Science & Technology Facilities Council
ISIS

ISIS upgrades

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

Proton Accelerators for Science and Innovation, 12–14 January 2012, FNAL

Science & Technology Facilities Council

ISIS

- 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)

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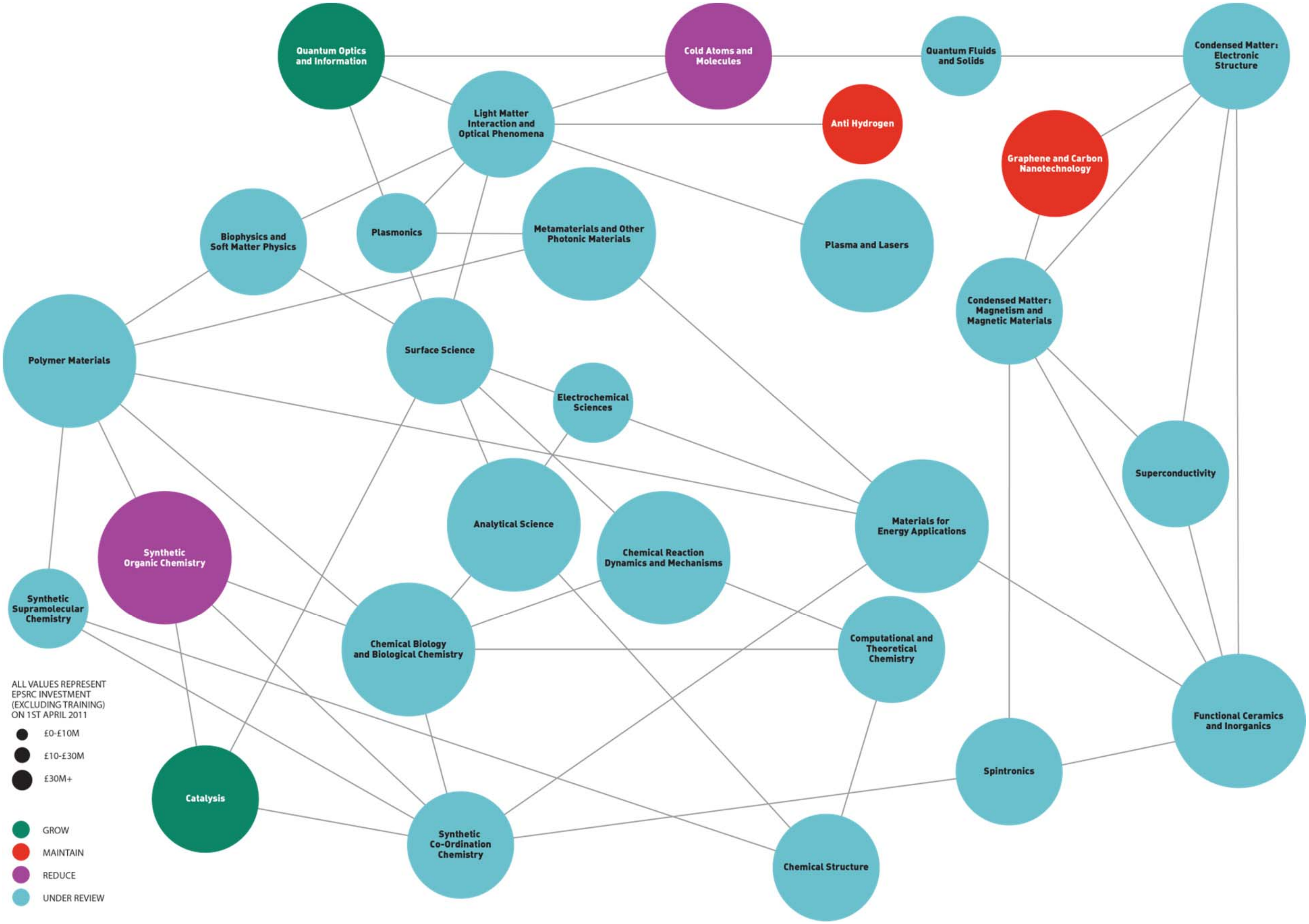

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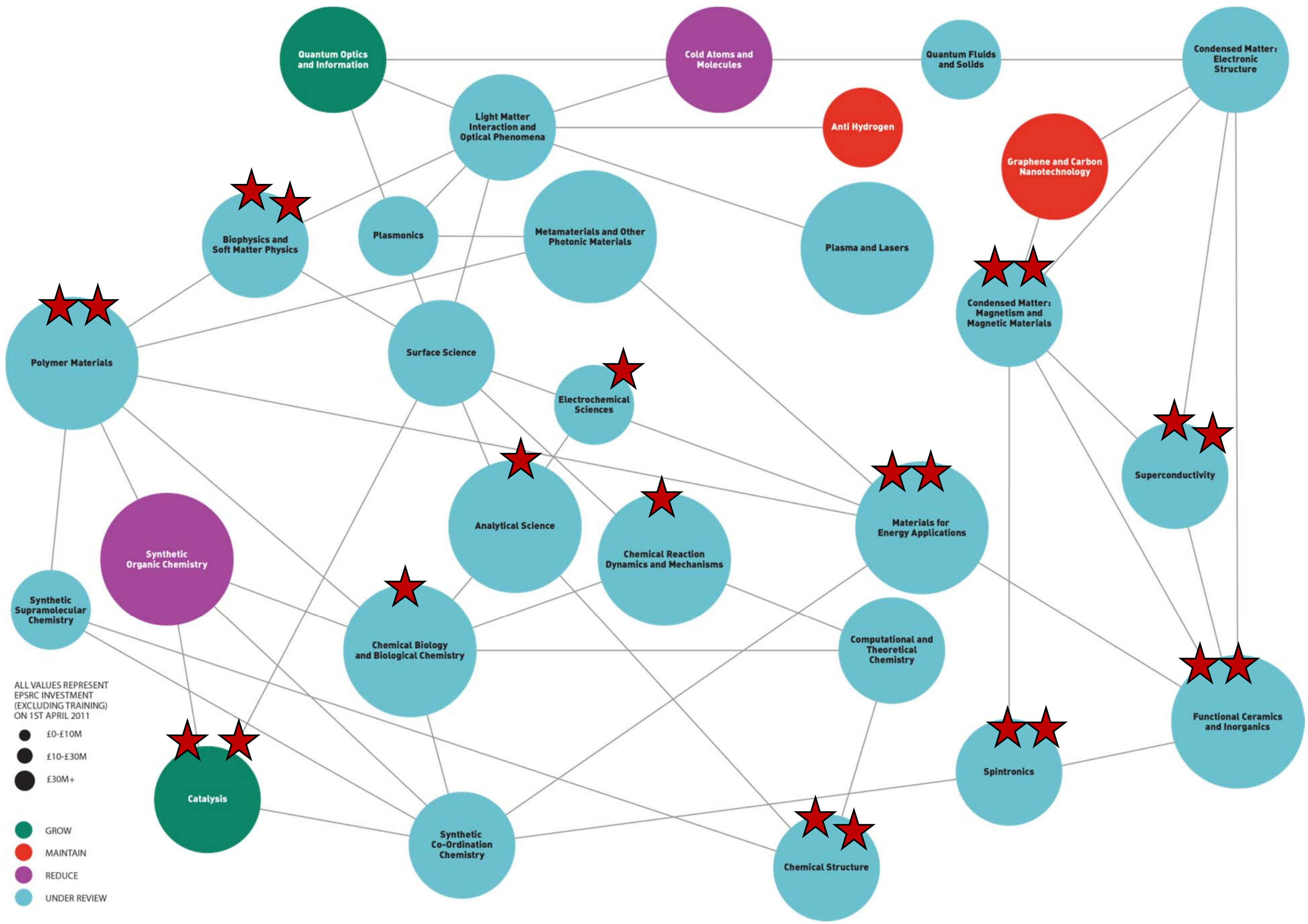
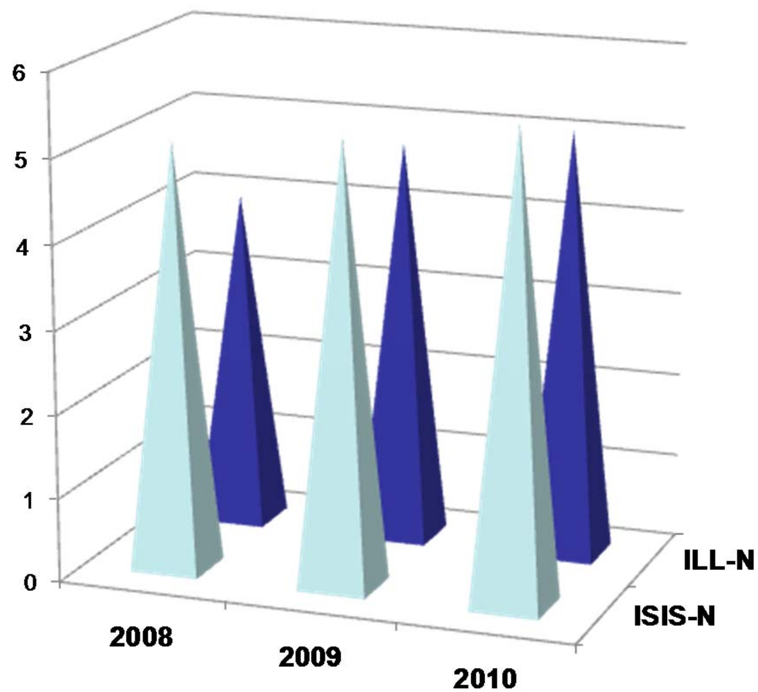
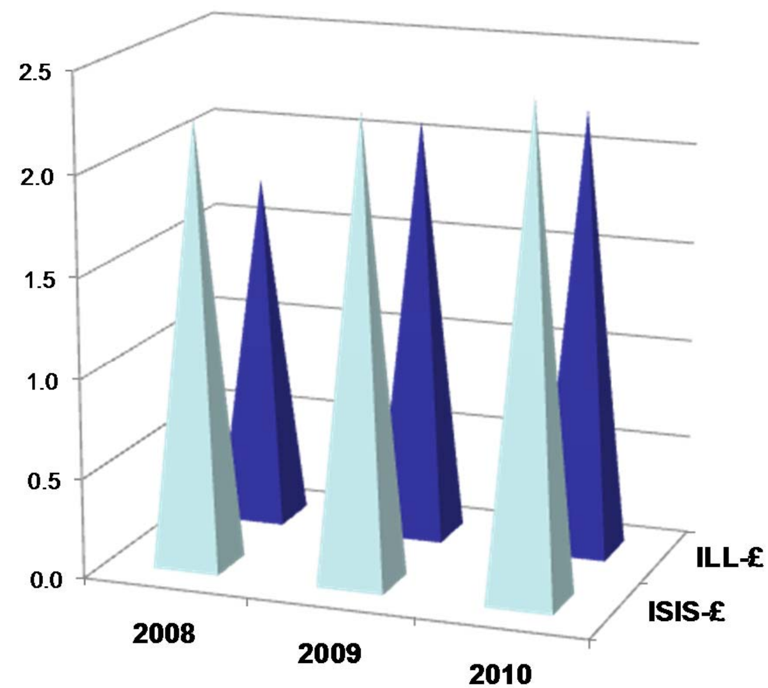


