

Science & Technology Facilities Council
ISIS

Operational experience with high beam powers at ISIS

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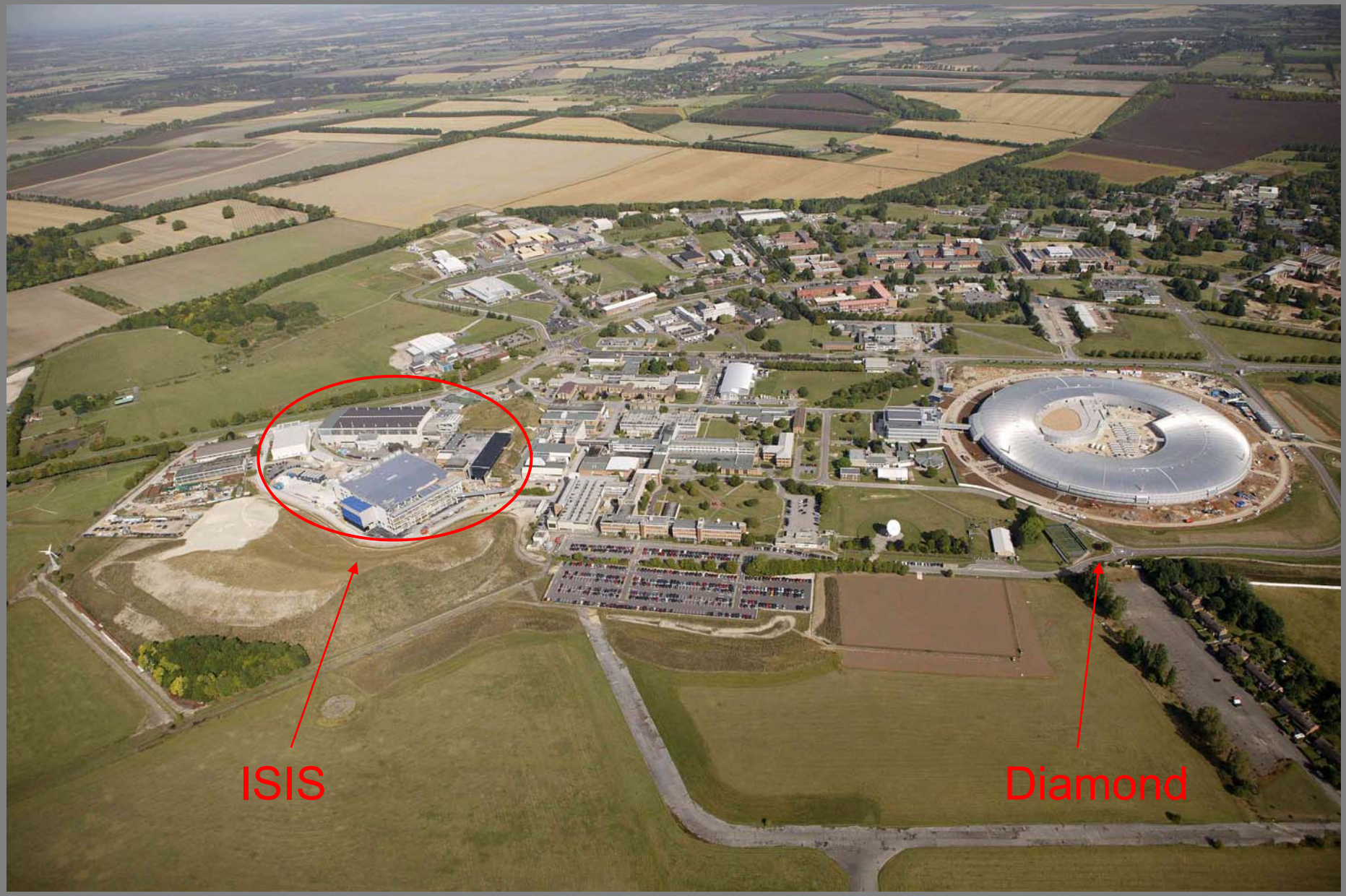


Science & Technology Facilities Council

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+ many, many more



Rutherford Appleton Laboratory, looking north



Rutherford Appleton Laboratory, looking north-east

ISIS — world's most productive spallation neutron facility

PSI
SNS
ISIS
J-PARC



Decreasing power


ISIS
the most
powerful pulsed
neutron spallation
source in the
world
GUINNESS WORLD RECORDS
CERTIFICATE
The world's most powerful pulsed neutron spallation source is ISIS, at the Rutherford Appleton Laboratory, Oxfordshire, UK.
It is capable of producing 4x10^16 fast neutrons per second

ISIS — world's most productive spallation neutron facility

ISIS
J-PARC, PSI, SNS



Decreasing number of target stations

ISIS: 800 MeV protons on to tungsten target

200 μA → 300 μA, 160 kW → 240 kW

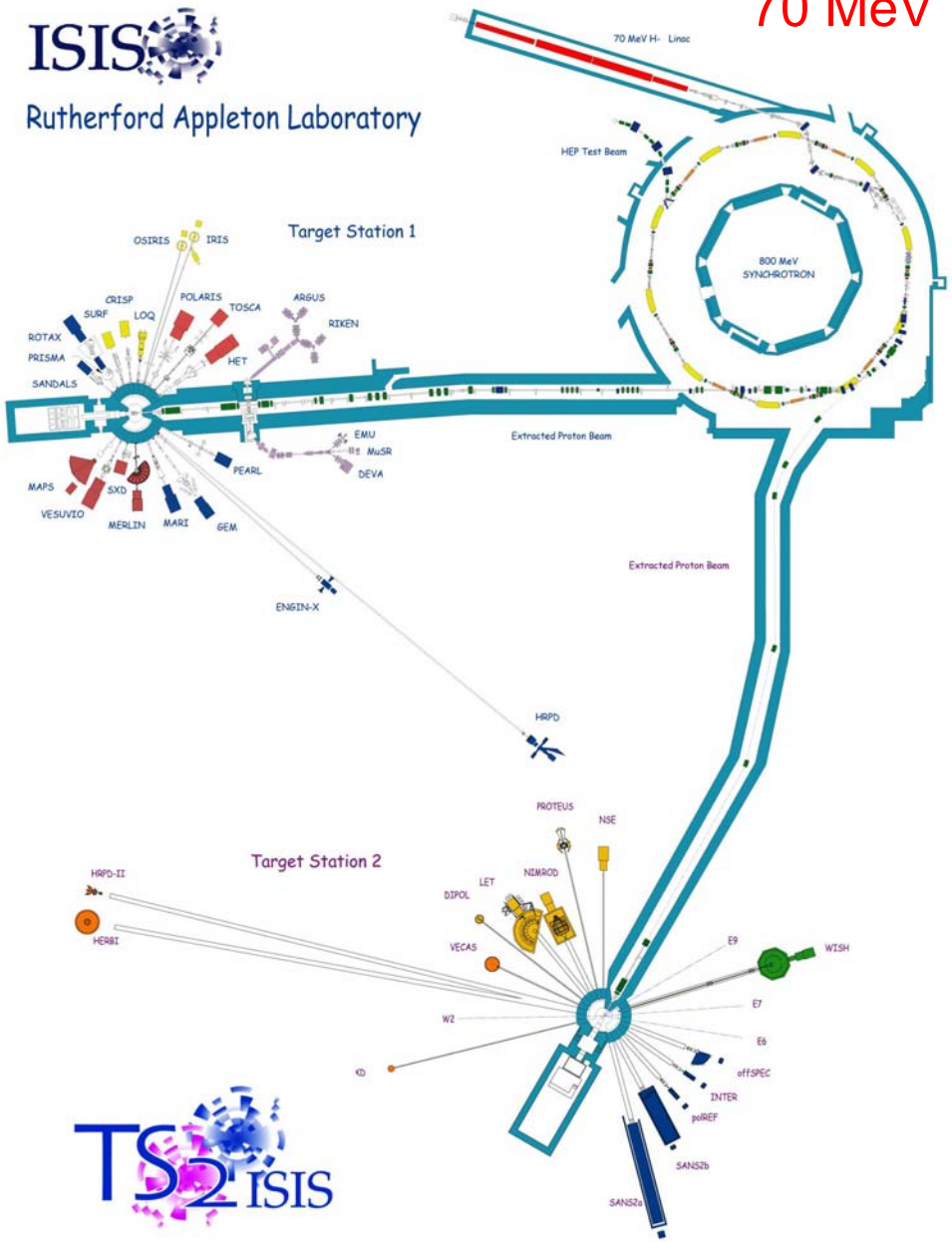
ISIS accelerators primarily a neutron factory

~800 experiments/year

~1600 visitors/year (~5000 visits)

