Challenges of reducing energy consumption at ISIS

David Findlay
Head, Accelerator Division
ISIS Department
Rutherford Appleton Laboratory / STFC

Energy for Sustainable Science, Lund, 14 October 2011

Overview of talk

- ISIS science programme
- ISIS hardware
- ISIS operations
- Scope for significant reductions in energy consumption?
- Conclusions

ISIS science

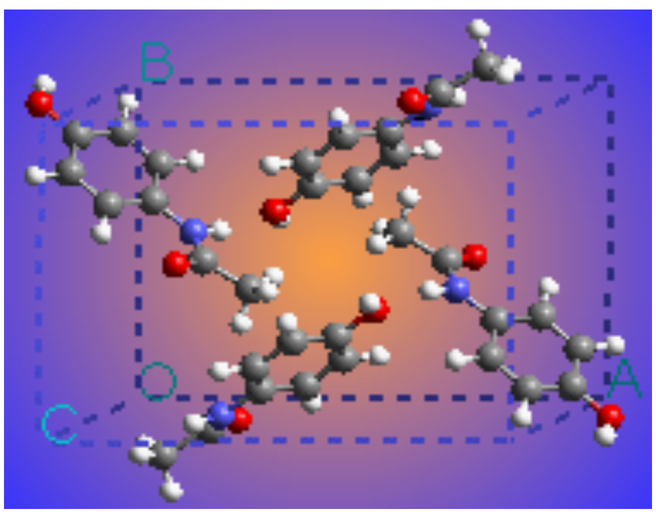
- World's most productive spallation neutron source (if no longer highest pulsed beam power)
- World-leading centre for research in the physical and life sciences
- National and international community of >2000 scientists — ISIS has been running since 1984
- Research fields include clean energy, the environment, pharmaceuticals and health care, nanotechnology, materials engineering and IT
- ~450 publications/year (~9000 total over 26 years)
- MICE (Muon Ionisation Cooling Experiment)

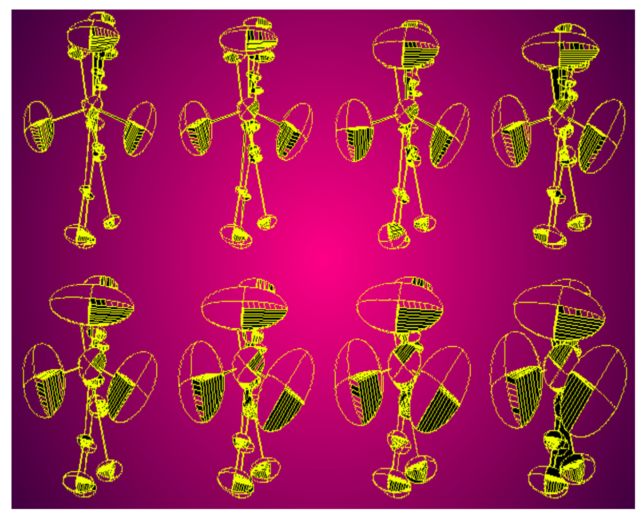
ISIS

Neutron sources — to investigate structure and dynamics of molecular matter

Complement light sources (e.g. Diamond in UK)