High-impact publications for ILL and ISIS

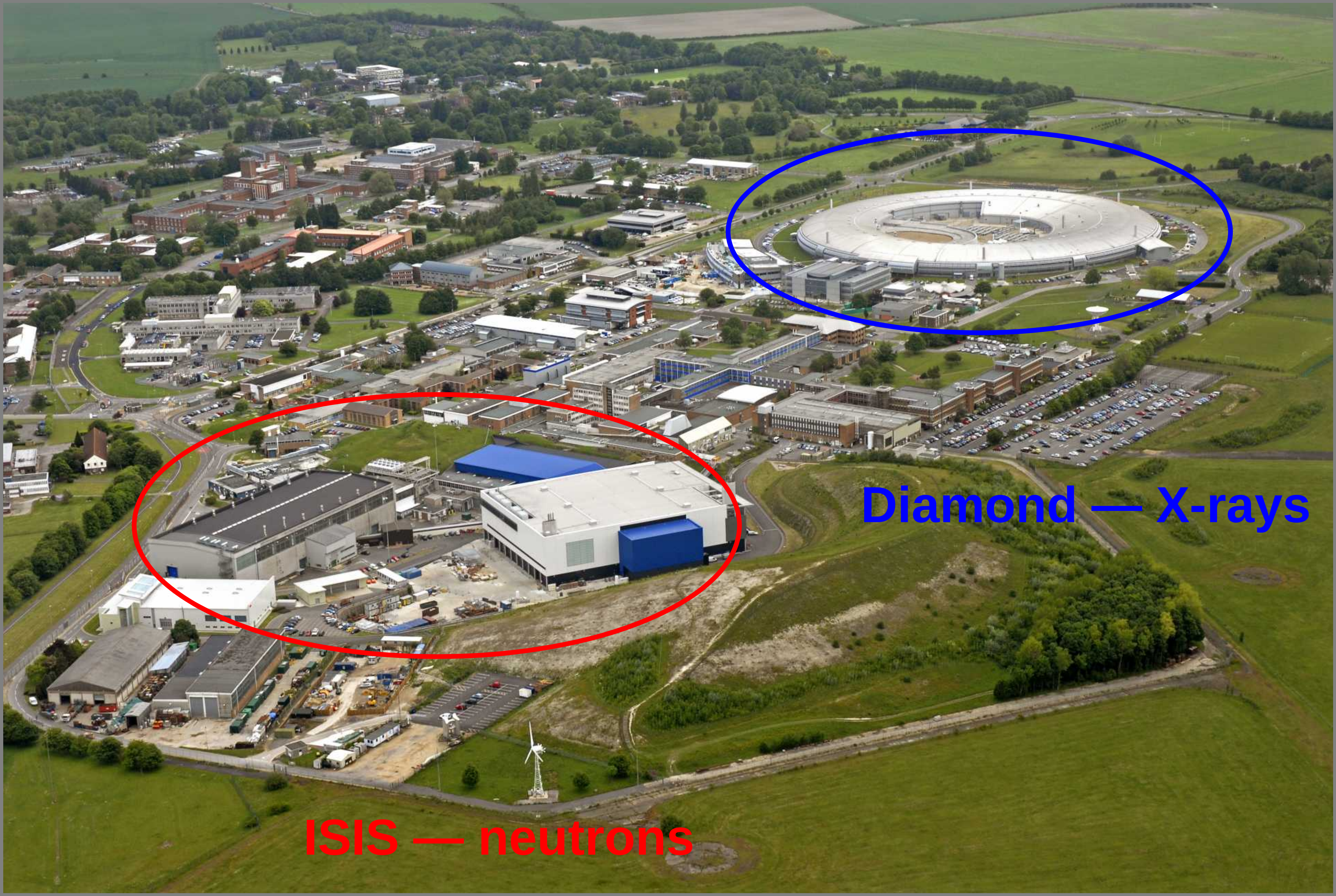


High-impact publications per instrument

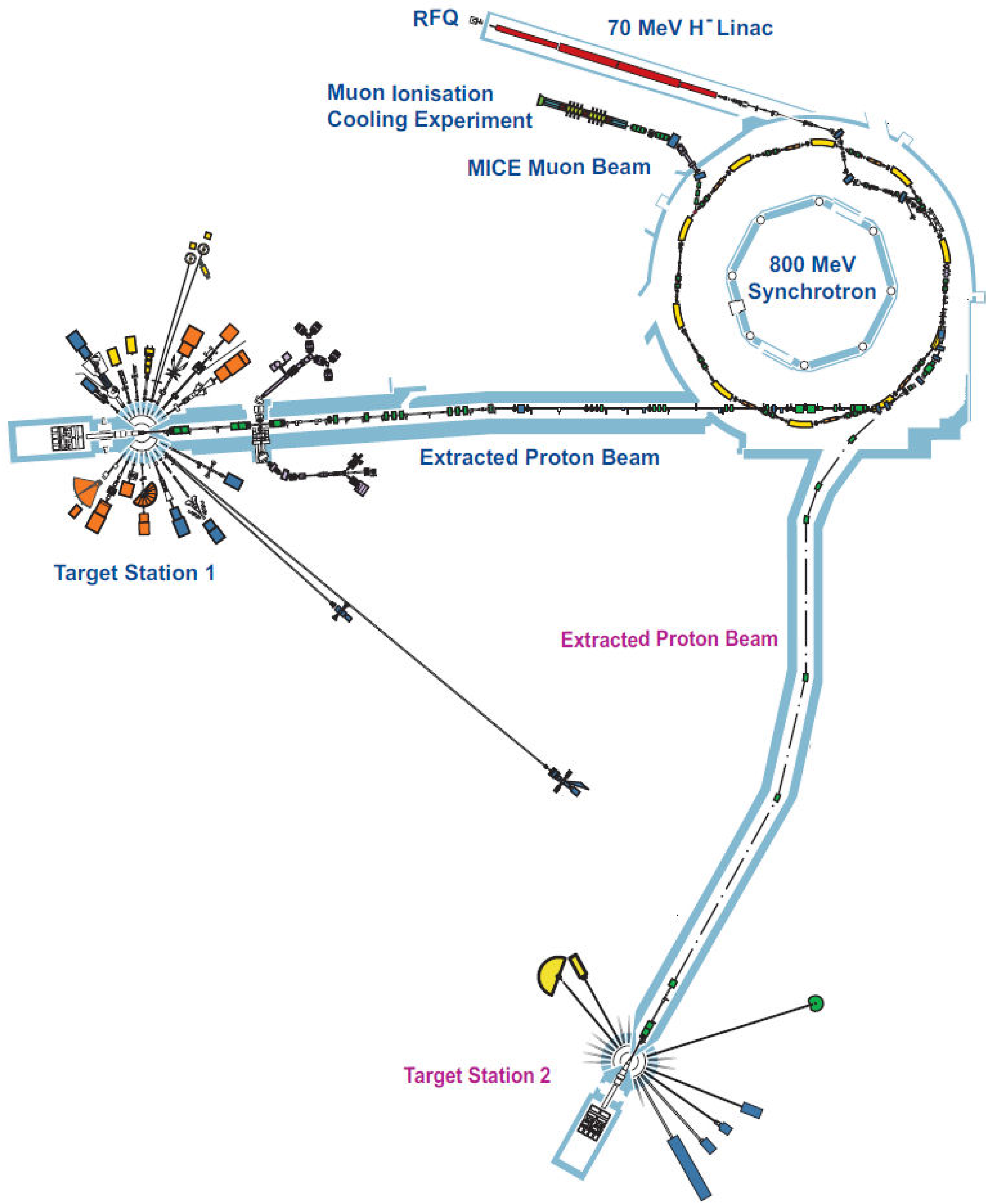


High-impact publications ÷ facility budget

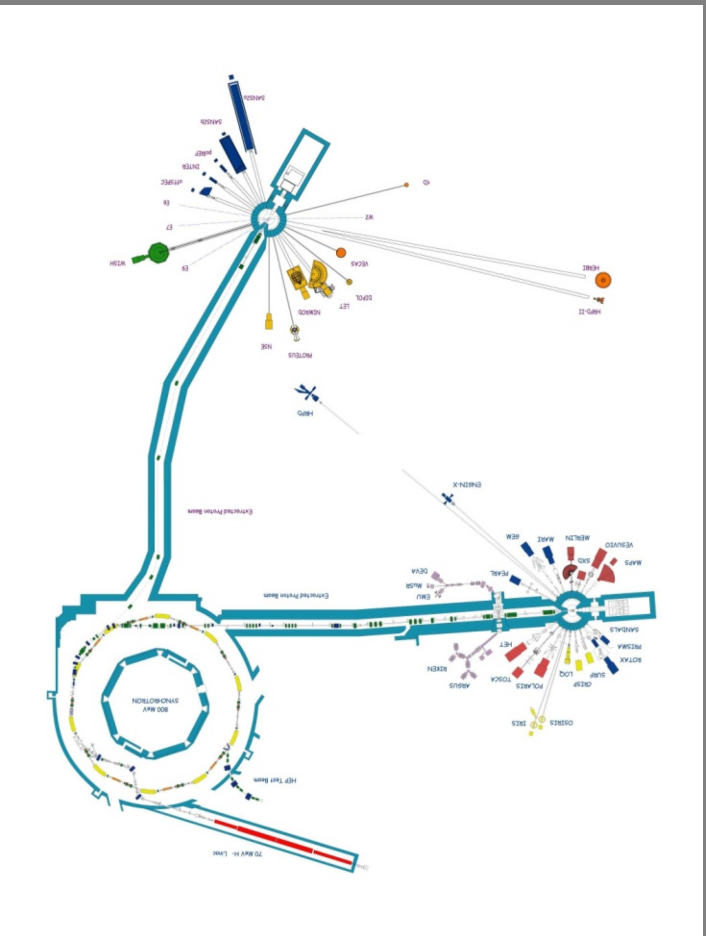
Average numbers of high-impact publications per year in 2008, 2009 and 2010: ISIS, 129; ILL, 162.



Rutherford Appleton Laboratory, Oxfordshire



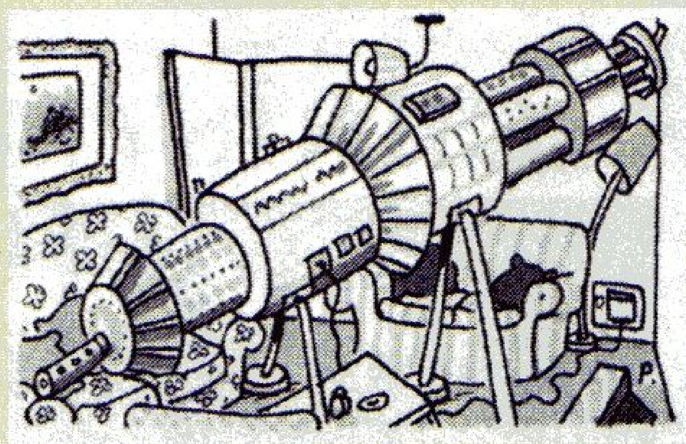
RFQ
70 MeV H$^-$ Linac
Muon Ionisation
Cooling Experiment
MICE Muon Beam
800 MeV
Synchrotron
Extracted Proton Beam
Target Station 1
Extracted Proton Beam
Target Station 2



ISIS from air

The Home Hadron Collider

Amazing scientific miniaturisation breakthrough allows you to discover the secrets of the universe in the privacy of your own home. Now you too can find the elusive Higgs Boson Particle!



- Self assembly
- Fits average size living room

Price €2billion

ISIS accelerators

Juvenile RFQ	
Venerable linac	
Mature synchrotron	~0.2 MW, 50 pps
Two target stations	40 pps to TS-1 10 pps to TS-2

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

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

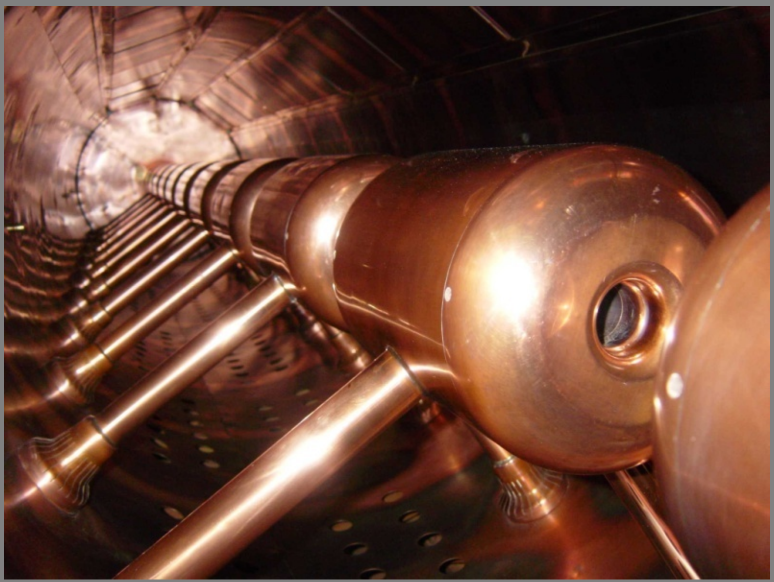
Synchrotron: 800 MeV proton, 50 Hz
5 µC each acceleration cycle
Dual harmonic RF system

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)