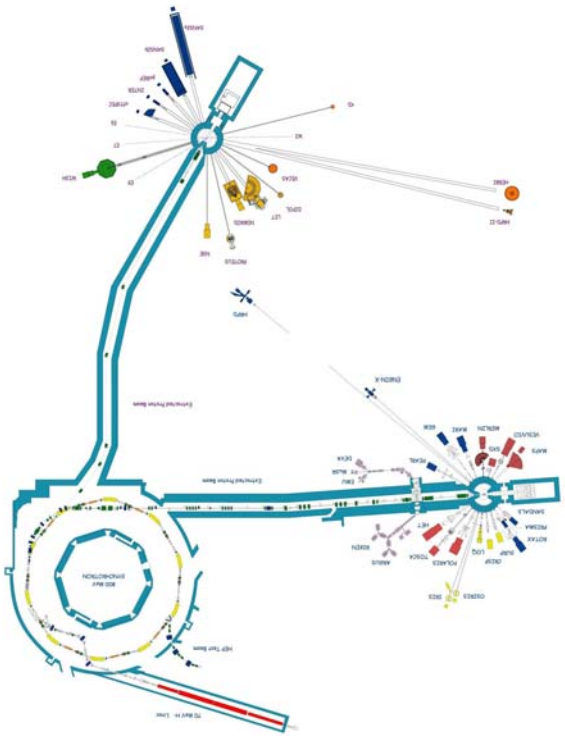
Also muon factory

70 MeV H^- linac



TS-1

800 MeV proton synchrotron





ISIS from air



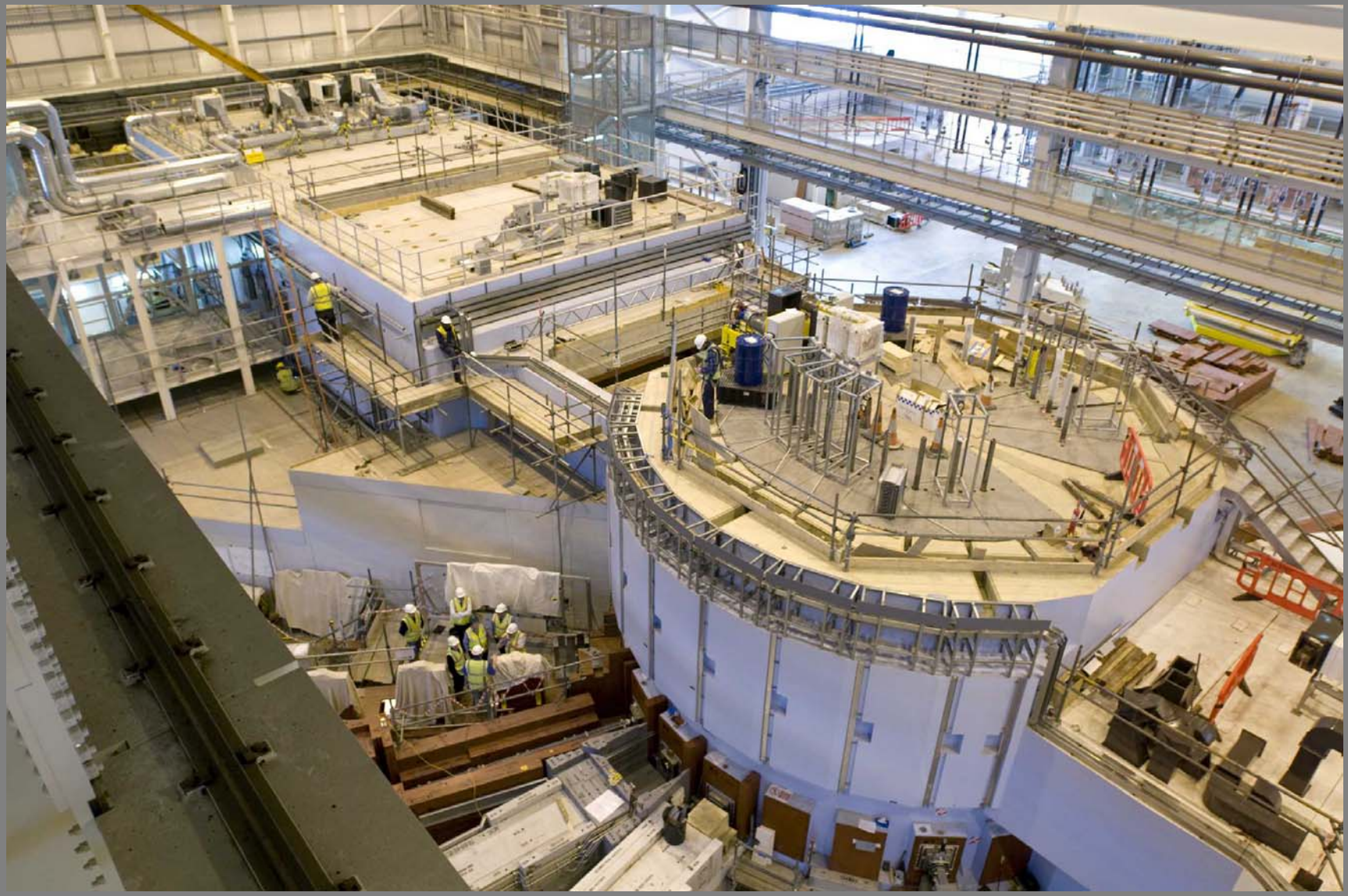
View down north side of ISIS 70 MeV H^- MeV linac



Superperiods 9, 0 and 1 of the ISIS 800 MeV synchrotron



ISIS TS-1 experimental hall



ISIS TS-2 experimental hall



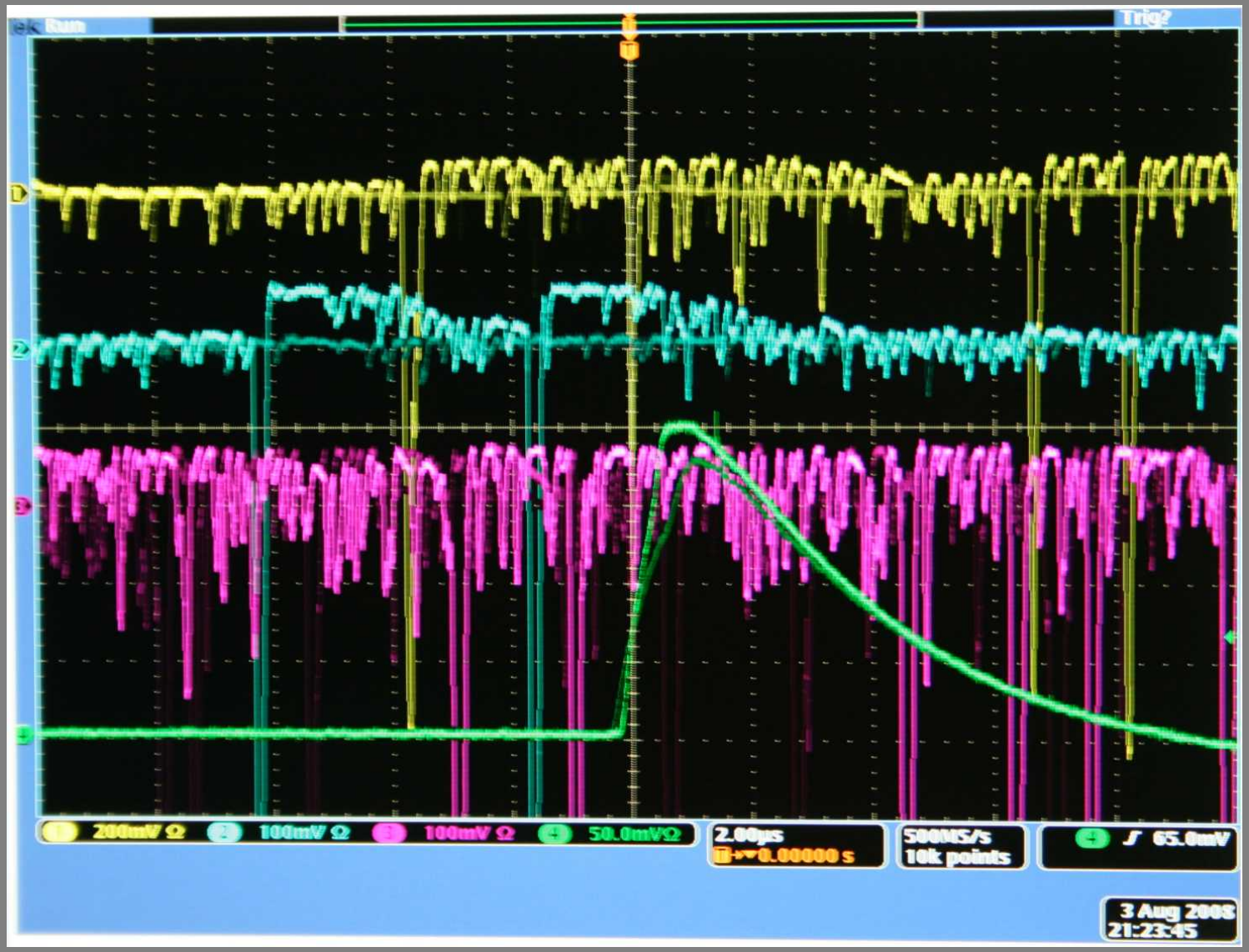
First beam to TS-1, 16 December 1984



First protons to TS-2, 14 December 2007



First neutrons from TS-2, 3 August 2008 — 1



First neutrons from TS-2, 3 August 2008 — 2

Typical machine parameter list

Machine parameters

Mean radius (3 × ISIS)	78.0 m
Repetition frequency	50 Hz
Injection energy from ISIS	0.8 GeV
Extraction energy (option of 8 GeV)	3 GeV
Number of circulating protons	3.75×10^{13}
Ring acceptance	304 π mm mrad
Magnet lattice type	racetrack
Number of ring superperiods	2
Number of 3-cell periods per arc	5
Number of arc cells	2 × 15
Number of straight section cells	2 × 7
Number of main B dipoles	2 × 10
Number of secondary b dipoles	2 × 5
Number of main D quadrupoles	2 × 22
Number of trim d quadrupoles	2 × 12
Number of main F quadrupoles	2 × 22
Number of trim f quadrupoles	2 × 12
Gamma transition	13.8
Horizontal betatron tune	11.7
Vertical betatron tune	7.4
Bending angle for B dipoles	16.5°
Bending angle for b dipoles	3.0°
Bending angle for 3-cell arc periods	36.0°
Length of main B dipoles	5.940 m
Length of secondary b dipoles	1.080 m
Length of main D quadrupoles	1.036 m
Length of main F quadrupoles	1.200 m
Length of trim quadrupoles	0.200 m
RMS unnorm. injection trans. emittance	19 π mm mrad
100% unnorm. injection trans. emittance	125 π mm mrad
100% unnorm. 3 GeV trans. emittance	50 π mm mrad
100% unnorm. 8 GeV trans. emittance	25 π mm mrad
100% norm. longitudinal emittance	<1.0 eV sec

