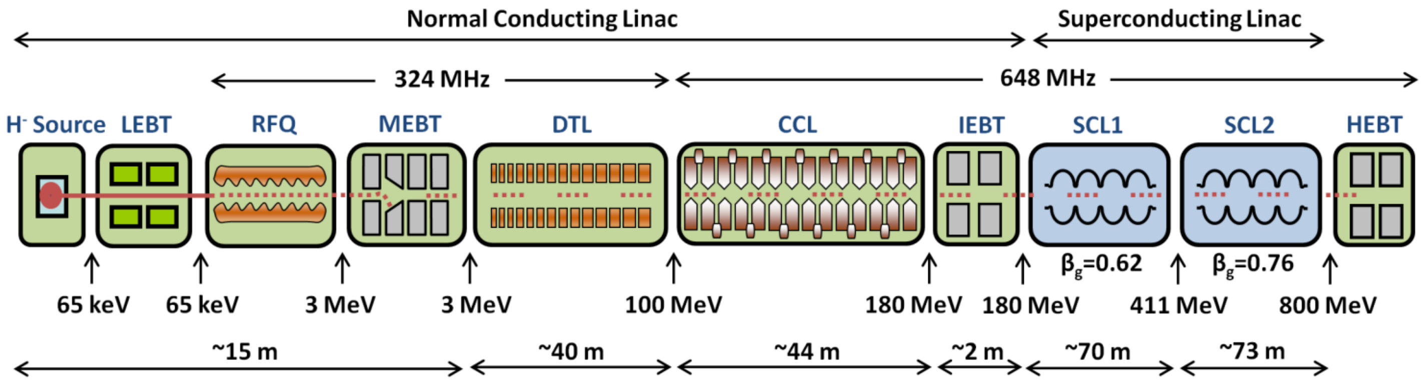
- This provides the opportunity to tailor the beam for optimal muon production at ~50 kHz and pulse length <10 ns (and would also allow the neutron production pulses to be optimised independently).

- 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.



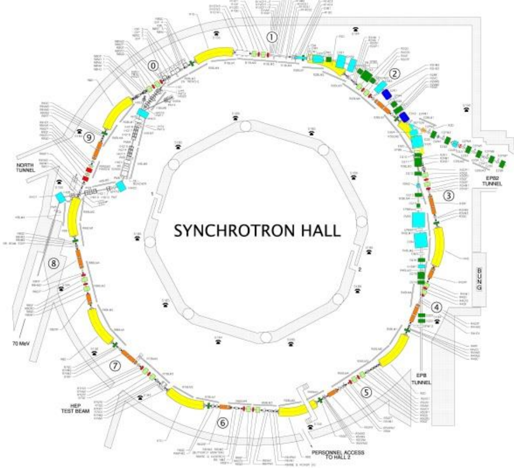
- Linac front end to 3 MeV would be based on FETS frequency and architecture.

- 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.

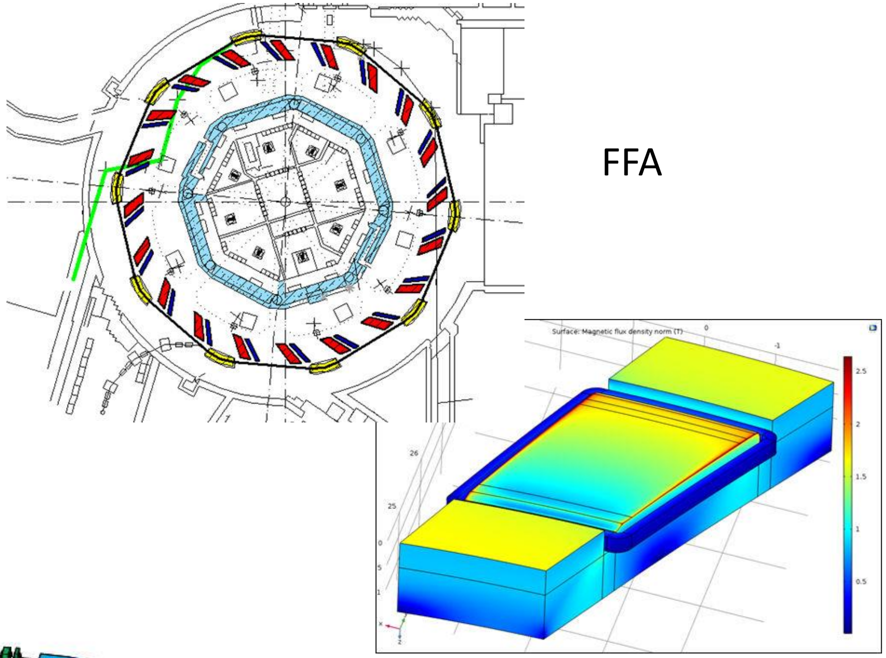
- If necessary the 800 MeV SCL design shown here could be curtailed at lower energy for injection to an FFA or RCS or extended to 1.2 GeV for injection into an accumulator ring.

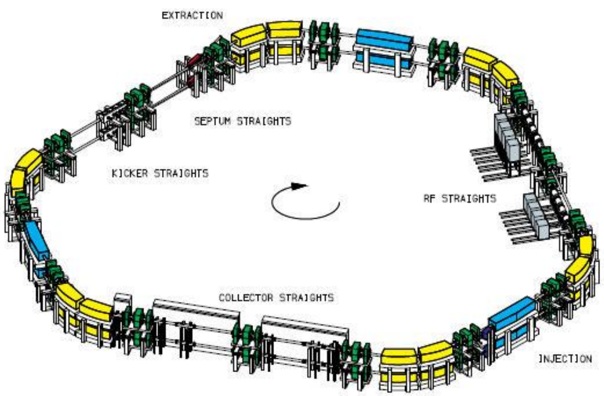
Accelerator options (2)

RCS



FFA





Accumulator ring

Accelerator options (3)

	RCS	FFA	AR
Extraction energy (GeV)	1.2	1.2	1.2
Injection energy (MeV)	~400 – 800 (footprint ~170 – 250 m)	~400 – 800 (footprint ~170 – 250 m)	1200 (footprint longest ~317 m)
Status of technology	Established but a few components need attention	Least conservative	Most conservative
Beam power	May need stacked rings to get much beyond 1 MW levels	High repetition rate easily gives above 1.2 MW, but also has to deliver at 50 Hz	Less challenging than RCS to achieve above 1.2 MW, but foil may be limit
Repetition rate	Fixed at design, e.g. 50 Hz (unless stacked rings)	Flexible, could be 100 Hz or more	Flexible, could be 100 Hz or more
Ring magnet size, technology and potential	Medium size, AC ramped fields, normal conducting, well established	Large size, DC fields, could be permanent or superconducting, more complicated design	Small size, DC fields, could be permanent or super conducting, simple design options
Ring magnet power supply size and power needs	Large, powerful unit for AC operation	Small, lower power for DC operation	Small, lower power for DC operation
Ring RF systems	Larger RF system: multiple cavities for high voltage, with variable frequency	Larger RF system: multiple cavities for high voltage, with variable frequency and larger aperture	Small RF system: fewer cavities for lower voltages, with fixed frequency
Vacuum vessel	Medium sized aperture, requires ceramic vessel in magnets	Large aperture	Small aperture
Collimation	Established methods	Beam loss control needs study	Established methods, simplest
Beam dynamics	Challenging at intensity limit, but operationally established. Loss control required for ~10000 turns	Challenging at intensity limit and needs R&D. Loss control required for ~10000 turns	Least challenging, loss control required for ~1000 turns

- 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.