Neutrons: ~0.1 eV $\rightarrow$ ~1Å

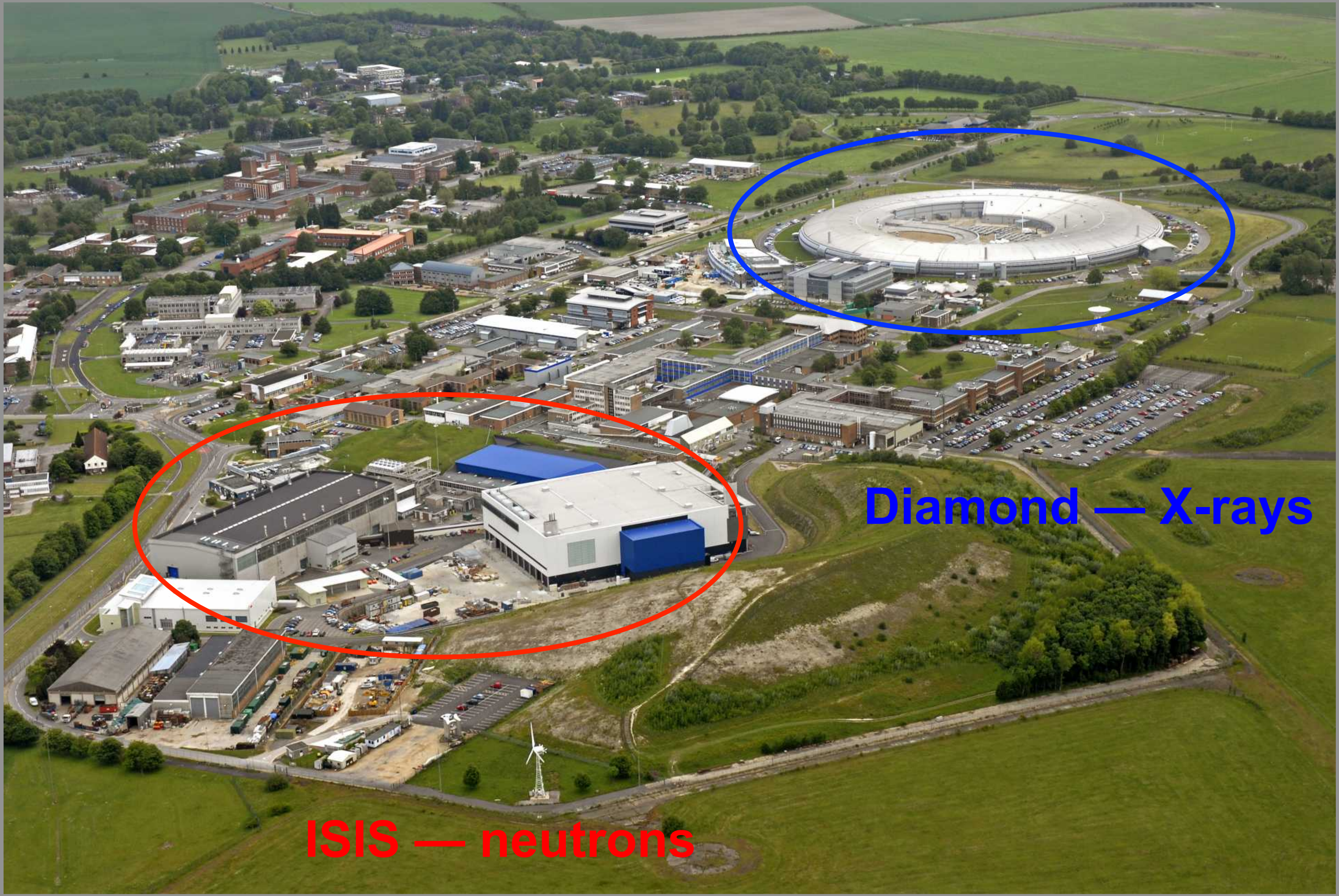




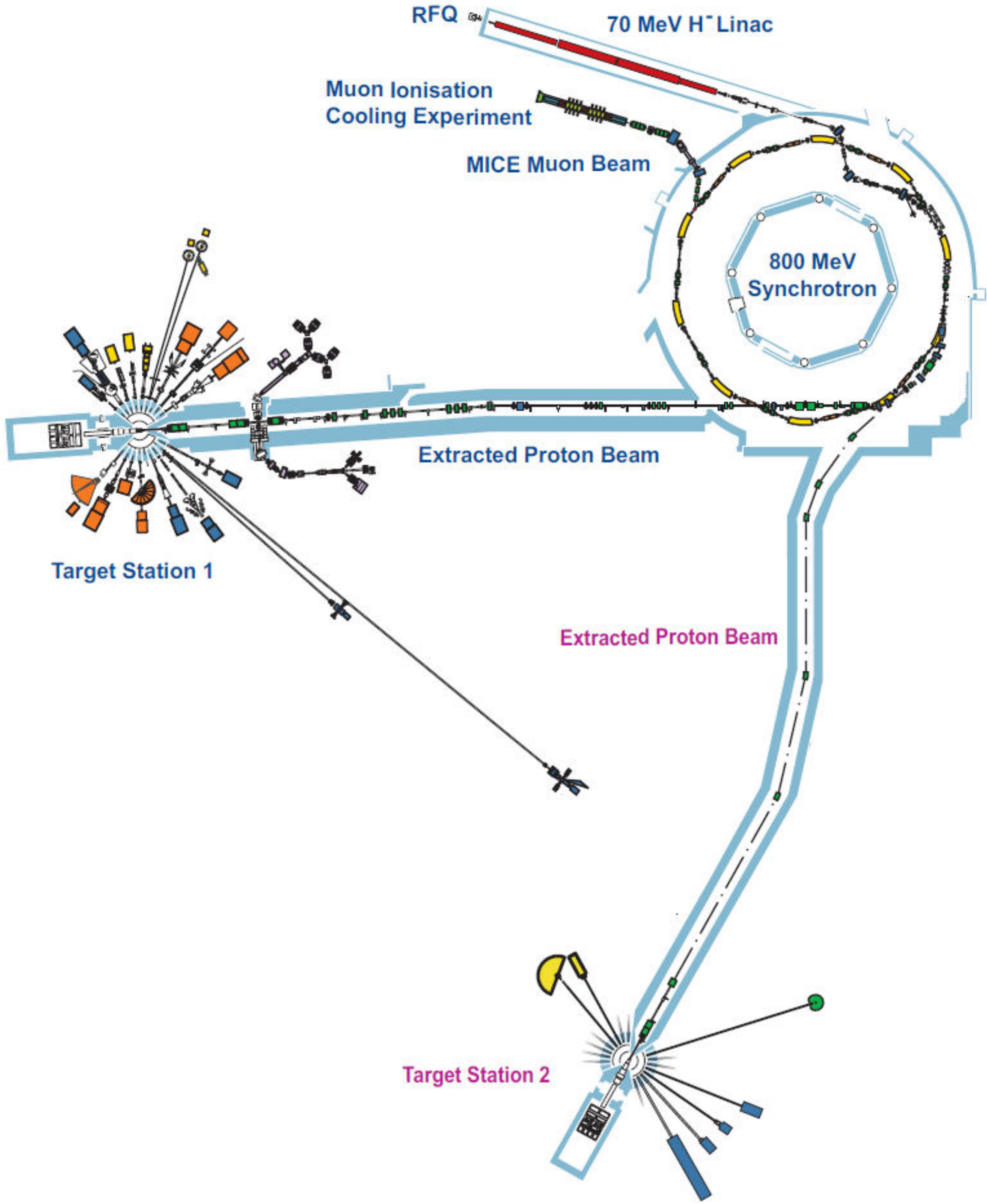
Structure Paracetamol Atomic motions

Impact of ISIS science

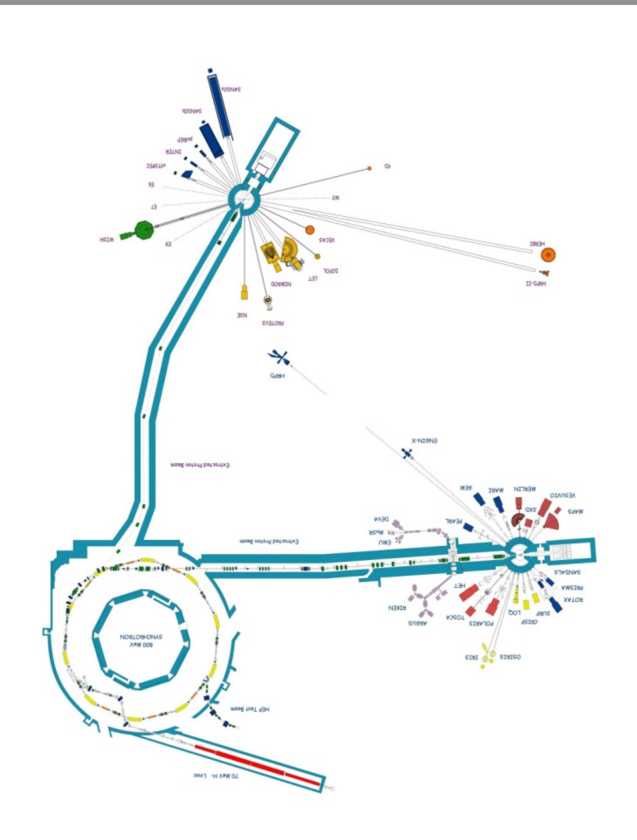
Global challenges	ISIS
Energy	✓✓✓✓
Living with environmental change	✓✓✓
Global threats to security	✓
Ageing: Life-long health and wellbeing	✓✓
Digital economy	✓✓✓
Nanoscience: through engineering to application	✓✓✓