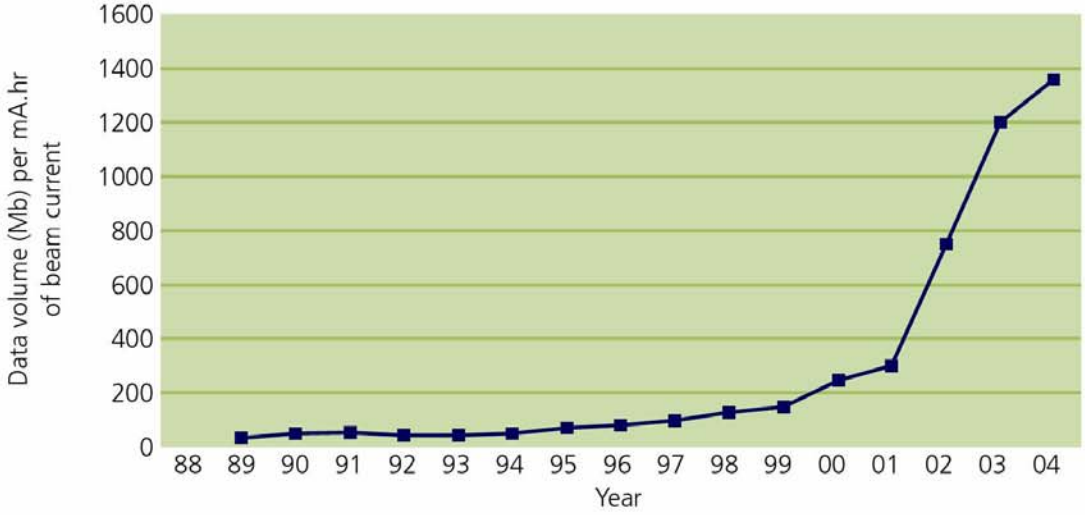
ISIS — key machine parameter list

Reliability

Output



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.

ISIS development from 1985 to 2005

Factors determining success of accel.-based user facility

- Proton power ← sometimes wrongly consider only this
- Proton conversion to neutrons
- Reliability
- Instrumentation
- Innovation
- Investment
- Support facilities
- Support staff
- Cost effectiveness
- User community



Instruments at ISIS



New hostel at ISIS

Reliable operation — highest priority

Spallation neutron sources are *not* accelerator R&D projects

Accelerator + target = neutron factory

Facility is successful if science is successful

Facility is failure if accelerator + target are failures



Typical ISIS running pattern

Maintenance/shutdown

~1 week machine physics + run-up

~40-day cycle

~3-day machine physics

} ~5/year

1 in ~3 machine physics periods lost due to equipment problems

220 days running maximum — any more would have substantial resource implications

Cycle no.	Start		Finish		Days				
					Nominal	Actual	Cumul.		
2007/01	Tuesday	09-Oct-07	Thursday	01-Nov-07	23	23.6	23.6		Cycle 2007/01 — confirmed
	Friday	02-Nov-07	Friday	02-Nov-07	1				Machine physics
	Saturday	03-Nov-07	Thursday	08-Nov-07	6				EPB2 work + minor maintenance
	Friday	09-Nov-07	Sunday	11-Nov-07	3				Run-up + machine physics
	Monday	12-Nov-07	Monday	12-Nov-07	1				Beam line permits
2007/02	Tuesday	13-Nov-07	Thursday	13-Dec-07	30	30.6	54.3		Cycle 2007/02 — confirmed
	Friday	14-Dec-07	Sunday	16-Dec-07	3				16-Dec-07 / ISIS anniversary / Few protons on to TS-2
	Monday	17-Dec-07	Sunday	20-Jan-08	35	54.3			[TS-1] Moderator change
	Monday	21-Jan-08	Sunday	03-Feb-08	14				Run-up + machine physics
	Monday	04-Feb-08	Monday	04-Feb-08	1				Beam line permits
2007/03	Tuesday	05-Feb-08	Thursday	13-Mar-08	37	37.6	91.9		Cycle 2007/03 — confirmed
	Friday	14-Mar-08	Sunday	16-Mar-08	3				Machine physics
	Monday	17-Mar-08	Thursday	27-Mar-08	11				Short shutdown — over Easter [Easter 21-24-Mar-08]
	Friday	28-Mar-08	Sunday	06-Apr-08	10				Run-up + machine physics
	Monday	07-Apr-08	Monday	07-Apr-08	1				Beam line permits
2008/01	Tuesday	08-Apr-08	Thursday	15-May-08	37	37.6	37.6		Cycle 2008/01 — confirmed [Bank Hol. 05-May]
	Friday	16-May-08	Sunday	18-May-08	3				Machine physics
	Monday	19-May-08	Thursday	29-May-08	11				Short shutdown [Bank Hol. 26-May]
	Friday	30-May-08	Sunday	08-Jun-08	10				Run-up + machine physics
	Monday	09-Jun-08	Monday	09-Jun-08	1				Beam line permits
2008/01½	Tuesday	10-Jun-08	Thursday	19-Jun-08	9	9.6	47.3		Extra week running to pay back lost ~week 11–19-Apr — TS-1 at 50 pps
	Friday	20-Jun-08	Thursday	03-Jul-08	14				Machine physics, few days off, run-up, repairs to linac #4 RF
2008/02	Friday	04-Jul-08	Thursday	24-Jul-08	20	20.6	67.9		Cycle 2008/02 — rescheduled — actually stops 0900 25-Jul
	Friday	25-Jul-08	Sunday	03-Aug-08	10				First "real" beam to TS-2
	Monday	04-Aug-08	Thursday	28-Aug-08	25	105.5			Change TS-1 moderator [Bank Hol. 25-Aug] (DOs off shift)
	Friday	29-Aug-08	Sunday	07-Sep-08	10				Run-up + machine physics (beam to both TS-1 and TS-2)
	Monday	08-Sep-08	Monday	08-Sep-08	1				Beam line permits (both TS-1 and TS-2)
2008/03	Tuesday	09-Sep-08	Thursday	16-Oct-08	37	37.6	105.5		Cycle 2008/03 (incl. beam to TS-2)
Simul-taneously	Friday	17-Oct-08	Sunday	19-Oct-08	3				Machine physics
	Friday	17-Oct-08	Sunday	16-Nov-08	31				Change TS-2 moderator — need to leave enough time as first change
	Monday	20-Oct-08	Thursday	30-Oct-08	11				Short shutdown
	Friday	31-Oct-08	Sunday	09-Nov-08	10				Run-up + machine physics (beam to TS-1 only)
	Monday	10-Nov-08	Monday	10-Nov-08	1				Beam line permits (both TS-1 only)
2008/04	Tuesday	11-Nov-08	Thursday	18-Dec-08	37	37.6	143.1		Cycle 2008/04 (incl. beam to TS-2 starting ~17-Nov)
	Friday	19-Dec-08	Sunday	21-Dec-08	3				Machine physics
	Monday	22-Dec-08	Sunday	25-Jan-09	35	75.3			TS-1 moderator change
	Cycle				Note: cycle days reckoned starting from Wednesday not Tuesday				
	Shutdown — *i.e.* machine off								
	Moderator change (TS-1 and/or TS-2)								

Crew: 5 teams of 4 — 24 hours/day, 365 days/year — even during shutdowns

Each team:
- Duty Officer
- Assistant Duty Officer
- Shift Technician
- Operations Assistant

} mostly "electrical"

Duty Officer responsible for all operations on his shift — including user operations

Team of 5 health physicists — one of whom on call

Accelerator and target: ~30 people on call at any one time 24 hours/day, 7 days/week — 45 names