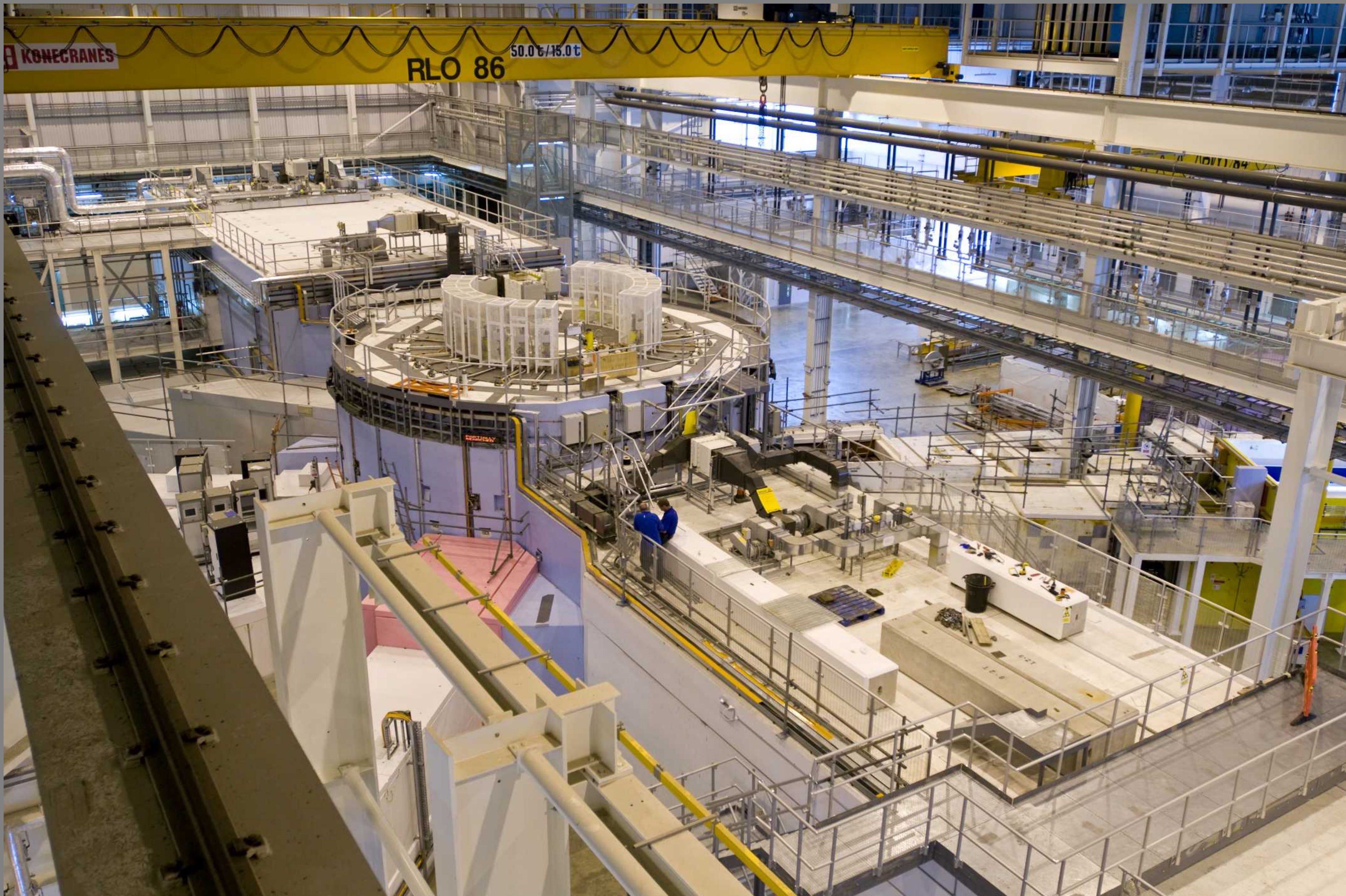
~340 staff



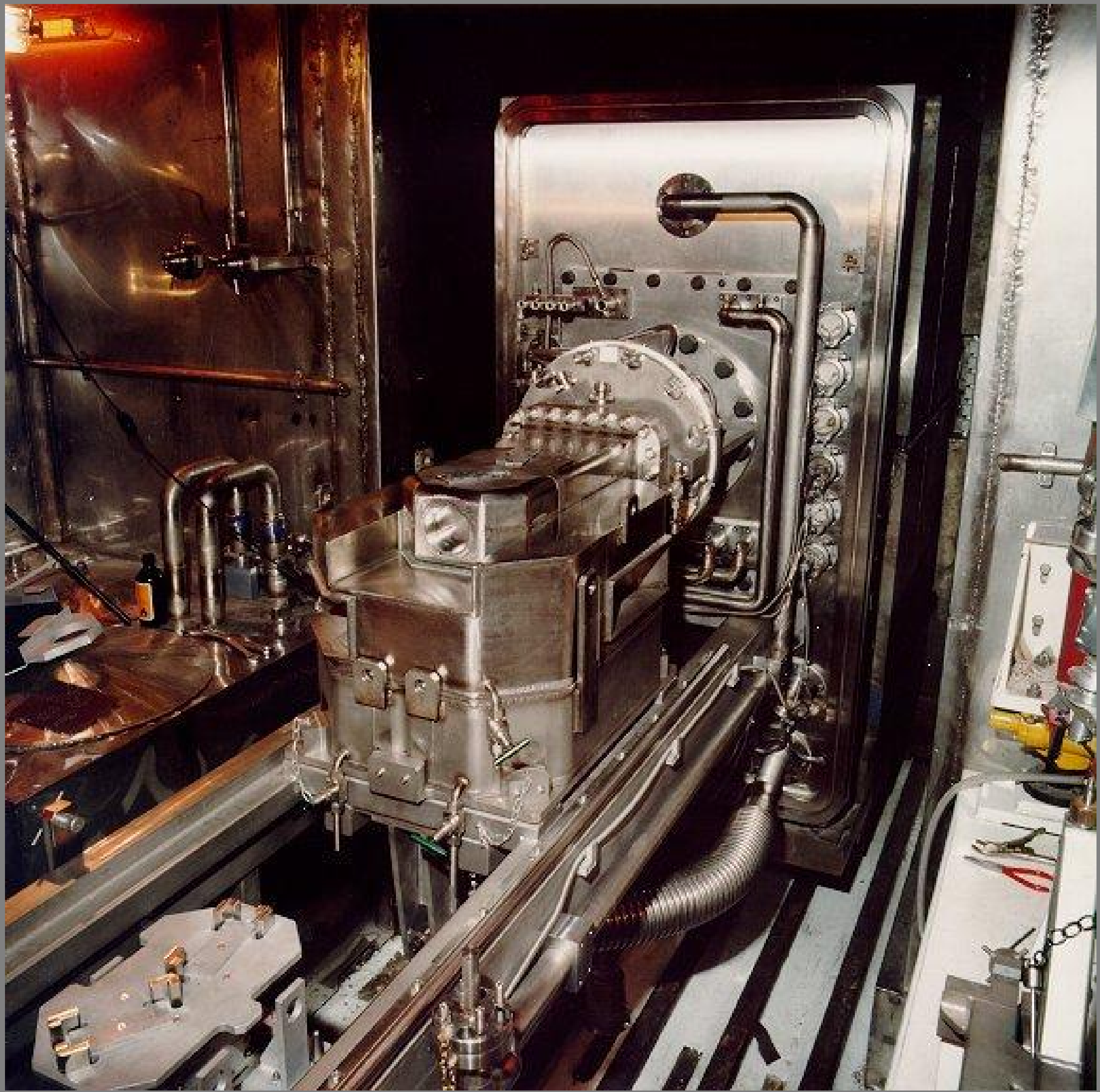
70 MeV 202 MHz 4-tank H⁻ linac

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

ISIS TS-1 experimental hall, 20 instruments



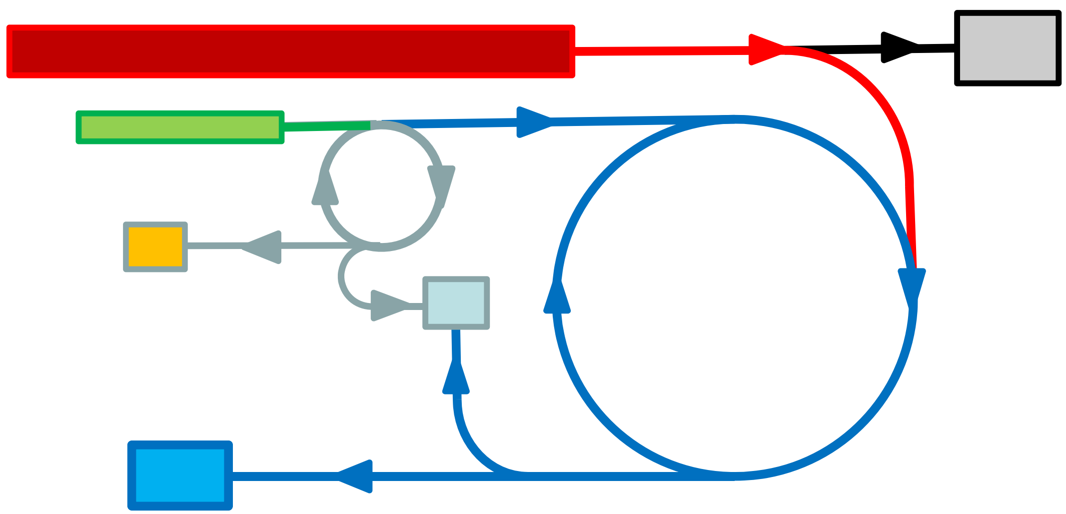
ISIS TS-2 experimental hall, 7 instruments + 4 under way

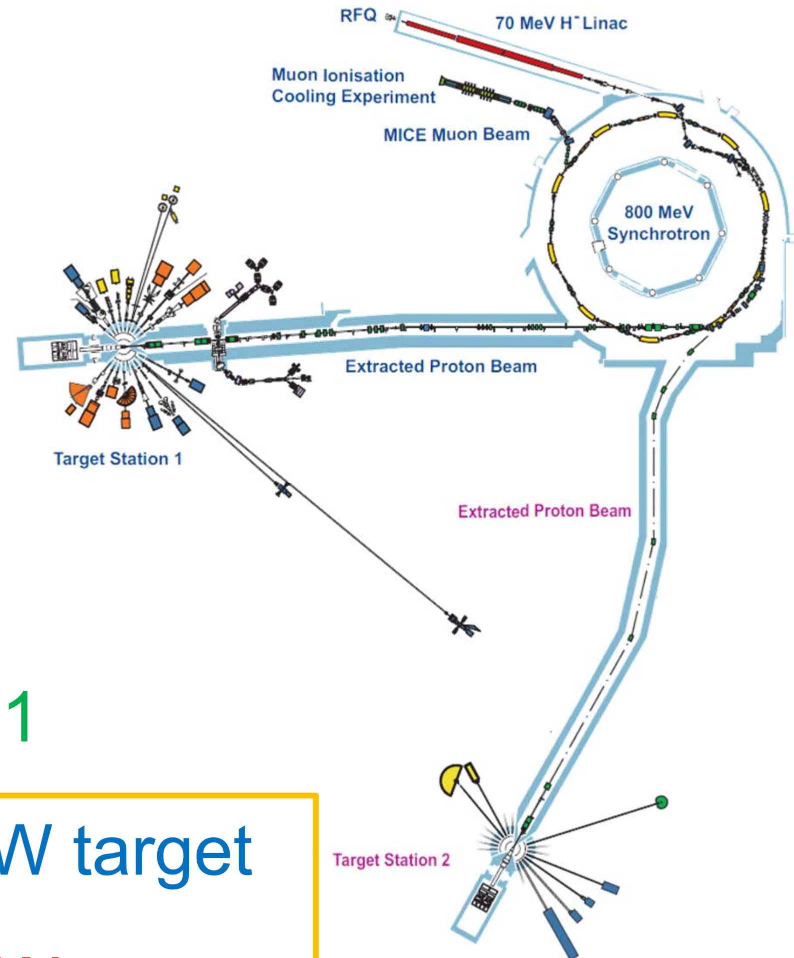


TS-1 tungsten target
(plate target)

TS-2 tungsten target (~solid cylinder)

ISIS Upgrades





0) Linac and TS-1 refurbishment

1) Linac upgrade, ~0.5 MW on TS-1

2) ~3 GeV booster synchrotron: MW target

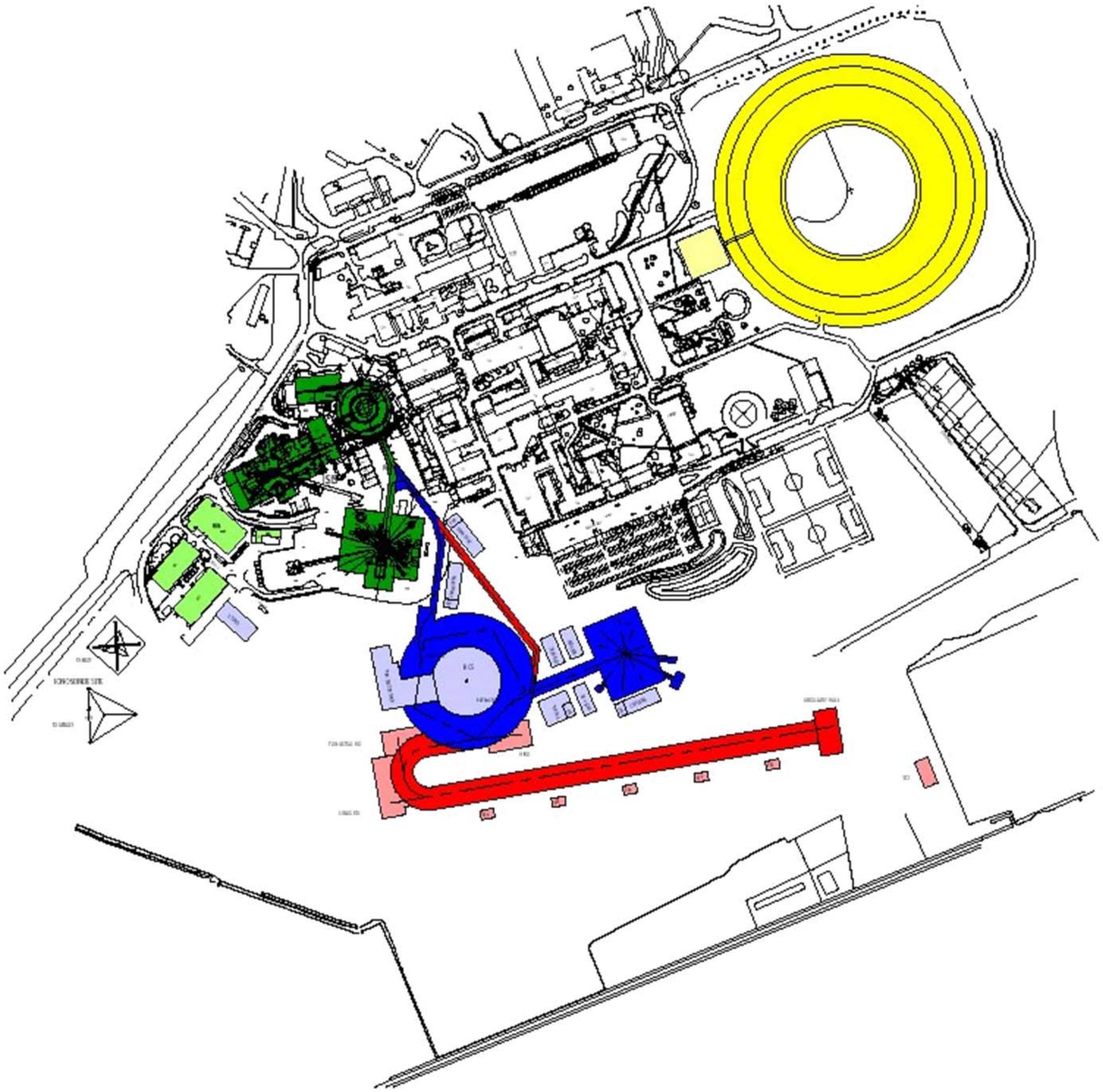
3) 800 MeV direct injection: 2–5 MW target

Overlap with NF proton driver

4) Upgrade 3) + long pulse mode option

Seen as one of four “big opportunities” for STFC

ISIS MW Upgrade Scenarios

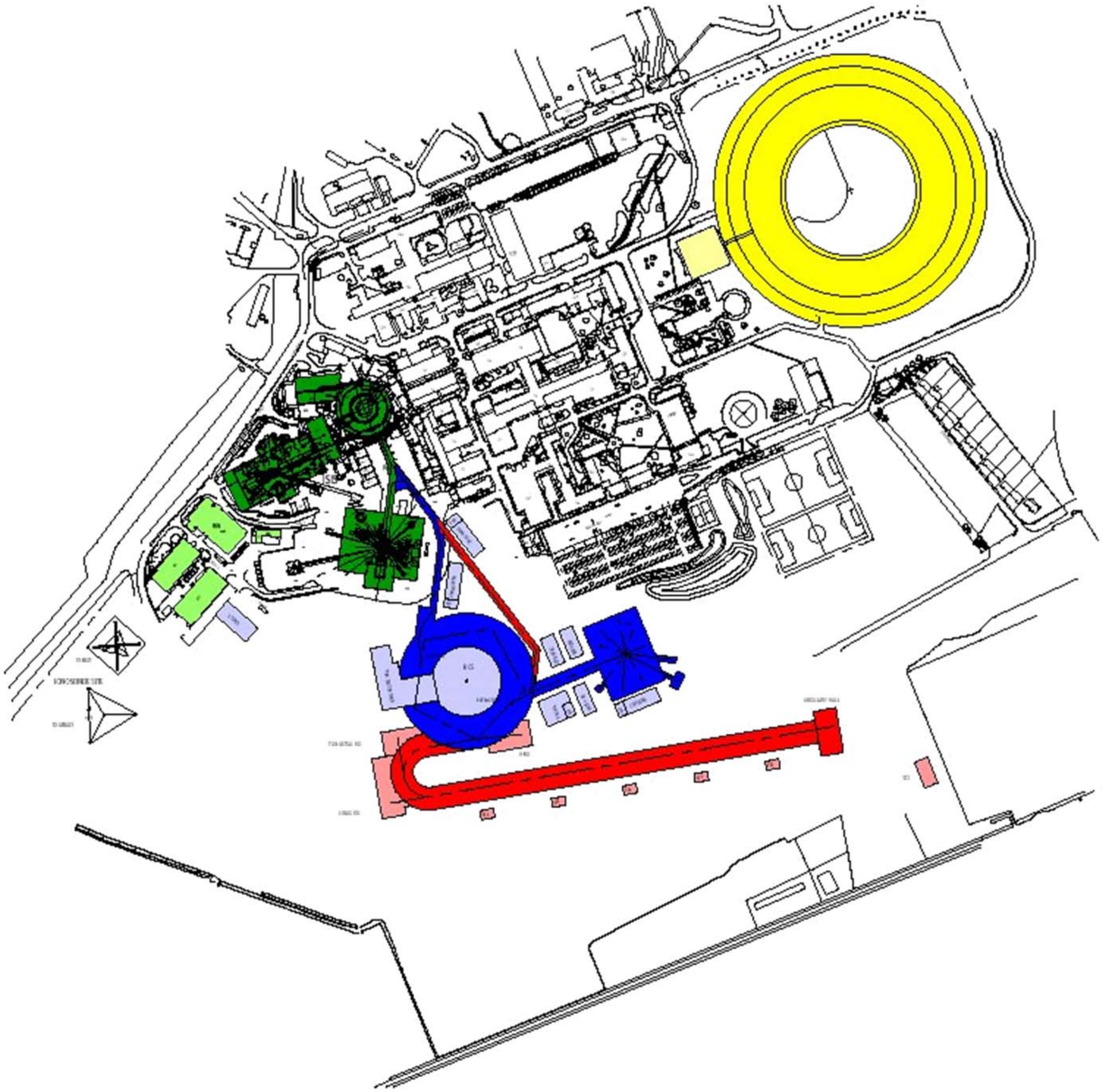


1) Replace 70 MeV ISIS linac by new ~180 MeV linac (~0.5 MW)

2) ~3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW, perhaps more)

3) Charge-exchange injection from 800 MeV linac (2 – 5 MW)

ISIS MW Upgrade Scenarios



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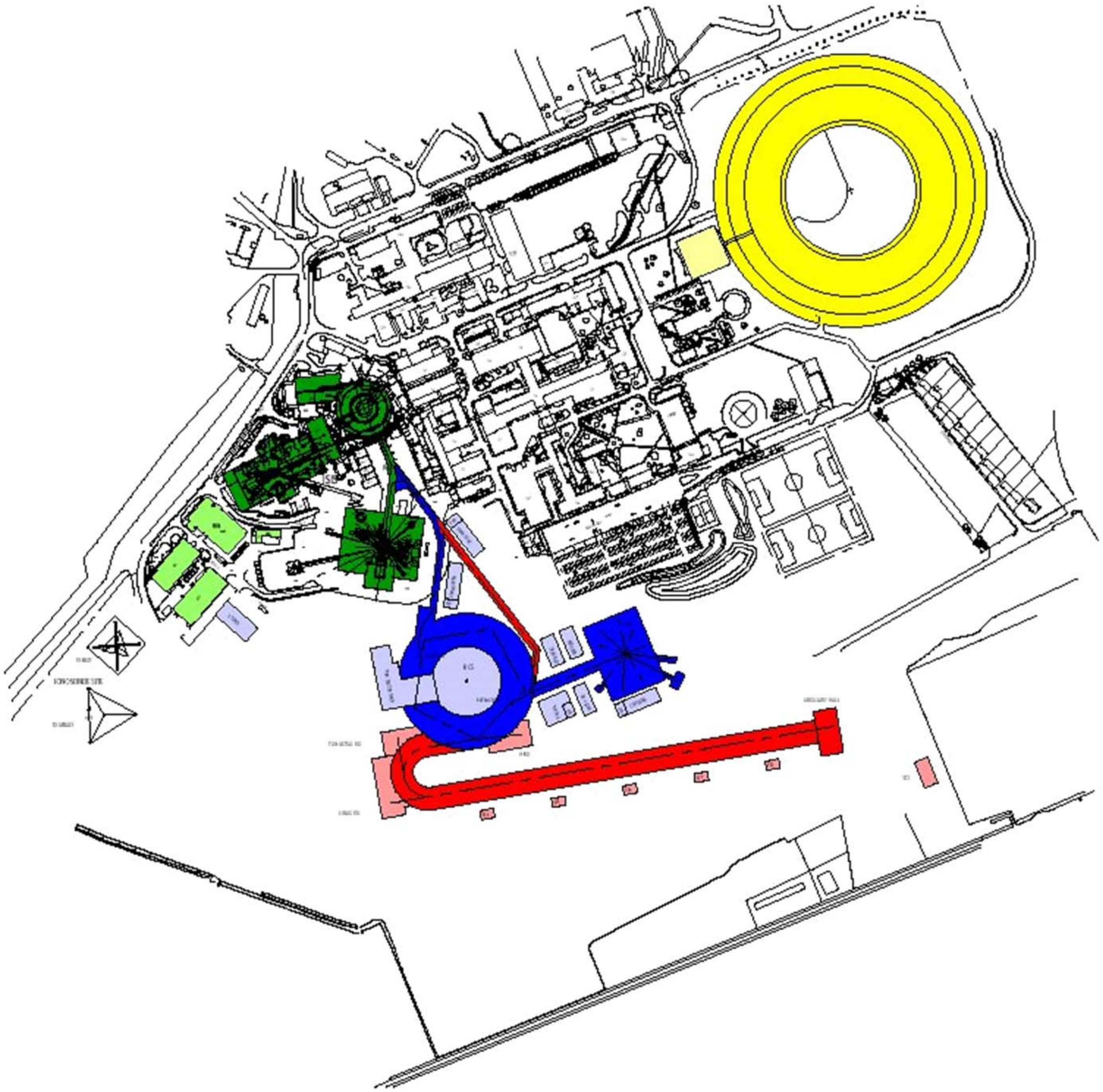


