EUROPEAN SPALLATION SOURCE

Neutron Sources

PART 3

Christine Darve
European Spallation Source

Outline

PART 1

- Background for neutron course
- Neutrons properties and their interactions
- Applications using Neutrons

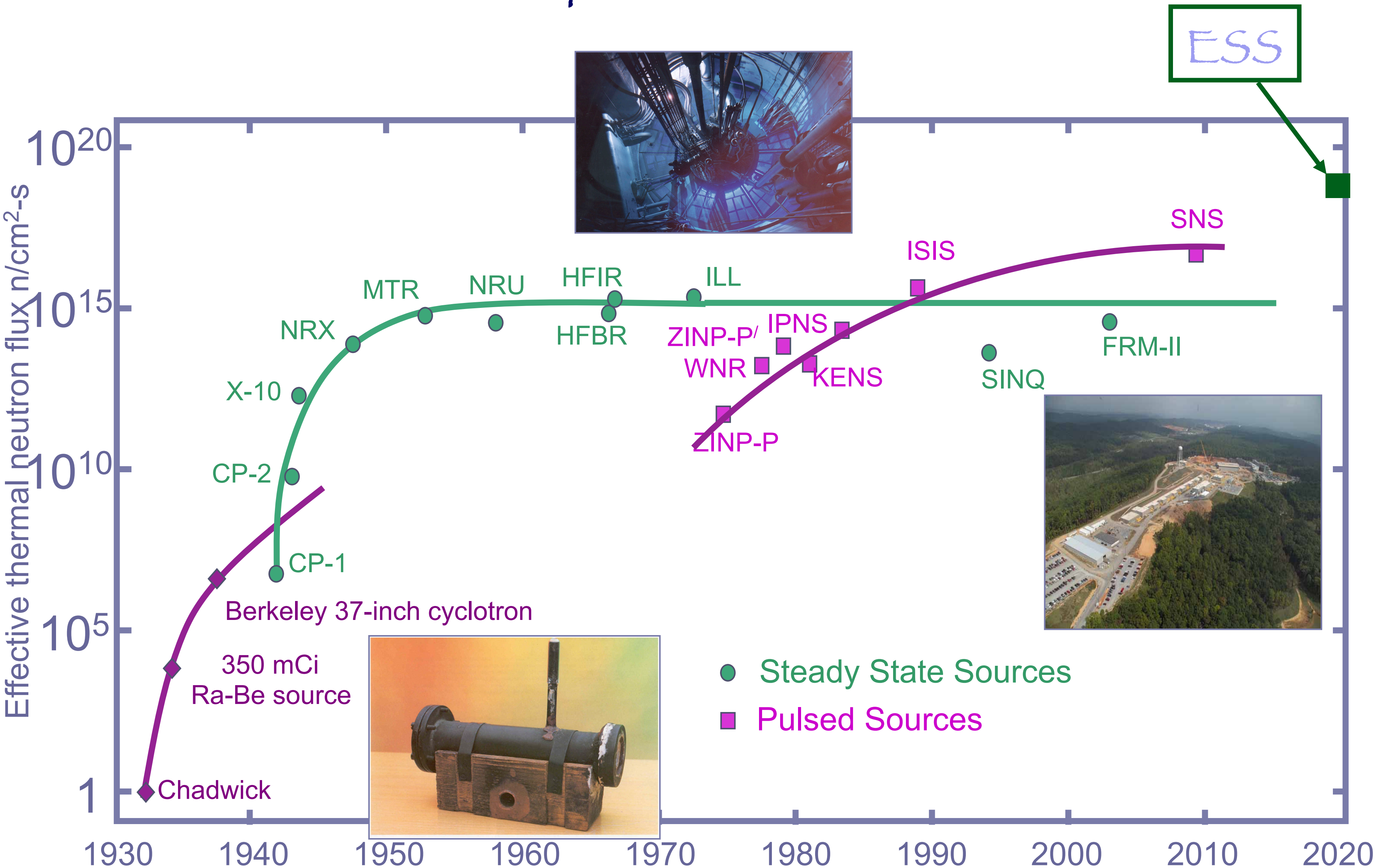
PART 2

- How to generate intense neutron beams
- High power proton linear accelerator

PART 3

- Examples of world-wide neutron sources