Instruments, sample & environment: ~15 people on call

Outline ISIS costs

~330 ISIS staff

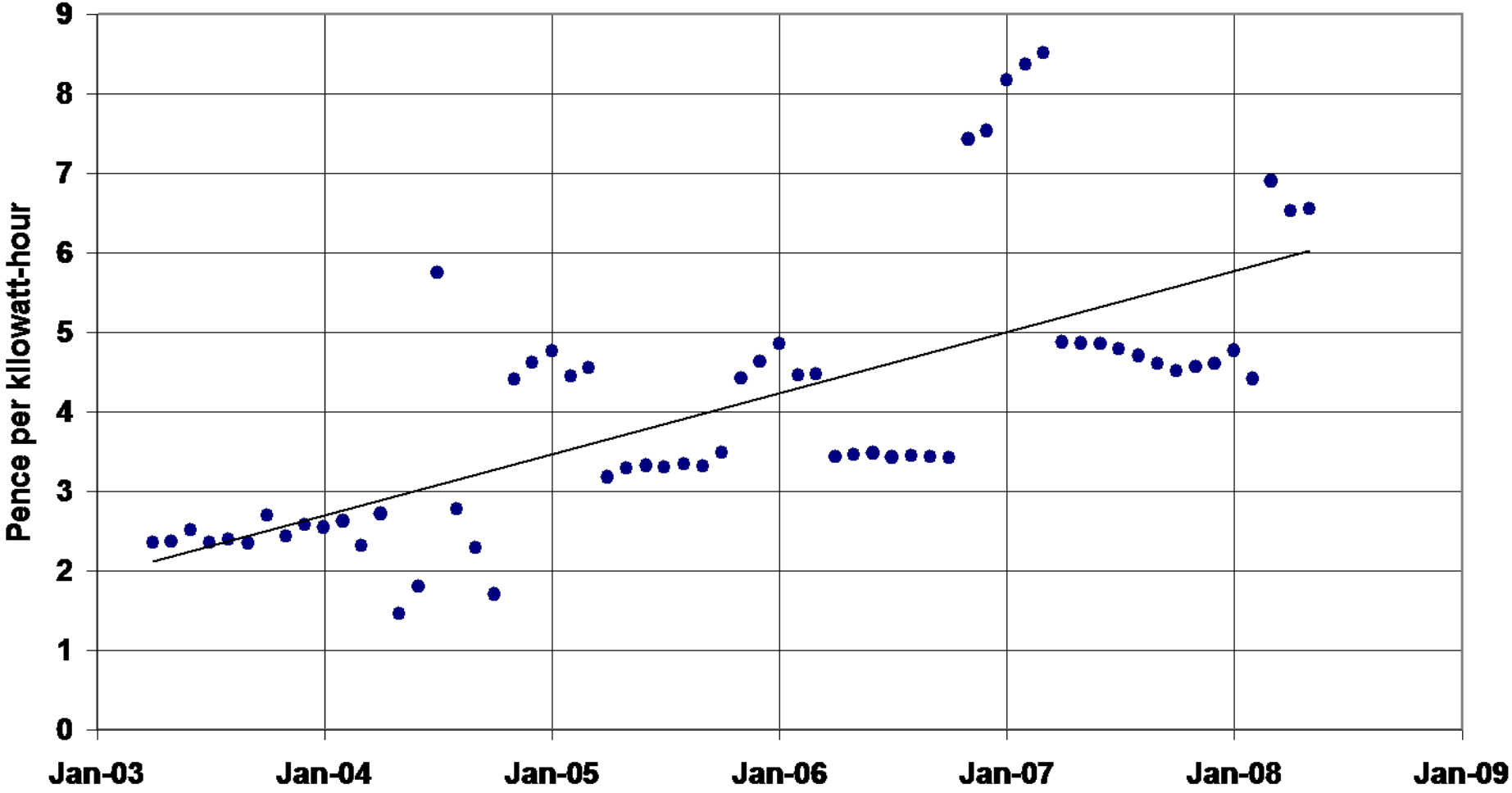
~£40M annual budget (excl. TS-2)

~150 staff for running accelerators and targets

~£4M/year obsolescence mitigation

~£3M/year electricity costs

Price of electricity



Operating ISIS

- Beam losses
  - Concentrated at one place — on collectors
  - Imperative to keep beam losses low (~1 W/m)
  - ISIS: ~1 kW lost, 163 m circumference, ~6 W/m
  - ISIS only ~0.2 MW, but ×2 beam losses would make life very difficult (2–3 mSv annual dose limit)
- Protection from activated machine components
- Time, distance, shielding — elementary, but important
- Explicitly included in designs

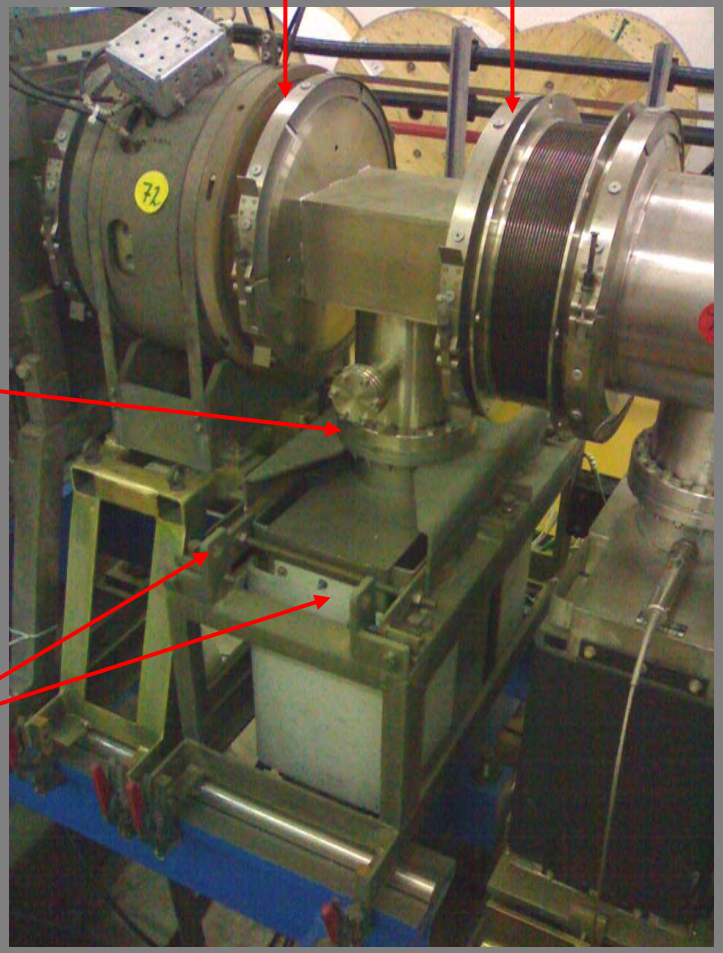
Some relevant issues

- Plan in detail — break down into many sub-tasks — estimate radiation doses for each sub-task
  - UK legal limit: 20 mSv/year
  - RAL investigation level: 6 mSv/year
  - ISIS practice: 3 mSv/year
- Design all new apparatus with active handling specifically in mind
  - Lifting lugs
  - V-band not Conflat seals
- Ensure plenty of space around
- Detailed project management of task

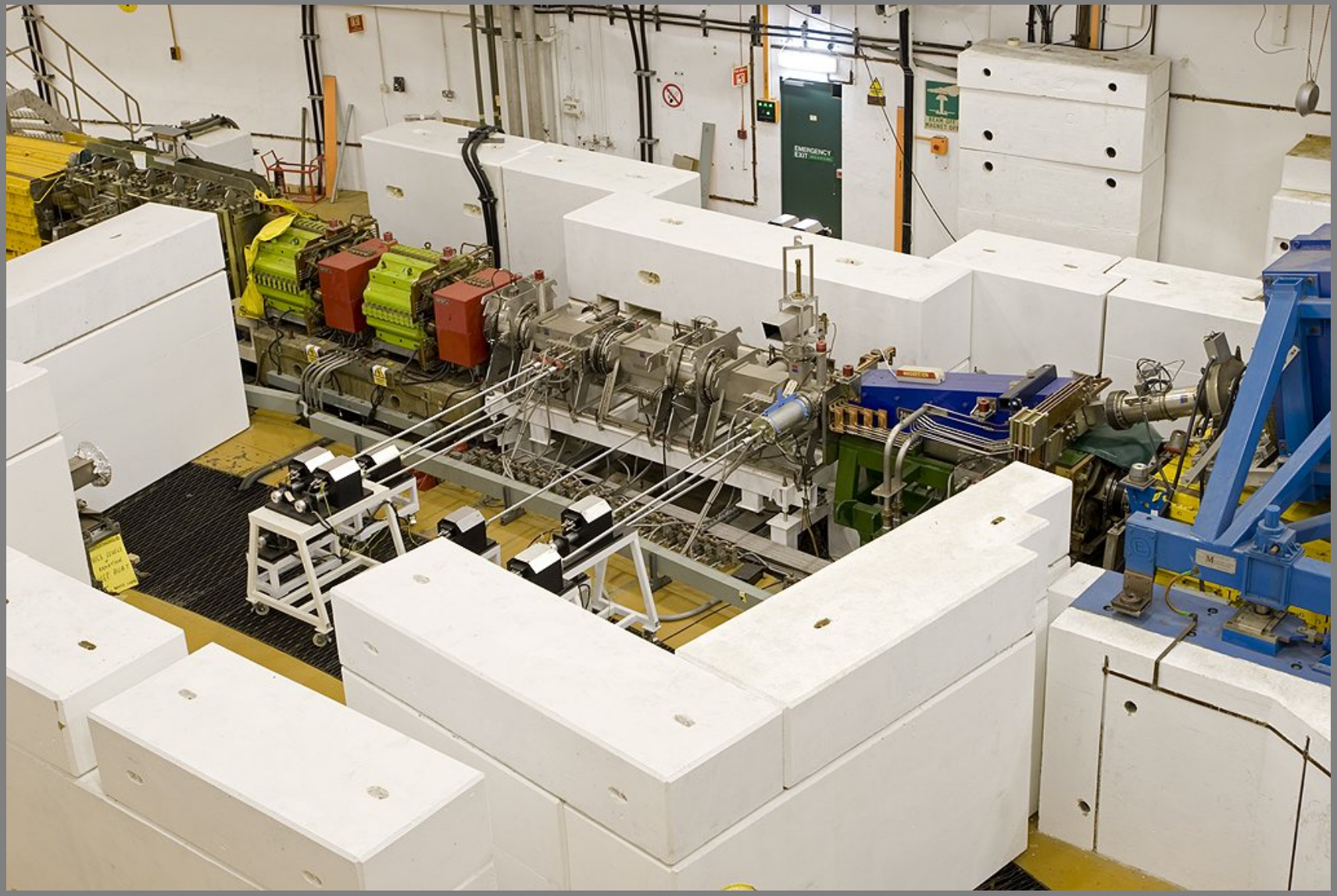
V-band seals

Conflat seals

Lifting lugs







Long mechanical drives to reduce need to work close to high-radiation locations (e.g. when changing motor drives for beam collimators)



ISIS synchrotron room — originally built for Nimrod

Ample space essential for repairs, exchange of large components, etc.