Rutherford Appleton Laboratory, Oxfordshire



RFQ
70 MeV H⁻ Linac
Muon Ionisation
Cooling Experiment
MICE Muon Beam
800 MeV
Synchrotron
Extracted Proton Beam
Target Station 1
Extracted Proton Beam
Target Station 2



ISIS from air

RFQ: 665 keV H^-, 4-rod, 202 MHz

Linac: 70 MeV H^-, 25 mA, 202 MHz, 200 μs, 50 pps

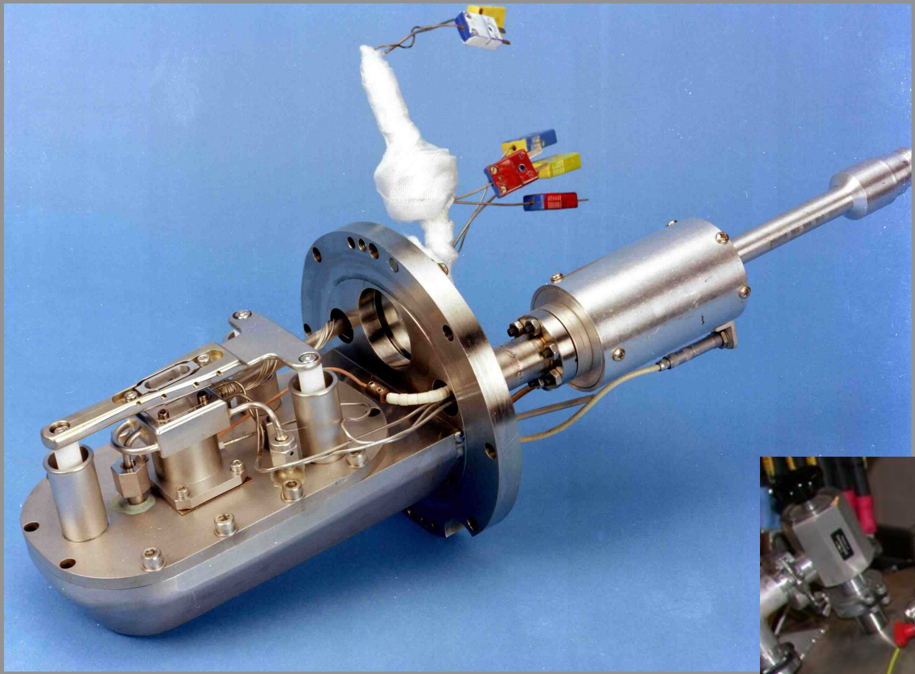
Synchrotron: 800 MeV proton, 50 Hz
5 μC each acceleration cycle
Dual harmonic RF system

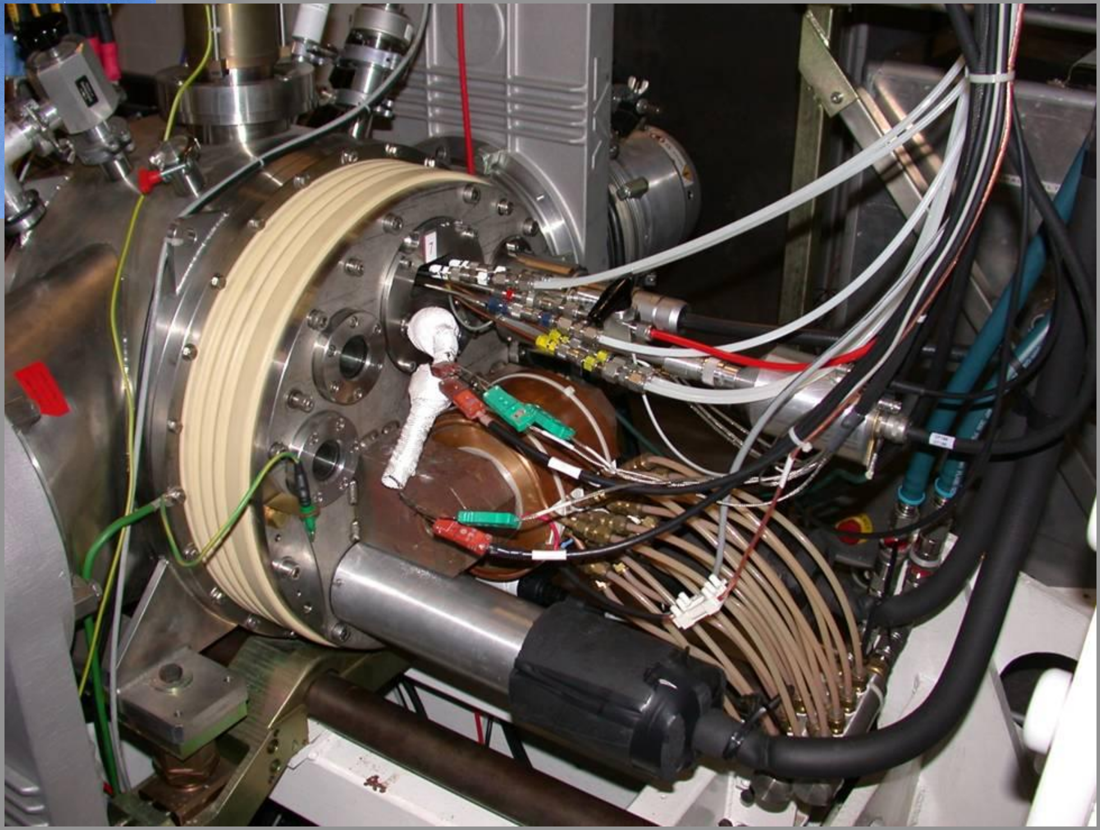
Targets: 2 × W (Ta coated)
Protons: 2 × ~100 ns pulses, ~300 ns apart