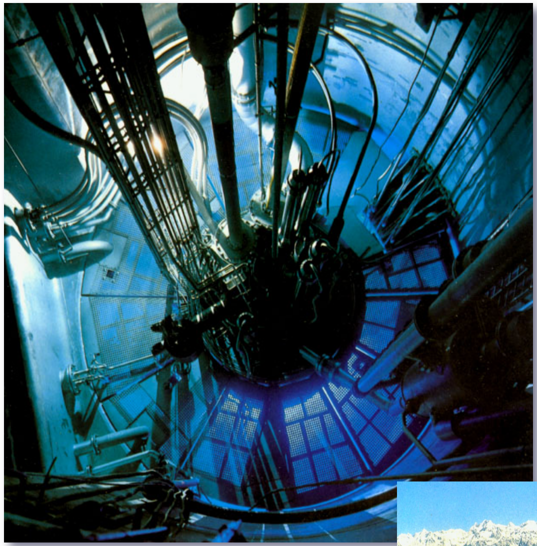
Evolution of the performance of neutron sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

Steady-state Neutron Source

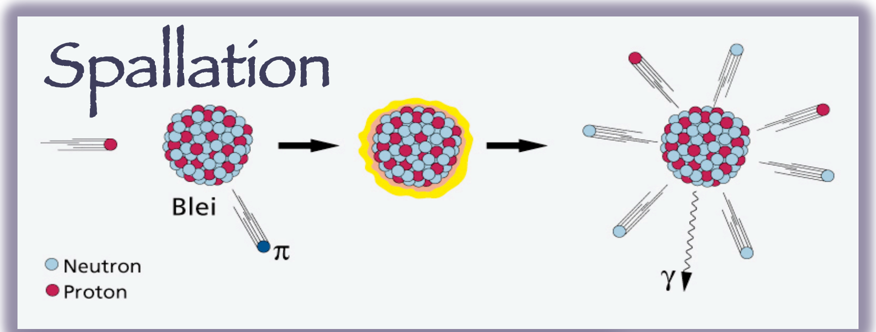
Institut Laue Langevin, Grenoble

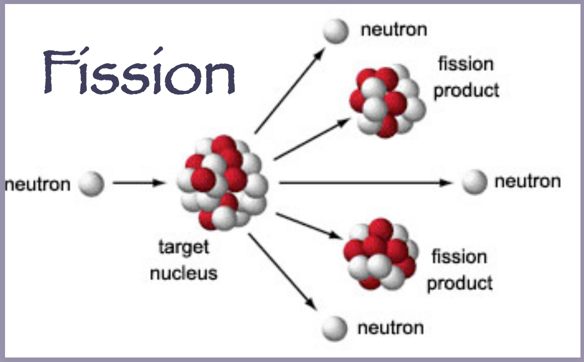


A 58MW High Flux research reactor optimized for neutron studies of condensed matter.