Nimrod sector





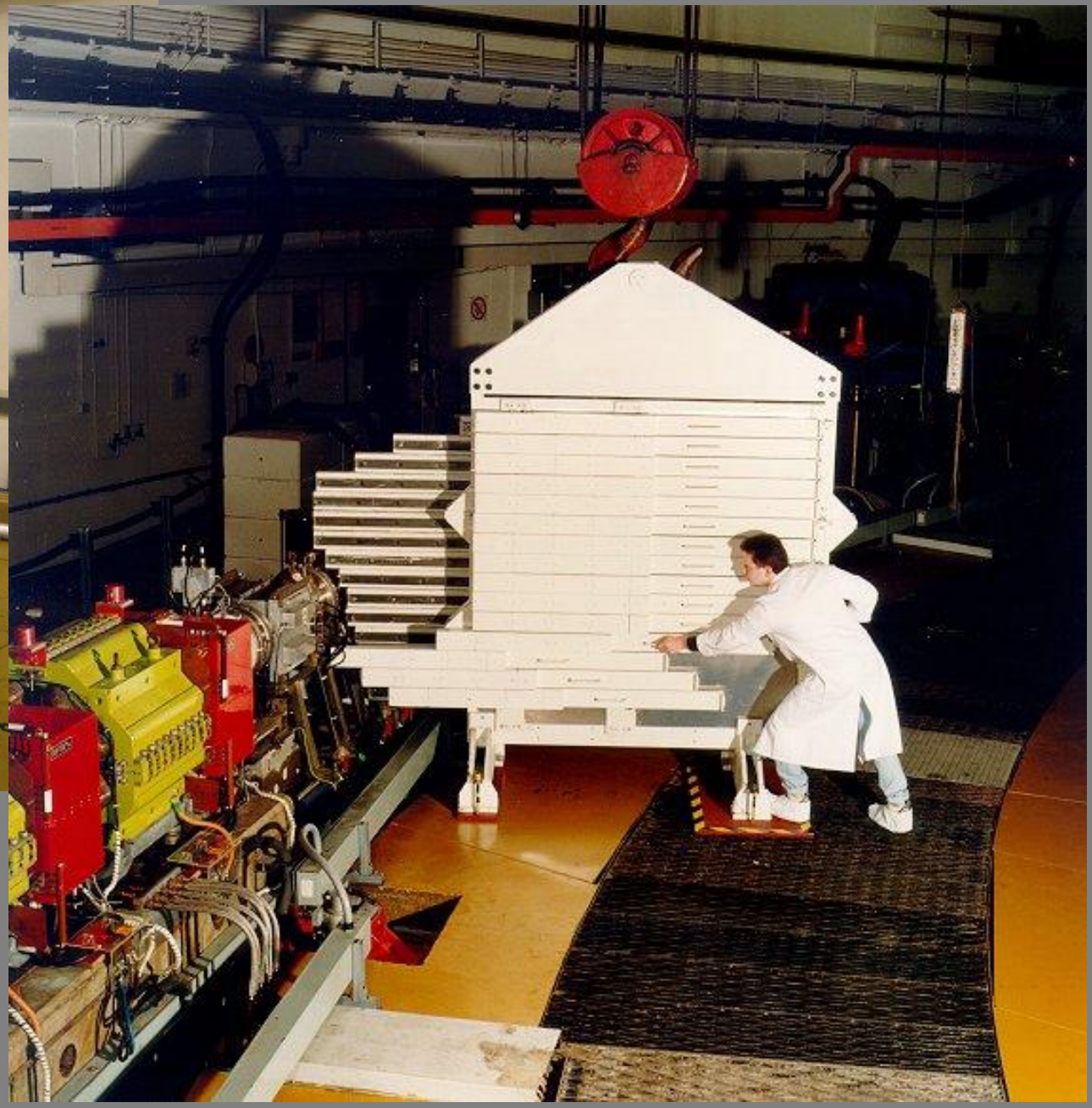




Overhead cranes very important — especially for handling activated components

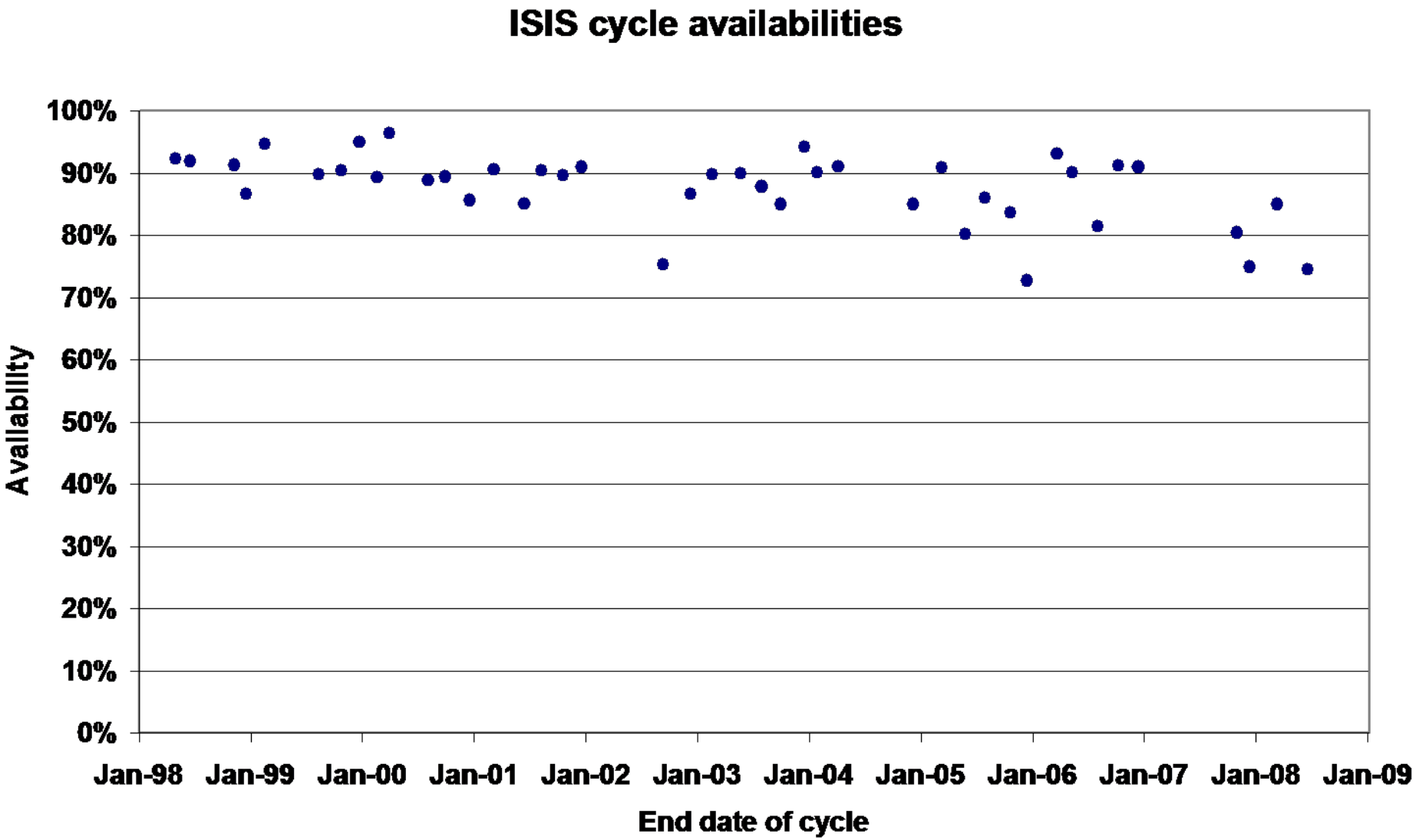
Aim to have two in each area



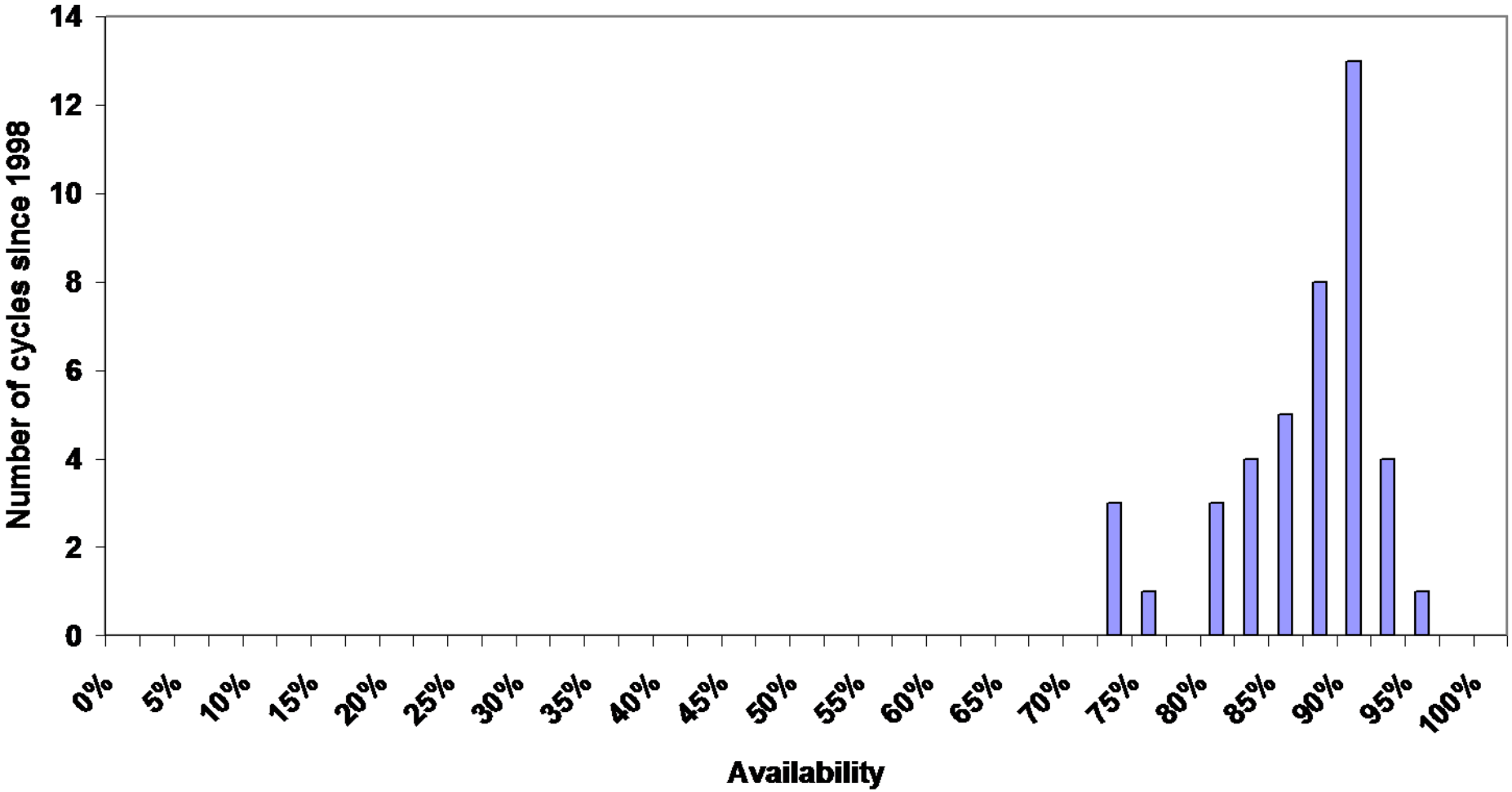


Shielding

Configurable shielding to reduce dose rates locally


ISIS cycle availabilities
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Availability