Recommendations

1. Keep development of RCS, accumulator ring and FFA 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 FFA 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 FFA 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.

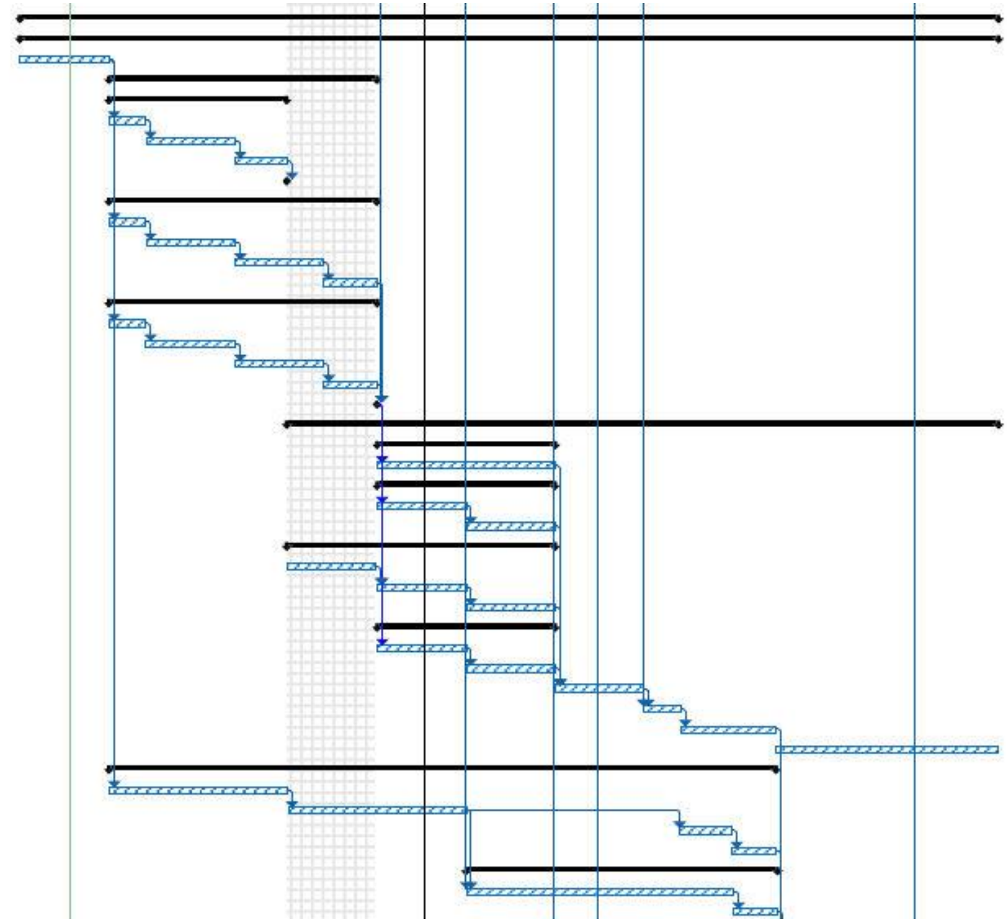
6. Continue to explore staged upgrade scenarios in order to minimise cost and downtime at each stage, feeding this information into the technical decision making process.

Turning the recommendations into a roadmap (1)

- Identified detailed tasks, critical milestones and interdependencies to meet the recommendations of the WG report and timescales implied by recent ESFRI and STFC neutron reviews and put these into a Gantt chart.

- For instance for the FFA Design and R&D work-package…

44	**FFAG DESIGN AND R&D**	Mon 02/01/17	Fri 31/12/27
45	SMALL-SCALE FFAG TEST RING ON END OF FETS	Mon 02/01/17	Fri 31/12/27
46	**Ring physics design**	Mon 02/01/17	Mon 01/01/18
47	**Component Prototyping**	Tue 02/01/18	Wed 06/01/21
48	**Magnet R&D**	Tue 02/01/18	Wed 01/01/20
49	Mechanical design	Tue 02/01/18	Fri 01/06/18
50	Procurement	Mon 04/06/18	Tue 04/06/19
51	Test and measurement	Wed 05/06/19	Wed 01/01/20
52	*Proceed with test ring interim decision point*	Wed 01/01/20	Wed 01/01/20
53	**RF R&D**	Tue 02/01/18	Tue 05/01/21
54	Physics/FEA Modelling	Tue 02/01/18	Fri 01/06/18
55	Mechanical design	Mon 04/06/18	Mon 03/06/19
56	Procurement	Tue 04/06/19	Fri 29/05/20
57	Test and measurement	Mon 01/06/20	Tue 05/01/21
58	**BPM R&D**	Tue 02/01/18	Wed 06/01/21
59	Physics/FEA Modelling	Tue 02/01/18	Thu 31/05/18
60	Mechanical design	Fri 01/06/18	Mon 03/06/19
61	Procurement	Tue 04/06/19	Mon 01/06/20
62	Test and measurement	Tue 02/06/20	Wed 06/01/21
63	*Proceed with test ring final decision point*	Wed 06/01/21	Wed 06/01/21
64	**Design and construction**	Wed 01/01/20	Fri 31/12/27
65	**Magnets/RF/BPMs**	Thu 07/01/21	Fri 06/01/23
66	Procurement	Thu 07/01/21	Fri 06/01/23
67	**Vacuum**	Thu 07/01/21	Thu 05/01/23
68	Mechanical design	Thu 07/01/21	Wed 05/01/22
69	Procurement	Thu 06/01/22	Thu 05/01/23
70	**Infrastructure + Shielding**	Wed 01/01/20	Fri 06/01/23
71	Shielding Modelling	Wed 01/01/20	Fri 01/01/21
72	Mechanical design	Thu 07/01/21	Wed 05/01/22
73	Procurement	Thu 06/01/22	Fri 06/01/23
74	**PSUs**	Thu 07/01/21	Fri 06/01/23
75	Electrical Specification	Thu 07/01/21	Wed 05/01/22
76	Procurement	Thu 06/01/22	Fri 06/01/23
77	**Installation**	Mon 09/01/23	Tue 02/01/24
78	**Integration**	Wed 03/01/24	Tue 04/06/24
79	**Test and measurement**	Wed 05/06/24	Mon 30/06/25
80	**Continued programme of experimental work**	Tue 01/07/25	Fri 31/12/27
81	1.2 GeV FFAG DESIGN FOR ISIS SYNCHROTRON HALL	Tue 02/01/18	Mon 30/06/25
82	**Initial FFAG design for ISIS synchrotron hall**	Tue 02/01/18	Wed 01/01/20
83	**Iterate with results from test ring component prototyping**	Thu 09/01/20	Thu 06/01/22
84	**Iterate with results from test ring test and measurement**	Sat 01/06/24	Tue 31/12/24
85	**Initial costing (including indicative linac cost)**	Wed 01/01/25	Mon 30/06/25
86	STAND ALONE FACILTY FFAG DESIGN	Fri 07/01/22	Mon 07/07/25
87	**Initial FFAG design for stand alone facility**	Fri 07/01/22	Tue 07/01/25
88	**Initial costing (including indicative linac cost)**	Wed 08/01/25	Mon 07/07/25



Turning the recommendations into a roadmap (2)

- And similarly for the other work-packages identified:

  - High Level Programme Leadership
  - Accumulator Ring and Rapid Cycling Synchrotron Design
  - Linac Design
  - Target, Moderator and Shielding Feasibility
  - Integrated Facility Technical Design
  - ISIS-II Construction

- Then fully resource loaded each task with estimates of FTE resource and cost required.