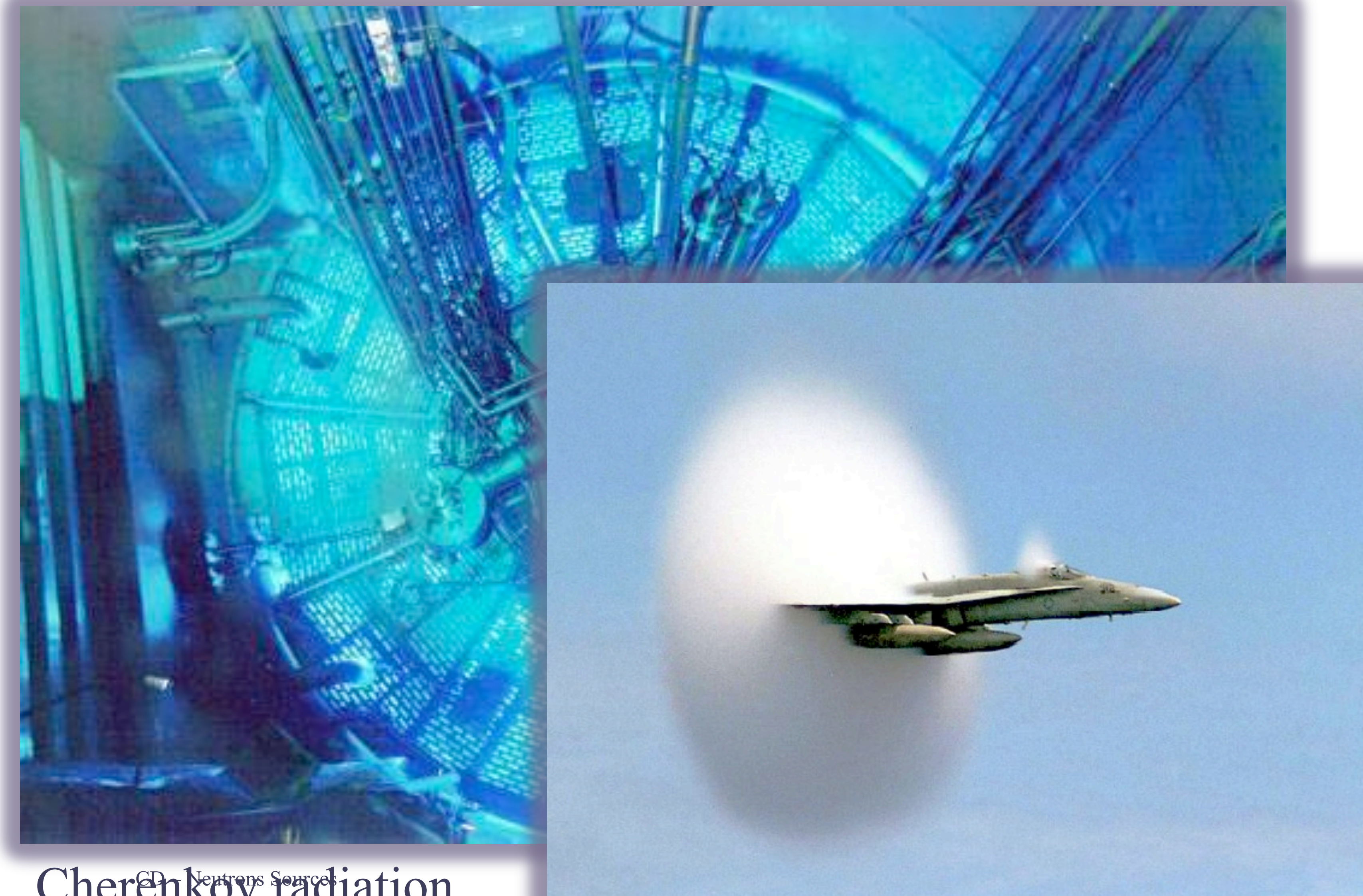
The most powerful steady state neutron source in the world.

Jointly owned by Britain, France and Germany (with Switzerland, Austria, Italy, Spain and Russia as minor partners)