1) Replace ISIS 70 MeV linac by new ~180 MeV linac (~0.5 MW)

2) Based on a ≈ 3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW, perhaps more)

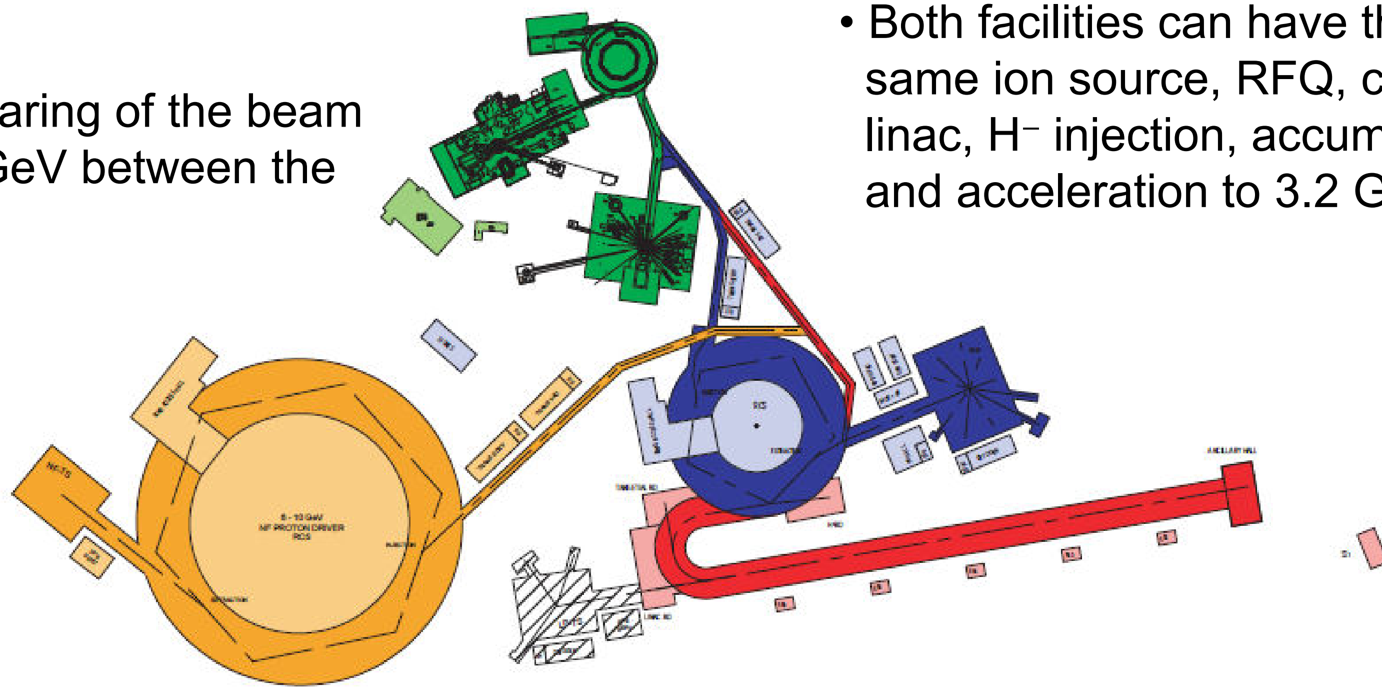
3) Charge-exchange injection from 800 MeV linac (2 – 5 MW)

More details: John Thomason's talk

Common proton driver for neutrons and neutrinos

- Based on MW ISIS upgrade with 800 MeV Linac and 3.2 GeV RCS

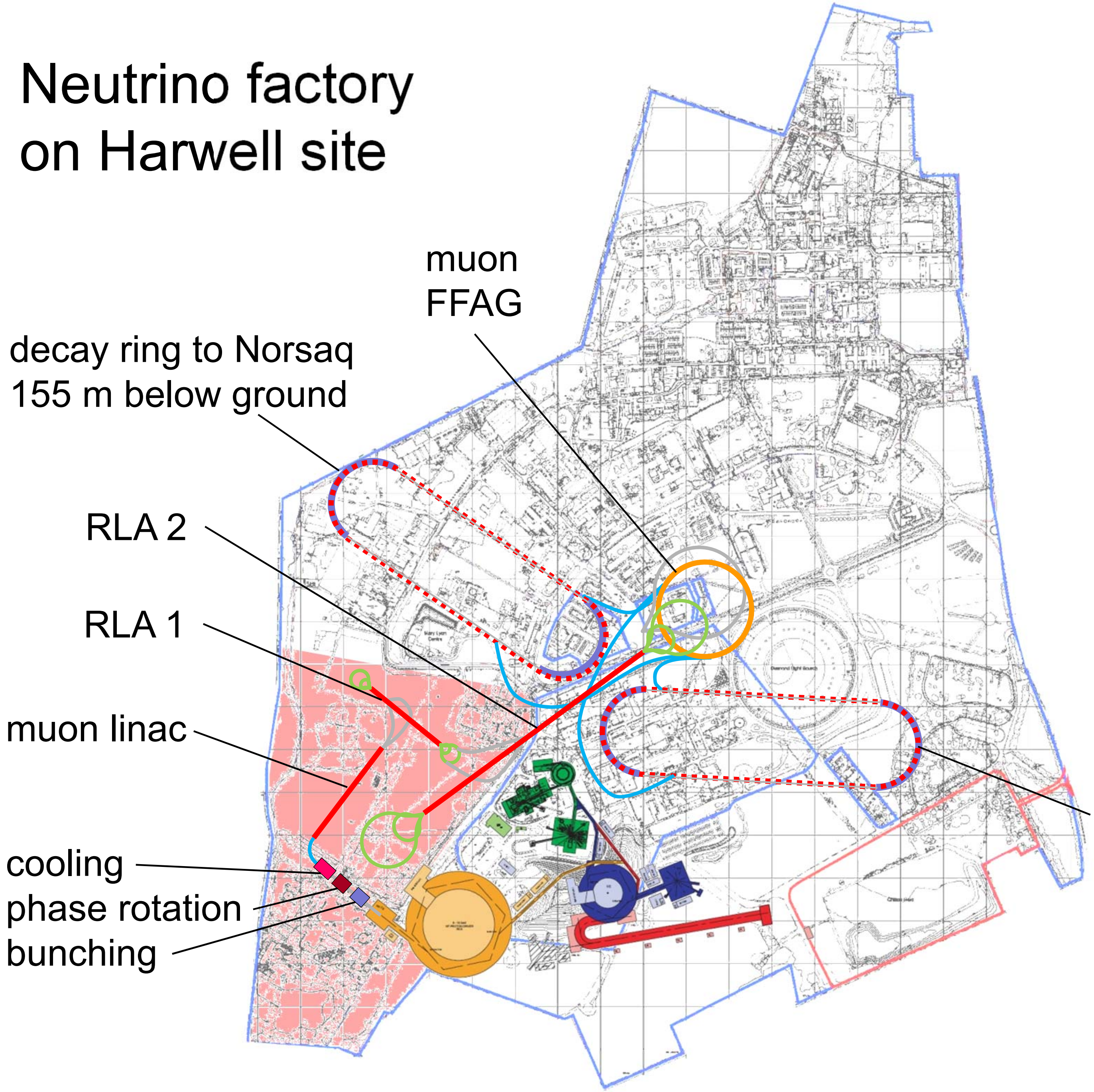
- Assumes a sharing of the beam power at 3.2 GeV between the two facilities



- Both facilities can have the same ion source, RFQ, chopper, linac, H⁻ injection, accumulation and acceleration to 3.2 GeV

- Requires additional RCS machine in order to meet the power and energy needs of the Neutrino Factory

Neutrino factory on Harwell site



- Extensive geological survey data available, but needs work to understand implications for deep excavation
- UKAEA land now not to be decommissioned until at least 2040 (unless we pay for it!)

ISIS upgrade option		Proton energy	Rep. rate	Mean current	Mean power	Neutrons *cf.* present
Linac + TS-1 refurb.	TS-1	800 MeV	40 pps	200 μA	0.16 MW	× 2
	TS-2	800 MeV	10 pps	50 μA	0.04 MW	× 1
Linac upgrade	TS-1	800 MeV	47 pps	552 μA	0.44 MW	× 4
	TS-2	800 MeV	3 pps	48 μA	0.04 MW	× 1
3.2 GeV synch.	TS-3	3.2 GeV	48 pps	308 μA	0.98 MW	× 6
	TS-2	3.2 GeV	2 pps	13 μA	0.04 MW	× 1
800 MeV ch. exch. inj.	TS-3	3.2 GeV	49 pps	1177 μA	3.77 MW	× 12
	TS-2	3.2 GeV	1 pps	24 μA	0.08 MW	× 2
	TS-3	*3.2 GeV*	*48 pps*	*1153 μA*	*3.69 MW*	× *12*
	TS-2	*800 MeV*	*2 pps*	*48 μA*	*0.04 MW*	× *1*

Useful neutrons scale less than linearly with power

ISIS upgrade option		Proton energy	Energy per pulse	Range in W	Beam diameter	°C in target per pulse
Linac + TS-1 refurb.	TS-1	800 MeV	3.2 kJ	23 cm	6 cm	1.8
	TS-2	800 MeV	3.2 kJ	23 cm	3 cm	7.3
Linac upgrade	TS-1	800 MeV	9.6 kJ	23 cm	6 cm	5.4
	TS-2	800 MeV	9.6 kJ	23 cm	3 cm	22
3.2 GeV synch.	TS-3	3.2 GeV	20kJ	130 cm	8 cm	1.2
	TS-2	3.2 GeV	20kJ	130 cm	3 cm	8.3
800 MeV ch. exch. inj.	TS-3	3.2 GeV	77 kJ	130 cm	8 cm	4.4
	TS-2	3.2 GeV	77 kJ	130 cm	3 cm	31
	TS-3	*3.2 GeV*	*77 kJ*	130 cm	8 cm	*4.4*
	TS-2	*800 MeV*	*19 kJ*	23 cm	3 cm	*44*

Beam area × range, density, specific heat — *very* approximate

Let N_f (neutrons/s) be fast neutron source strength,

let P (kW) be proton beam power,

let r_t (cm) be characteristic dimension of fast-neutron-producing target,

let ϕ (neutrons/cm²/s) be fast flux intercepted by moderator,

assume N_i (neutrons/s) to be number of neutrons useful for neutron beam line instruments,

and assume volume of fast-neutron-producing target to scale with power (*i.e.* there is a limiting watts/cm³ for removing heat).