Moderators: TS-1: 2 × H_2O, 1 × liq. CH_4, 1 × liq. H_2
TS-2: 1 × liq. H_2 / solid CH_4, 1 × solid CH_4

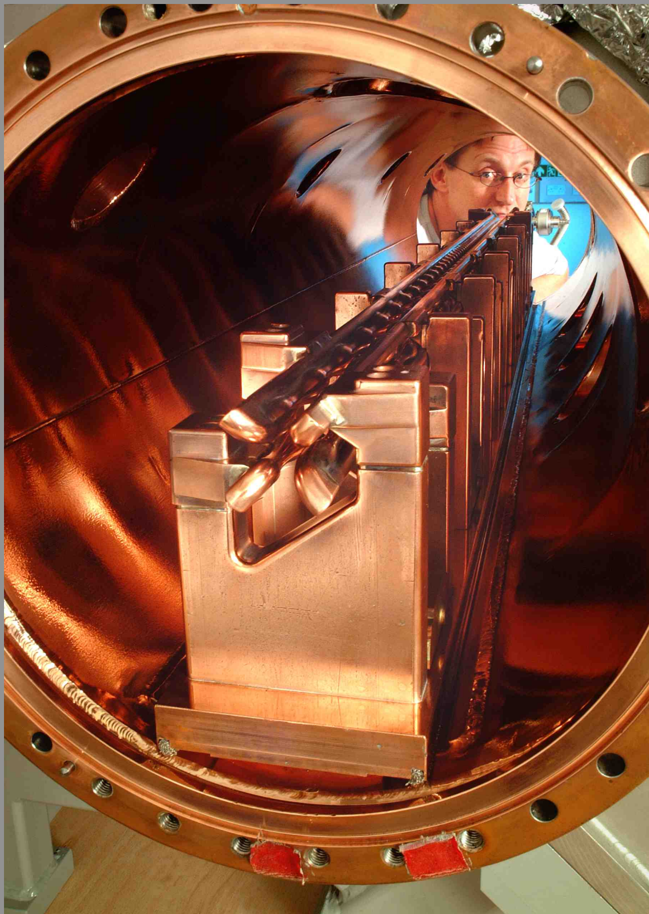
Instruments: TS-1: 20 TS-2: 7 (+ 4 more now funded)

