Status of neutron facilities

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IOP Particle Accelerators and Beams Annual Conference 2009

Neutron facilities

- Fission-based ←
- Fusion-based
- Accelerator-based
  - Irradiations
  - Nuclear physics
  - Therapy
  - Atomic and molecular physics
    - Spallation neutron sources

Current high power proton accelerators running spallation neutron sources:

PSI (Villigen, Switzerland)
SNS (Oak Ridge)
LANSCE (Los Alamos)
ISIS (RAL, Oxon.)
J-PARC (Tokai-mura)

Decreasing mean proton beam power

ESS
CSNS

IPNS (closed 2008)
KENS (closed 2005)

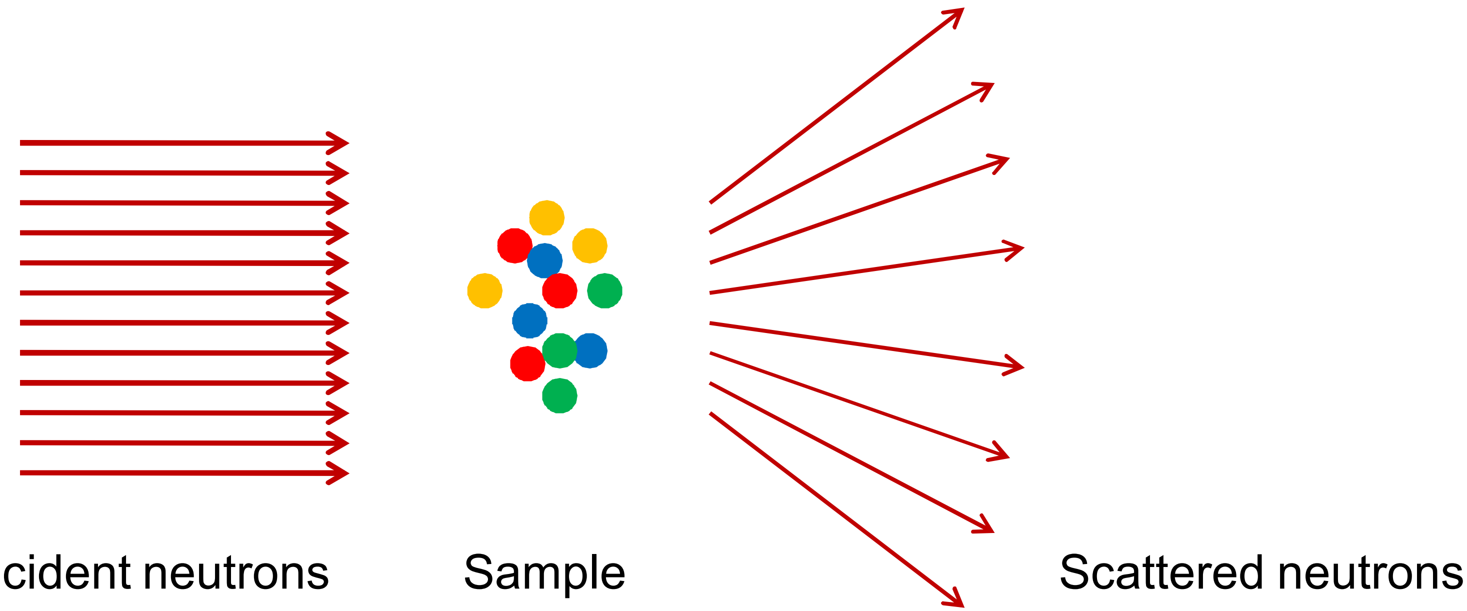
Guinness Book of Records — can no longer show this photo

What are spallation neutron sources for?

Basically, for unravelling the structure and dynamics of molecules

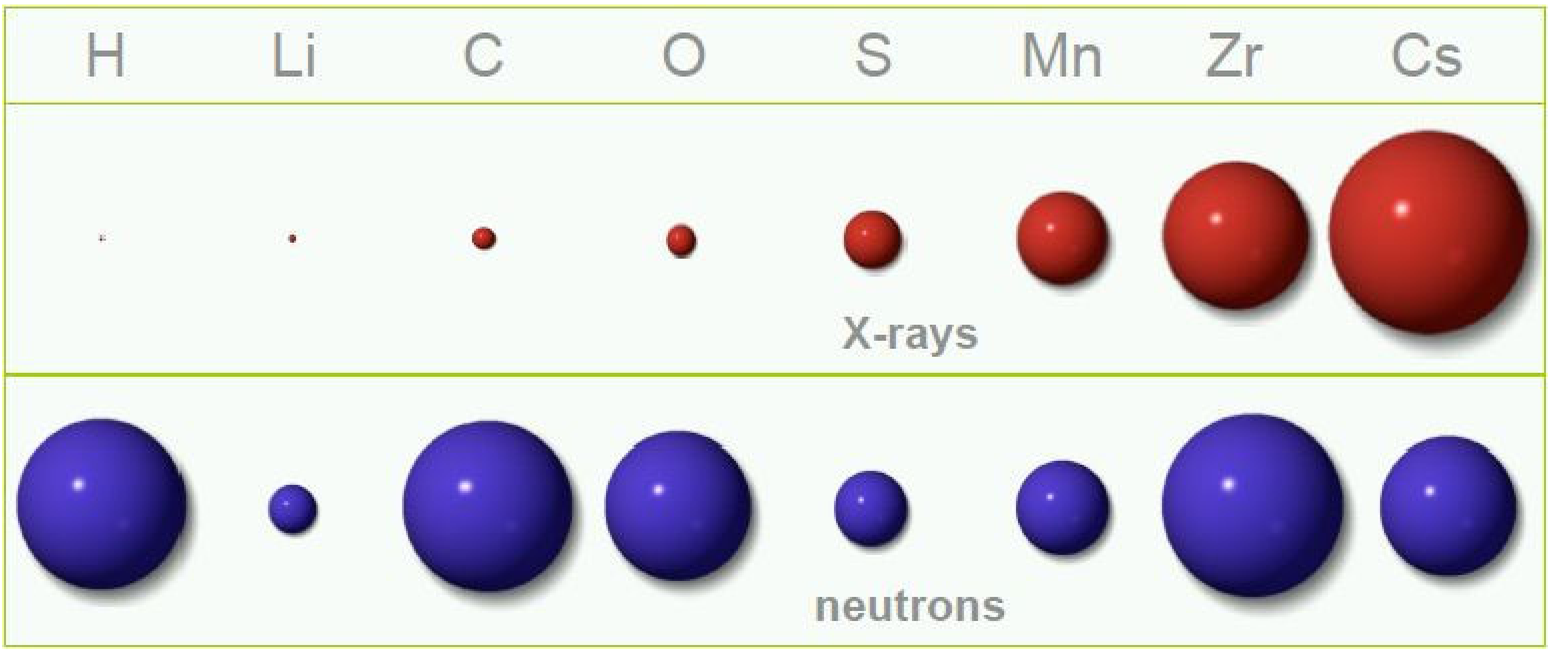
For neutrons, *very* roughly, 1 Å ≈ 0.1 eV

Pulsed (except PSI)