- Particular assignment of FTE resource categories were used throughout:

  - Accelerator Physics
  - Mechanical Engineering
  - Mechanical Technical
  - Electrical/Electronics Engineering
  - Electrical/Electronics Technical
  - RF Engineering
  - Neutron/Muon Science
  - Neutronics
  - Civil Engineering and Architecture
  - Project Management
  - Other (for instance project administration, procurement and legal services, etc.)

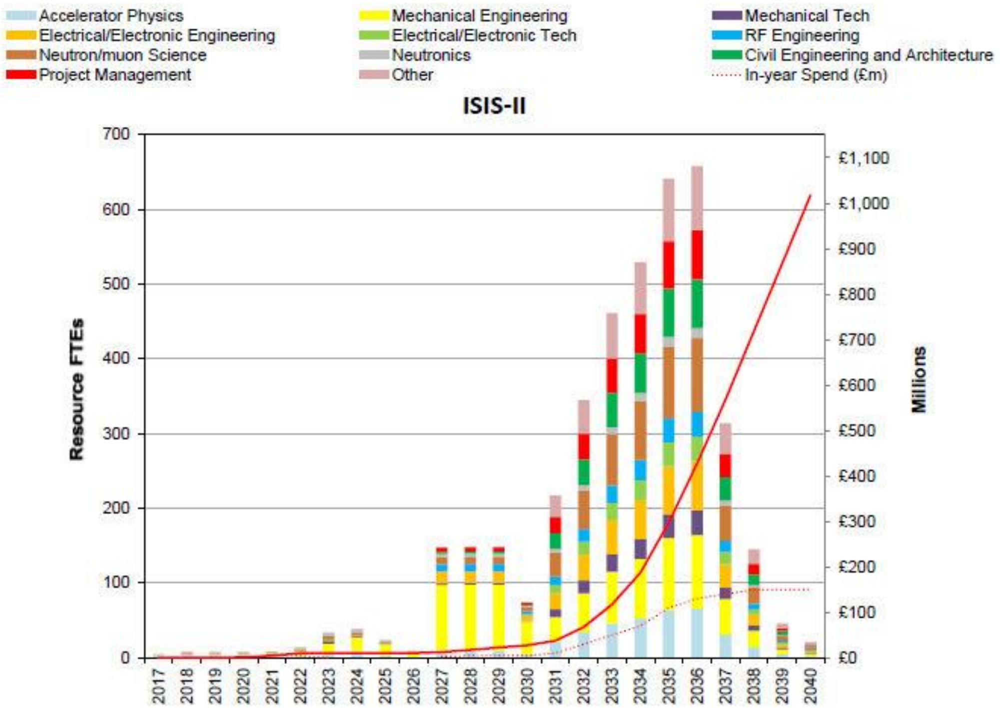
Turning the recommendations into a roadmap (3)

- For instance for the FFA Design and R&D work-package…

	Task Name	Duration	Accelerator Physics	Mechanical Engineering	Mechanical Tech	Electrical/Electronic Engineering	Electrical/Electronic Tech	RF Engineering	Neutron/Muon Science	Neutronics	Civil Engineering and Architect	Project Management	Other (Admin etc.)	Cost
		Year	FTE											£M
44	**FFAG DESIGN AND R&D**													
45	**SMALL-SCALE FFAG TEST RING ON END OF FETS**													
46	**Ring physics design**	1.0	3.0	0.2										0.00
47	**Component Prototyping**													
48	**Magnet R&D**													
49	Mechanical design	0.4	0.1	1.0	0.2									0.00
50	Procurement	1.0	0.1											0.30
51	Test and measurement	0.6	0.1	0.2		0.3								0.00
52	*Proceed with test ring interim decision point*													
53	**RF R&D**													
54	Physics/FEA Modelling	0.4	0.1					0.5						0.00
55	Mechanical design	1.0	0.1	0.5				0.3						0.00
56	Procurement	1.0		0.1				0.1						0.60
57	Test and measurement	0.6	0.1			0.2		0.3						0.00
58	**BPM R&D**													
59	Physics/FEA Modelling	0.4	0.3	0.2		0.2								0.00
60	Mechanical design	1.0	0.1	0.5		0.3								0.00
61	Procurement	1.0		0.1										0.25
62	Test and measurement	0.6	0.3			0.2								0.00
63	*Proceed with test ring final decision point*													
64	**Design and construction**													
65	**Magnets/RF/BPMs**													
66	Procurement	2.0		0.1										6.50
67	**Vacuum**													
68	Mechanical design	1.0		0.5										0.00
69	Procurement	1.0		0.1										0.20
70	**Infrastructure + Shielding**													
71	Shielding Modelling	1.0								0.3				0.00
72	Mechanical design	1.0		0.5							0.2			0.00
73	Procurement	1.0		0.1										0.20
74	**PSUs**													
75	Electrical Specification	1.0				0.5								0.00
76	Procurement	1.0				0.1								3.00
77	**Installation**	1.0	0.1	0.2	2.0	0.2	2.0							0.20
78	**Integration**	0.4	0.1	0.2	1.0	0.2	1.0							0.10
79	**Test and measurement**	1.1	5.0											0.00
80	**Continued programme of experimental work**	2.5	2.0											0.00
81	**1.2 GeV FFAG DESIGN FOR ISIS SYNCHROTRON HALL**													
82	**Initial FFAG design for ISIS synchrotron hall**	2.0	2.0											0.00
83	**Iterate with results from test ring component prototyping**	2.0	1.5	0.2										0.00
84	**Iterate with results from test ring test and measurement**	0.6	1.5	0.2										0.00
85	**Initial costing (including indicative linac cost)**	0.5		0.2										0.05
86	**STAND ALONE FACILTY FFAG DESIGN**													
87	**Initial FFAG design for stand alone facility**	3.0	2.0	0.2										0.00
88	**Initial costing (including indicative linac cost)**	0.5		0.2										0.00

Turning the recommendations into a roadmap (4)

- This then allows representations of resource allocation by year, or cumulatively by resource category for the complete ISIS-II activity.