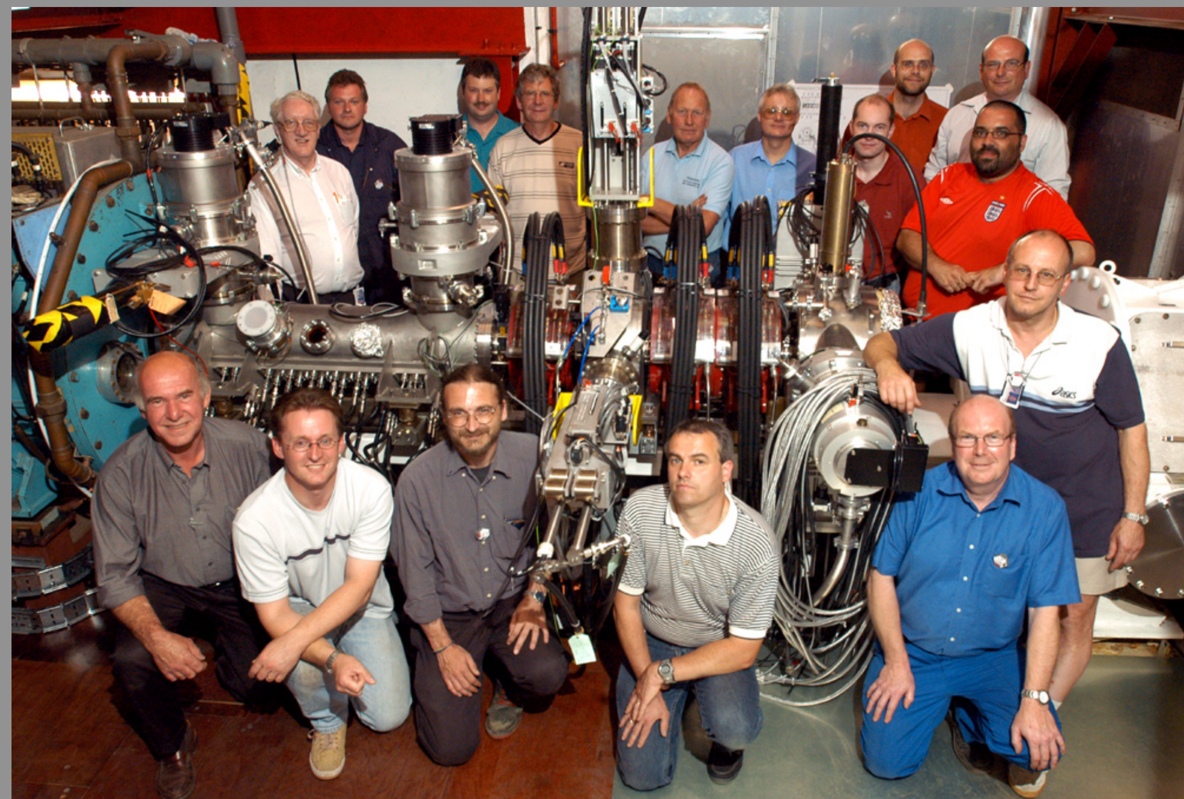
~340 staff





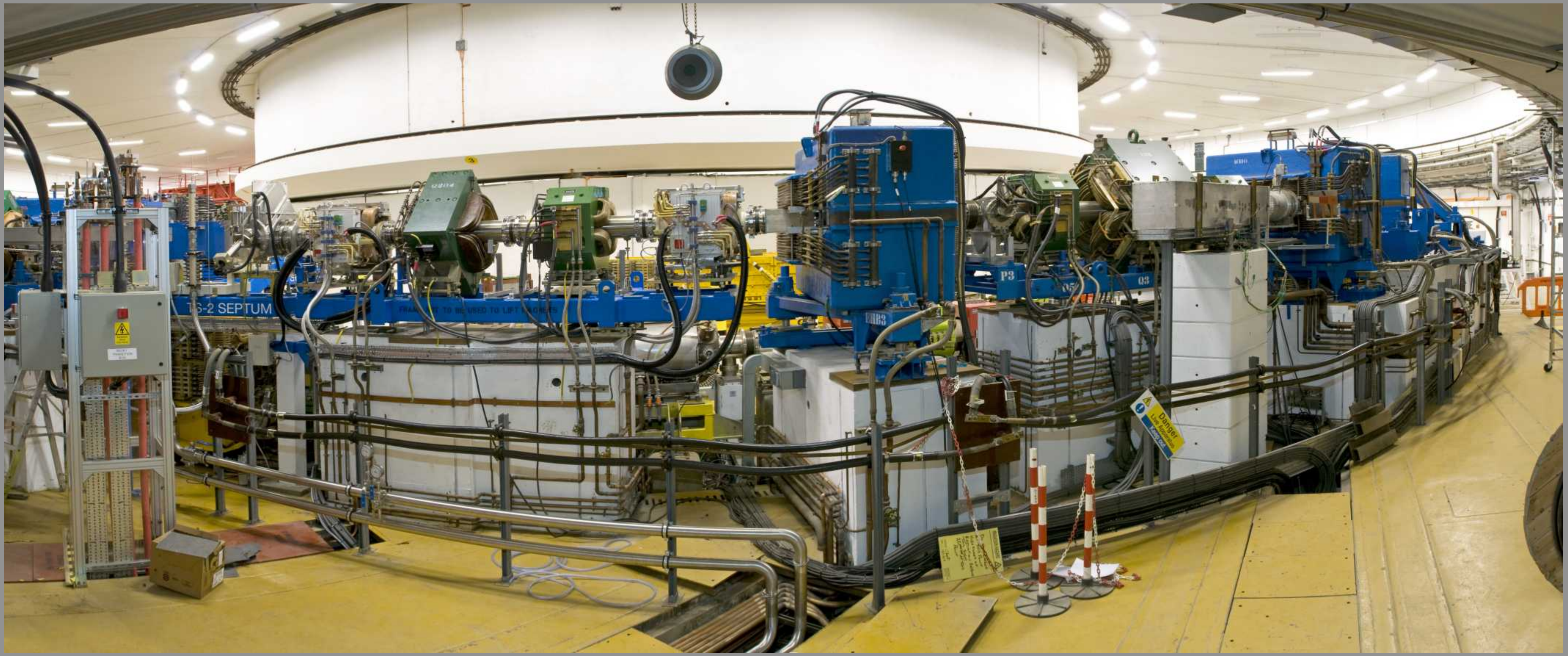
–35 kV H$^-$ ion source





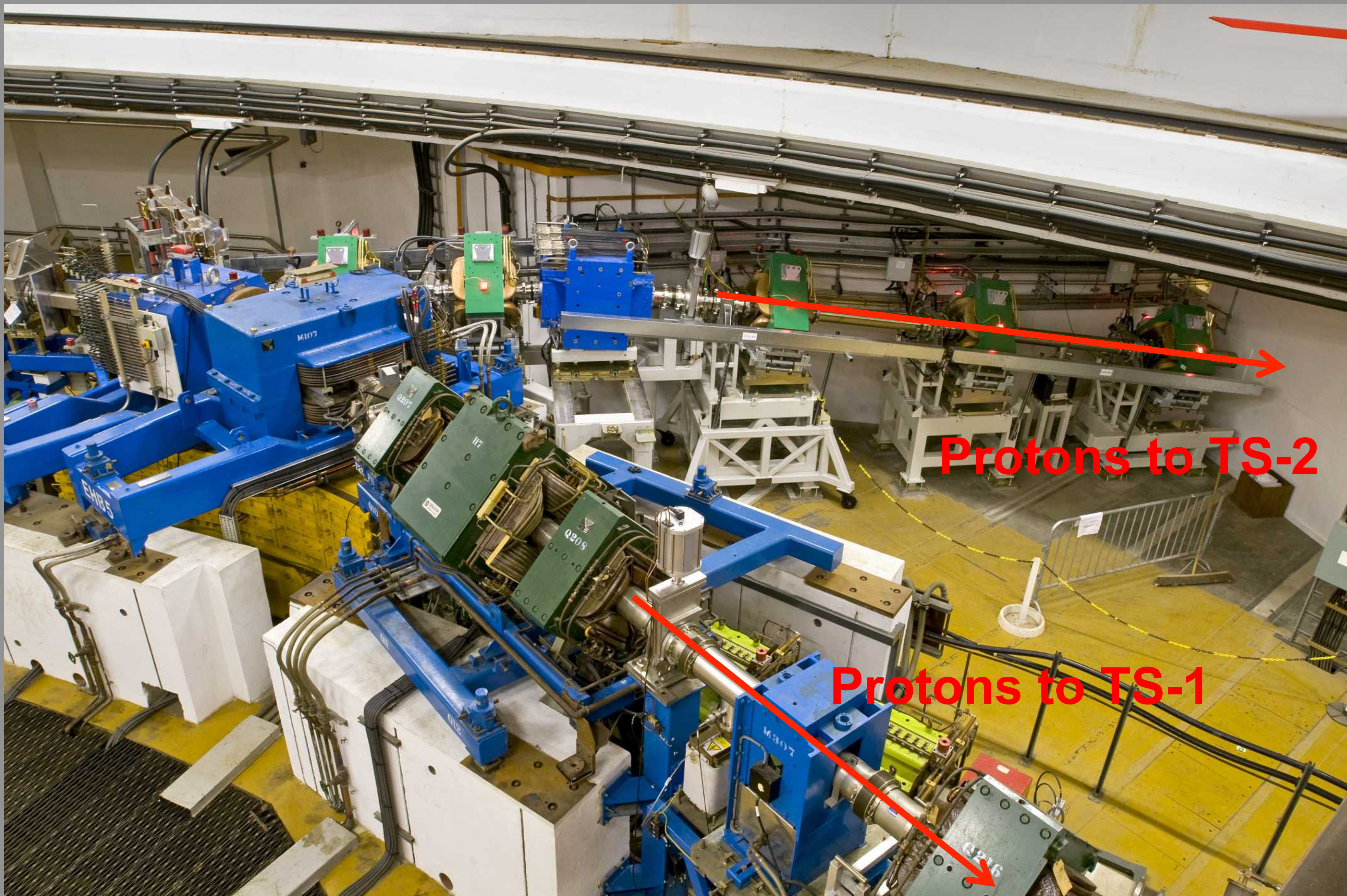
665 keV 4-rod 202 MHz RFQ

70 MeV 202 MHz 4-tank H^- linac