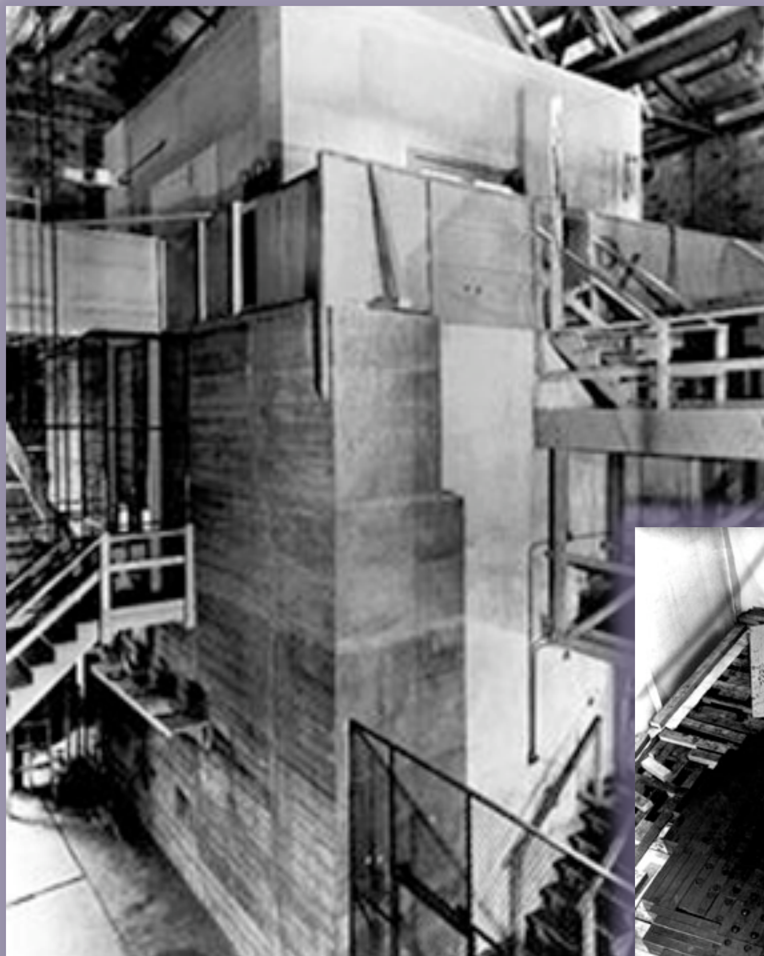


ILL reactor pool

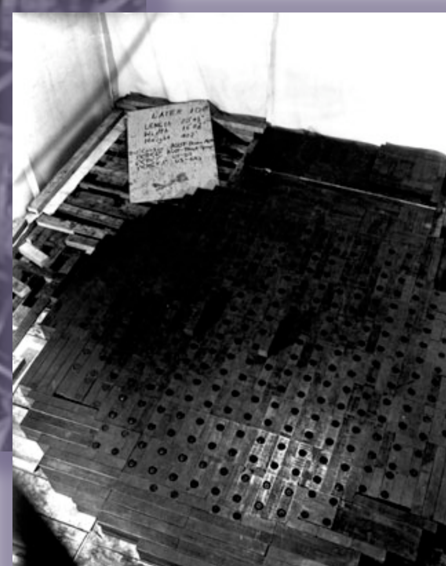


Cherenkov radiation

Neutron Production CP1



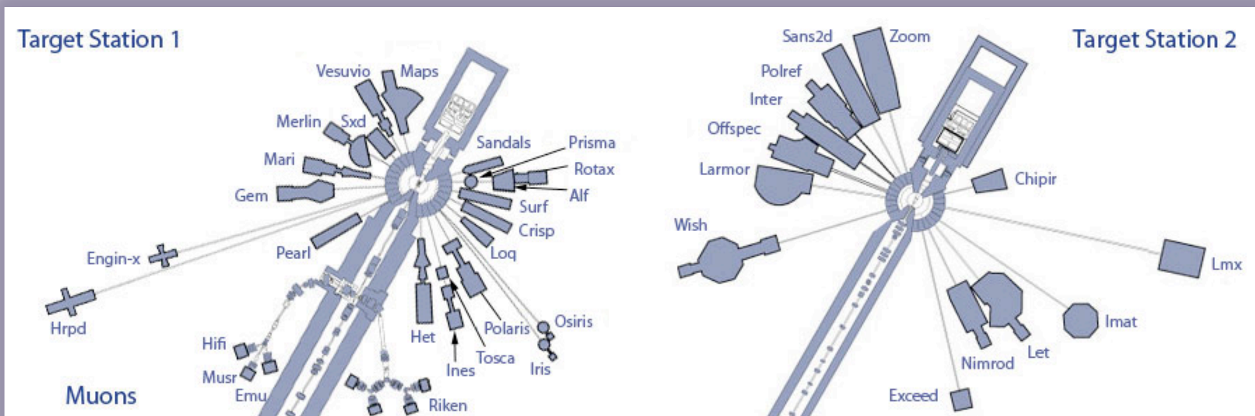
Chicago Pile 1, 2/12/1942



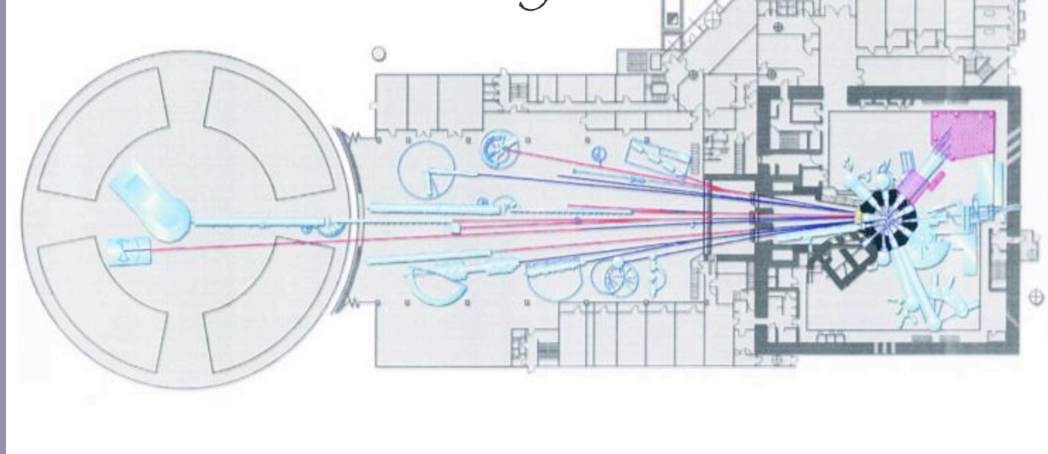
The 19th layer of graphite covering layer 18 containing slugs of uranium oxide. Parts of the wooden scaffolding and surrounding balloon cloth also are visible. The completed pile contained 771,000 pounds of graphite, 80,590 pounds of uranium oxide and 12,400 pounds of uranium metal when it went critical. It cost about $2.7 million to produce and build. The pile took the form of a flattened ellipsoid which measured 25 feet wide and 20 feet high.