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
End date of cycle

Cycle availability histogram



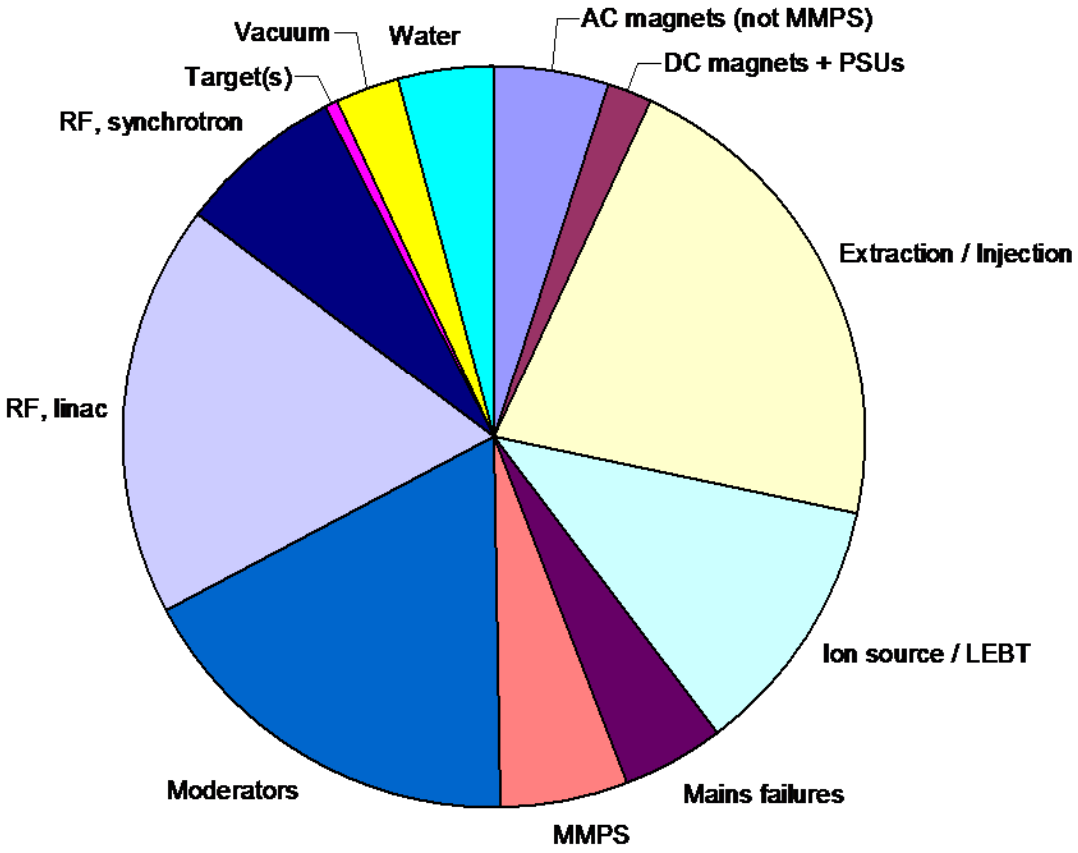
Availabilities only as good as they are because machine runs only for ~2/3 year

Breakdown of unavailabilities by cause

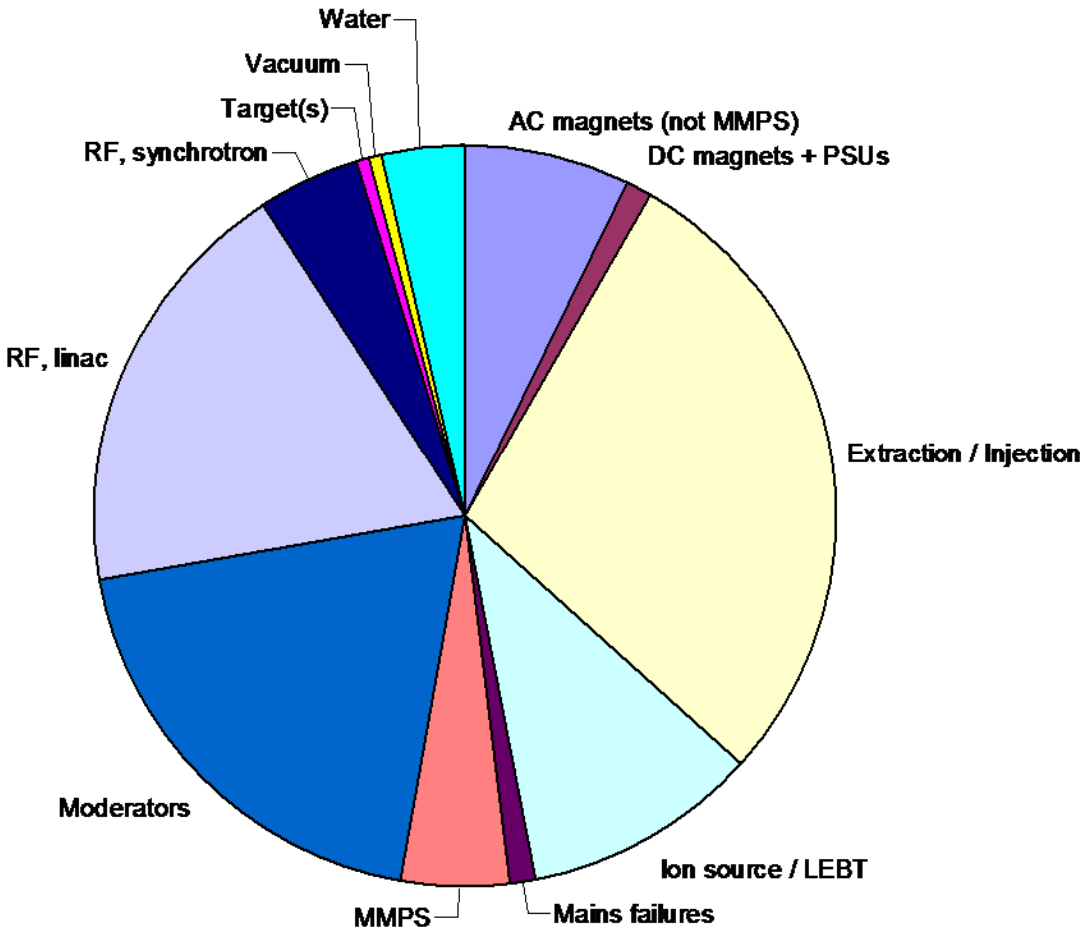
- Twelve categories — always some arbitrariness*
- “Major” breakdowns

* E.g. is linac tank RF window failure a vacuum or an RF problem?