Neutron and light sources complementary

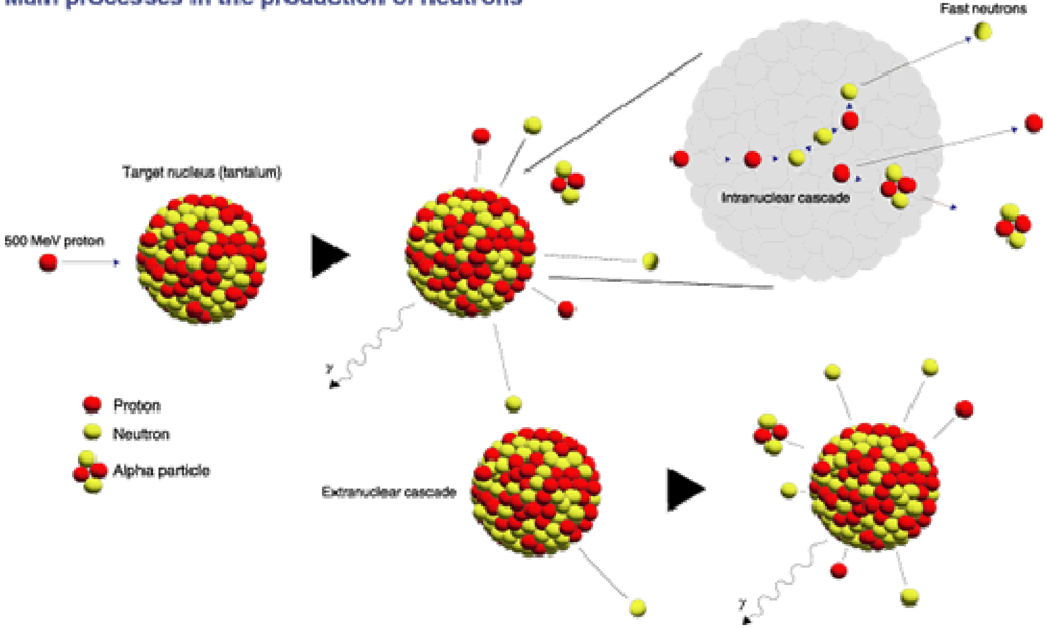
X-ray cross-sections

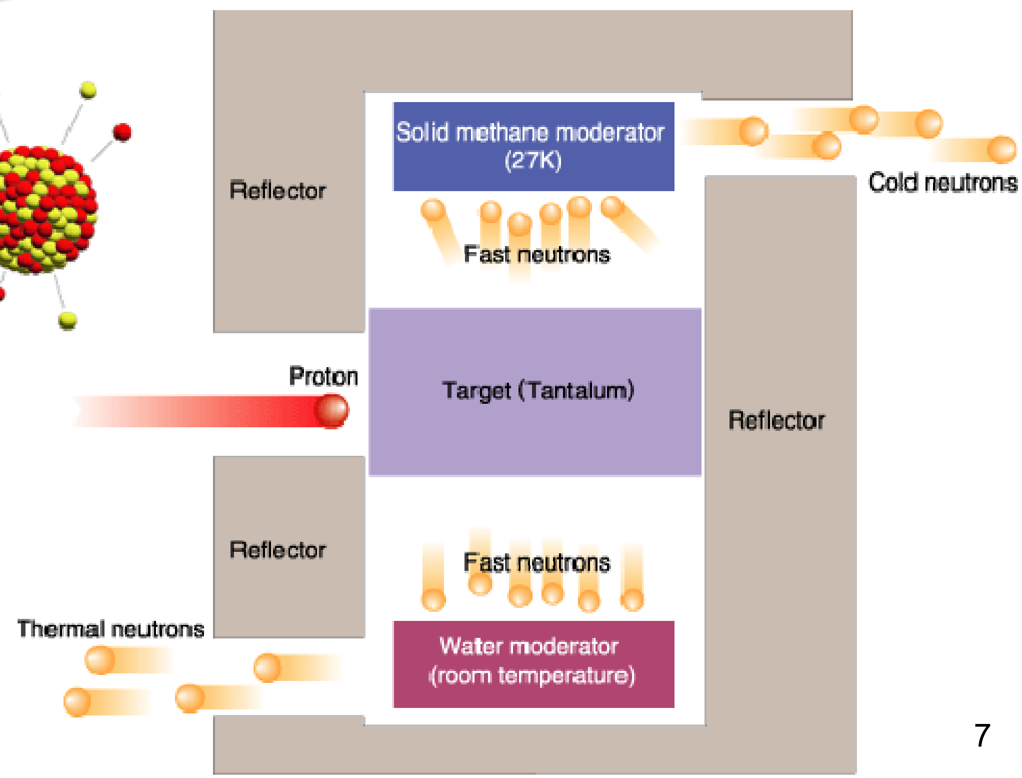


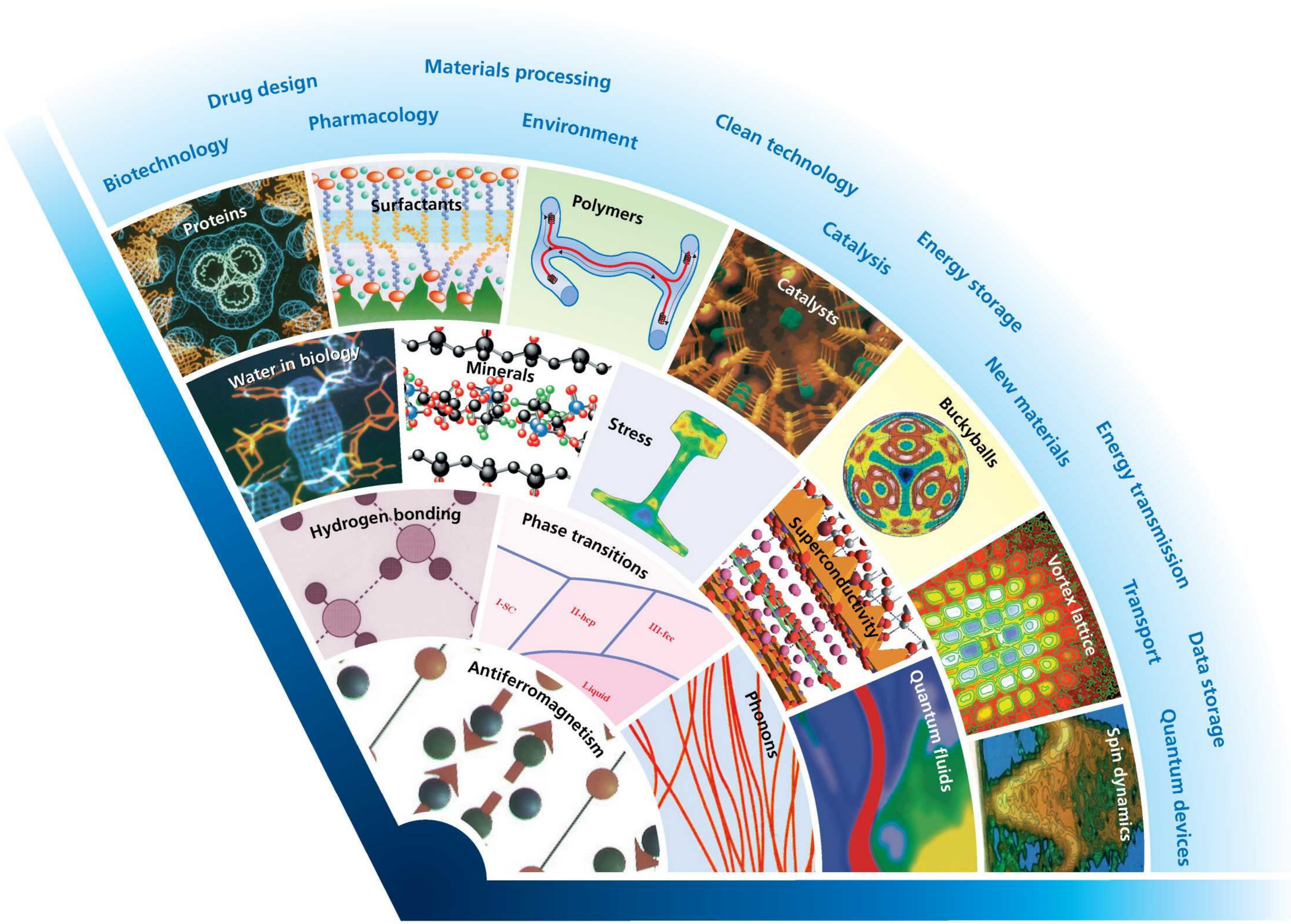
Neutron cross-sections

Need ~meV neutrons, not ~MeV neutrons, so moderation

Main processes in the production of neutrons







R&D fields for spallation neutron sources

Spallation neutron sources are **user facilities**

— users don’t care about the accelerators

Factors for success of accelerator-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 ← **this is key**

PSI	590 MeV cyclotron — not pulsed	1.2 MW
SNS	1 GeV H^- linac + accumulator ring	0.9 MW[2]
LANSCE	800 MeV H^+ / H^- linac + accumulator ring (0.1 MW)	0.8 MW
ISIS	70 MeV H^- linac + 800 MeV H^+ synchrotron	0.2 MW
J-PARC	180 MeV H^- linac + 3 GeV + 50 GeV synchrotrons	0.2 MW[1]

1: For limited time during commissioning; ultimate design 1 MW with 400 MeV linac.

2: Still commissioning; 1 MW design operation.

ESS	~2.5 GeV, 50 mA, 2 ms, 20 pps linac + no accumulator ring	5 MW
CSNS	81 MeV H^- linac + 1.6 GeV H^+ synchrotron	0.1 MW[3]
MW ISIS	3 GeV synchrotron 800 MeV injection from synch. or linac	1–5 MW

Wide range of architectures — not yet any obvious “best”

3: Phase 1 only. Upgradeable to ~0.2–0.5 MW in Phases 2 and 2'.

Target just as important as accelerator

Water-cooled plate target OK to ~1 MW

Hg targets used at SNS and J-PARC
    Cavitation pitting issues?