Then, very approximately,

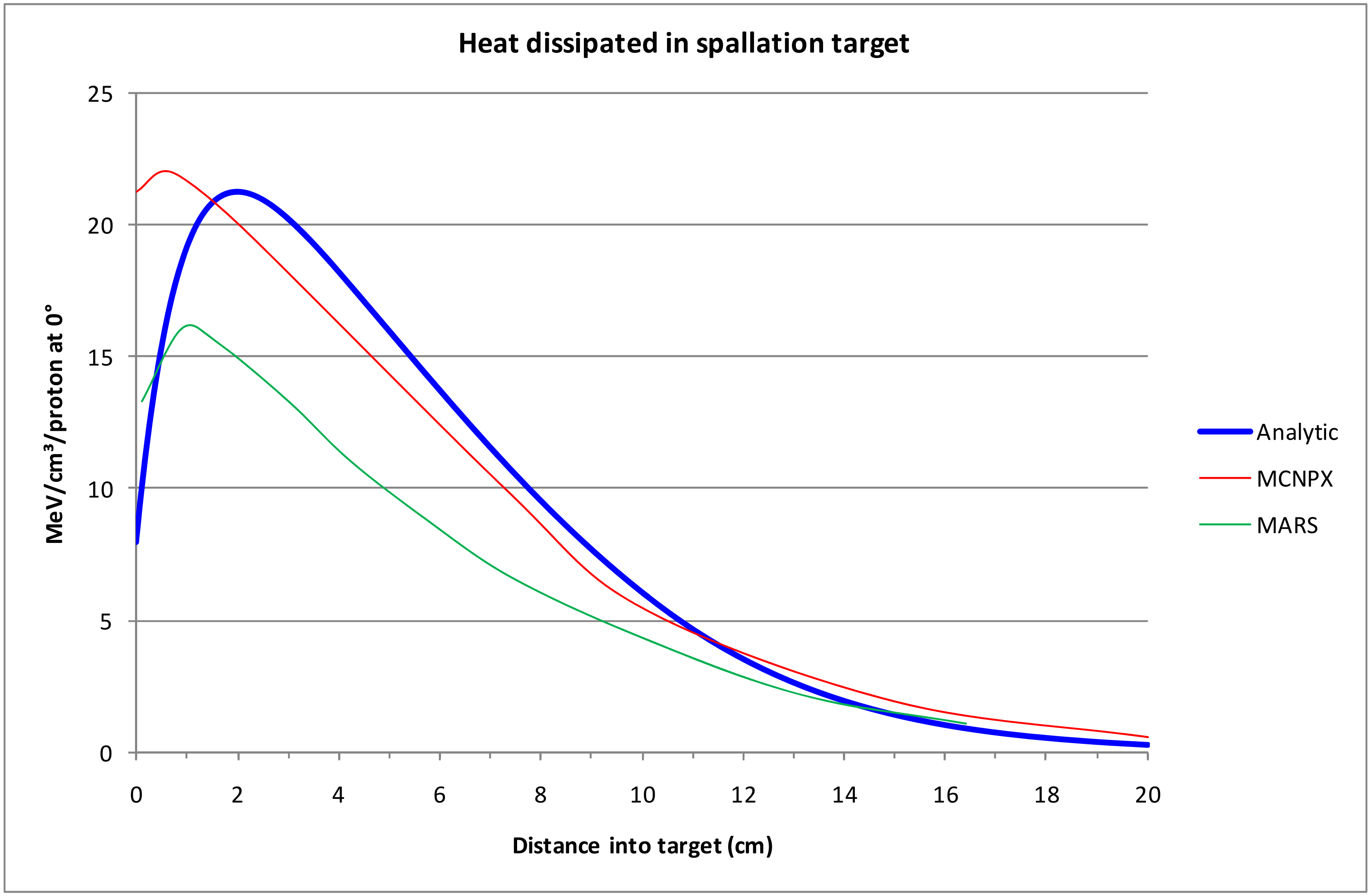
$N_f \propto P$,

$r_t \propto P^{1/3}$,

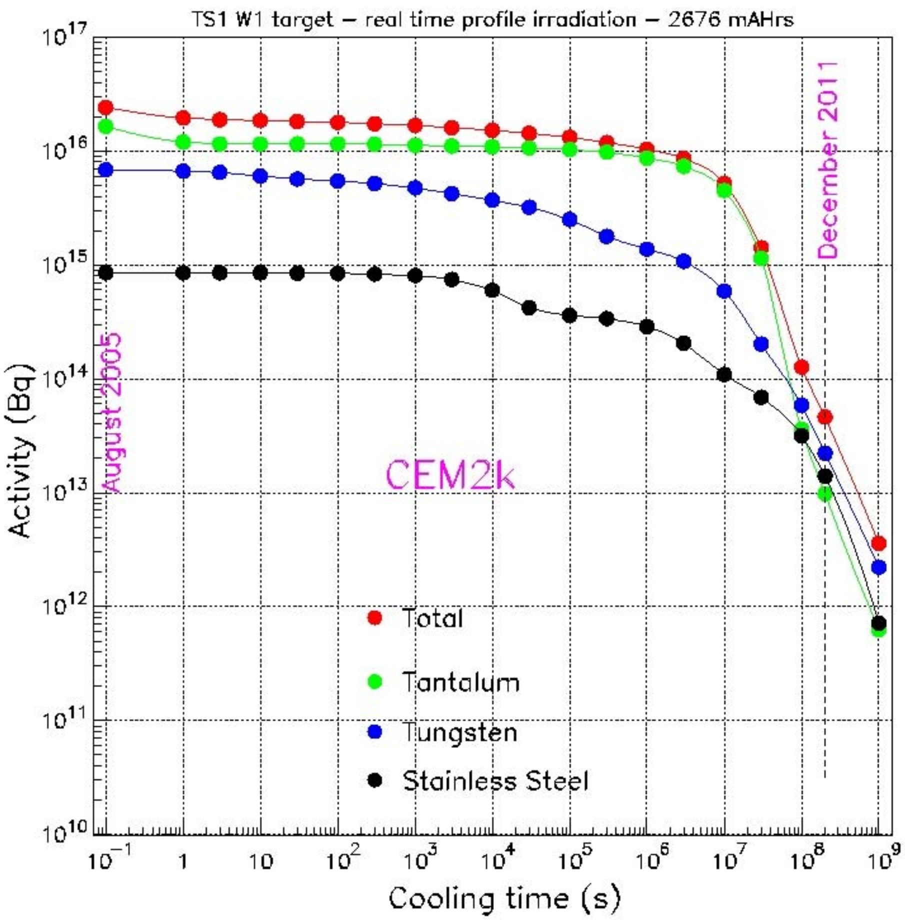
$\phi \propto N_f / r_t^2$,

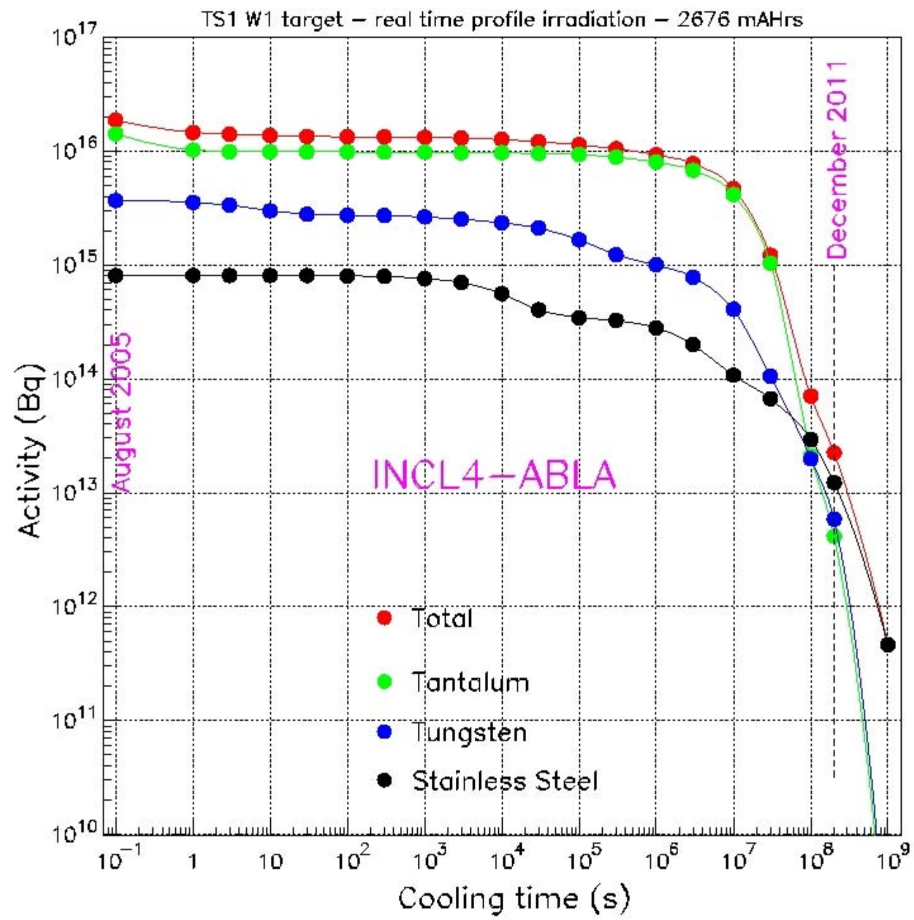
$N_i \propto \phi$,

and so $N_i \propto P/(P^{1/3})^2 = P^{1/3}$



Simple three-dimensional analytic model of heat dissipated in target





Activities of ISIS tungsten target removed in 2005

Summary

Staged set of upgrades

Lot of design work being done [other WG]

We’ll certainly upgrade TS-1 — scenario 0

Linac upgrade (to ~0.5 MW) possible nationally

Higher powers internationally

Interested in establishing limits for solid targets

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STFC's four "big opportunities"

HiPER [1]

Square Kilometre Array (SKA) [2]

Free Electron Light Source

ISIS Upgrades

[1] European **Hi**gh **P**ower laser **E**nergy **R**esearch facility

[2] 3000 dishes each 15 m in diameter

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

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Target Upgrade TS1

Matt Fletcher
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Rutherford Appleton Laboratory / STFC

Proton Accelerators for Science and Innovation, 12–14 January 2012, FNAL

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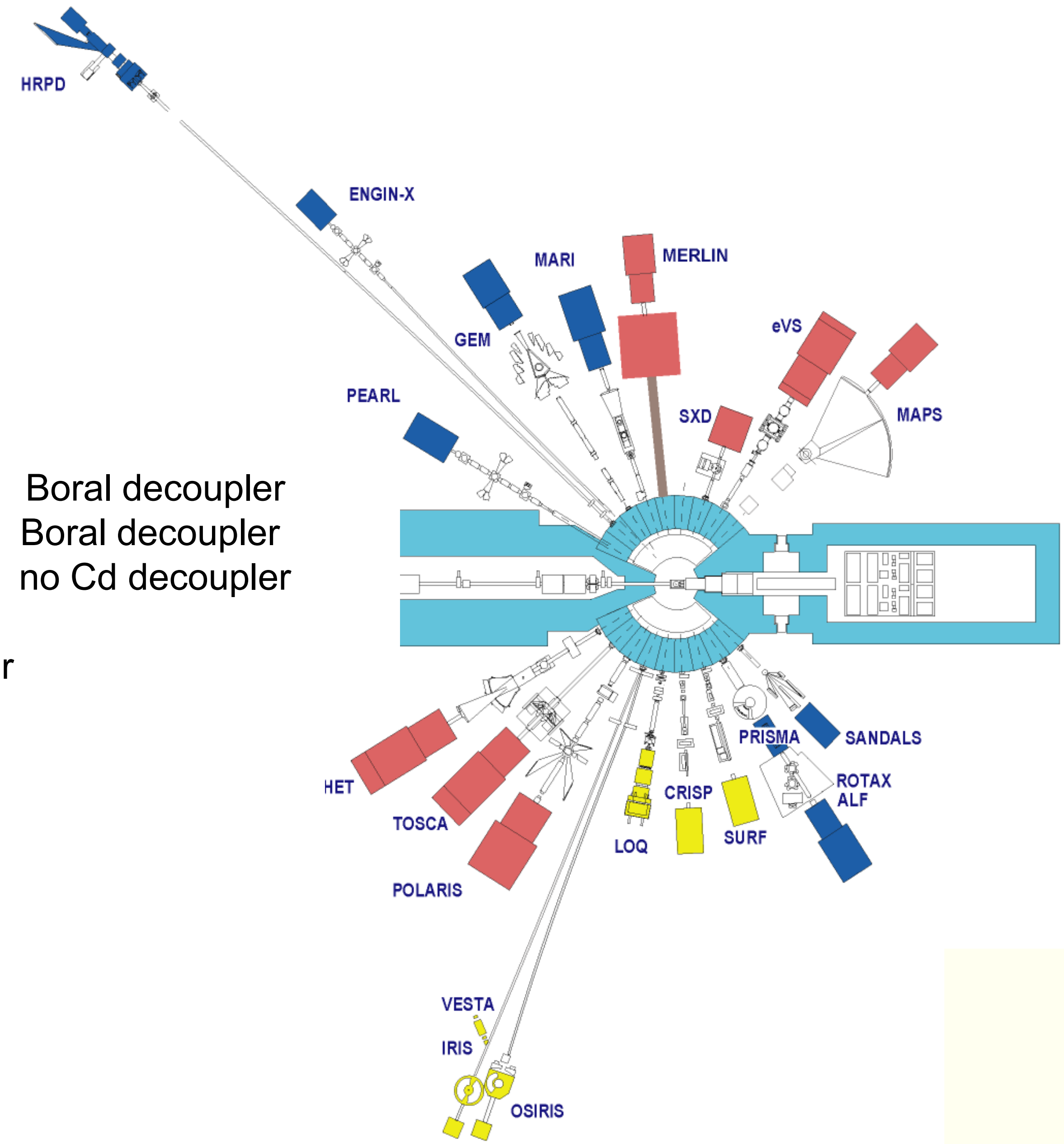
- Tungsten target D_2O cooled
- Moderators
  - H_2O 0.5 l Gd poison Boral decoupler
  - CH_4 0.5 l Gd poison Boral decoupler
  - H_2 0.8 l no poison no Cd decoupler
- Beryllium (D_2O cooled) reflector
- 18 Neutron Beam Holes



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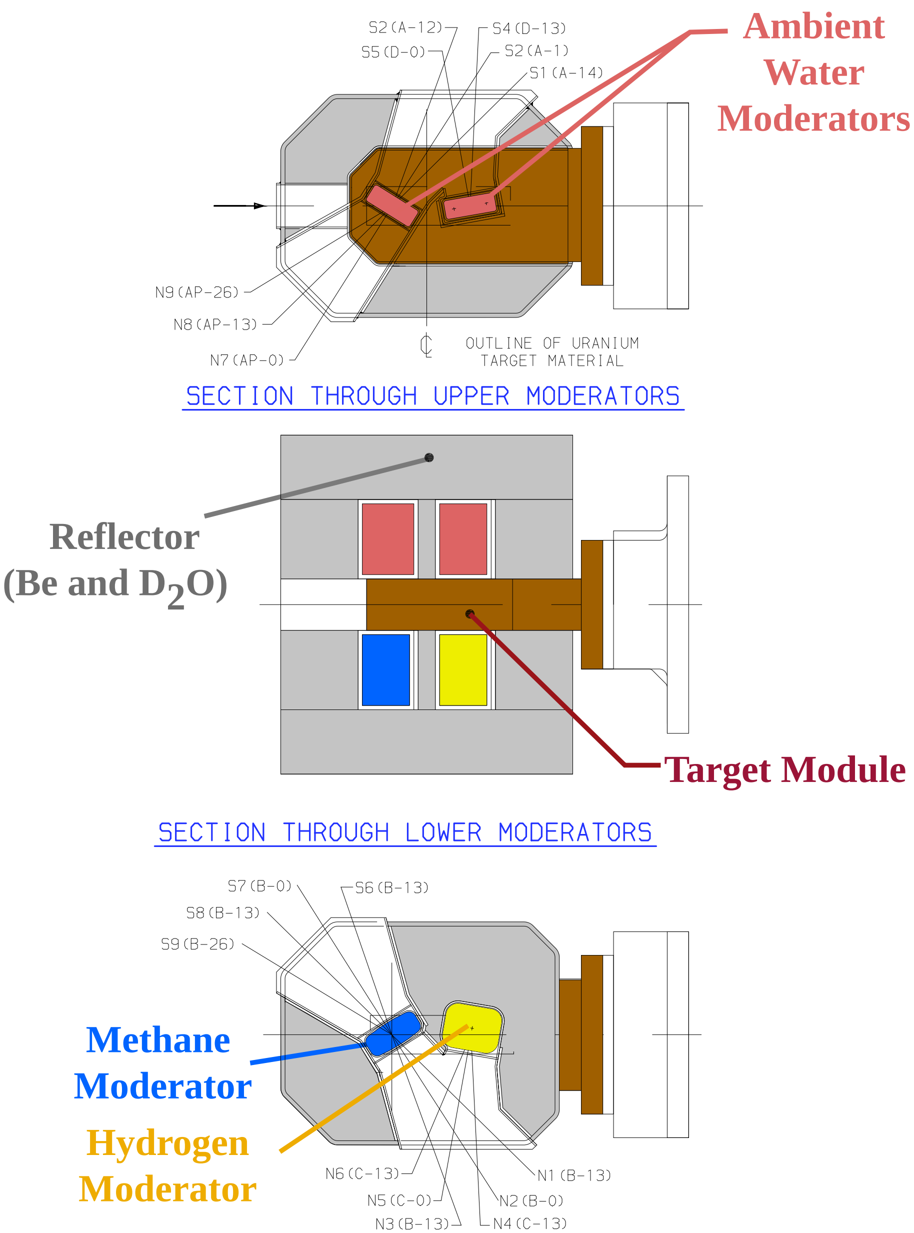

