ISIS Upgrades — A Status Report

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CCLRC
— one of the UK’s Research Councils

Daresbury Laboratory
SRS

Rutherford Appleton Laboratory
ISIS
Diamond
ISIS — world’s leading spallation neutron facility

**PSI**
**ISIS**
**SNS**
**J-PARC**

Decreasing power — at present

**ISIS**: 800 MeV protons on to tungsten target
200 µA → 300 µA, 160 kW → 240 kW

But ISIS accelerators primarily a neutron factory
- ~800 experiments/year
- ~1600 visitors/year
## Typical machine parameter list

<table>
<thead>
<tr>
<th>Machine parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean radius (3 x ISIS)</td>
<td>78.0 m</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Injection energy from ISIS</td>
<td>0.8 GeV</td>
</tr>
<tr>
<td>Extraction energy (option of 3 GeV)</td>
<td>3 GeV</td>
</tr>
<tr>
<td>Number of circulating protons</td>
<td>$3.75 \times 10^8$</td>
</tr>
<tr>
<td>Ring acceptance</td>
<td>304 nm / mm rad</td>
</tr>
<tr>
<td>Magnetic lattice type</td>
<td>rectangular</td>
</tr>
<tr>
<td>Number of ring superperiods</td>
<td>2</td>
</tr>
<tr>
<td>Number of 3-cell periods per arc</td>
<td>5</td>
</tr>
<tr>
<td>Number of arc cells</td>
<td>$2 \times 15$</td>
</tr>
<tr>
<td>Number of straight section cells</td>
<td>$2 \times 7$</td>
</tr>
<tr>
<td>Number of main B dipoles</td>
<td>$2 \times 10$</td>
</tr>
<tr>
<td>Number of secondary b dipoles</td>
<td>$2 \times 5$</td>
</tr>
<tr>
<td>Number of main D quadrupoles</td>
<td>$2 \times 22$</td>
</tr>
<tr>
<td>Number of trim D quadrupoles</td>
<td>$2 \times 12$</td>
</tr>
<tr>
<td>Number of main F quadrupoles</td>
<td>$2 \times 22$</td>
</tr>
<tr>
<td>Number of trim F quadrupoles</td>
<td>$2 \times 12$</td>
</tr>
<tr>
<td>Gamma transition</td>
<td>13.8</td>
</tr>
<tr>
<td>Horizontal betatron tune</td>
<td>11.7</td>
</tr>
<tr>
<td>Vertical betatron tune</td>
<td>7.4</td>
</tr>
<tr>
<td>Bending angle for B dipoles</td>
<td>16.5°</td>
</tr>
<tr>
<td>Bending angle for b dipoles</td>
<td>3.0°</td>
</tr>
<tr>
<td>Bending angle for 3-cell arc periods</td>
<td>36.0°</td>
</tr>
<tr>
<td>Length of main B dipoles</td>
<td>5.940 m</td>
</tr>
<tr>
<td>Length of secondary b dipoles</td>
<td>1.080 m</td>
</tr>
<tr>
<td>Length of main D quadrupoles</td>
<td>1.080 m</td>
</tr>
<tr>
<td>Length of main F quadrupoles</td>
<td>1.200 m</td>
</tr>
<tr>
<td>Length of trim quadrupoles</td>
<td>0.200 m</td>
</tr>
<tr>
<td>RMS uniform injection trans. emittance</td>
<td>19 x mm / mm rad</td>
</tr>
<tr>
<td>100% uniform injection trans. emittance</td>
<td>125 x mm / mm rad</td>
</tr>
<tr>
<td>100% uniform 3 GeV trans. emittance</td>
<td>50 x mm / mm rad</td>
</tr>
<tr>
<td>100% uniform 8 GeV trans. emittance</td>
<td>25 x mm / mm rad</td>
</tr>
<tr>
<td>100% norm. longitudinal emittance</td>
<td>&lt;1.0 eV / mm rad</td>
</tr>
</tbody>
</table>
ISIS — key machine parameter list

Reliability
Output
Rutherford Appleton Laboratory, looking north
70 MeV H⁻ linac

800 MeV proton synchrotron
ISIS from air
ISIS

First beam December 1984

10 amp-hours delivered on 12 December 2005

36,000 C
2.25E+23 protons
4.4E+24 neutrons
7.5 g neutrons

~£30M/g (excl. capital costs)
ISIS development from 1985 to 2005

Average ISIS beam current per cycle.