Pb-Bi target proved at 1 MW at PSI

Proposed: rotating target

Important to couple moderators to primary target as closely as possible

PSI — Villigen, Switzerland

870 keV Cockcroft-Walton

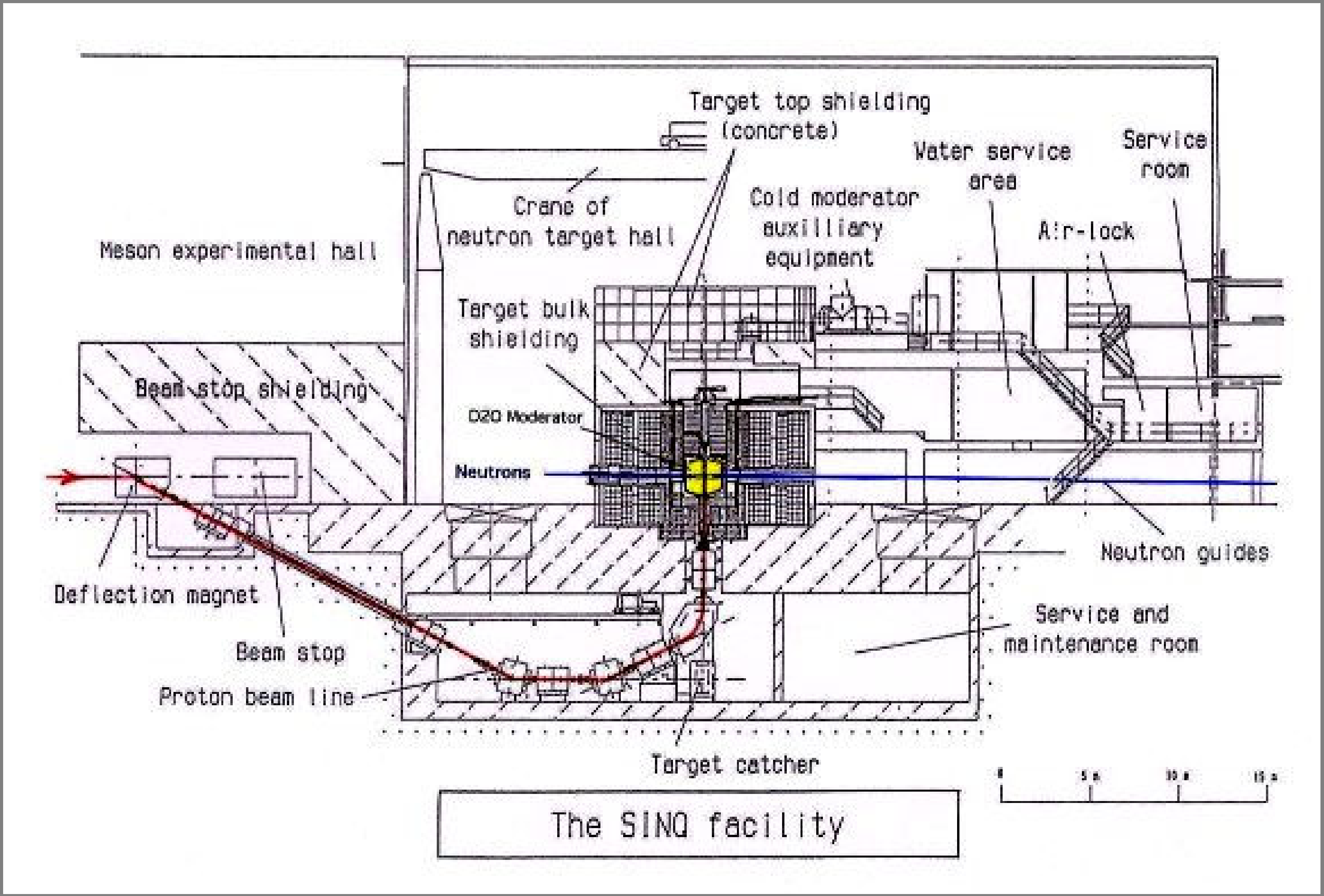
72 MeV 4-sector cyclotron

590 MeV 8-sector cyclotron
- 2 mA DC
- ~200 turns
- 51 MHz RF resonators, gap voltage ~1 MV

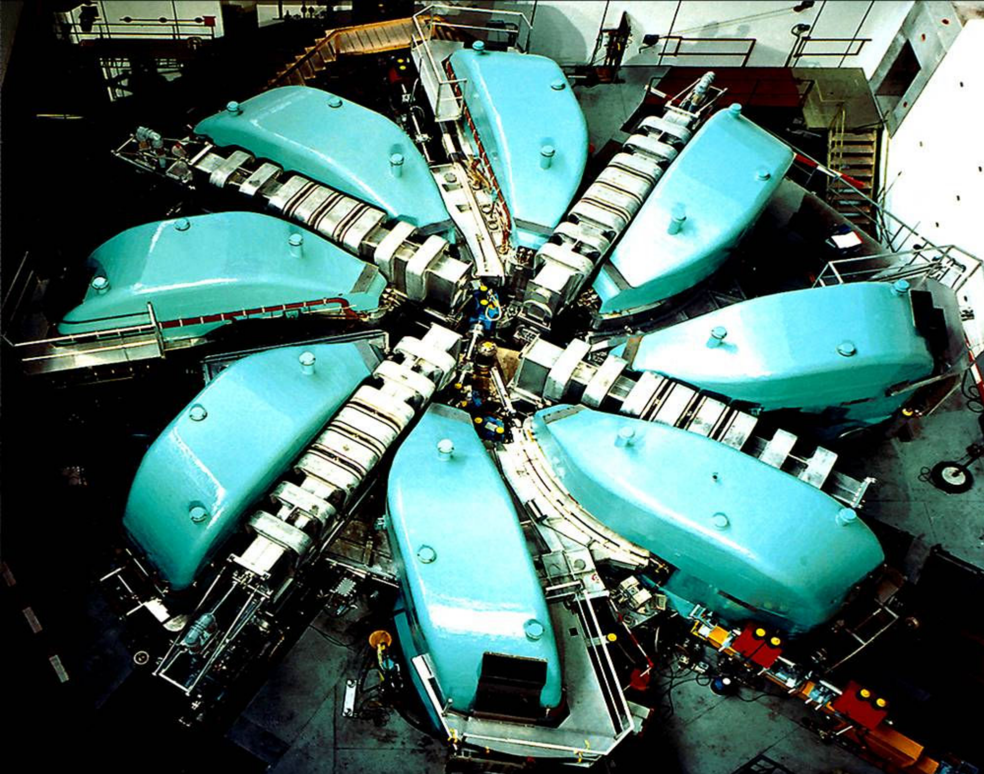
Target: lead rods in zircaloy tubes, heavy water coolant

Megapie — 1 MW protons on to Pb-Bi target (2006)