Instrumentation

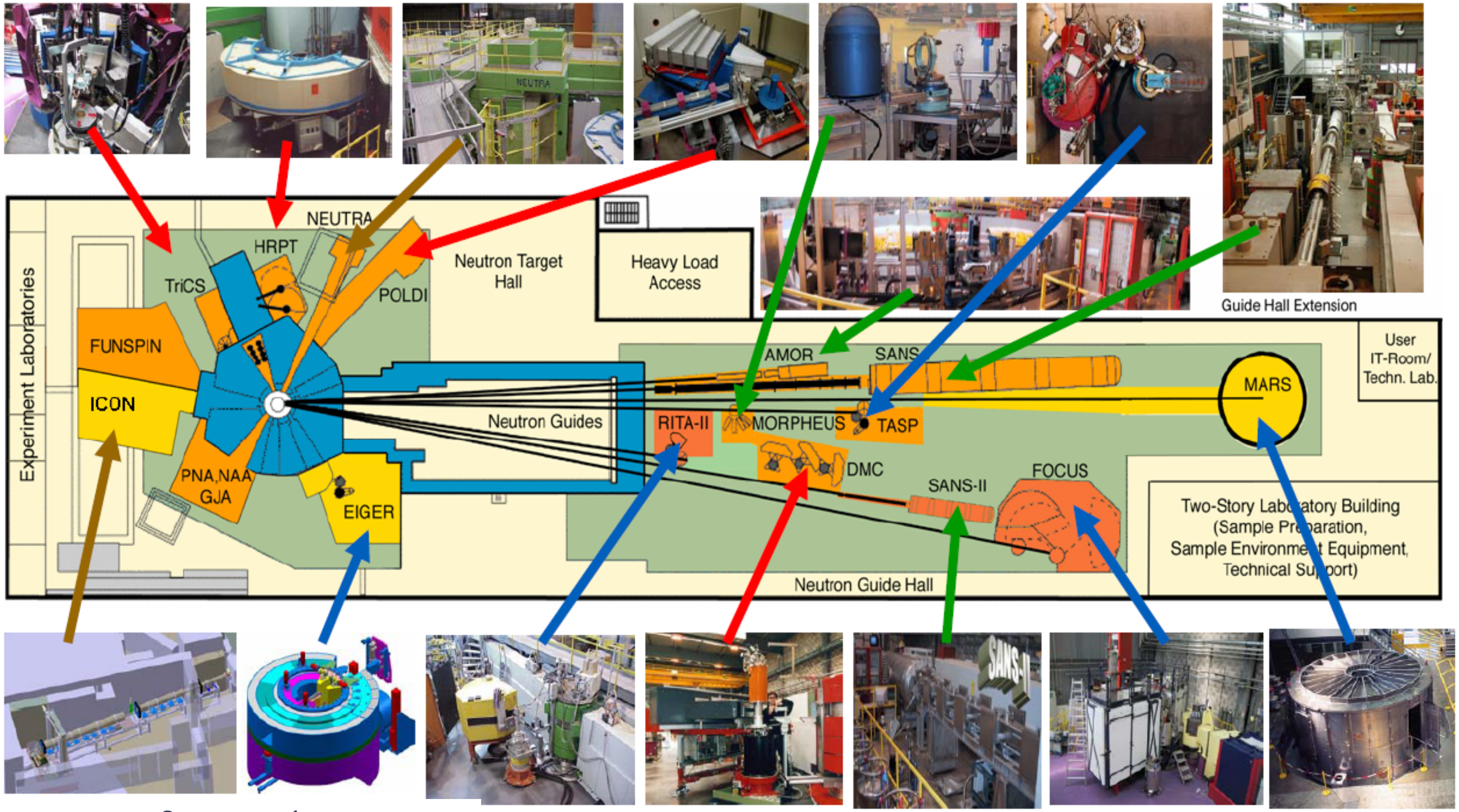
ISIS, UK



FRM-II, Germany



SINQ



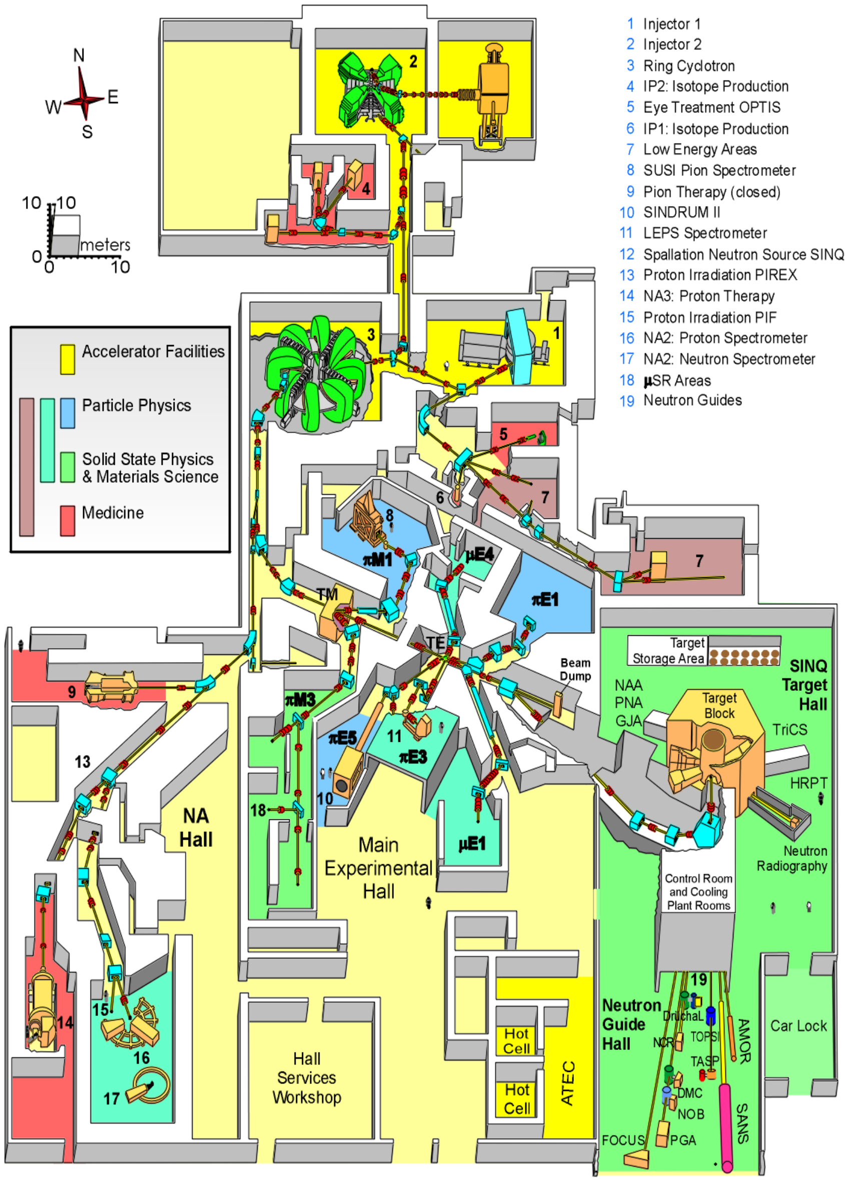
Scientific applications

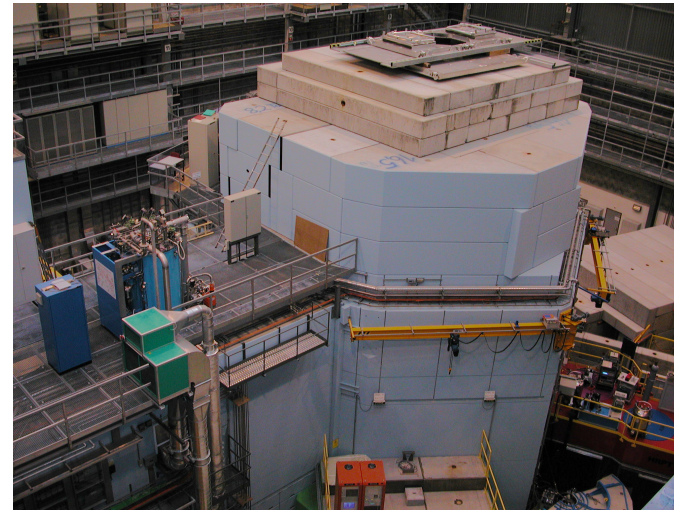
Solid state physics