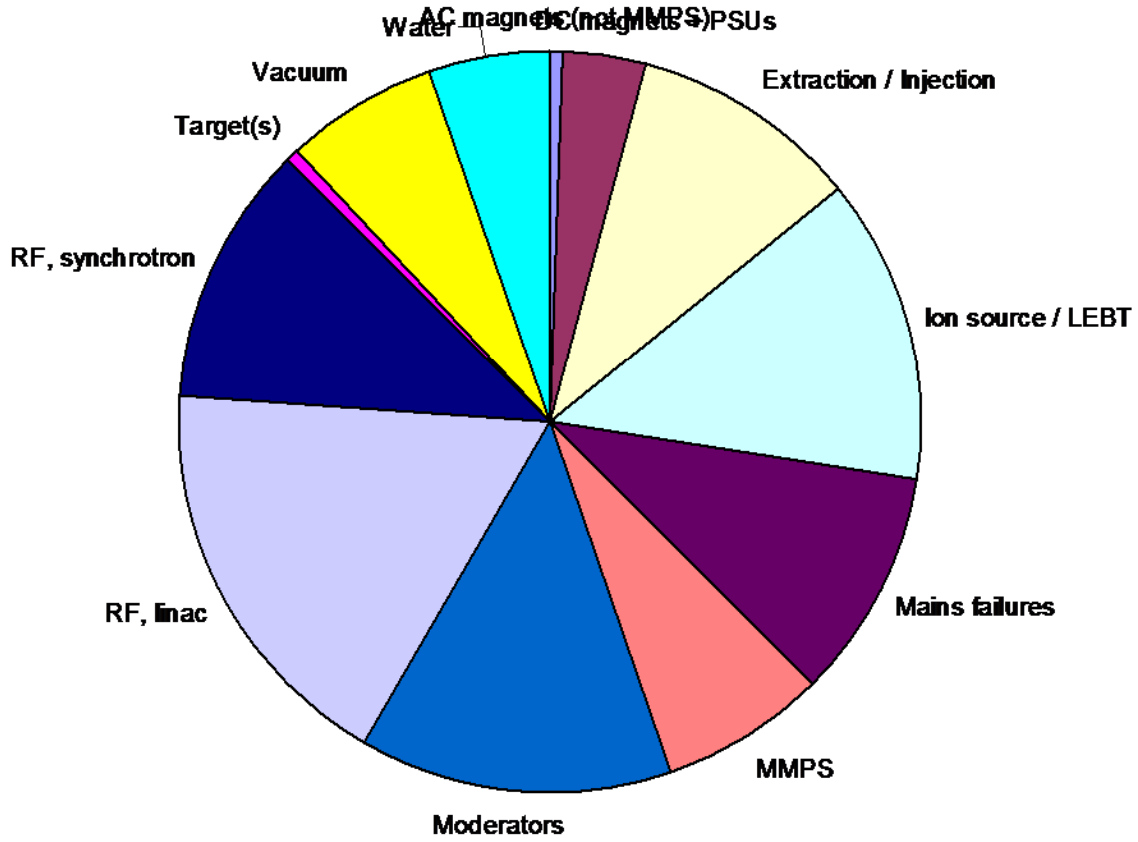
ISIS off-time by category 1998–2008



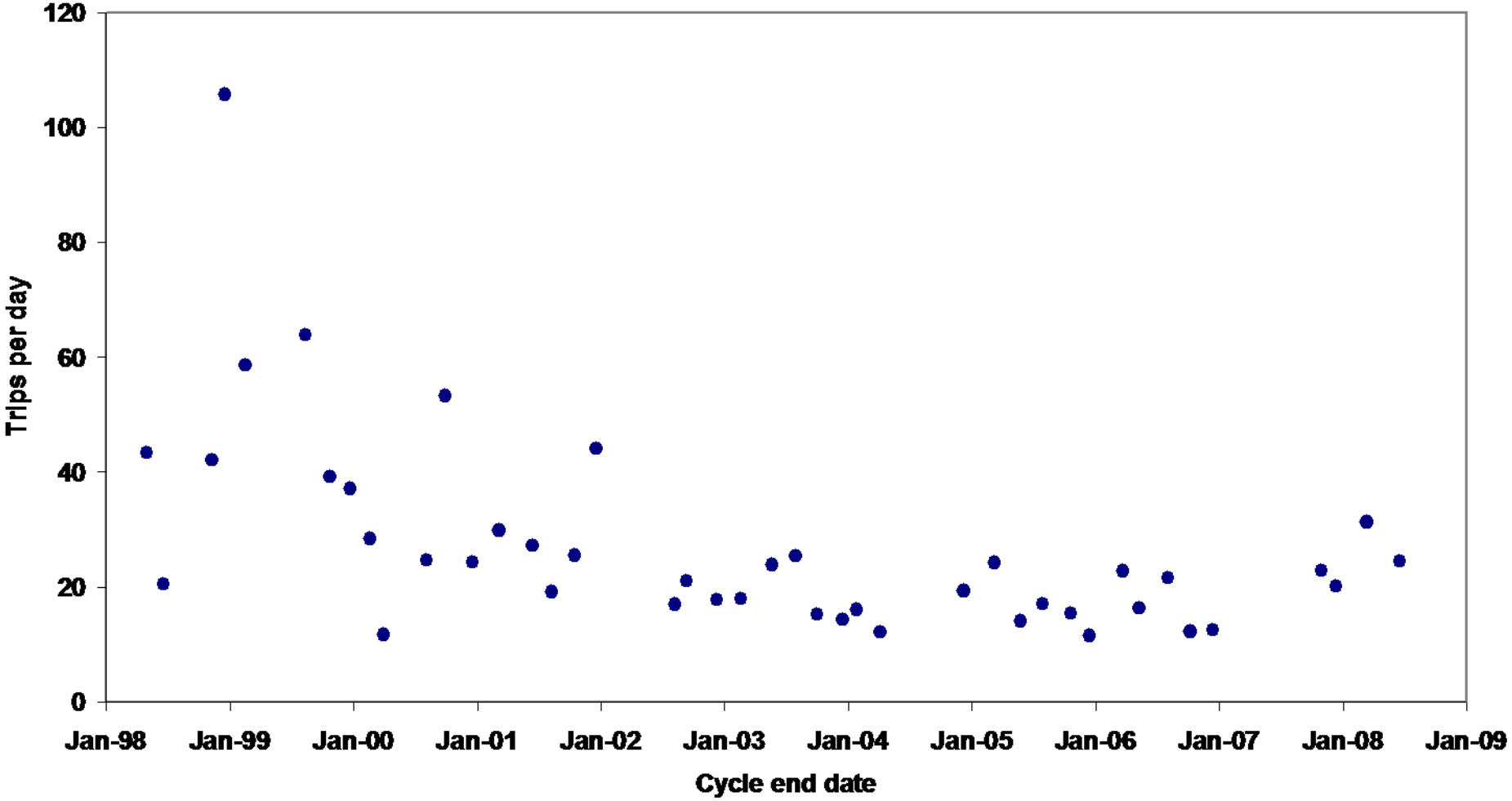
ISIS off-time by category 1998–2003



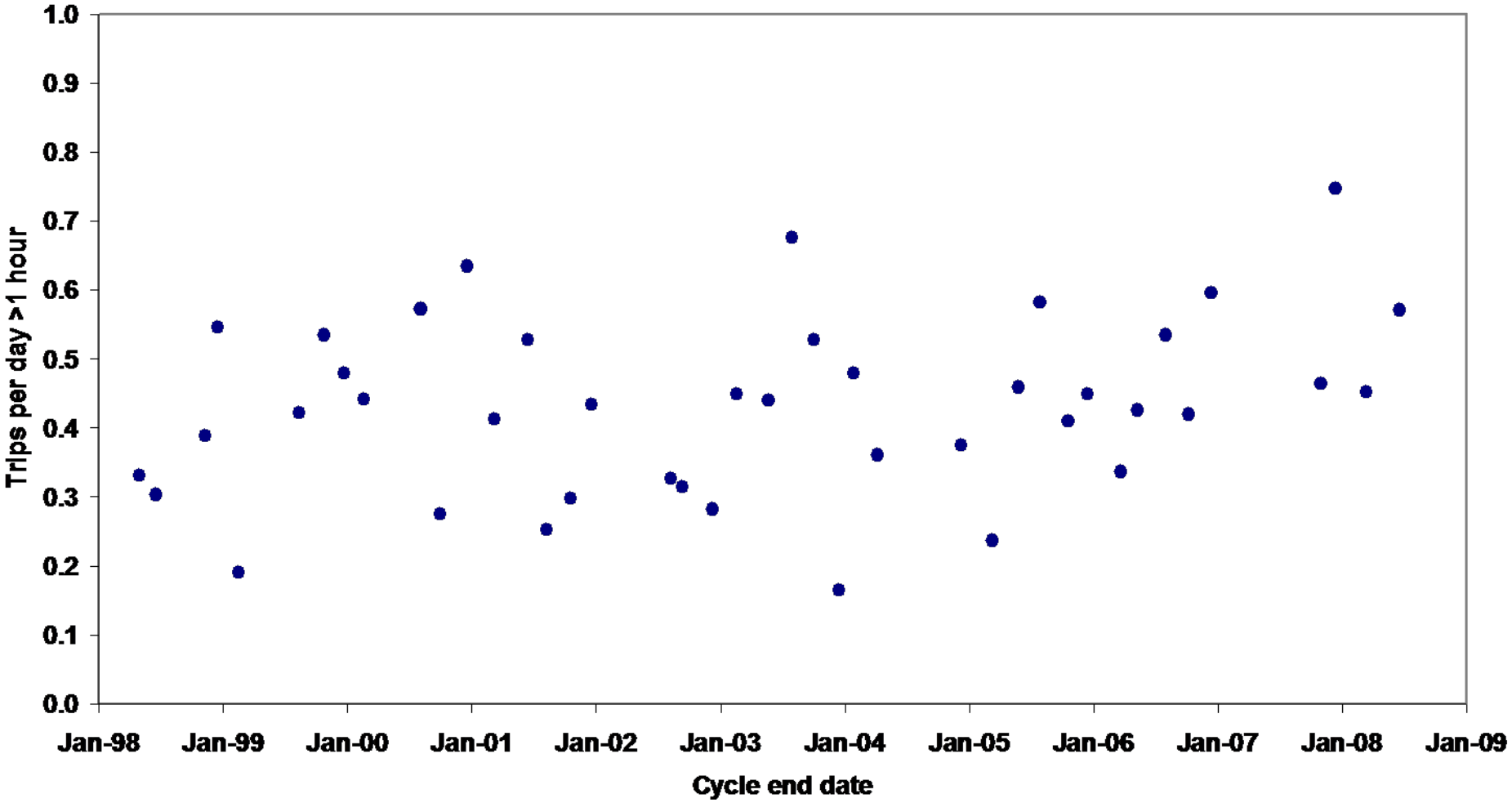
ISIS off-time by category 2004–2008



ISIS trips per day in 1633 scheduled days running during 1998–2008



ISIS trips per day >1 hour in 1633 scheduled days during 1998–2008



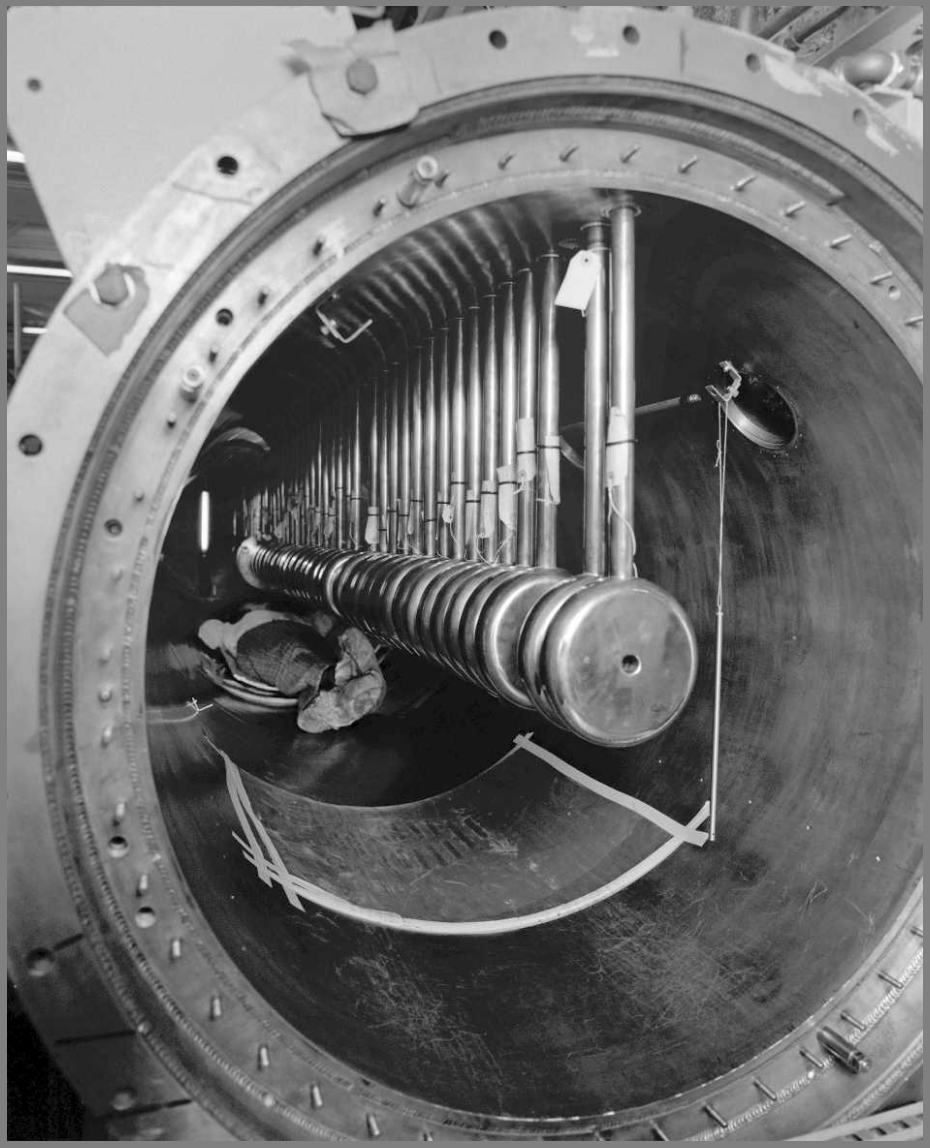
Maintaining ISIS:

Achieve availabilities shown *only* because don't run the rest of the time

Try to operate a "just in time" preventative maintenance régime, but effectively partly/mostly responsive régime — too expensive otherwise

Before big jobs in synchrotron room, ~2 weeks cooling

Did wait ~4 months before starting major refurbishment of extracted proton beam line to TS-1



Maintenance of linac Tank 1 in 1970s

Ensuring ISIS continues to operate

Replacement and upgrading of installed equipment

Some ISIS equipment old — already second-hand when ISIS built in early 1980s

Obsolescence mitigation programme running at ~several per cent of current asset value — ~£4M/year

Obsolescence programme (began 1998) includes:

- Replacement of synchrotron main magnet PSU
- Replacement of Cockcroft-Walton by RFQ