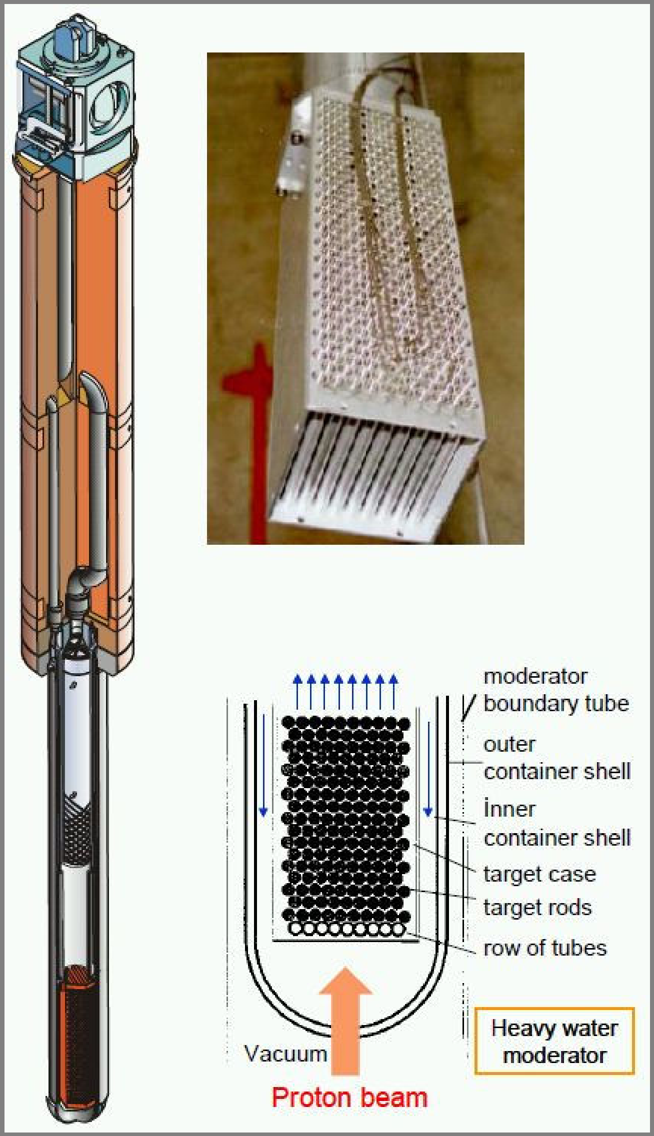
Also: muons, therapy



PSI — Villigen, Switzerland




C.M.I
25000Kgs



PSI spallation target

SNS — Oak Ridge, Tennessee

First pulsed superconducting proton linac

2.5 MeV RFQ — 402 MHz

Beam chopper — slow wave

DTL to 86 MeV, coupled-cavity linac to 195 MeV — 402 MHz

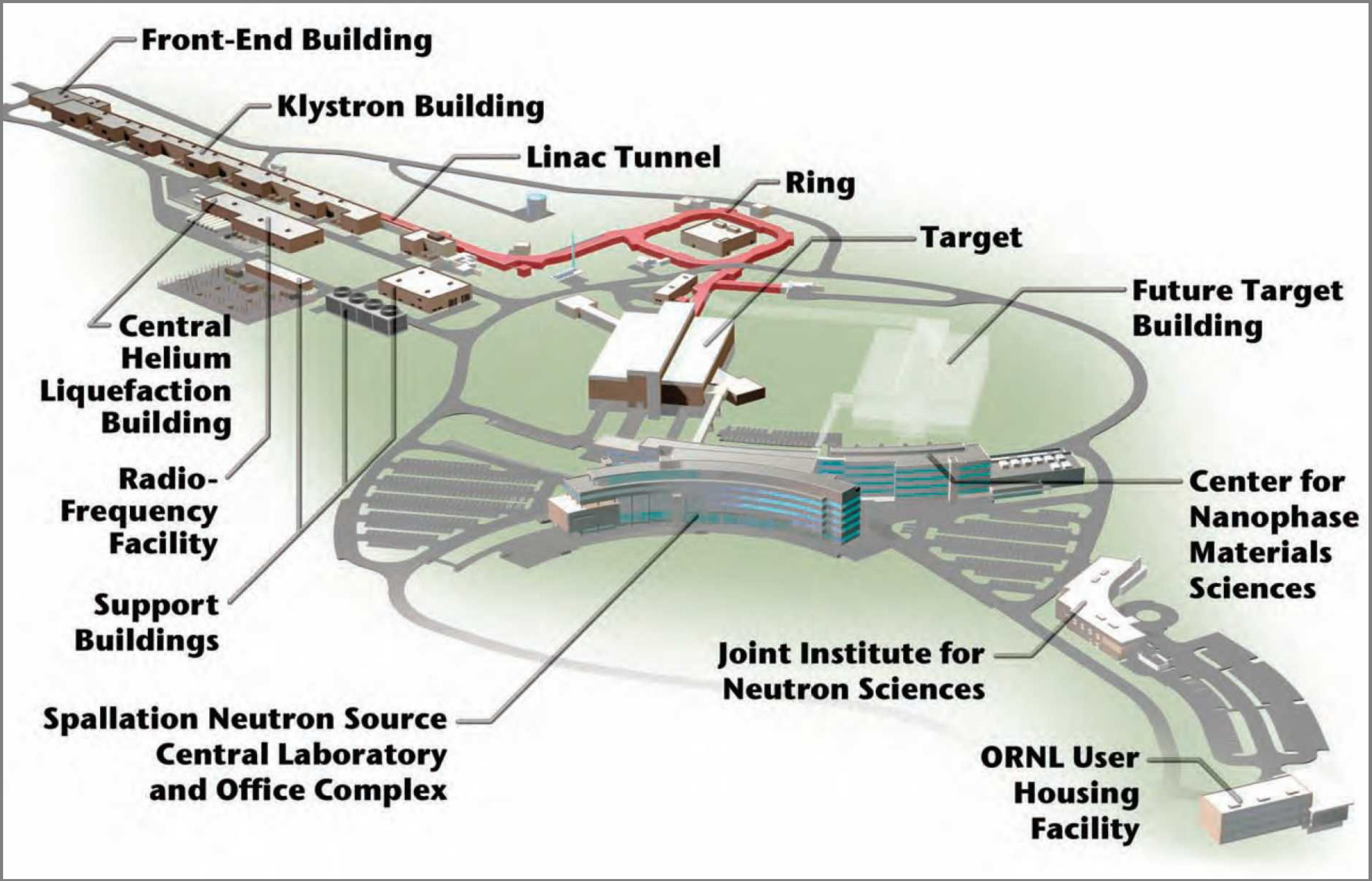
Superconducting linac to ~1000 MeV — 805 MHz

Accumulator ring — 1.06 and 2.12 MHz

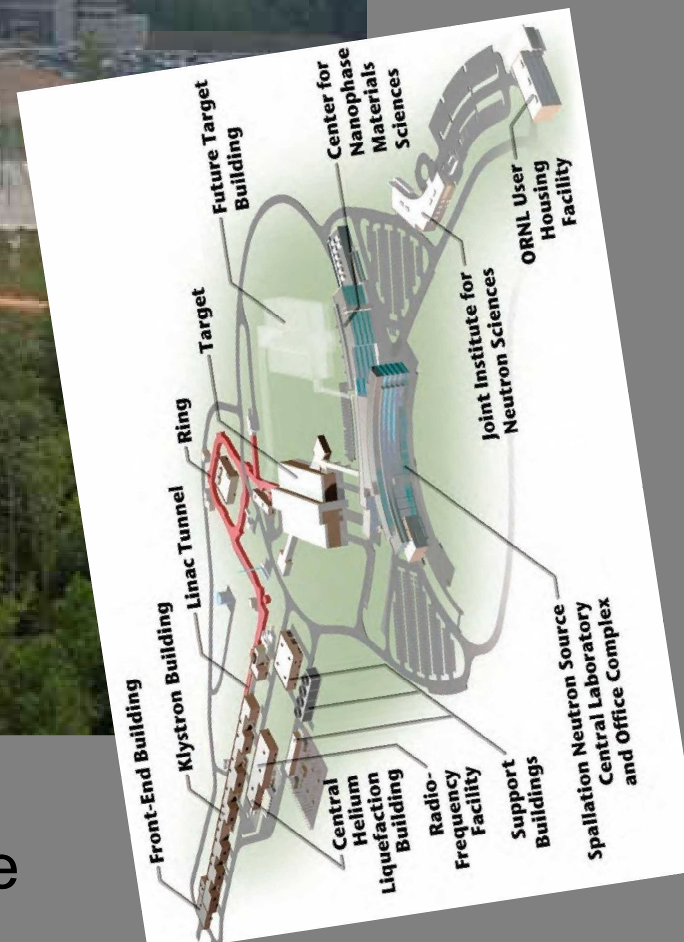
Target: mercury in stainless steel vessel

DTL uses permanent magnet quadrupoles

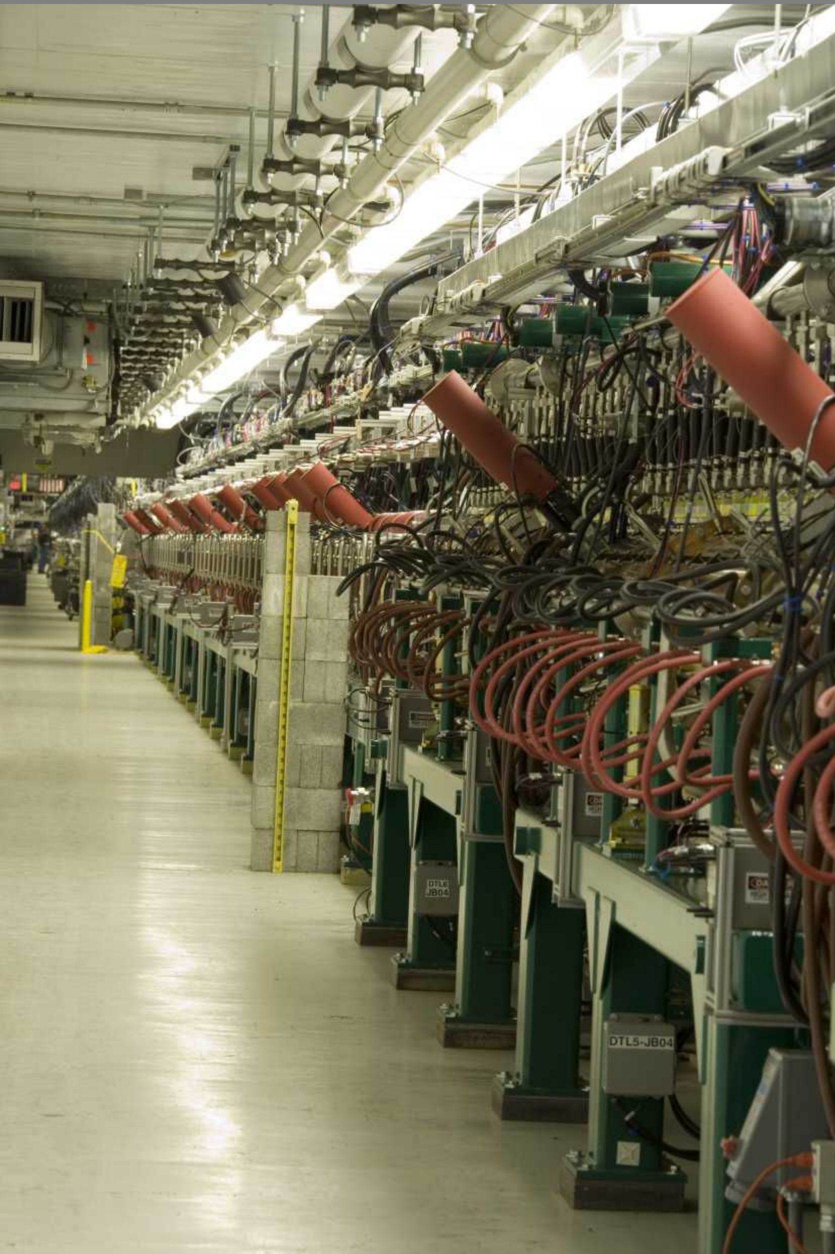
Issues of reproducibility of performance of SCL