Materials science
Biology
Medicine
Environmental science

Types of Instruments

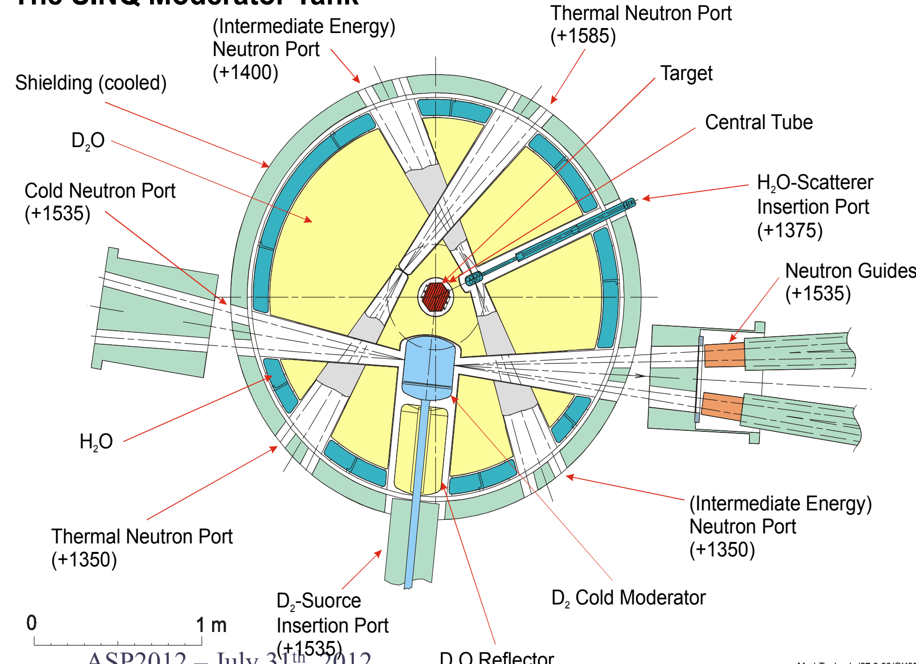
Diffractometers
Small-angle scattering
Reflectometers
spectrometers
Neutron radiography