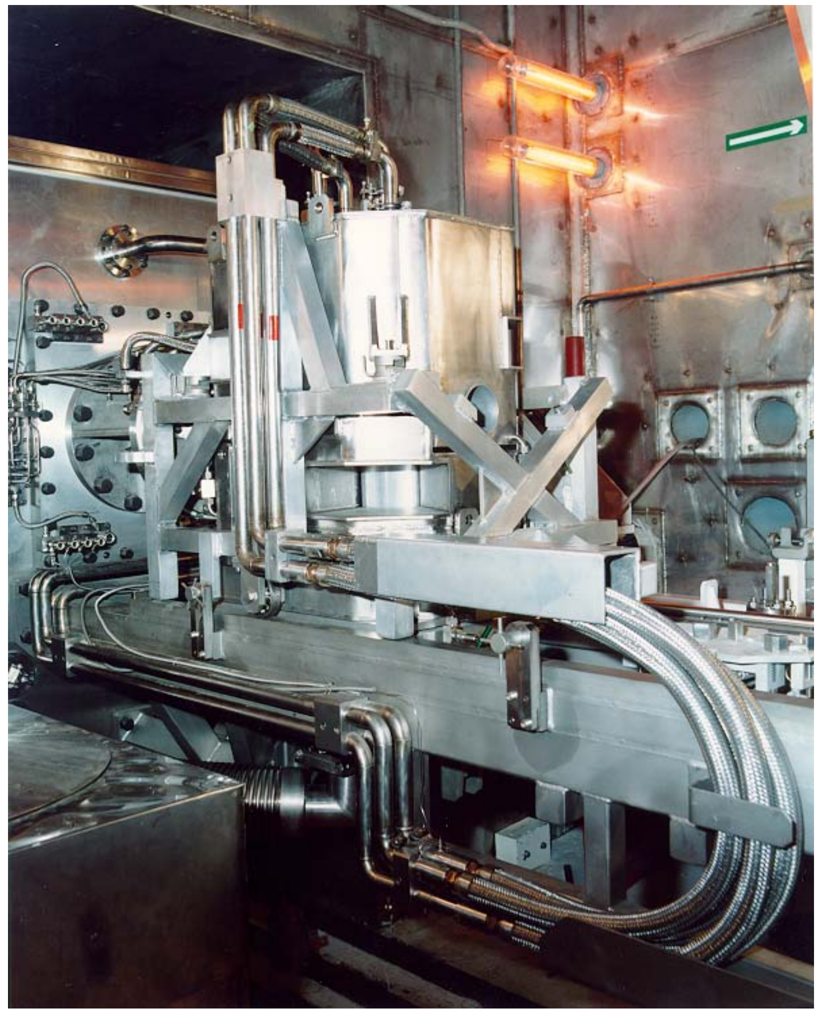

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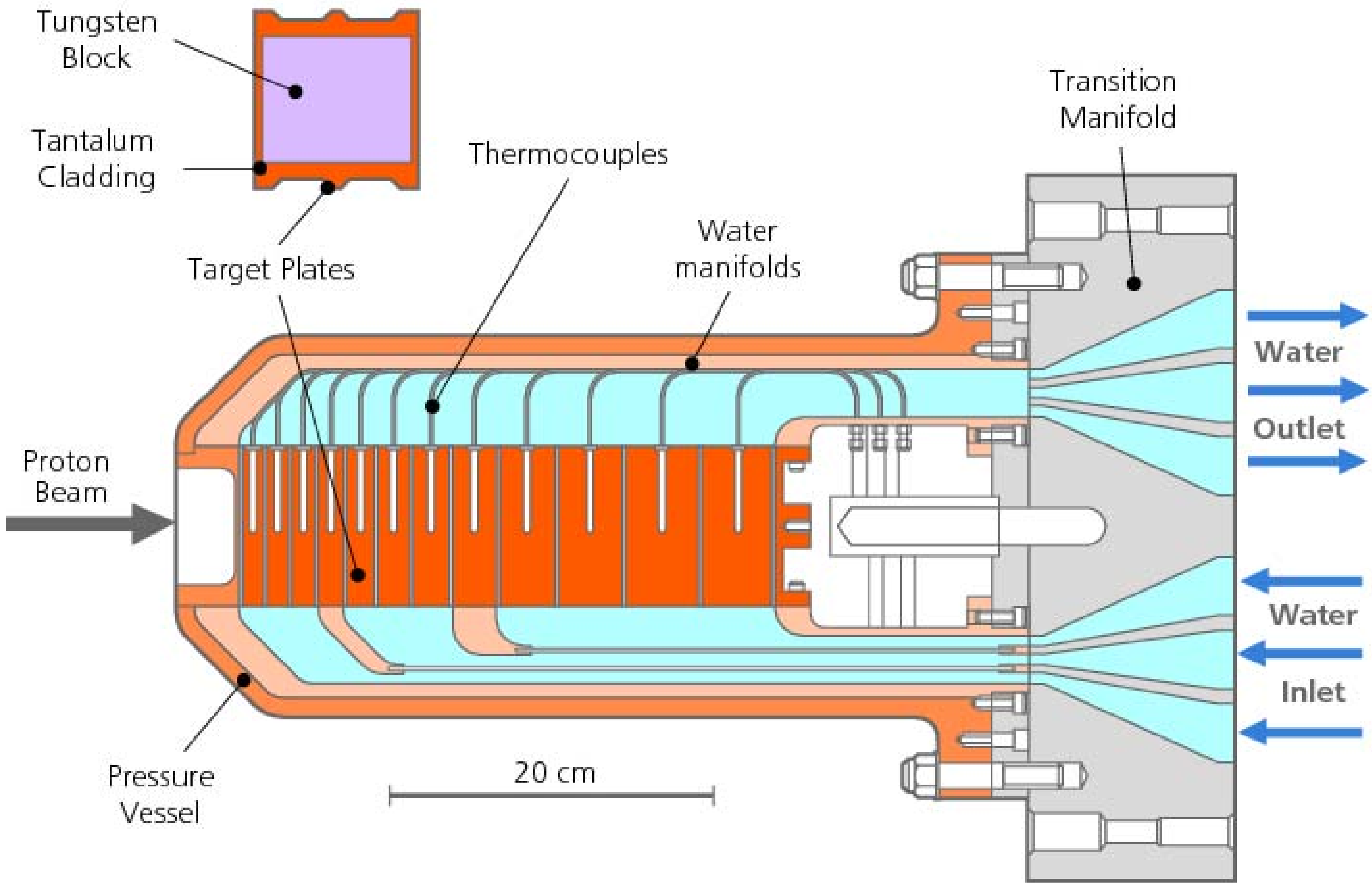

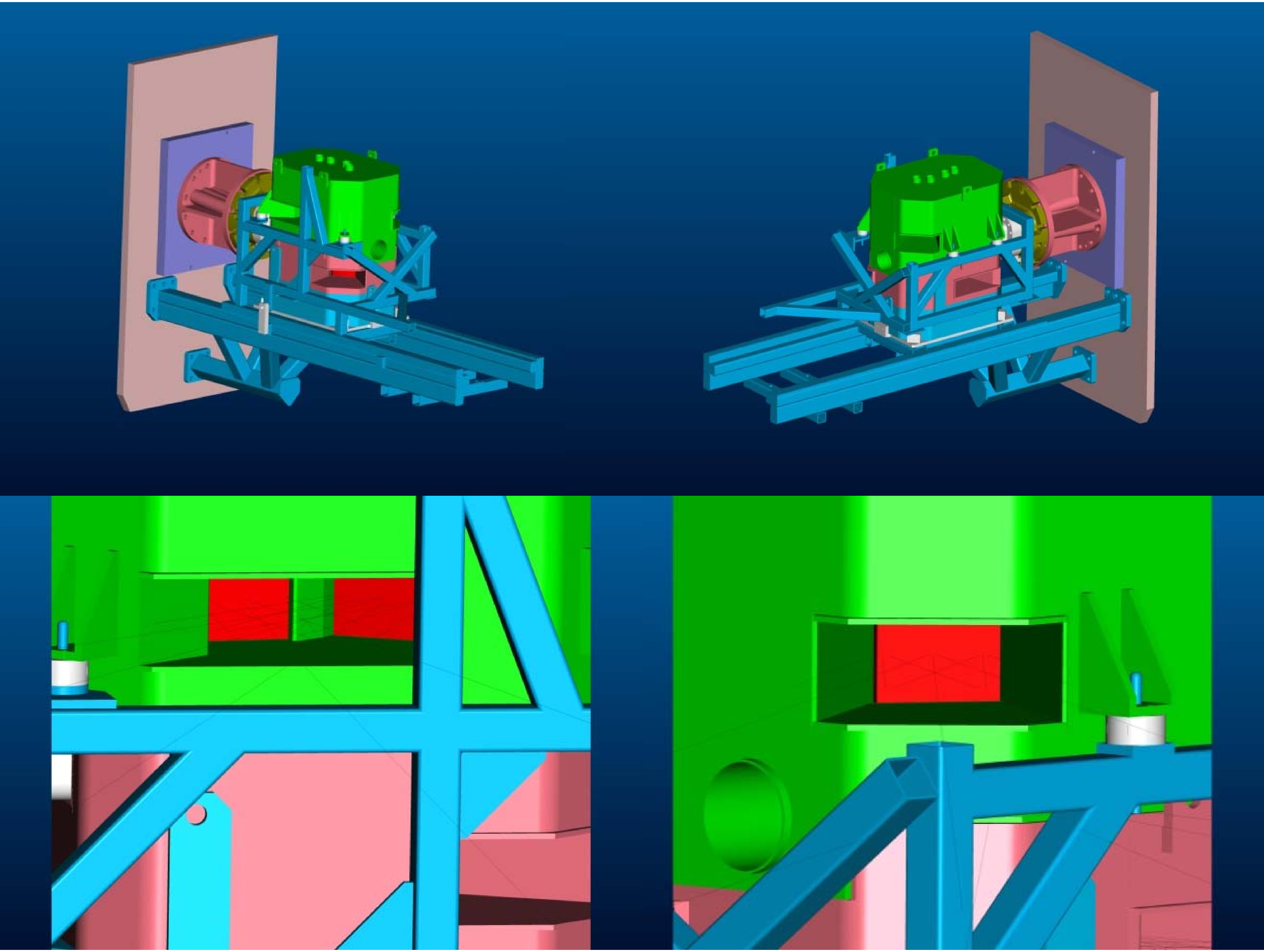

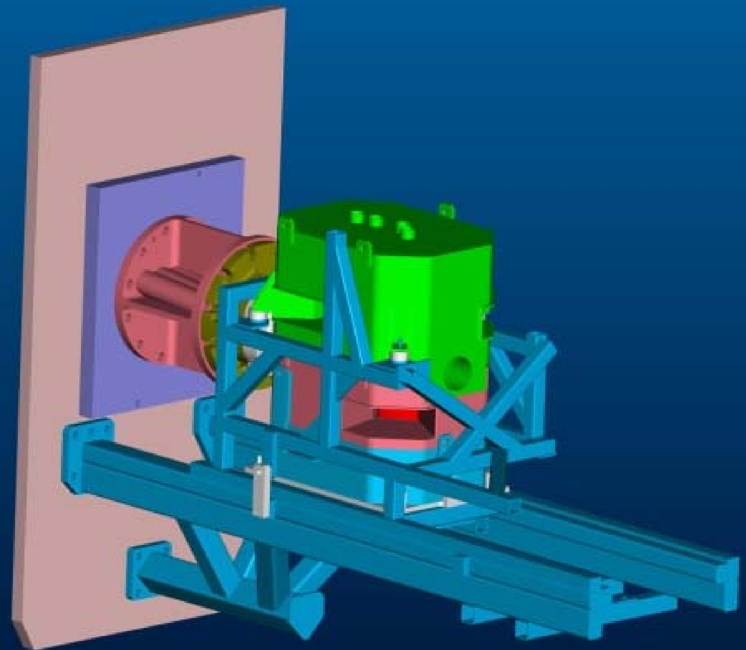
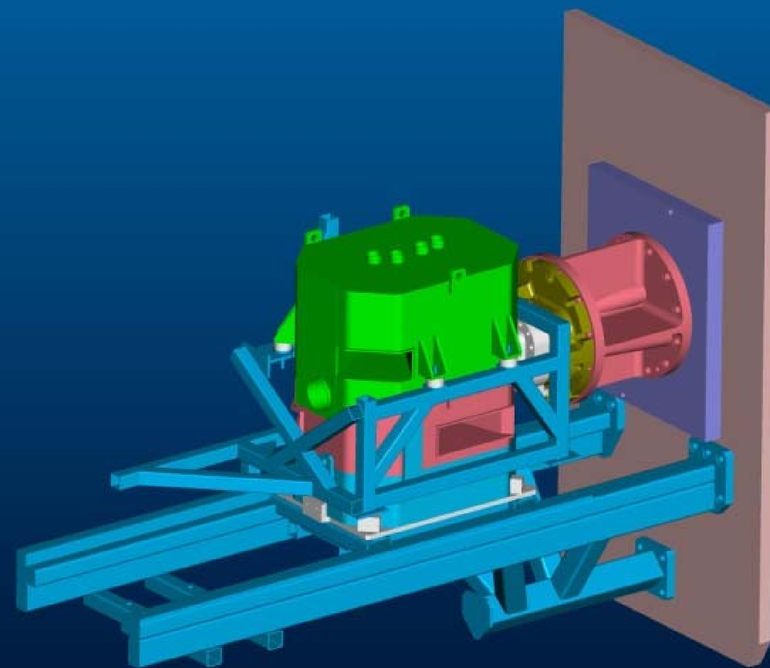
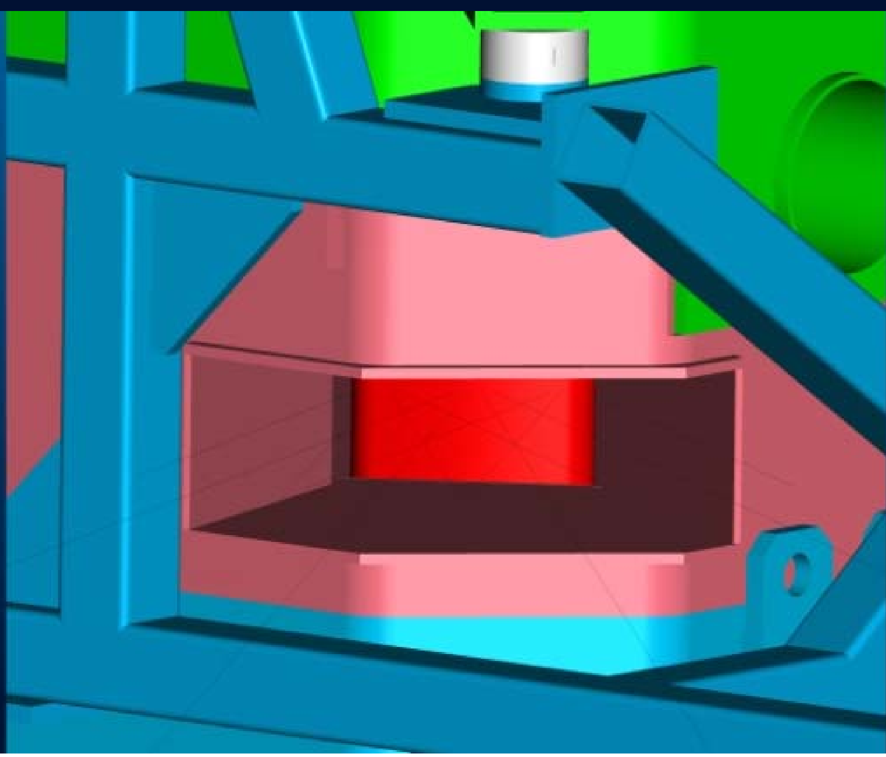
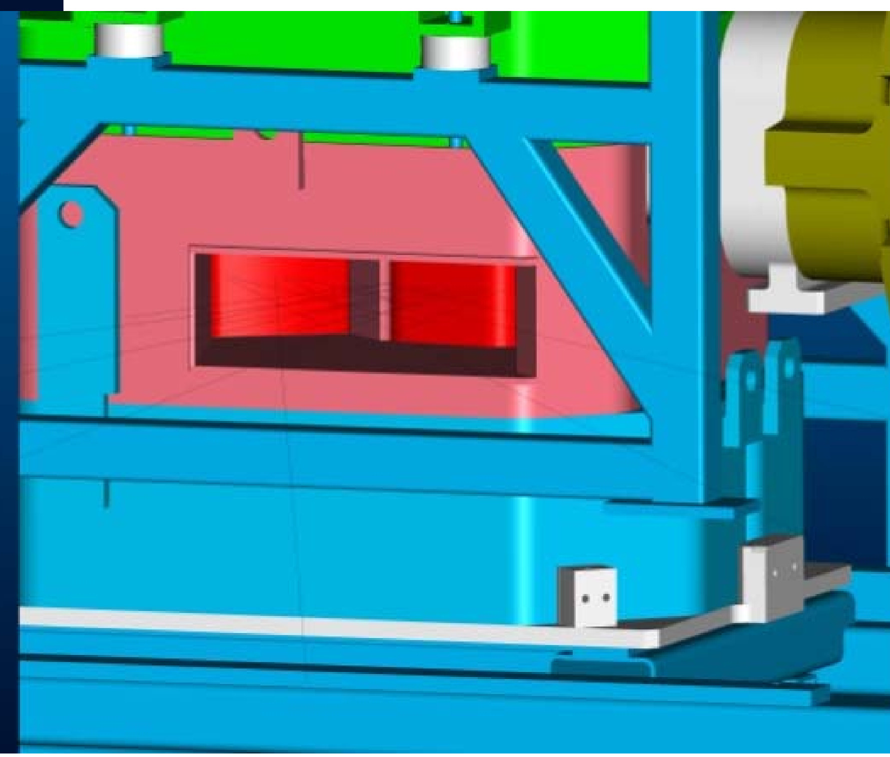