1.3–3.1 + 2.6–6.2 MHz 70–800 MeV proton synchrotron

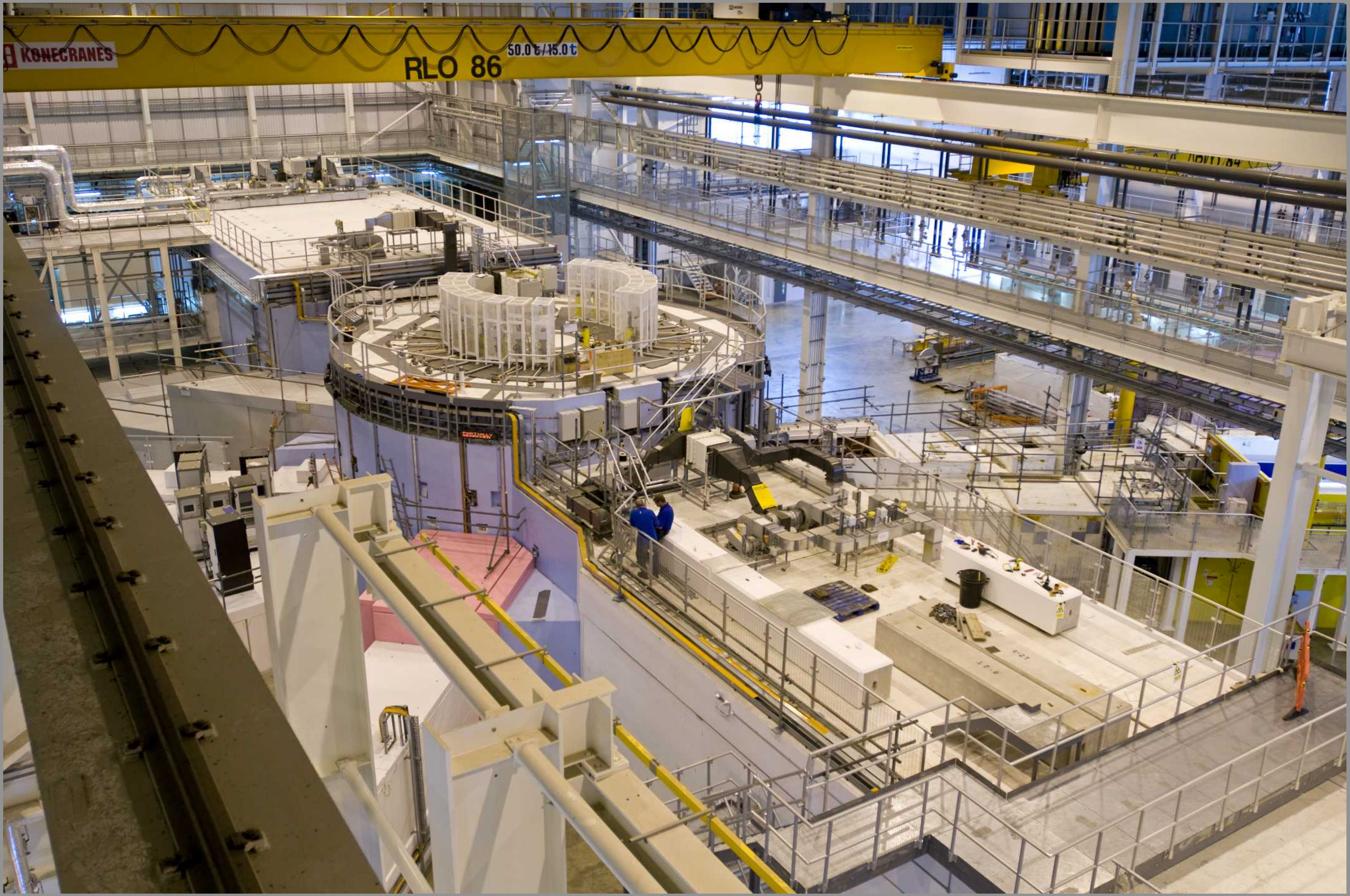
Superperiods 9, 0 and 1 of 800 MeV synchrotron



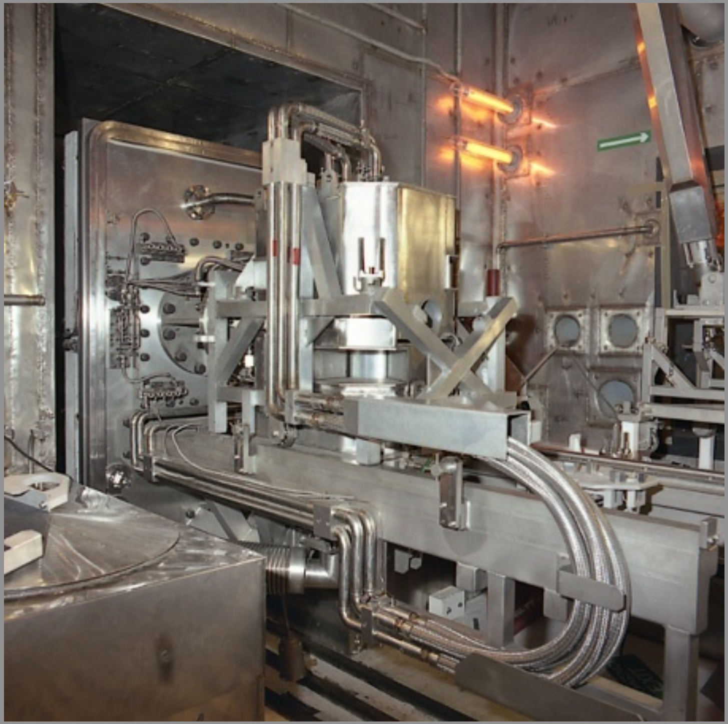
EPB1 and EPB2 to TS-1 and TS-2 above synchrotron