As ISIS instrument performance has increased, the amount of data taken per mA.hr of proton current has risen sharply.
Factors determining success of accelerator facility

- Source strength  ← often wrongly consider only this
- Reliability
- Instrumentation
- Innovation
- Investment
- Support facilities
- Support staff
- Cost effectiveness
- User community
ISIS upgrades:

New extraction straight for the synchrotron
Replacement of the Cockcroft-Walton by RFQ
Installation of a second harmonic RF system
Replacement and upgrading of installed equipment
Improved diagnostics + beam dynamics simulations
Construction of a second target station
Design and construction of a front end test stand
MICE experiment
Upgrade schemes for ~1 MW and beyond
Upgrades — ideal

Upgrade 1

Upgrade 2
Upgrades — ideal

Upgrades — typical?
View down north side of ISIS 70 MeV H⁻ MeV linac
Superperiods 9, 0 and 1 of the ISIS 800 MeV synchrotron
ISIS experimental hall
Old extraction straight with collimators
New extraction straight with collimators and septum
New extraction straight with collimators and septum (2)
RF screen inside ceramic vacuum chamber
New collimators, looking downstream
Old Cockcroft-Walton 665 kV H⁻ pre-injector
665 keV 202.5 MHz four-rod RFQ pre-injector
(Frankfurt - RAL collaboration)
RFQ closely coupled to Tank 1 of drift tube linac
RFQ 202.5 MHz rod and stem structure
Four 2RF cavities in Straights 4, 5, 6 & 8
1RF

1RF + 2RF
RF voltage
\[ V = V_0(\sin \phi + \delta \sin(2\phi + \theta)) \]

\( \delta \) and \( \theta \) chosen to minimise loss during injection, trapping and acceleration cycle.
2RF: High power driver Cavity
Ferrite-loaded 2RF cavity
2.6 - 6.2 MHz over 10 ms
(200 - 2000 A bias)
2RF control block diagram

- Frequency sweeper
- Beam compensation loop
- Voltage loop
- Cavity tuning
- Phase loop
Progress on dual harmonic RF system

Hardware commissioning complete

Odd teething trouble

Commissioning with beam being fitted around user programme — restrictive in practice

Scheduled to run DHRF in user cycle starting September

Details: Seville, MOPCH114
        Appelbee, THPCH111
Low output impedance RF cavity driver

To reduce sensitivity to beam-induced voltages in cavities

Original aim was cathode follower

Now anode follower
(tube analogue of inverting op-amp circuit)

LOI HPD output impedance 30 - 50 Ω

Normal ISIS HPD output impedance ~few kΩ

Factor ~100 reduction

ANL - ISIS - KEK collab.  Irie, MOPCH118
Old and new chokes for synchrotron main magnet power supply
Old motor-alternator set for 800 A p-p AC current for synchrotron main magnets
New UPSs for AC current for synchrotron main magnets
Old capacitor bank for resonating at 50 Hz with synchrotron main magnets
New capacitor bank (~one-third of size)
Multi-channel residual gas ionisation beam profile monitor

Warsop, MOPCH115
Pine, TUPCH036
Scintillator-based beam loss monitors
Optimised for cold neutron production

Low repetition rate Low power
10 Hz 48 kW
100 ms frame 60 µA
<table>
<thead>
<tr>
<th>TS-2 Instrument</th>
<th>Performance cf. TS-1</th>
<th>Performance cf. ILL</th>
<th>Particular features</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTER</td>
<td>x 20 compared to SURF</td>
<td>World Leading</td>
<td>Wide simultaneous Q range</td>
</tr>
<tr>
<td>polREF</td>
<td>x 20 compared to SURF / CRISP</td>
<td>World Leading</td>
<td>Wide simultaneous Q range, control of polarization direction</td>
</tr>
<tr>
<td>offSPEC</td>
<td>x 20 compared to SURF</td>
<td>World Leading Unique capability</td>
<td>Wide Qx, Qy range. First instrument dedicated to off-specular studies</td>
</tr>
<tr>
<td>SANS2a/b</td>
<td>x 40 compared to LOQ</td>
<td>Comparable to D22 at ILL</td>
<td>Particularly wide simultaneous Q range. Q min limited to 0.002 Å⁻¹</td>
</tr>
<tr>
<td>NIMROD</td>
<td>x 10 compared to SANDALS for Q 0.01 to 1 Å⁻¹ with comparable resolution</td>
<td>World leading Unique capability</td>
<td>High Q range, extended to low Q values</td>
</tr>
<tr>
<td>LMX</td>
<td>x 40 compared to SXD</td>
<td>Highly competitive with VIVALDI at ILL</td>
<td>Quasi Laue: benefits from TOF</td>
</tr>
<tr>
<td>HRPD-2</td>
<td>x 10 compared to HRPD for d spacings &gt; 1.5Å</td>
<td>World Leading</td>
<td>Emphasis on larger structures, highest resolution</td>
</tr>
<tr>
<td>WISH</td>
<td>x 10 compared to GEM for d-spacings &gt; 10Å</td>
<td>World leading for high resolution magnetic powder diffraction</td>
<td>Dedicated high resolution magnetic powder diffractometer</td>
</tr>
<tr>
<td>LET</td>
<td>x 10 compared to MARI at 10 meV; unique access to lower energies.</td>
<td>World Leading</td>
<td>Wide dynamic range: 0.01 to 80meV Position sensitive detector</td>
</tr>
<tr>
<td>HERBI</td>
<td>x 10 better resolution than IRIS, wider dynamic range, similar flux</td>
<td>Highly competitive with IN16 at ILL</td>
<td>Particularly wide dynamic range</td>
</tr>
</tbody>
</table>
Aerial view with location of Second Target Station
Hill to be removed
Hill being removed – 1
Hill being removed – 2
Hill removed
Building starts on excavated site
Second Target Station (TS-2) at present
Reconfiguration of existing buildings
Route of proton beam line to TS-2 (looking upstream)
143 m proton beam line from synchrotron to TS-2
Target