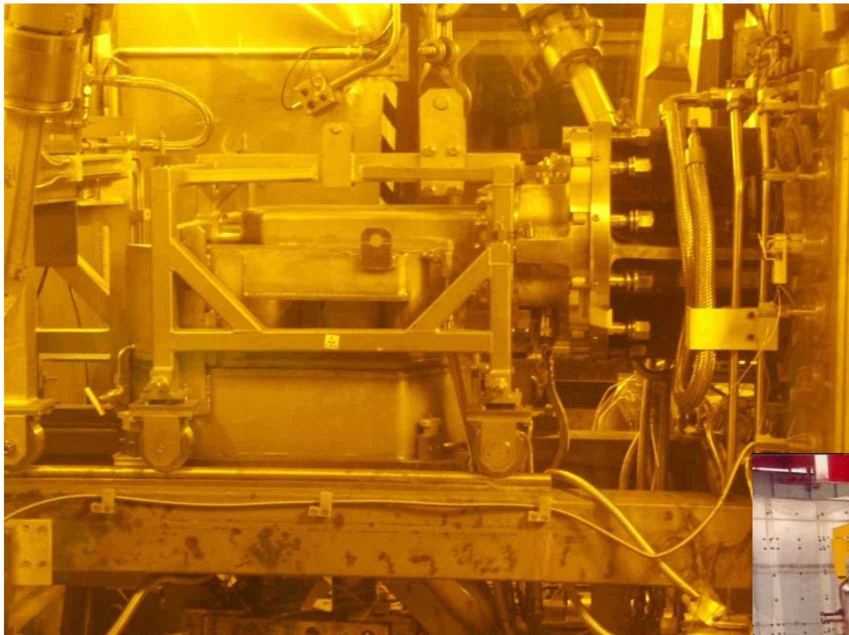

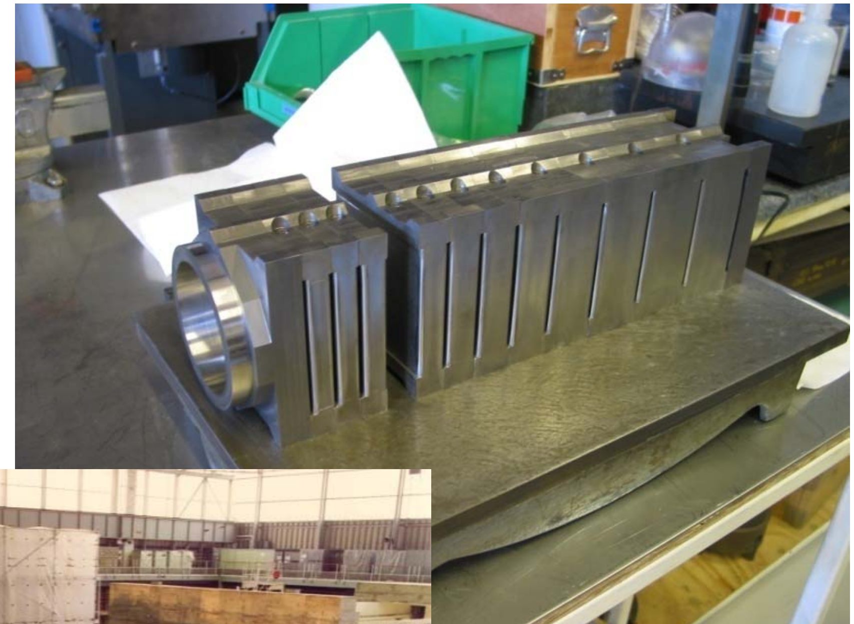

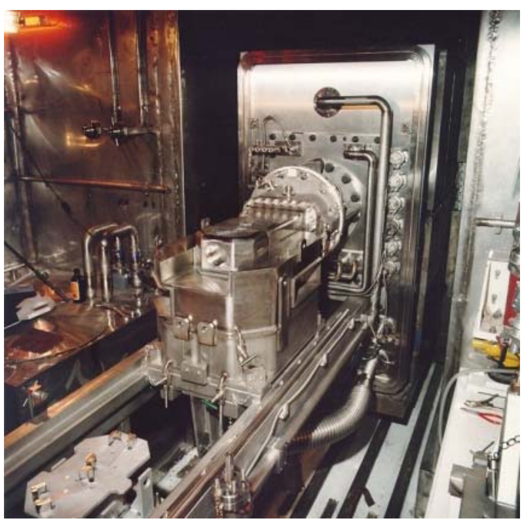

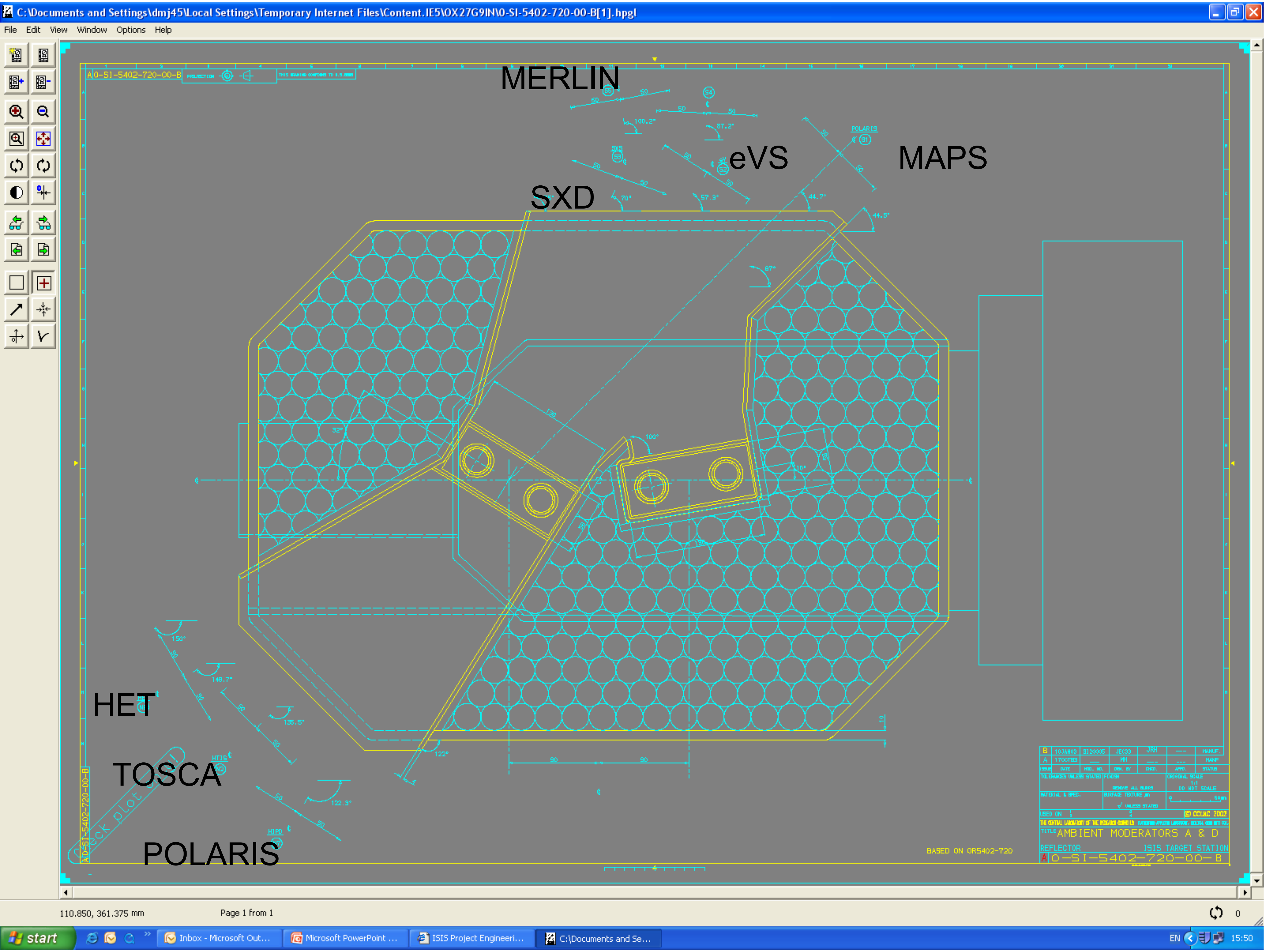
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A 0-SI-5402-720-00-B
BASED ON OR5402-720
AMBIENT MODERATORS A & D
REFLECTOR
ISIS TARGET STATION
A 0-SI-5402-720-00-B
110.850, 361.375 mm
Page 1 from 1
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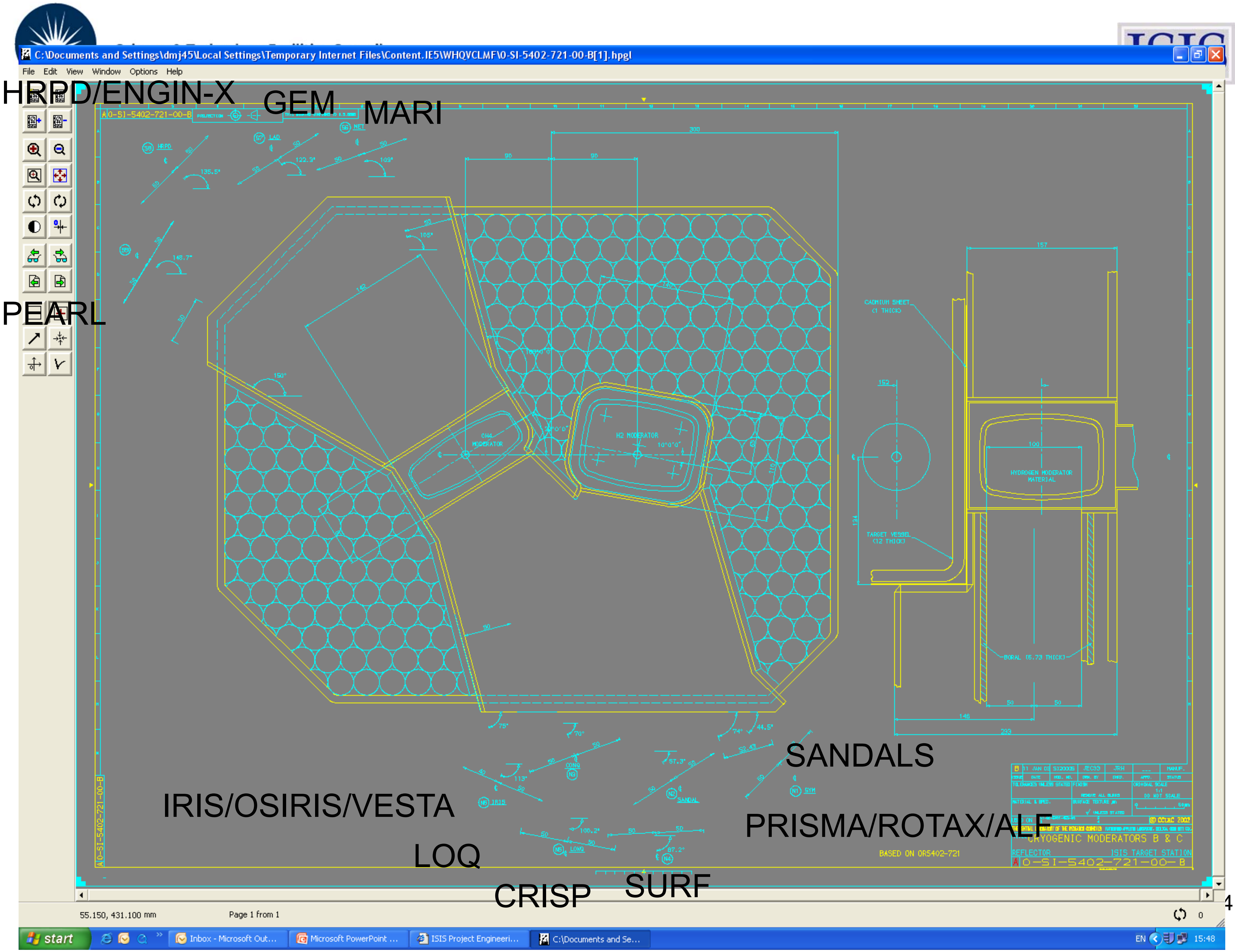
HRPD/ENGIN-X
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IRIS/OSIRIS/VESTA
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H2 MODERATOR
CH4 MODERATOR
CADMIUM SHEET (1 THICK)
TARGET VESSEL (12 THICK)
HYDROGEN MODERATOR MATERIAL
BORAL (6.73 THICK)
BASED ON OR5402-721
CRYOGENIC MODERATORS B & C
REFLECTOR
ISIS TARGET STATION
A 0-SI-5402-721-00-B
55.150, 431.100 mm
Page 1 from 1

Constraints on the design of new instruments for TS-1

- Neutron beam line heights unchanged
  - Avoid realigning half the instruments (costly, time consuming)
- Beam lines aligned with current moderators (Except N3 - SURF which could be realigned to the bottom front moderator)
  - Changing a void vessel window – 1-2 year shutdown and substantial risk to future operations
- Two top moderators – ambient
  - Making top moderators cryogenic is not practical with existing transfer lines
- Two bottom moderators cryogenic