	Duration	Accelerator Physics	Mechanical Engineering	Mechanical Tech	Electrical/Electronic Engineering	Electrical/Electronic Tech	RF Engineering	Neutron/Muon Science	Neutronics	Civil Engineering and Architecture	Project Management	Other (Admin etc.)	Cost
Task Name	Years	FTE											£M
ISIS-II		465.0	942.5	204.0	437.7	192.4	225.9	618.5	105.1	390.7	401.6	494.4	1017.50

Turning the recommendations into a roadmap (5)

- ISIS-II work has significant synergy (and sometimes tension) with other accelerator activities ongoing in the UK (and worldwide).

- As part of the 'neutron theme' for the 2017 STFC Accelerator Strategic Review it was decided to expand the ISIS-II Gantt chart to cover relevant activities, and then to follow through the methodology to produce resource estimates.

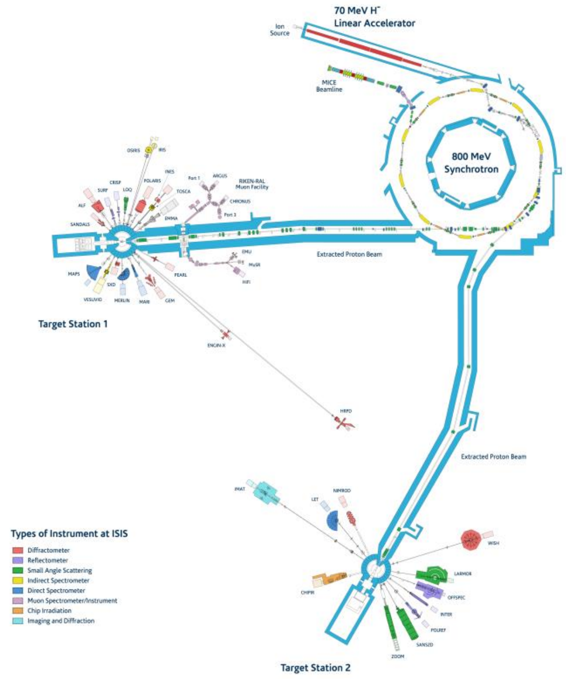
- The specific activities covered were:

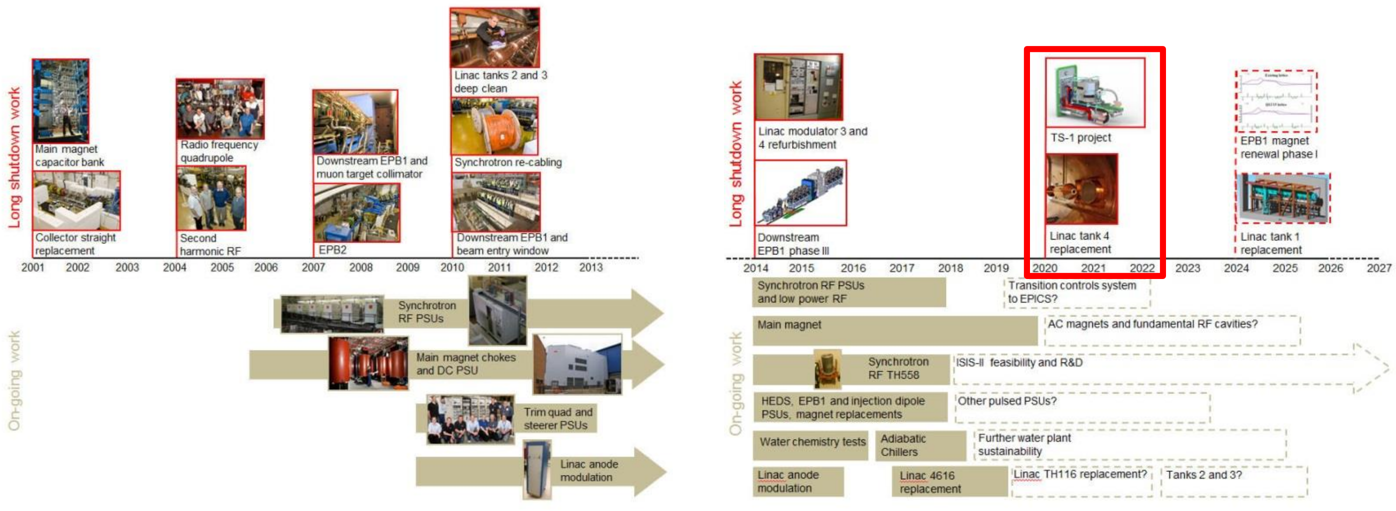
  - ISIS Operations and Sustainability
  - FETS
  - Ion Source Development
  - IBEX
  - ESS
  - PIP-II
  - Integrable Optics

- As an overview…

ISIS Operations and Sustainability

- ISIS supports a national and international community of more than 3000 scientists and gives unique insights into the properties of materials on the atomic scale, providing information which complements that provided by photon-based techniques. ISIS accelerator and target activities are principally aimed at facilitating the programme of equipment renewal and upgrades required to keep the present ISIS accelerators running optimally and sustainably for the lifetime of the facility. (See Philip King's talk for details of the forthcoming TS-1 Project)





FETS

- The Front End Test Stand (FETS) project is a generic proton accelerator R&D programme involving ISIS, ASTeC, JAI, Imperial College London, University College London, Huddersfield University, Warwick University and ESS Bilbao. The production of beams as envisaged with FETS will enable higher intensity beams (with less beam loss) for neutron production.

High brightness H^- ion source

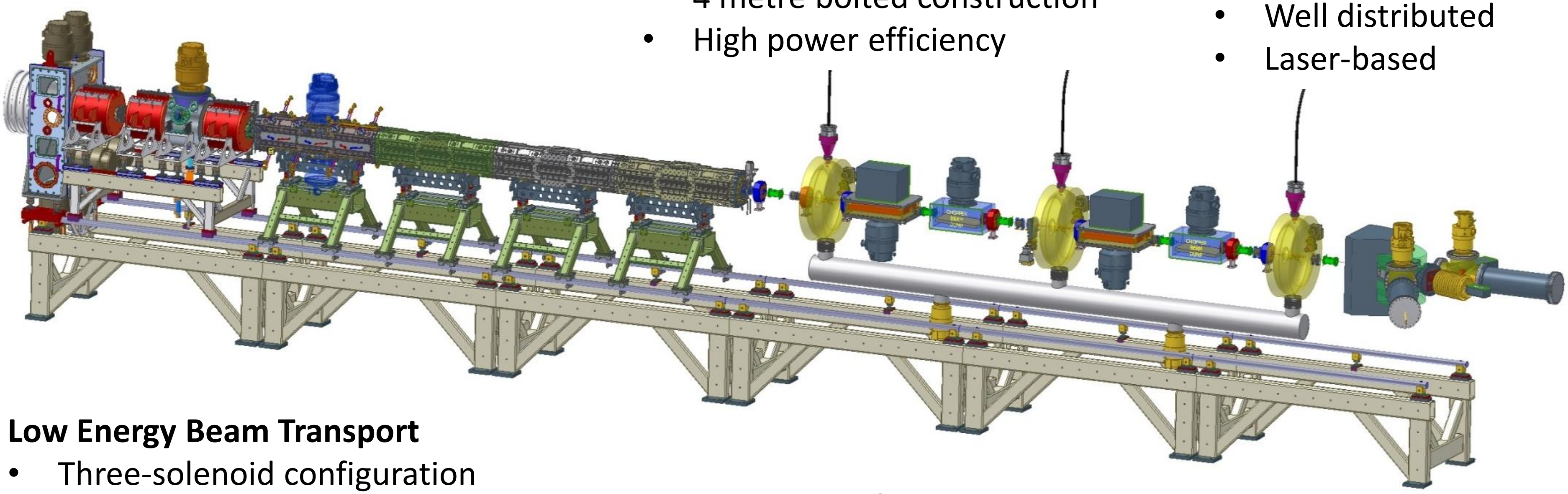
- 4 kW peak-power arc discharge
- 60 mA, 0.25 π mm mrad beam
- 2 ms, 50 Hz pulsed operation