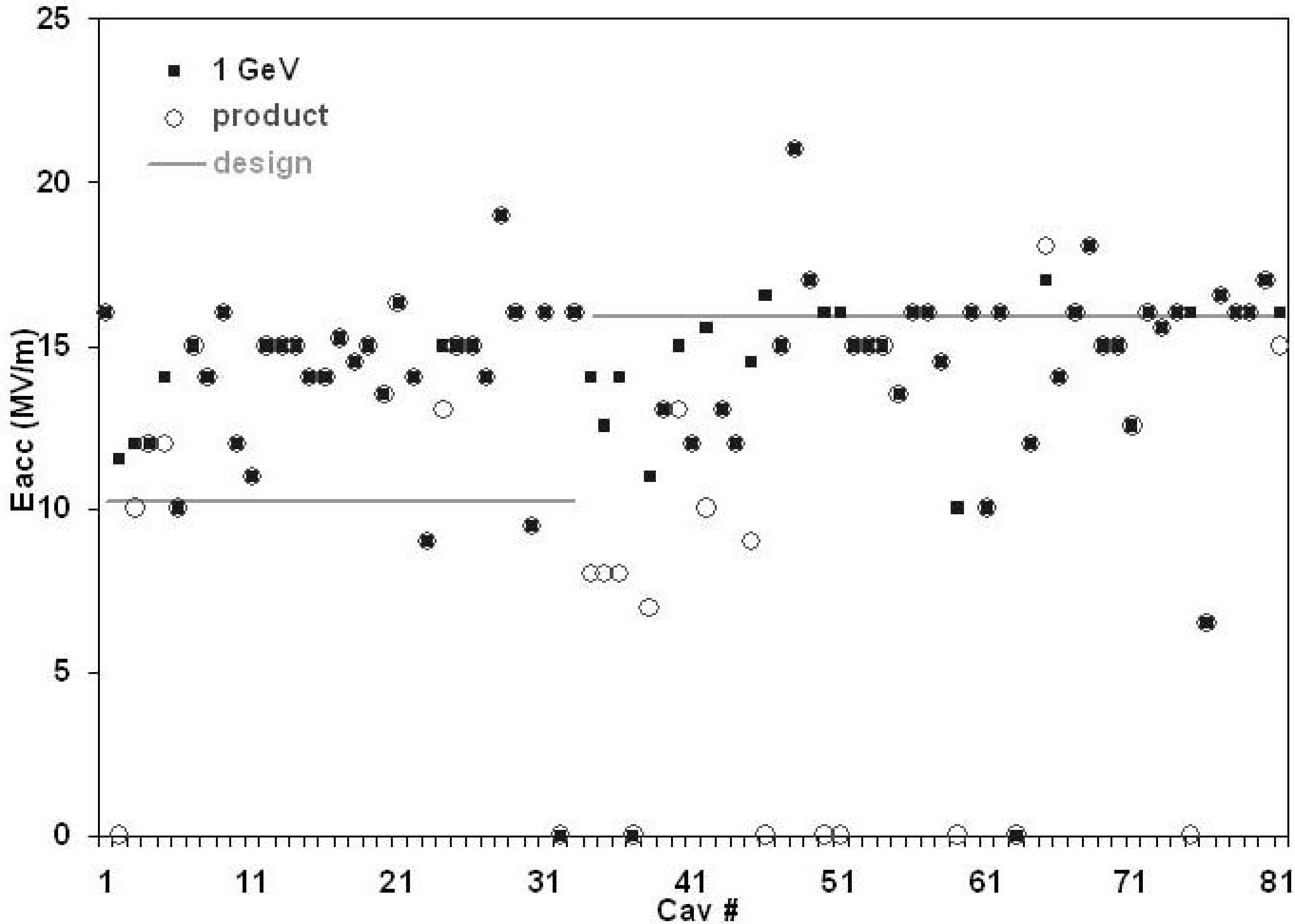


SNS — Oak Ridge



SNS — Oak Ridge


DTL5-JB04



SNS cavity gradients — from EPAC-08

LANSCE — Los Alamos, New Mexico

2 × 750 keV Cockcroft-Waltons — H^- + H^+ simultaneously

Beam chopper — slow wave

DTL to 100 MeV — 201 MHz

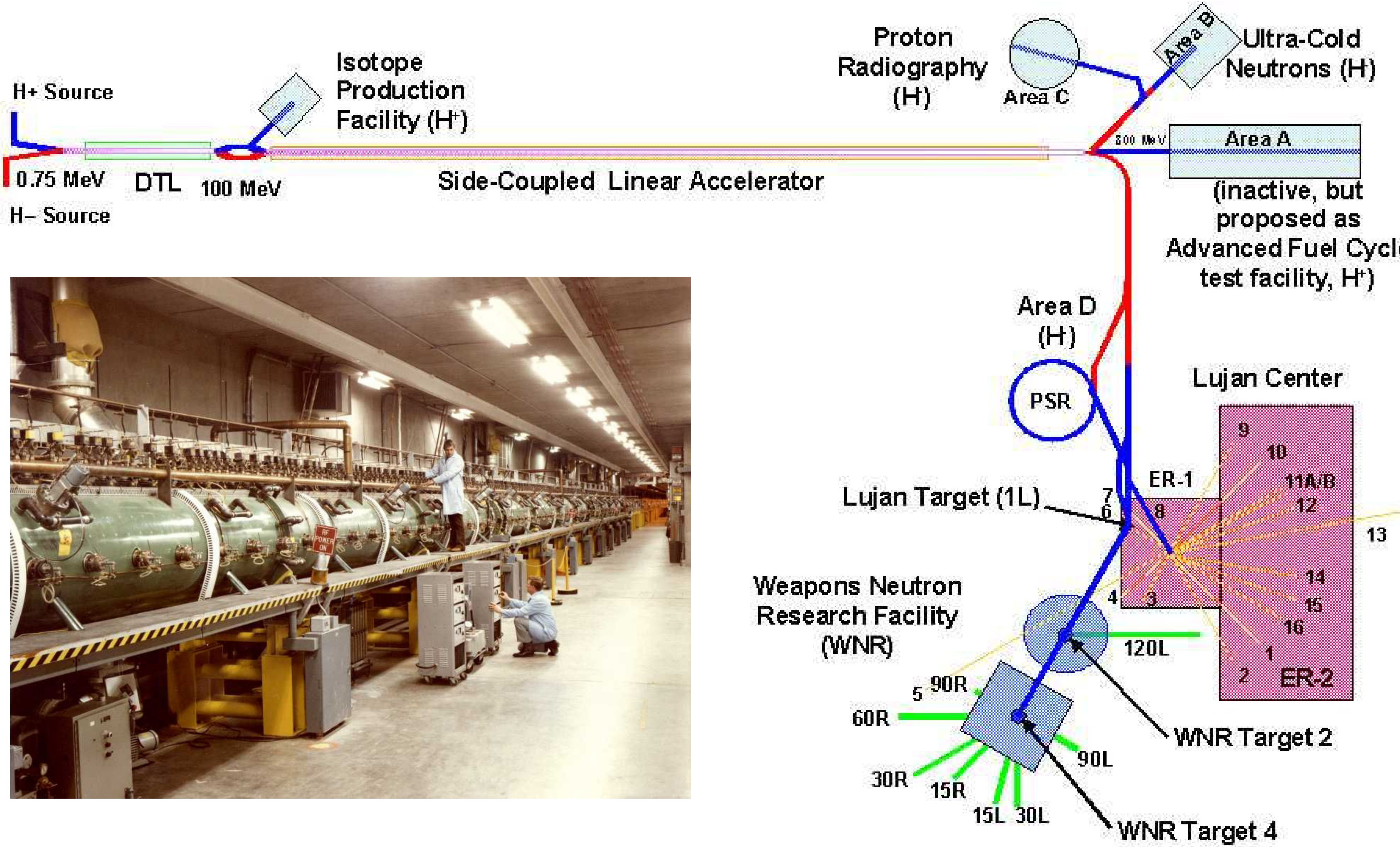
Coupled-cavity linac to 800 MeV — 805 MHz