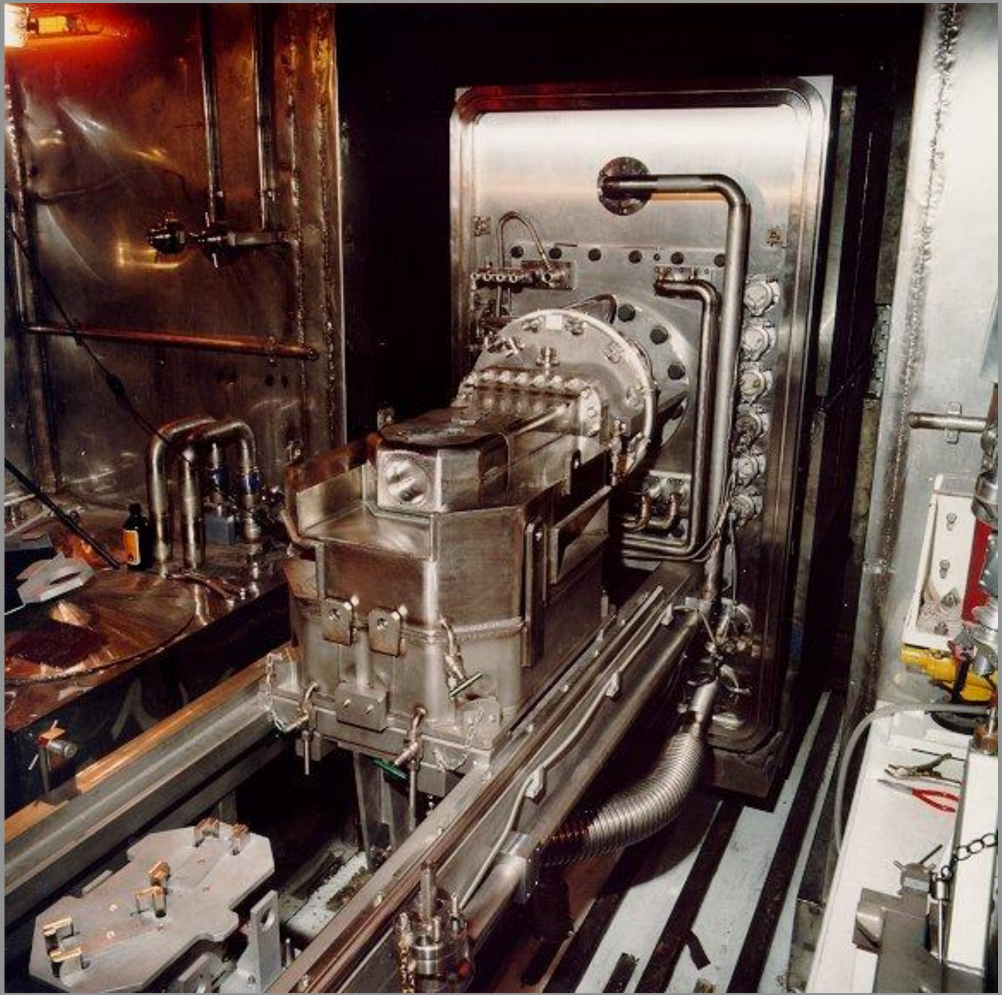
EPB1 shielding

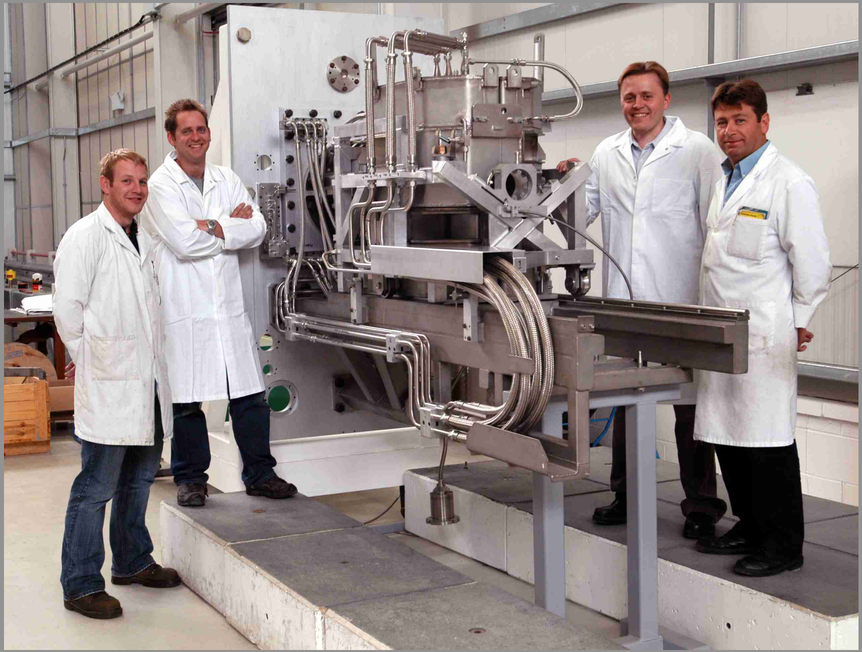
ISIS TS-1 experimental hall, 20 instruments



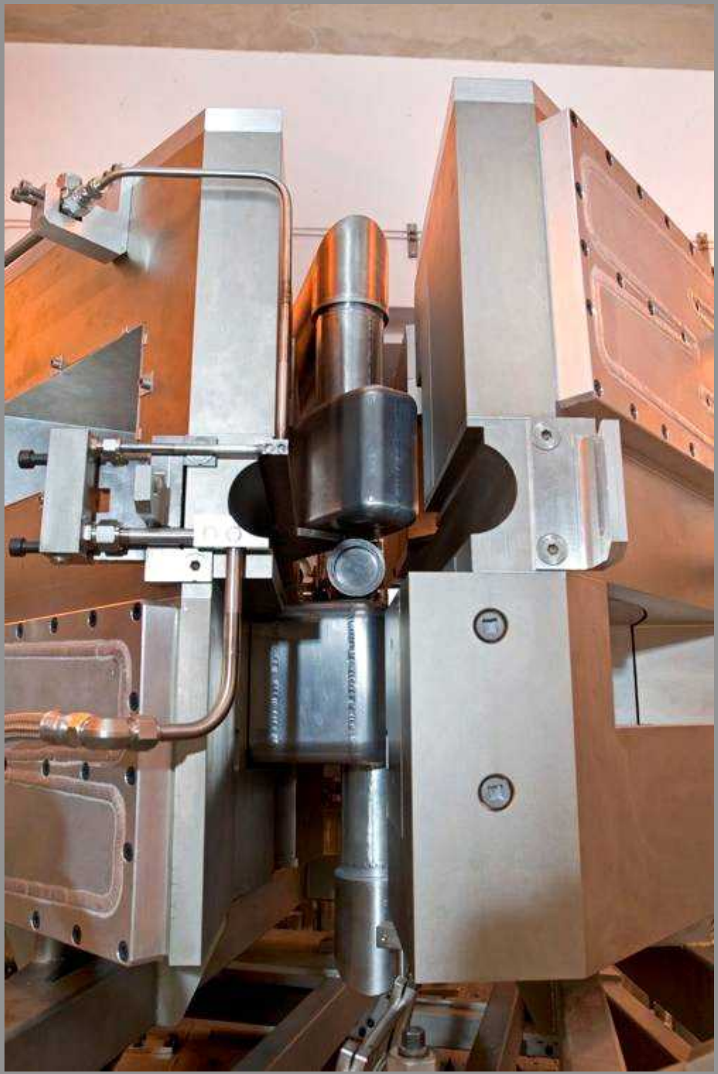
ISIS TS-2 experimental hall, 7 instruments + 4 under way