Radio Frequency Quadrupole

- Four-vane, 324 MHz, 3 MeV
- 4 metre bolted construction
- High power efficiency

Diagnostics

- Non-interceptive
- Well distributed
- Laser-based



Low Energy Beam Transport

- Three-solenoid configuration
- Space-charge neutralisation
- 5600 Ls^{-1} total pumping speed

Medium Energy Beam Transport

- Re-buncher cavities and EM quads
- Novel ‘fast-slow’ perfect chopping
- Low emittance growth

Ion Source Development in the ISIS Low Energy Beams (LEB) Group

2× Scaled Source

Penning Surface Plasma Sources have an H^- current density an order of magnitude above other source technologies.

2× scaled Penning source is the only way to deliver the >60 mA currents at 10 % duty cycle required for the FETS project.

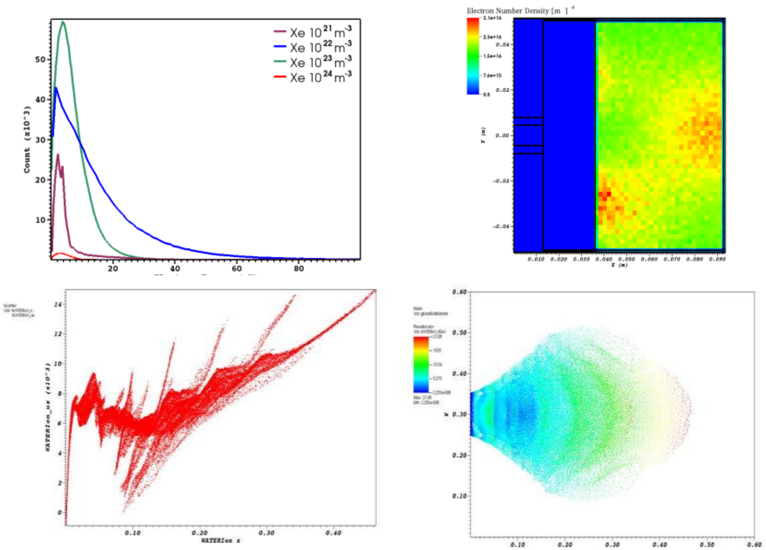
Developing this technology to minimise sputtering and maximise current is essential to produce long lifetime sources. These developments can also be applied to the ISIS operational source.

RF Volume Source

The new ISIS MEBT will reduce beam loss in tank 1 by a third and will reduce the source current requirement to 30 mA. This opens the door to using state-of-the-art maintenance-free RF volume source technologies. This would save approximately 1-2 FTE and £80k per annum and deliver increased availability to ISIS users.

VSim

Fully kinematic PIC code for modelling plasma. Already used for 2 UK Space Agency Grants to develop ECR/Microwave thrusters: IMPULSE and AQUAJET. This knowledge can be used to develop proton sources.



Now developing a caesiated surface model.
Will also be used to study HV vacuum breakdown.

The LEB Group has unique highly transferable skills sought after by industry for consultancy and development projects.

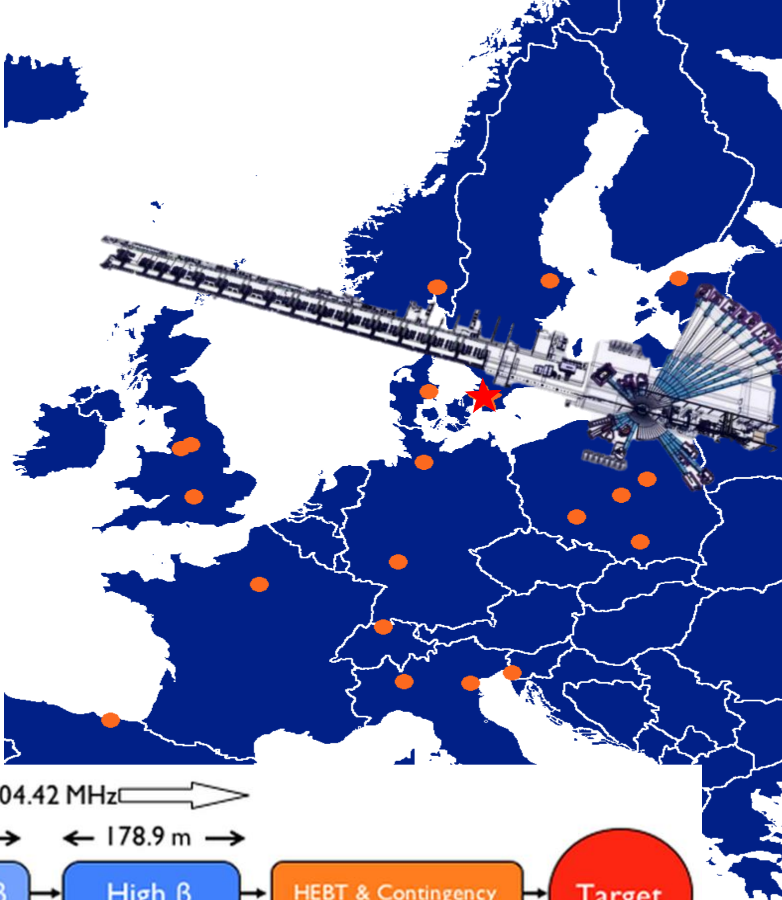
SIEMENS

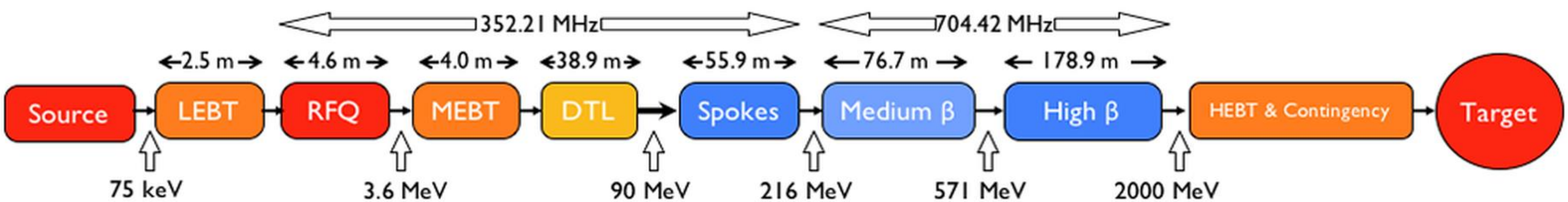
Rapiscan systems

ASML

ESS (see Ciprian Plostinar's talk)

- The **European Spallation Source** (**ESS**) is a multi-disciplinary research facility based on what will be the world's most powerful pulsed neutron source. At least 17 European countries will act as partners in the construction and operation of ESS in Lund, Sweden. As the world's next-generation neutron source, ESS will enable scientists to see and understand basic atomic structures and forces at length and time scales unachievable at other spallation sources. ISIS will contribute to 3 ESS instruments (Loki, Freia and Vespa). UK accelerator contributions total £42M.