H^- + H^+: good alignment important

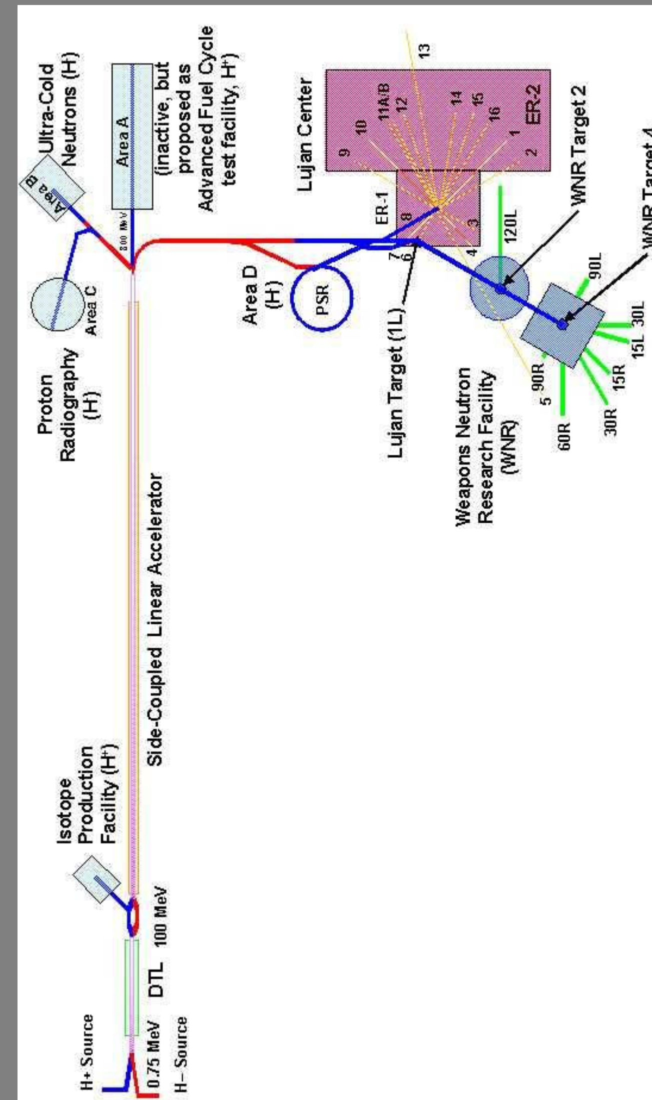
Accumulator ring — PSR — 2.80 MHz

Target: tungsten

Oldest such facility — began 1972

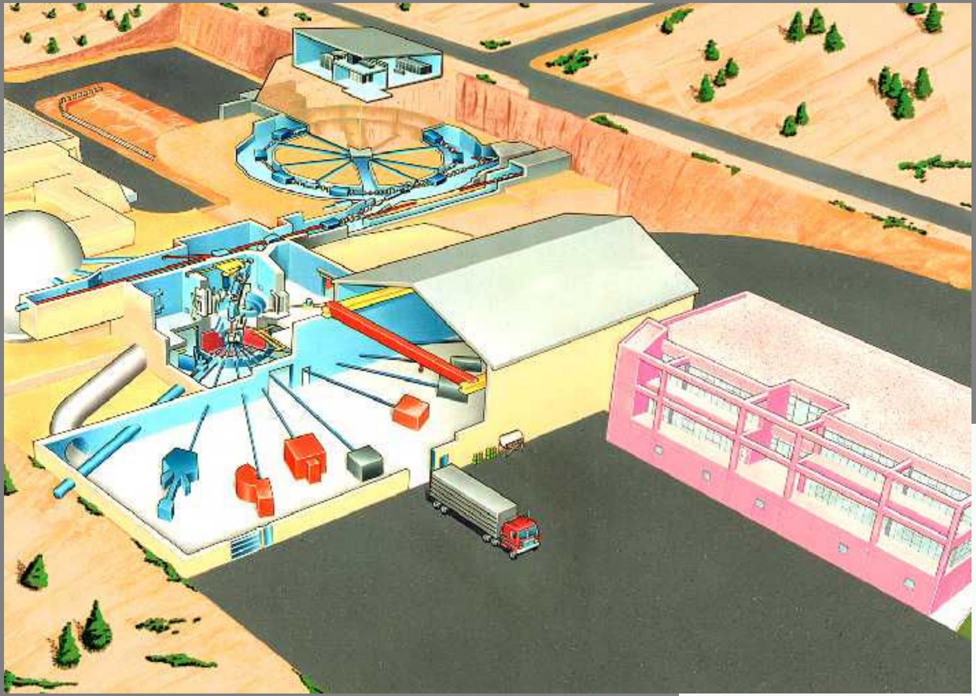

H+ Source
0.75 MeV
H– Source
DTL
100 MeV
Isotope Production Facility (H+)
Side-Coupled Linear Accelerator
Proton Radiography (H-)
Area C
Area B
Ultra-Cold Neutrons (H-)
800 MeV
Area A
(inactive, but proposed as Advanced Fuel Cycle test facility, H+)
Area D (H-)
PSR
Lujan Center
Lujan Target (1L)
ER-1
ER-2
9
10
11A/B
12
13
14
15
16
1
2
3
4
6
7
8
Weapons Neutron Research Facility (WNR)
120L
5
90R
60R
30R
15R
15L
30L
90L
WNR Target 2
WNR Target 4

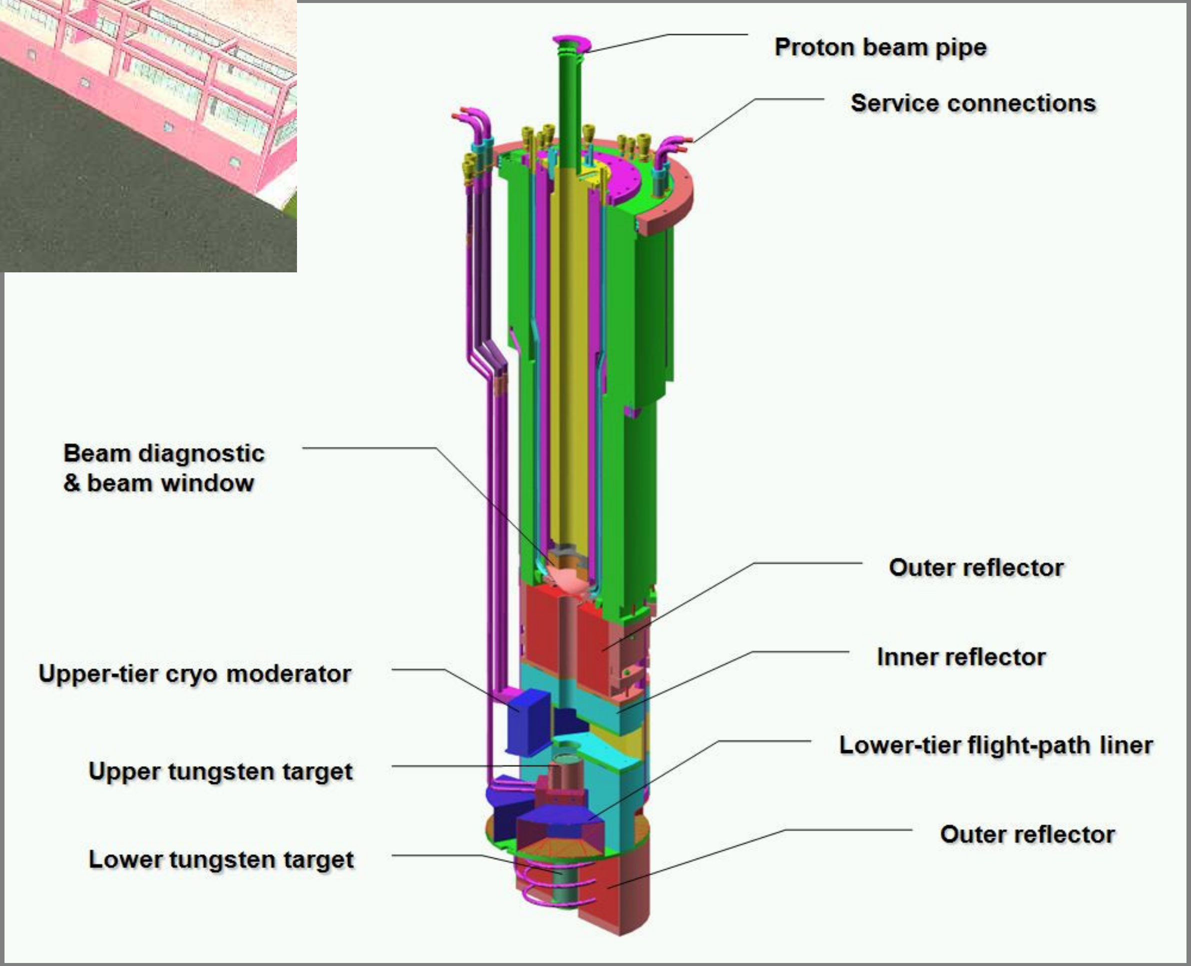
LANSCE



Ultra-Cold Neutrons (H⁻)
Area B
Area A
800 MeV
(inactive, but proposed as Advanced Fuel Cycle test facility, H⁺)
Lujan Center
ER-1
ER-2
Area C
Proton Radiography (H⁻)
Area D (H⁻)
PSR
Lujan Target (1L)
WNR Target 2
WNR Target 4
Weapons Neutron Research Facility (WNR)
120L
90L
30L
15L
15R
30R
60R
90R
Isotope Production Facility (H⁺)
Side-Coupled Linear Accelerator
100 MeV
DTL
0.75 MeV
H+ Source
H– Source

LANSCE




Proton beam pipe
Service connections
Beam diagnostic
& beam window
Outer reflector
Inner reflector
Upper-tier cryo moderator
Lower-tier flight-path liner
Upper tungsten target
Outer reflector
Lower tungsten target

ISIS — world's most productive spallation neutron facility

ISIS
J-PARC, LANSCE, PSI, SNS

↓ Decreasing number of target stations

ISIS: 800 MeV protons on to tungsten targets, 0.2 MW
TS-1, 0.16 MW, 40 pps; TS-2, 0.04 MW, 10 pps
~800 neutron experiments per year
~1600 visitors/year (~5000 visits)