Beam line Length 143 m

$\theta = 15^\circ$

$\theta = 7.2^\circ$

$\theta = 1.2^\circ$

At target: 36 mm diameter, non-divergent, achromatic
Shielding around proton beam line to TS-2
Magnets for new proton beam line to TS-2

Birch, WEPLS119
RAL Front End Test Stand

1. Demonstration of high quality chopped beam for HPPAs
2. Front end of possible new ISIS linac

Posters
MOPCH112
MOPCH116
MOPCH117
TUPCH019
TUPCH037
TUPLS088
TUPLS090
Front End Test Stand main components

High brightness H⁻ ion source (60 mA, 2 ms, 50 pps)
Magnetic Low Energy Beam Transport (LEBT)
High current, high duty factor RFQ (3 MeV, 324 MHz)
Very high speed beam chopper (1–2 ns switching)
Comprehensive diagnostics

ASTeC - Imperial College - ISIS - Warwick collab. (+ EU)
Ion source development programme — based on ISIS surface Penning source

70 mA and 1200 µs cf. ISIS 35 mA, 200 µs
3-solenoid magnetic LEBT
324 MHz RFQ cold model and bead pull machine
Beam chopper (tandem chopper originally developed for ESS)

1.4 kV pulses with sub-2-ns rise- and fall-times

A tuneable helical structure with adjustable delays replaces the meander line deflector.
MICE — Muon ionisation cooling experiment

International collaboration using muons from parasitic target on ISIS synchrotron (UK, EU, CH, US, Japan)

Aim: to design, construct and operate a section of muon cooling channel for a neutrino factory

Integrated into ISIS operations programme

Yoshida, WEOAPA03,
Tilley, WEPLS002
Blondel, THPCH164
MICE beam line on ISIS synchrotron
Experimental cooling channel
MICE overall layout
ISIS as built

4 $\mu$C per pulse

→ 6 $\mu$C with 2RF
Second Target Station (TS-2) being built

Existing target station (TS-1) continues to run
Beam line EPB-2 to TS-2 joined to synchrotron

First protons to TS-2: Oct. 2007

Both TS-1 and TS-2 run
Possible future scenarios:

3 GeV 50 pps synchrotron and third target station (TS-3) built

Both TS-1 and TS-2 continue to run
Beam line EPB-3 joined to EPB-2

800 MeV protons accelerated to 3 GeV

$3 \text{ GeV} \times 300 \ \mu\text{A} \approx 1 \ \text{MW}$

1 MW can be delivered to TS-3

TS-1, TS-2 and TS-3 can all run
Probably rationalise operating régime by closing down TS-1
New 180 MeV linac built
TS-2 and TS-3 continue to run
New 180 MeV linac replaces old 70 MeV linac

TS-2 and TS-3 run

>1 MW to TS-3 now possible, provided that 3 GeV synchrotron can hold >3 μC per bucket
If 3 GeV synchrotron designed to allow acceleration to 8 GeV at reduced repetition rate, muon-producing target for neutrino factory possible
Alternatively, build stand-alone system based on 3 GeV synchrotron with 180 MeV linac + two 1.2 GeV booster synchrotrons

TS-3 can now run at 2½ MW quite separately from TS-1 and TS-2

5 MW option also possible
Could let present ISIS linac and synchrotron go
But keep TS-2 running by taking beam from booster synchrotron
Muon-producing target for neutrino factory added
ISIS:

Began running in 1984
Continuous series of upgrades since 2002
Second Target Station running ~end 2008
Expect to run ISIS until ~2020