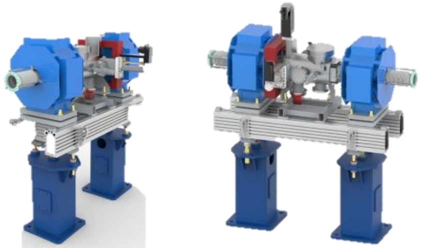




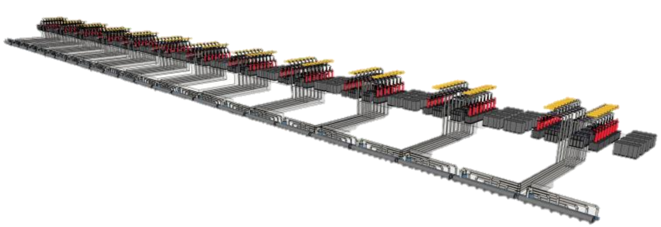
UK Accelerator IKC Delivery

High Beta Cavities (88 Total)

Linac Warm Units (75 Total)

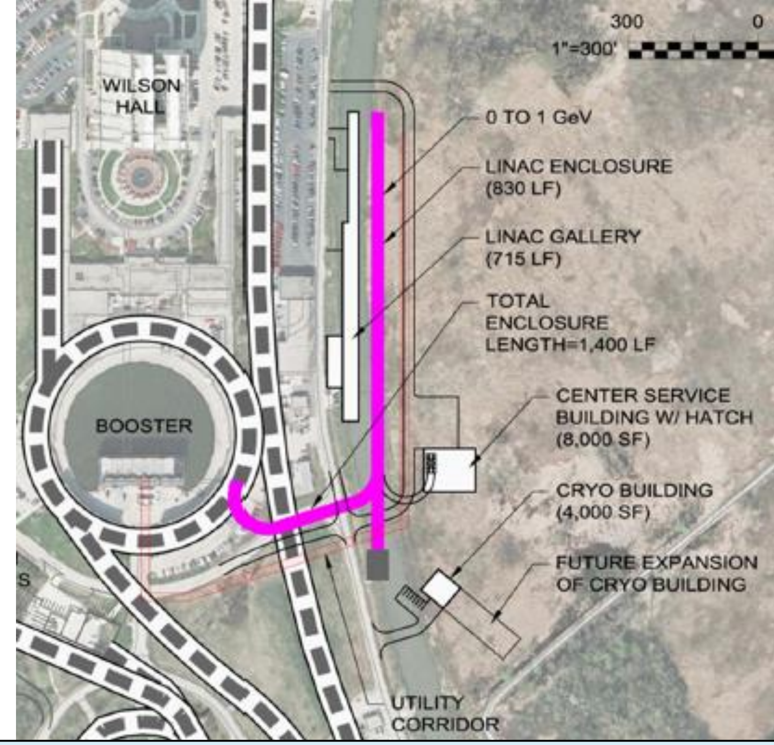


RF Distribution (146 HPRF Feeds)



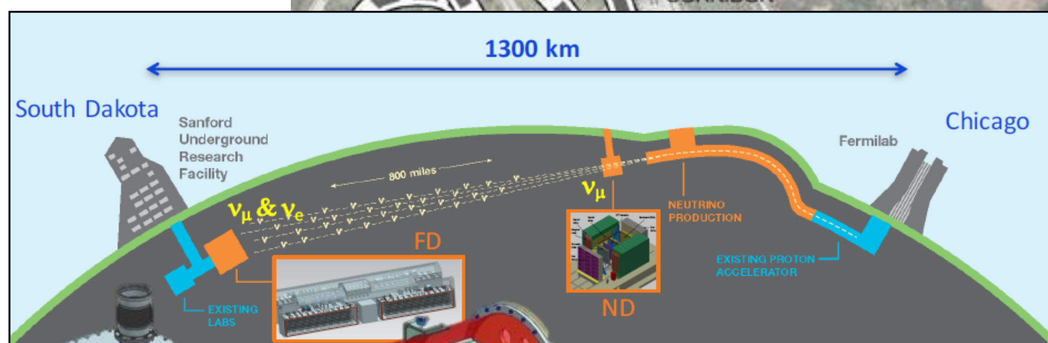
PIP-II

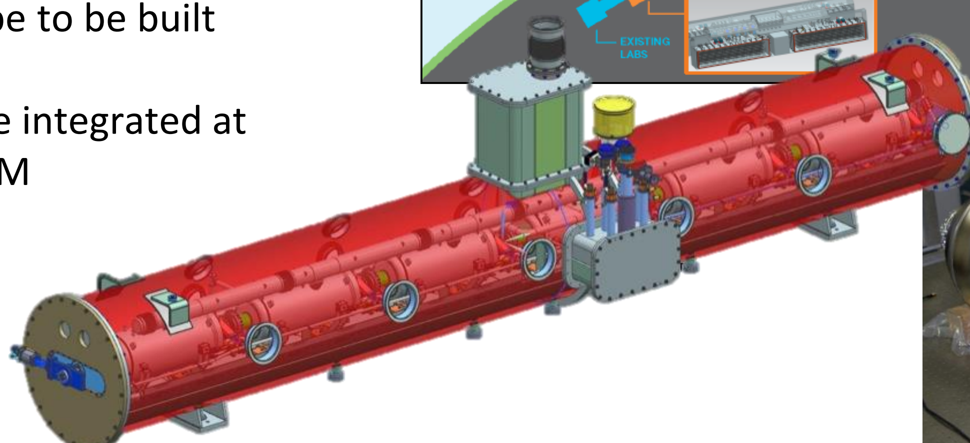
Proton **I**mprovement **P**lan-II (PIP-II) is FNAL's plan for providing powerful, high-intensity proton beams to the laboratory's experiments. Will position FNAL as the leading laboratory in the world for accelerator-based neutrino experiments. The heart of PIP-II is a 800-MeV superconducting linear accelerator, which capitalizes on the lab's expertise in SRF technologies. Along with modest improvements to FNAL's existing Main Injector and Recycler accelerators, the SC linac, will provide the MW proton beam that is needed for the Long-Baseline Neutrino Facility.