- New extraction kicker drivers
- Modern anode PSUs for linac and synchrotron
- Refurbishment of extraction straight
- New interlock system (IEC 61508)
- New water plant
- New injection and extraction PSUs
- New trim quadrupole PSUs
- Electricity distribution systems
- …

ISIS:

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

Observations from ISIS experience (1):

- Reliable operation is more important than advanced design
- Do everything possible to minimise beam losses
- Always design with active handling in view right from the outset
- Have as much space around equipment as possible
- Never be prevented from installing overhead cranes
- Always rehearse key operations if possible
- *Never* buy just one or even two of anything
- Commission everything *before* the users arrive

Observations from ISIS experience (2):

Never put untested equipment on to the machine

Build as many off-line test/conditioning rigs as possible

Project-manage shutdowns

Don’t be too ambitious with time scales

Cosset equipment engineers

Don’t skimp machine physics

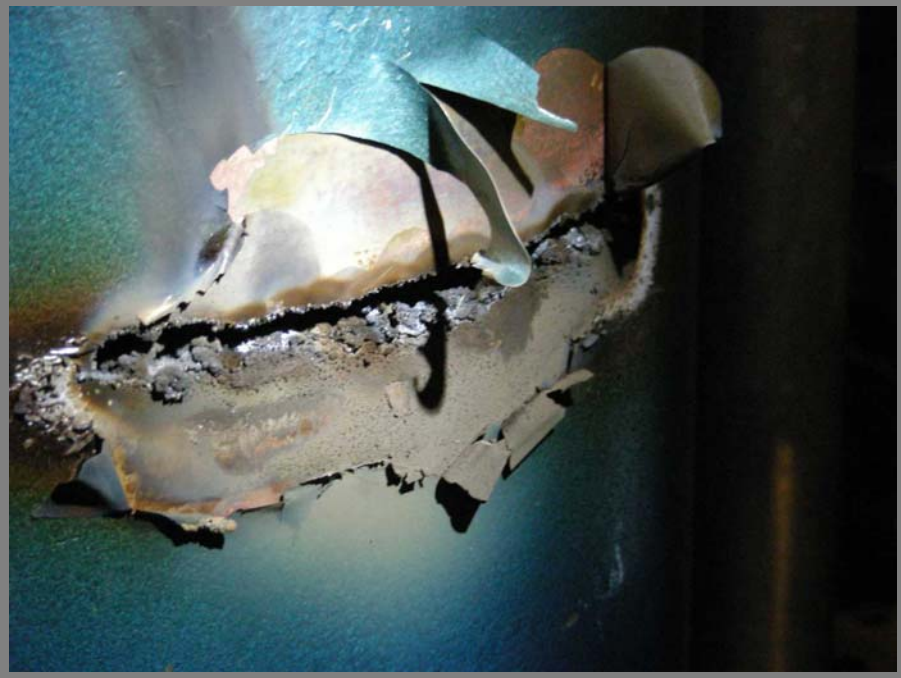
Under-run RF tubes if possible — significant gains in lifetimes

[Total 15]


ISIS








CAU
NO S






20. 12. 2006




FH200 LC-3