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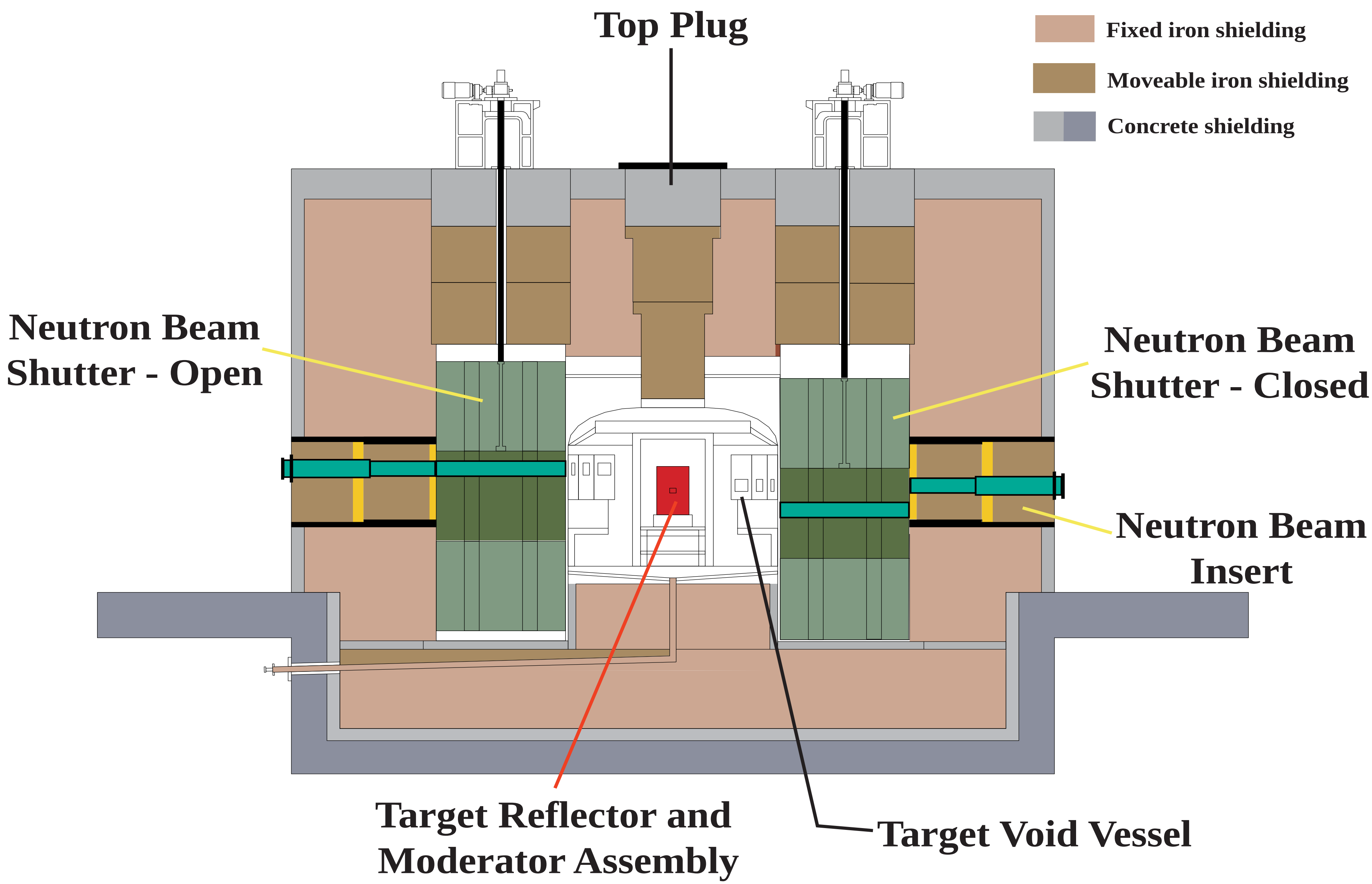
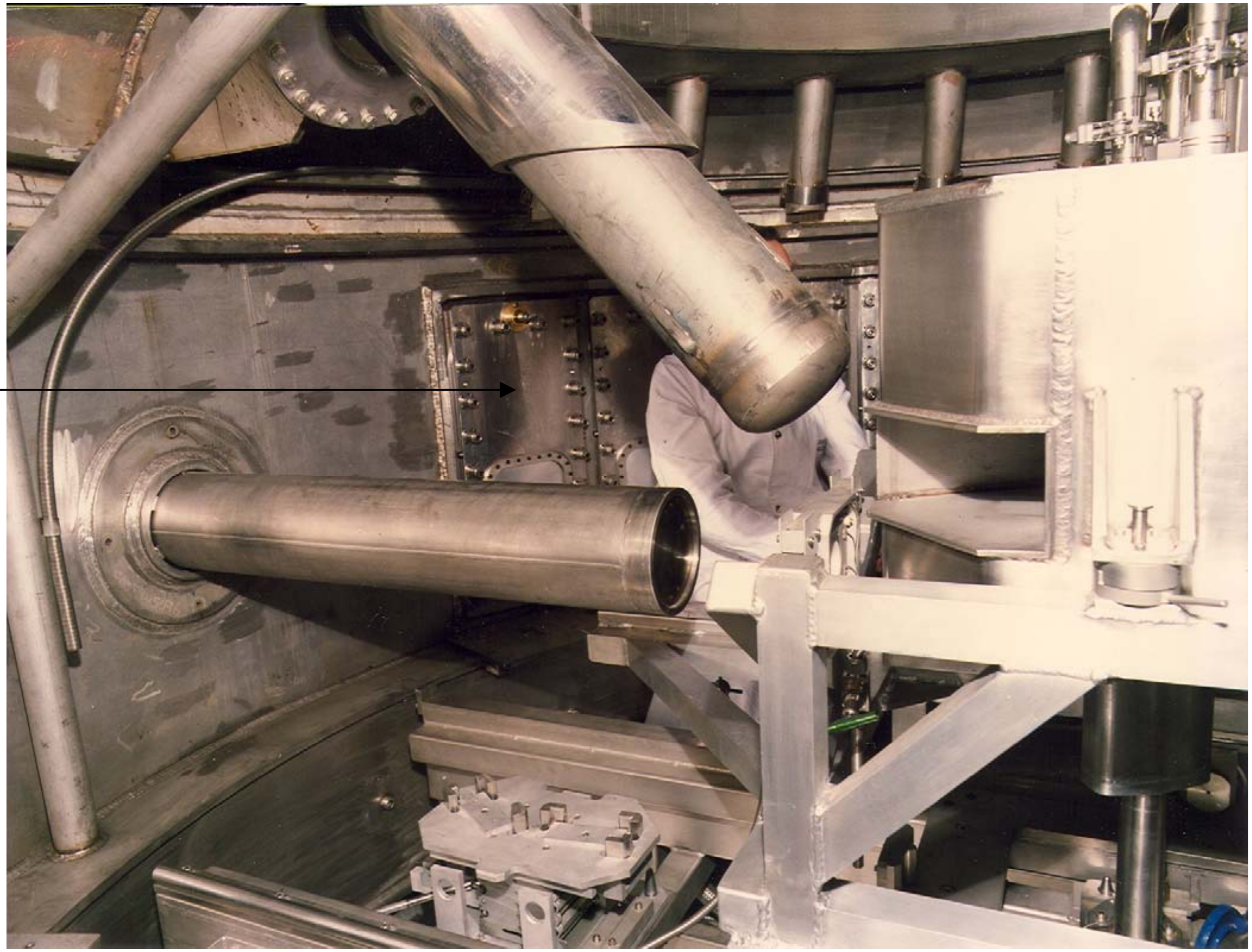


Void
Vessel
Window



Options for the design of new instruments for TS-1

- Moderator materials
- Target, moderator and reflector geometry
- Poison and decoupler materials and arrangement
- Addition of pre-moderator(s)

- To perform an efficient optimisation each instrument should define a quantitative metric which is representative of its performance

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Constraints

- Existing, Operating and Old (25+ years)
- Cost / Benefit
- Beam Input – linked to Accelerator upgrade

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Constraints

- Flight line position
- Shielding to be at least the same
- Reliable
- Upgradeable in the future
- Life of targets >5 years
- Risk Low
- Change suspect parts
- Time
- Documentation
- Diagnostics
- Instrumentation upgrades not part of the project

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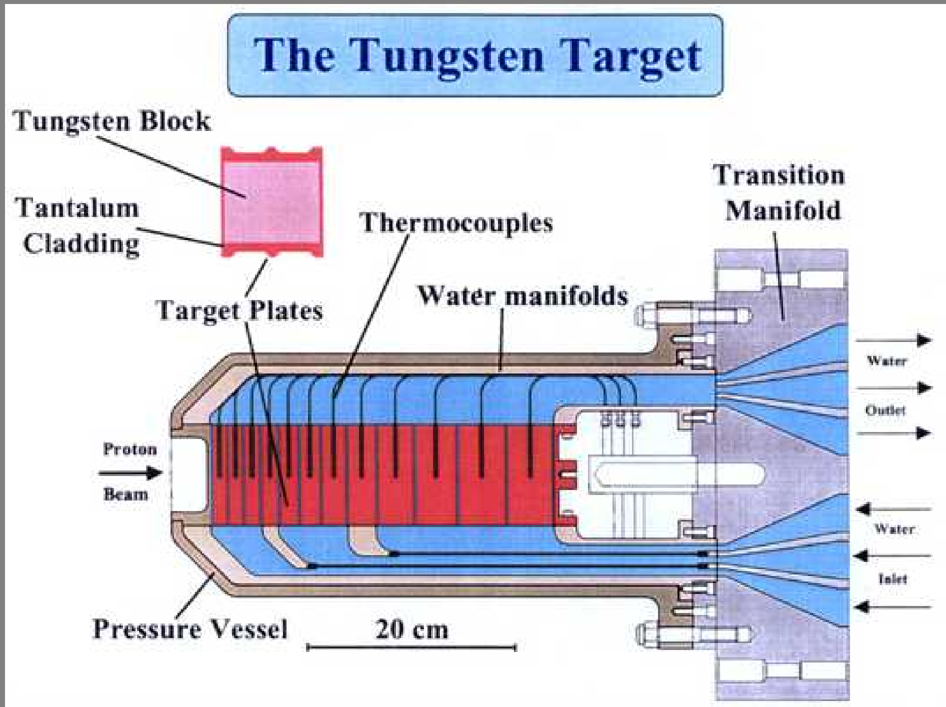
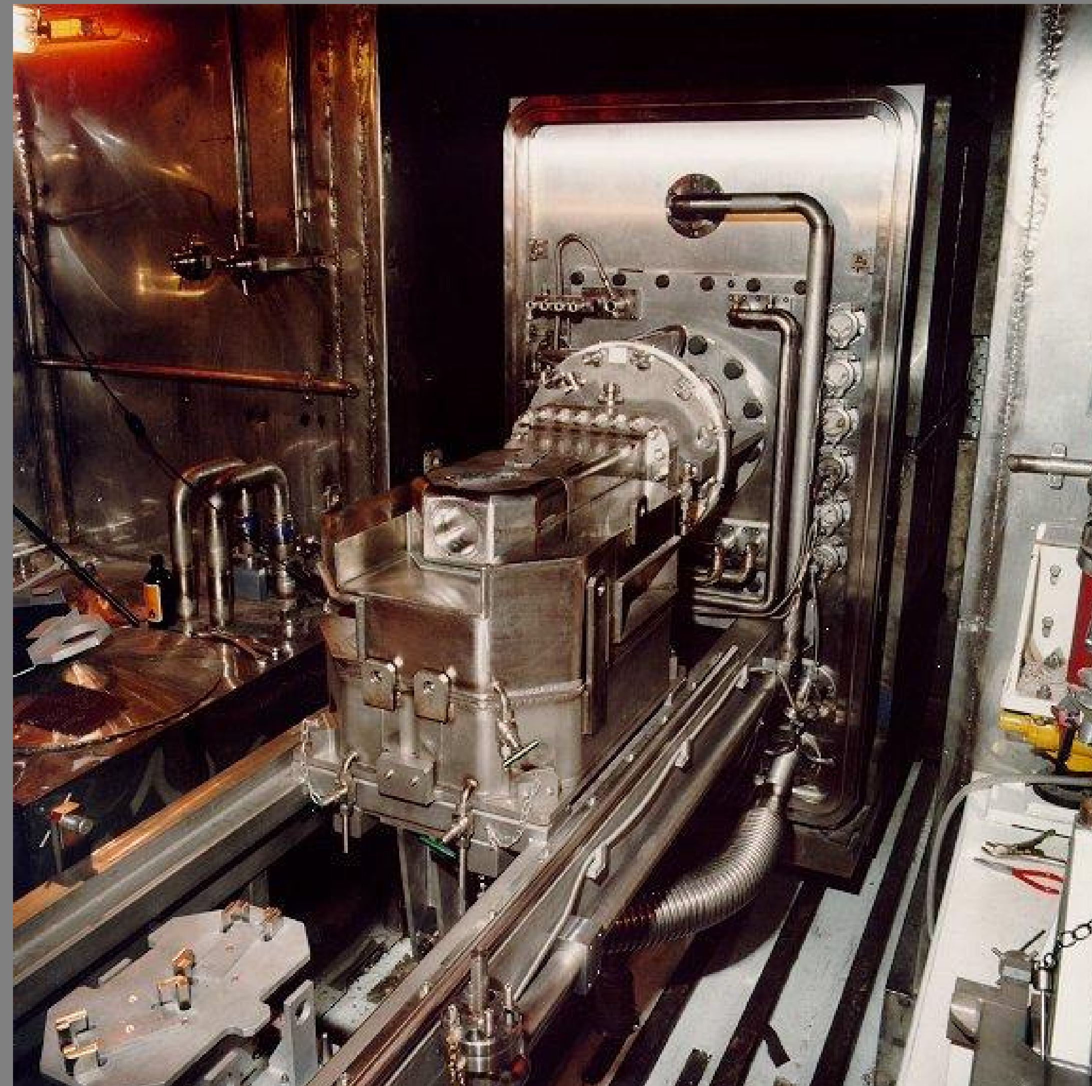
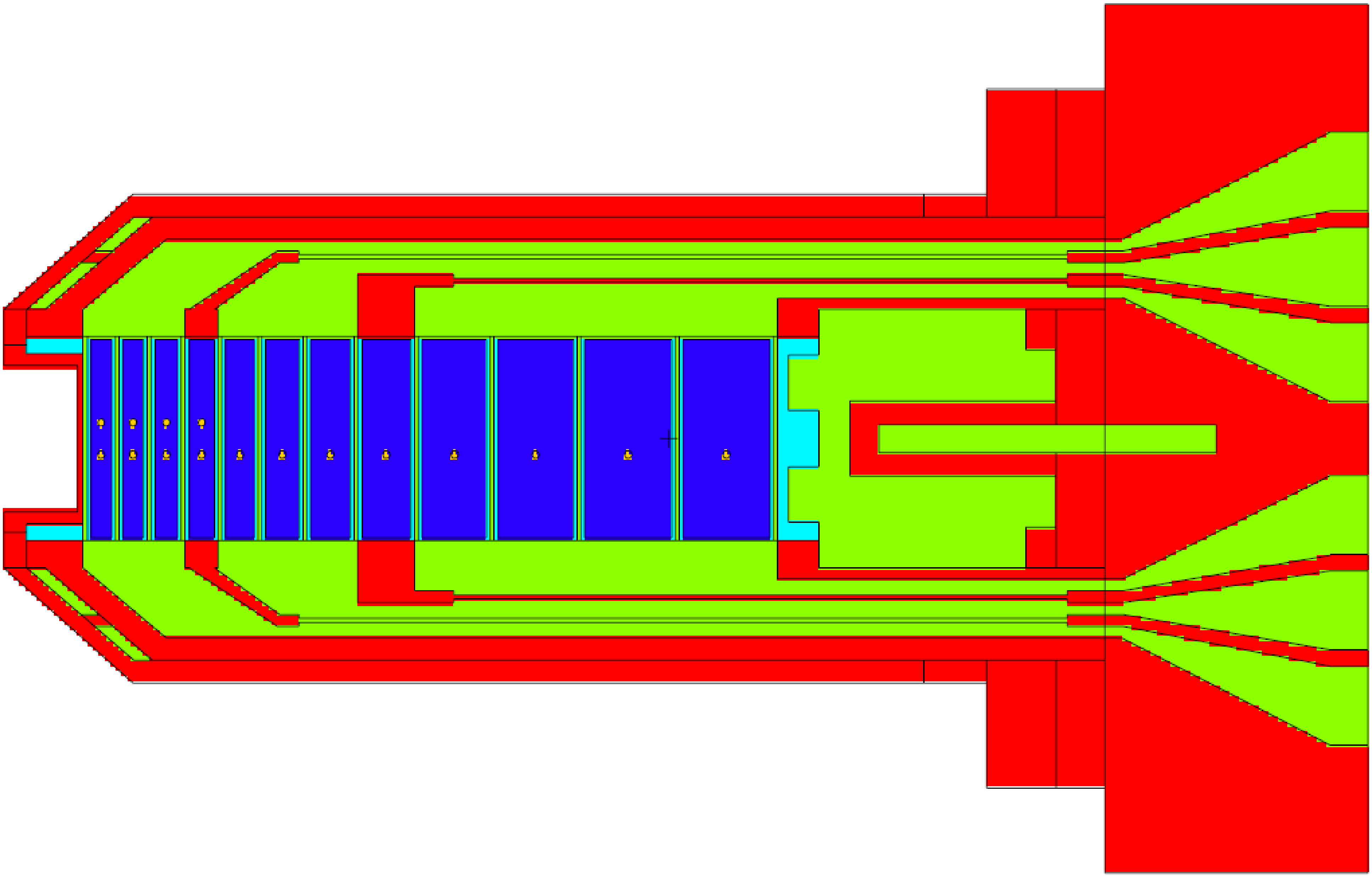
Constraints

- Conservative approach
  - Known materials / cooling
  - Bench tested where possible
  - Manufacturing routes understood
- Flexibility for change within moderators
- Possible development moderator....



TS-1 tungsten
target (plates)





Geometry and materials for MCNPX , ISIS W target #1