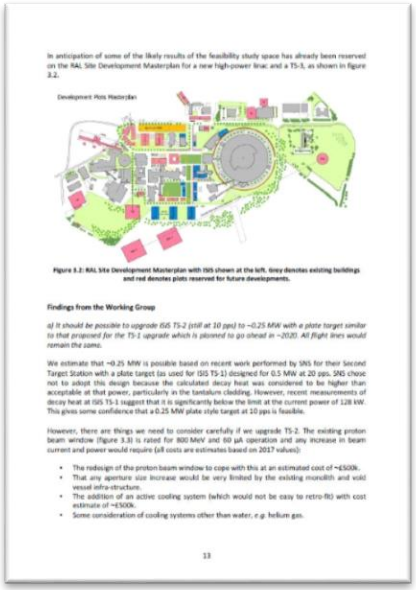
HB650 Cryomodules

- 4 total cryomodules
- 6 cav. each (650 MHz, 5-cell)
- First HB650 prototype to be built at FNAL
- Next 3 × HB650 to be integrated at Daresbury, UK - £24M





So in summary…


In anticipation of some of the likely results of the feasibility study space has already been reserved on the RAL Site Development Masterplan for a new high-power linac and a TS-3, as shown in figure 3.2.

Development Plots Masterplan

Figure 3.2: RAL Site Development Masterplan with ISIS shown at the left. Grey denotes existing buildings and red denotes plots reserved for future developments.

Findings from the Working Group

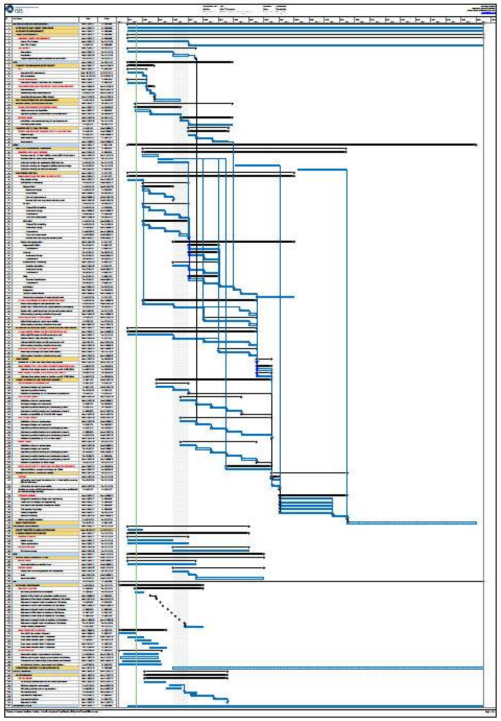
a) It should be possible to upgrade ISIS TS-2 (still at 10 pps) to ~0.25 MW with a plate target similar to that proposed for the TS-1 upgrade which is planned to go ahead in ~2020. All flight lines would remain the same.

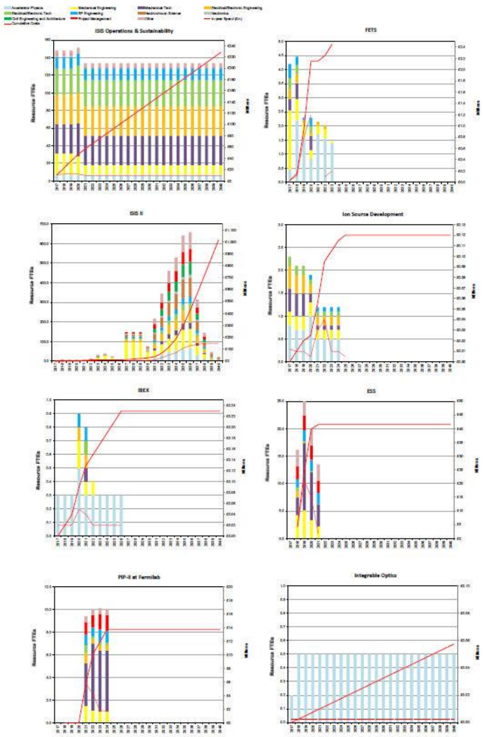
We estimate that ~0.25 MW is possible based on recent work performed by SNS for their Second Target Station with a plate target (as used for ISIS TS-1) designed for 0.5 MW at 20 pps. SNS chose not to adopt this design because the calculated decay heat was considered to be higher than acceptable at that power, particularly in the tantalum cladding. However, recent measurements of decay heat at ISIS TS-1 suggest that it is significantly below the limit at the current power of 128 kW. This gives some confidence that a 0.25 MW plate style target at 10 pps is feasible.

However, there are things we need to consider carefully if we upgrade TS-2. The existing proton beam window (figure 3.3) is rated for 800 MeV and 60 μA operation and any increase in beam current and power would require (all costs are estimates based on 2017 values):

- The redesign of the proton beam window to cope with this at an estimated cost of ~£500k.
- That any aperture size increase would be very limited by the existing monolith and void vessel infra-structure.
- The addition of an active cooling system (which would not be easy to retro-fit) with cost estimate of ~£500k.
- Some consideration of cooling systems other than water, e.g. helium gas.

13

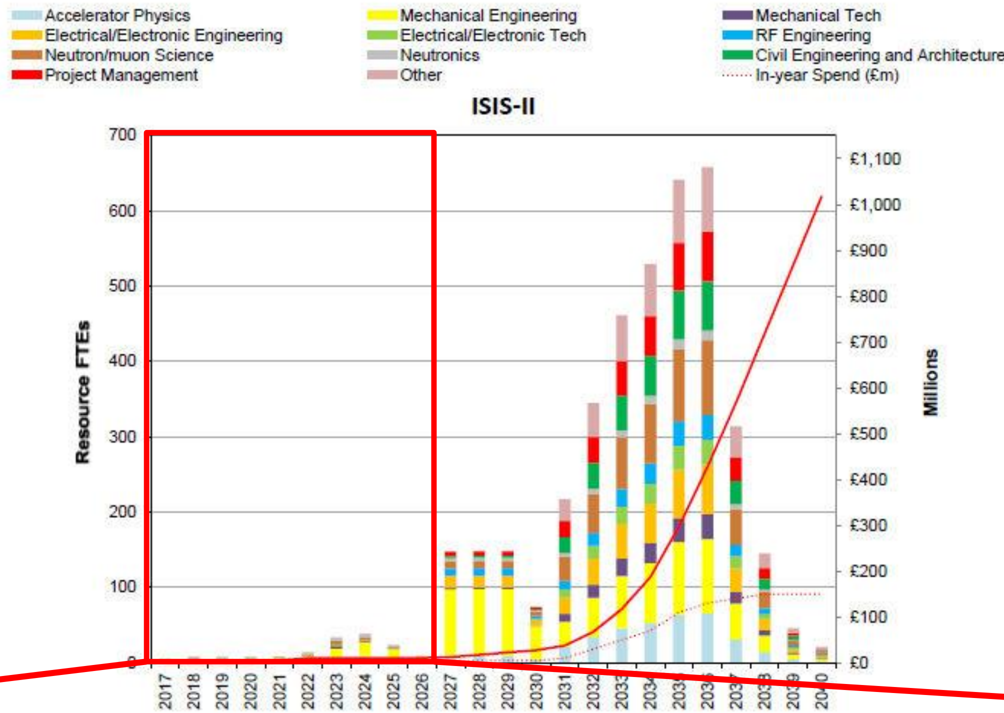




+ Other relevant activities

ISIS-II Roadmap (1)