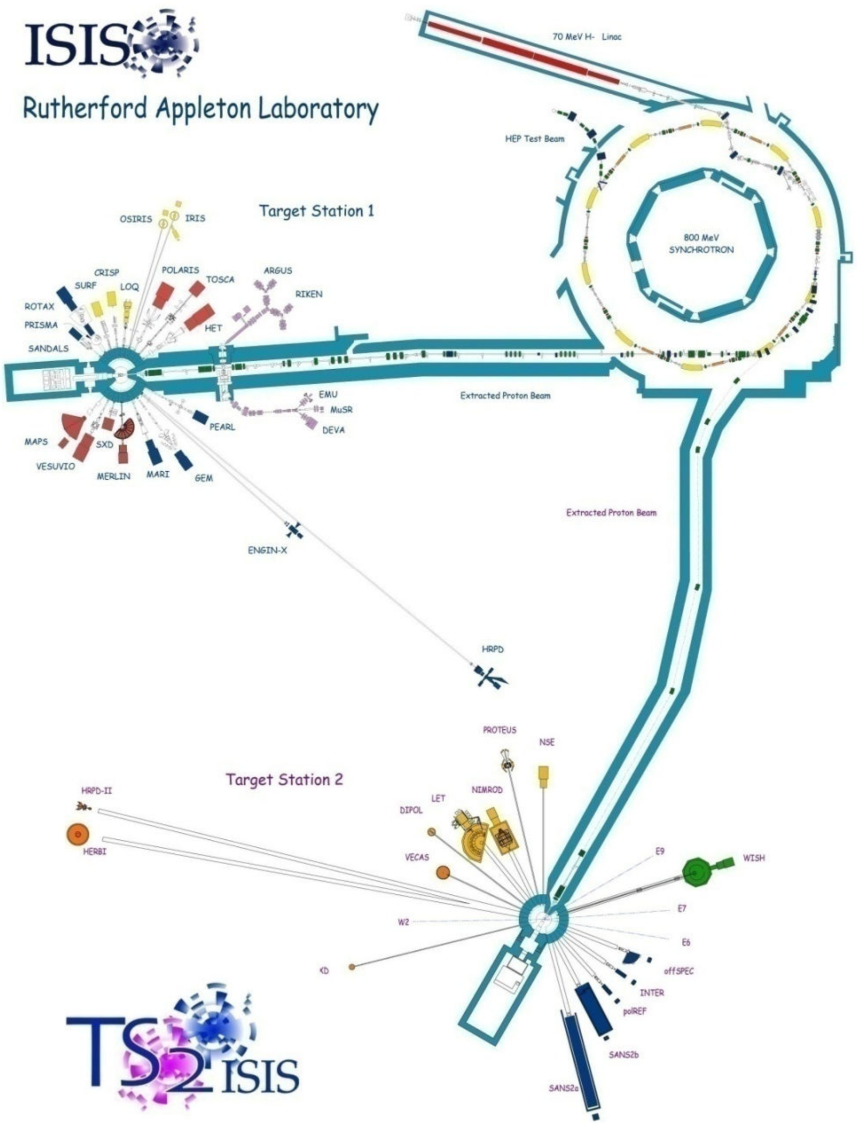
Also: muons

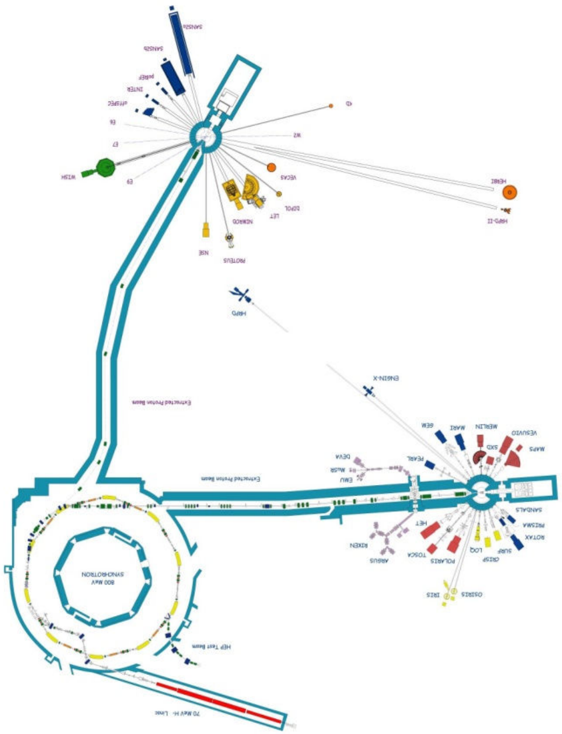
665 keV H^- RFQ

70 MeV H^- linac

800 MeV proton synchrotron

TS-1





ISIS — Oxfordshire

ISIS 70 MeV H^- DTL
202 MHz

ISIS 800 MeV
proton synchrotron
1.3–3.1 and 2.6–6.2 MHz

TS-1, plates Tungsten targets TS-2, solid cylinder

J-PARC — Tokai-Mura

3 MeV RFQ — 324 MHz

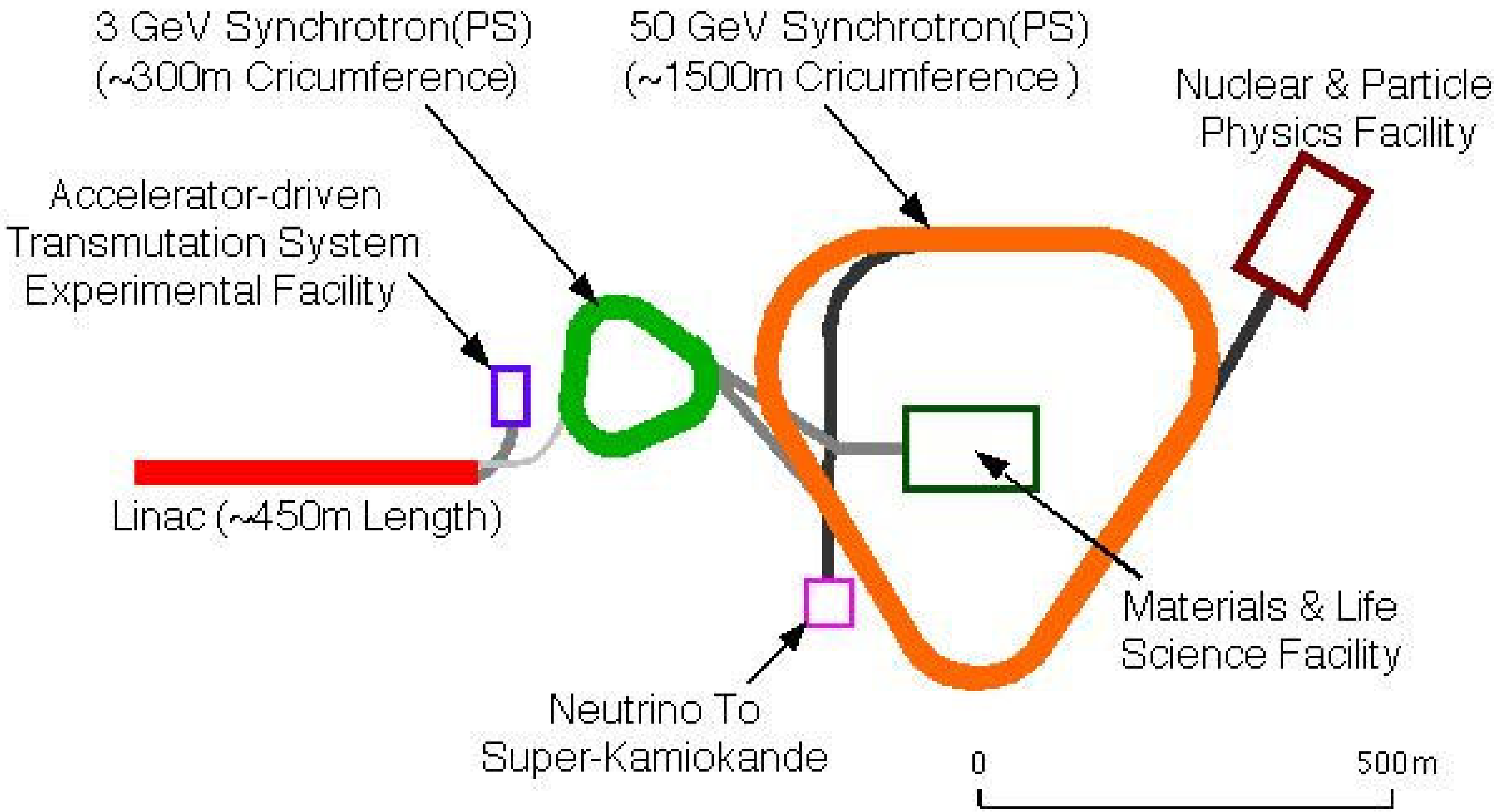
Beam chopper — RF, deflecting

DTL to 50 MeV, separated DTL to 191 MeV — 324 MHz

Synchrotron to 3 GeV — 0.94–1.67 and 1.88–3.34 MHz

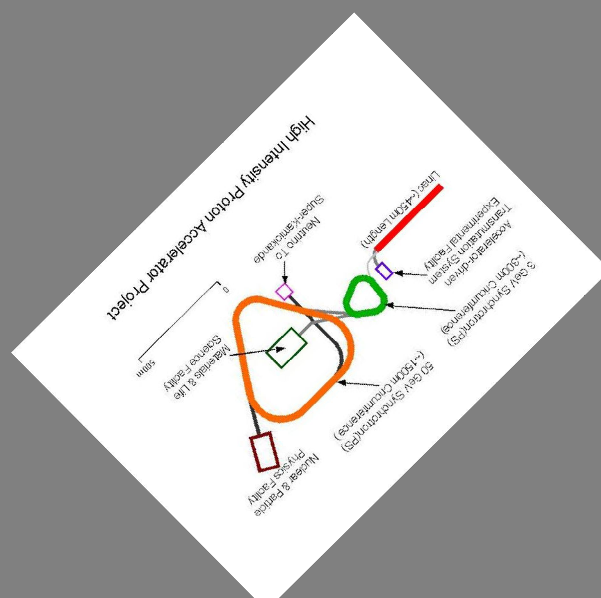
Mercury target

DTL uses electromagnetic quadrupoles



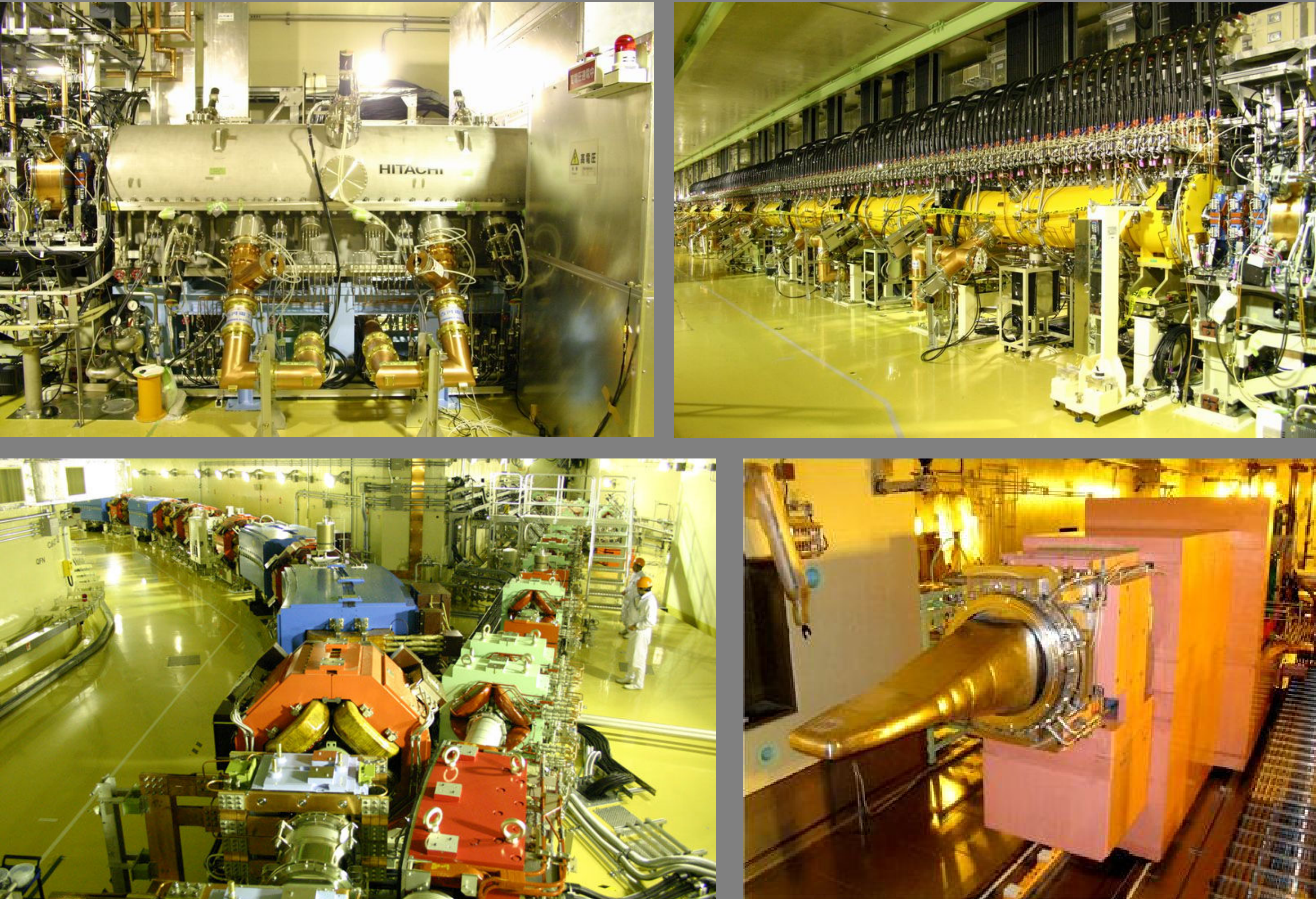
High Intensity Proton Accelerator Project

J-PARC



J-PARC

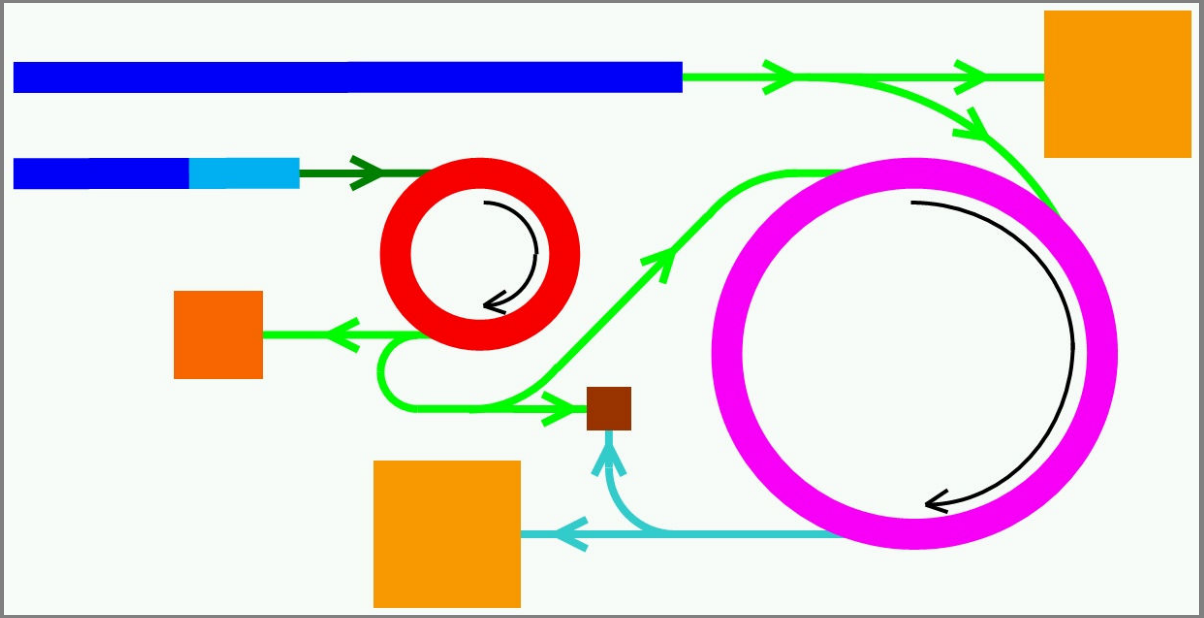
Pacific Ocean



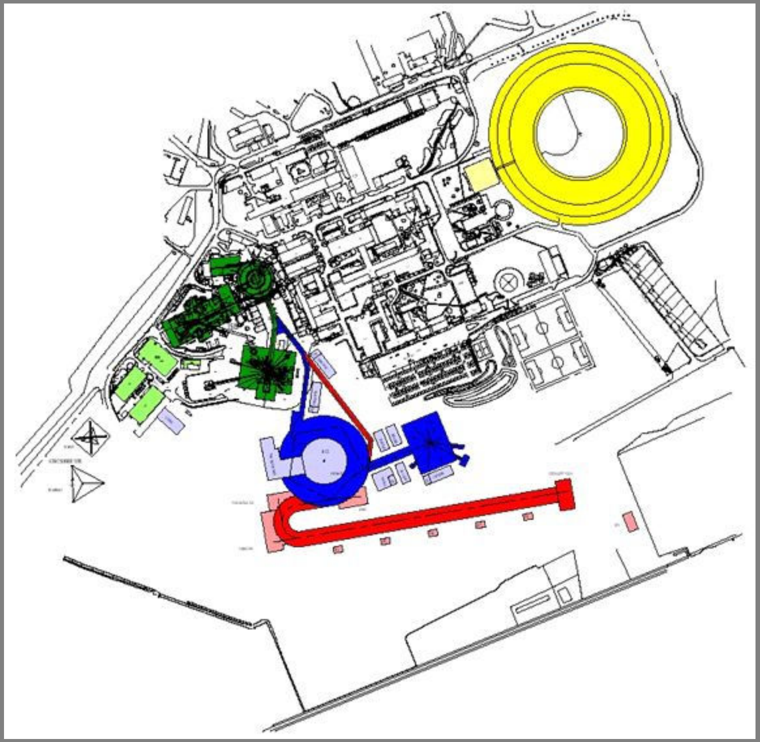