TS-1 tungsten target
(plate target)



TS-2 tungsten target (solid cylinder)

ISIS operations

Typically 180 days a year running *for users*

Maintenance/shutdown
~1–2 weeks machine physics + run-up
~40-day cycle
~3-day machine physics

~5/year

Machines run ~250 days per year overall

Only too aware of cost of electricity — recent ~20% price increase — a real drain on our resources

Scope for electricity consumption reductions

1. Run for less time
2. Run at lower beam powers
3. Modify plant
4. Modify operating patterns

1. Run for less time?

Cost of electricity = ~15% of total annual budget

ISIS off power = ~0.3 × ISIS on power

ISIS off energy = ~0.2 × ISIS on energy

Cut one cycle out of five?
Use less electricity
Save ~2% total budget, but lose ~20% of science

→ ineffective

2. Run at lower beam powers?

Repetition rate

- Synchrotron fixed at 50 pps (lattice magnets resonated with capacitor banks)

Charge in each beam pulse

- Nearly all systems independent of charge in each beam pulse
- Typically, RF cavities, beam loading << cavity power

→ ineffective

Science & Technology Facilities Council
Rutherford Appleton Laboratory

ISIS

3. Modify plant?

12 MW with both target stations running

Approximate breakdown:

Ancillary plant	2.8 MW
Main magnet power supply	2.0
Synchrotron RF	1.6
TS-1 + TS-2 instruments	1.1
Extracted proton beam line 1	1.0
Extracted proton beam line 2	1.0
Linac	0.8
Injection and extraction septums	0.6
EPB2 septum	0.4
Miscellaneous	0.2
Lighting	0.2
HEDS PSUs	0.2
Injection dipole	0.1

Ancillary plant, ~2.8 MW

Mostly for water circulation and cooling
e.g. water to cool beam transport magnets,
temperature-stabilised water for RF cavities,
low-electrical-conductivity water for anodes,
chilled water for air conditioning

Cool 12.0–2.8 MW with COP = 4 plant? 2.3 MW

Miles of water pipes, hundreds of pumps and heat exchangers[1]

Some plant ~40 years old — steadily being replaced

[1] Even heat exchangers for copper sulphate liquid resistors

Main magnet power supply, ~2.0 MW

- Runs 10 × lattice dipoles and 30 × lattice quadrupoles
- $(600 + 400 \sin(2\pi.50.t))$ A, up to 10 kV, resonant
- ~1 MW DC + ~1 MW AC losses
- Completely impractical to change magnets
- But, already replaced old lossy capacitors in capacitor bank
- And, already replaced ~1 MW motor-alternator set by 4 × 300 kVA solid-state generators

Synchrotron RF, ~1.6 MW

6 × 1RF systems + 4 × 2RF systems — swept

1.3–3.1 MHz   2.6–6.2 MHz

16 × high-power tetrodes — 100 kW for heaters alone

Power consumed set by cavity powers, ferrite biases, and need to retain precise amplitudes and phases

Over-riding requirement is for stability (~10000 turns)

Hardware replacement programmes on operational machines

Limited by

- available capital
- people to change hardware
- need to install new systems alongside old systems
- regulatory radiation dose limits
- opportunities for commissioning new equipment
- need to preserve user programmes

Example — replacement of ISIS TS-1 beam exit window and last three quadrupoles in 2010
— 6 months to do — >2 years to prepare

4. Modify operating patterns?

Power up later, switch off hardware during unscheduled beam-off times?

— need for stability dominates

New régime introduced at ISIS

— "dimming" proton beam transport lines during extended beam-off trips

— but can provoke hardware faults in older equipment — *e.g.* earth leakages in 40-year-old magnets in difficult locations

Conclusions

ISIS is a mature spallation neutron source

Not particularly energy-inefficient

Very difficult, expensive and time-consuming to significantly change hardware

Prefer to spend capital on more science than on less energy consumption

Time to build in energy efficiencies is at design stage

But need to ensure energy efficiencies secured now don't compromise science in the future!

Science & Technology Facilities Council
Rutherford Appleton Laboratory

ISIS

ISIS

Science & Technology
Facilities Council

Waste heat from ISIS

All heat into atmosphere

Four large systems, geographically separated (2 sets cooling towers, 1 set air-blast coolers, 1 set water chillers) — capturing waste heat not easy

ISIS does not run all the time — dual systems necessary

~85–90% of RAL annual kWh is electricity

Science & Technology Facilities Council
Rutherford Appleton Laboratory

ISIS

Economics of installing more efficient plant

Linac — shunt impedance low by modern standards
— new higher frequency linac + klystrons? — save
~0.2 MW, or ~£0.1M/year *cf.* ~£30M capital

Proton beam line to TS-1 — 49 elderly quadrupoles
— could optimise better — save ~30% of present
~0.7 MW, or ~£0.1M/year *cf.* ~£2M capital cost

Synchrotron RF anode PSUs — 20 kV, 20 A PSUs
— thyristor-based → IGBT-based — save ~10%,
or ~£10k/year *cf.* ~£200k capital cost

+ some very substantial operational overheads