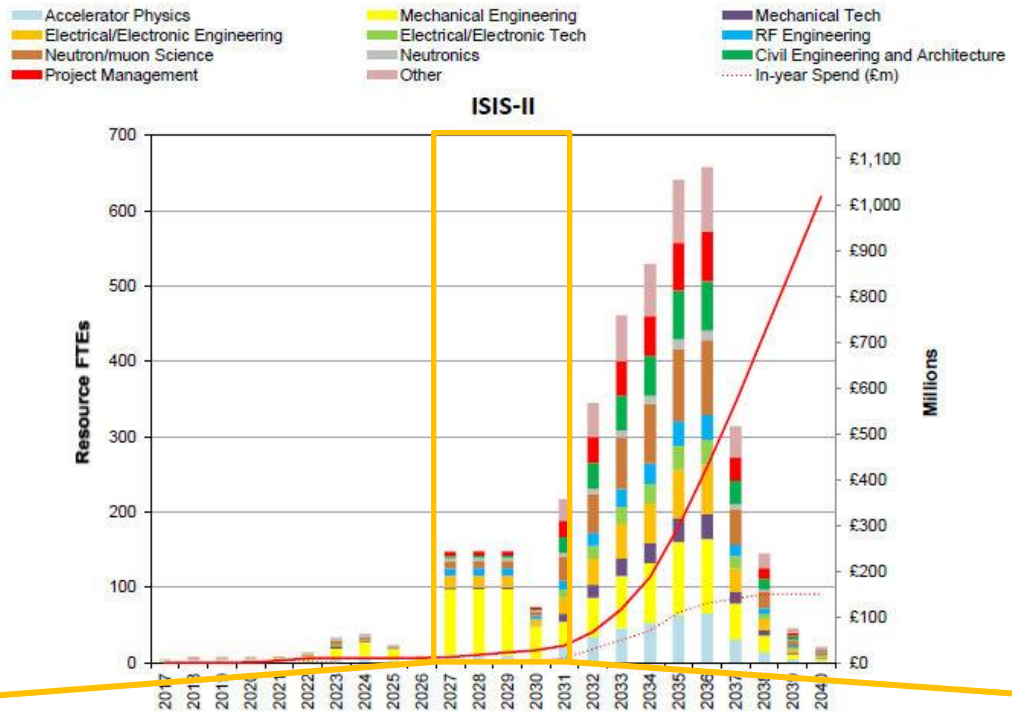
- This activity can be readily split into three distinct phases:



1) Feasibility, design studies and R&D (2017-2027). In general resource levels for this activity are within the envelope of the ISIS facility budget. However, in the period 2023-2025 requirements for mechanical engineering towards FFA design and target, moderator and shielding feasibility studies become larger than ISIS can provide. This issue could be addressed by increased (and earlier) involvement of the Target Studies Group in Technology Department, university engineering departments and contract effort. The main requirement for additional funding beyond that available from the ISIS facility budget is associated with building a small-scale FFA test ring (~£10M) during the period 2021-2024.

ISIS-II Roadmap (2)

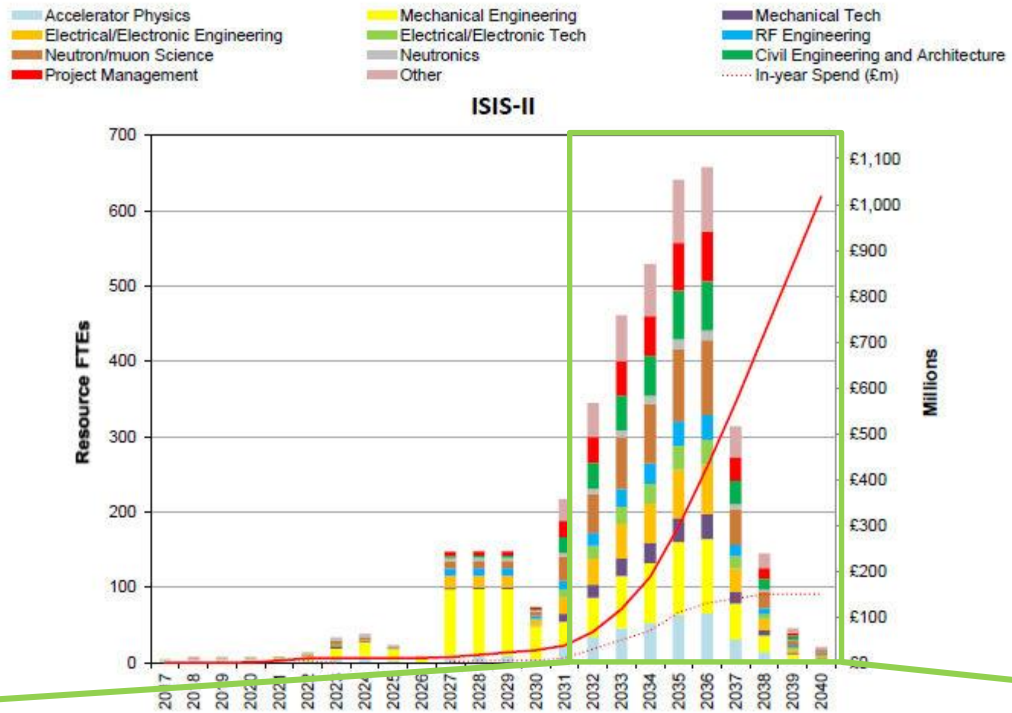
- This activity can be readily split into three distinct phases:



2) Integrated facility technical design (2027-2031). Following the decision on exactly what should be built a largely new team of ~150 FTE will be required to produce a full 'shovel-ready' design. This will require significant recruitment in all key technical areas. It should be noted that for phases 2) and 3) indicative FTEs and costs now reflect design and build of the whole facility rather than just accelerators and targets.

ISIS-II Roadmap (3)

- This activity can be readily split into three distinct phases:



3) ISIS-II construction (2031-2040). Indicative FTEs reflect the effort currently involved in ESS construction, which is on a similar scale. For simplicity the breakdown in effort of various types has been taken as constant throughout the build – the reality would obviously be somewhat different. The cumulative cost of the project has been given as a round figure of ~£1B (excluding FTEs), but this is only intended as a very early indication of the actual cost.

- Supported by related UK accelerator activities

Next Steps

- The intention of the ISIS-II Roadmap is to allow an appropriate period of feasibility, design studies and R&D to evaluate both stand-alone facility and reuse of ISIS infrastructure options in order to make a fully informed decision on what ISIS-II design should then be carried forward to an integrated facility technical design and eventual construction.

- In December 2017 the ISIS Management Committee gained the endorsement of the ISIS Facility Board for this roadmap as a sensible way forward.

- On 6 July 2018 and external review was held by technical experts to scrutinise the fine detail before embarking on the design studies and R&D for ISIS-II. Although the final report has yet to be delivered, the outbrief was very positive.

- ISIS has registered 'ISIS-II Design Studies and R&D' with STFC as one of its three 'Priority Projects' (along with Endeavour and ISEC).