J-PARC RFQ, linac, synchrotron (injection) and target

ESS Scandinavia, Lund — 5 MW long pulse

CSNS, Dongguan



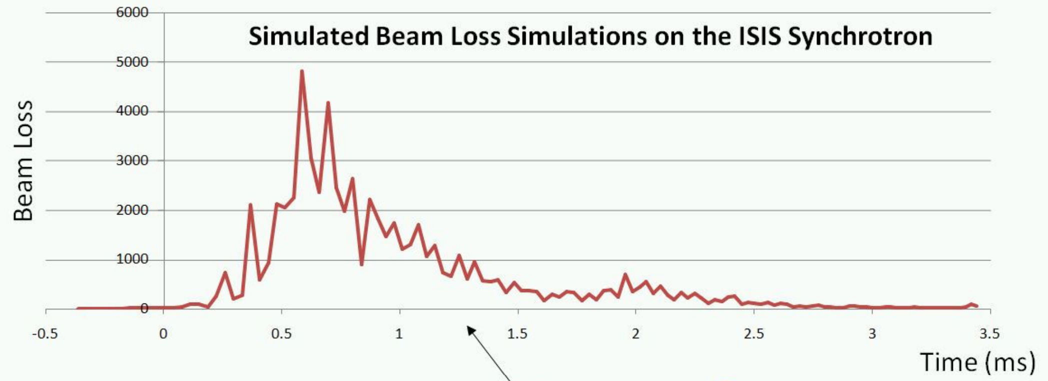
Possible ISIS upgrades



800 MeV linac, 3 GeV synchrotron and TS-3 on RAL site

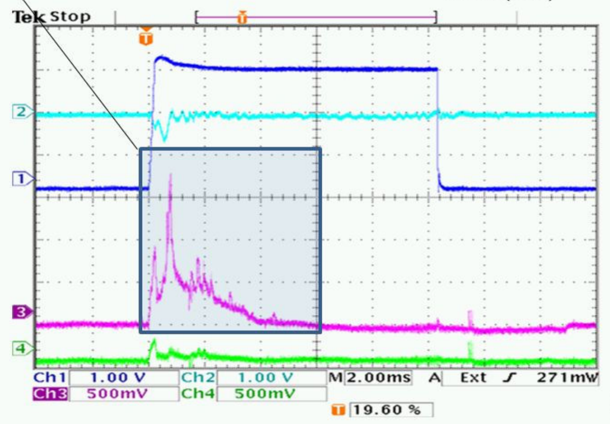
Modelling for high power proton accelerators

~1 W/metre for ~1 MW — very challenging



Simulation ran for 10 days
on 64 CPU's

Simulated beam loss: 9 %
Measured Beam Loss: 8 %



Operational issues for high power proton accelerators

Minimise beam losses to minimise induction of radioactivity in machine structures

Key operational consideration: minimise doses to people!

Explicitly include handling/working implications during design

Currently interesting time for spallation neutron sources

2 × 1 MW ~$1½B pulsed — will complement CW 1 MW

Looking forward to next few years

ISIS