SINQ Spallation Neutron Source



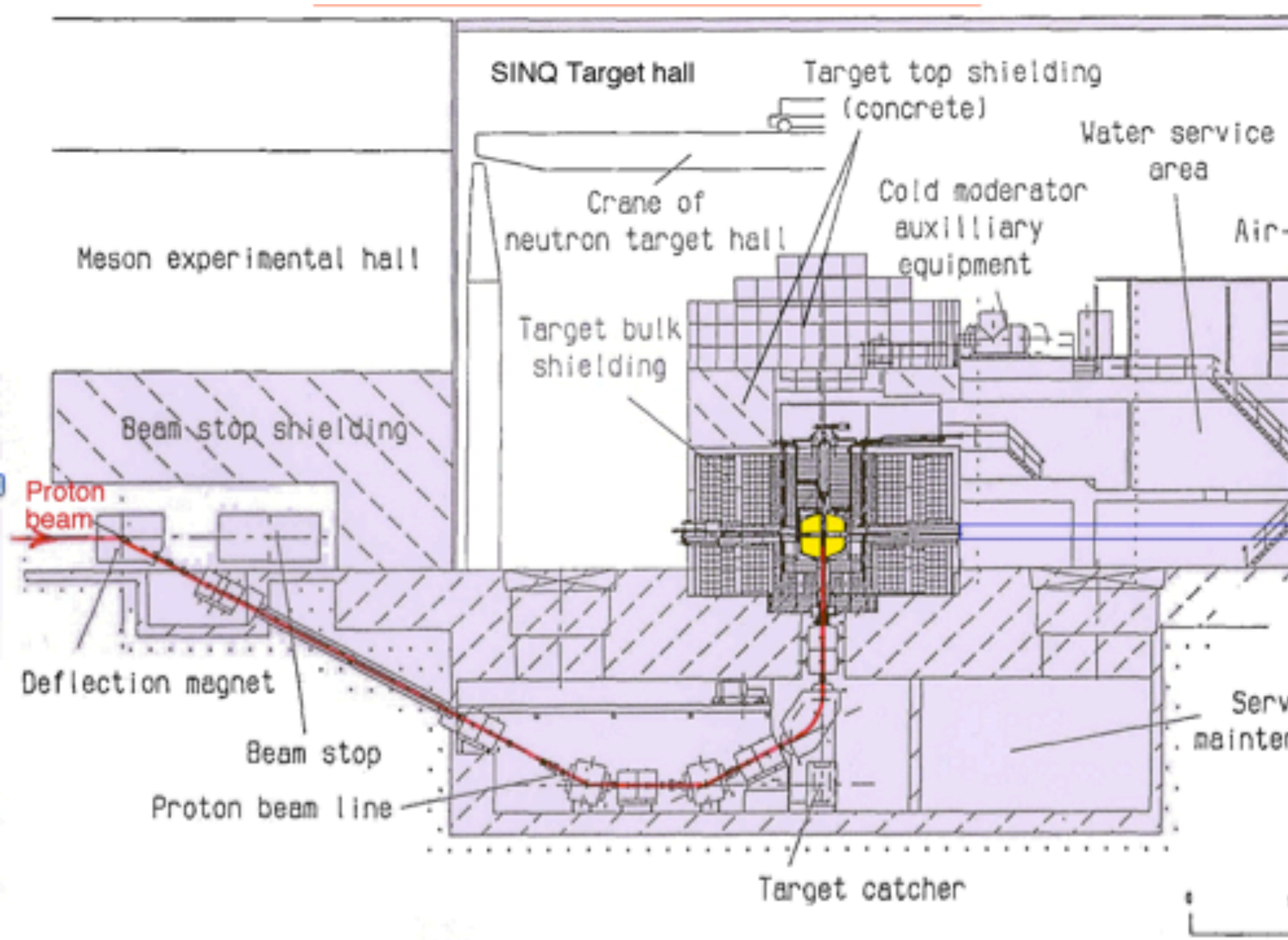


The SINQ Moderator Tank

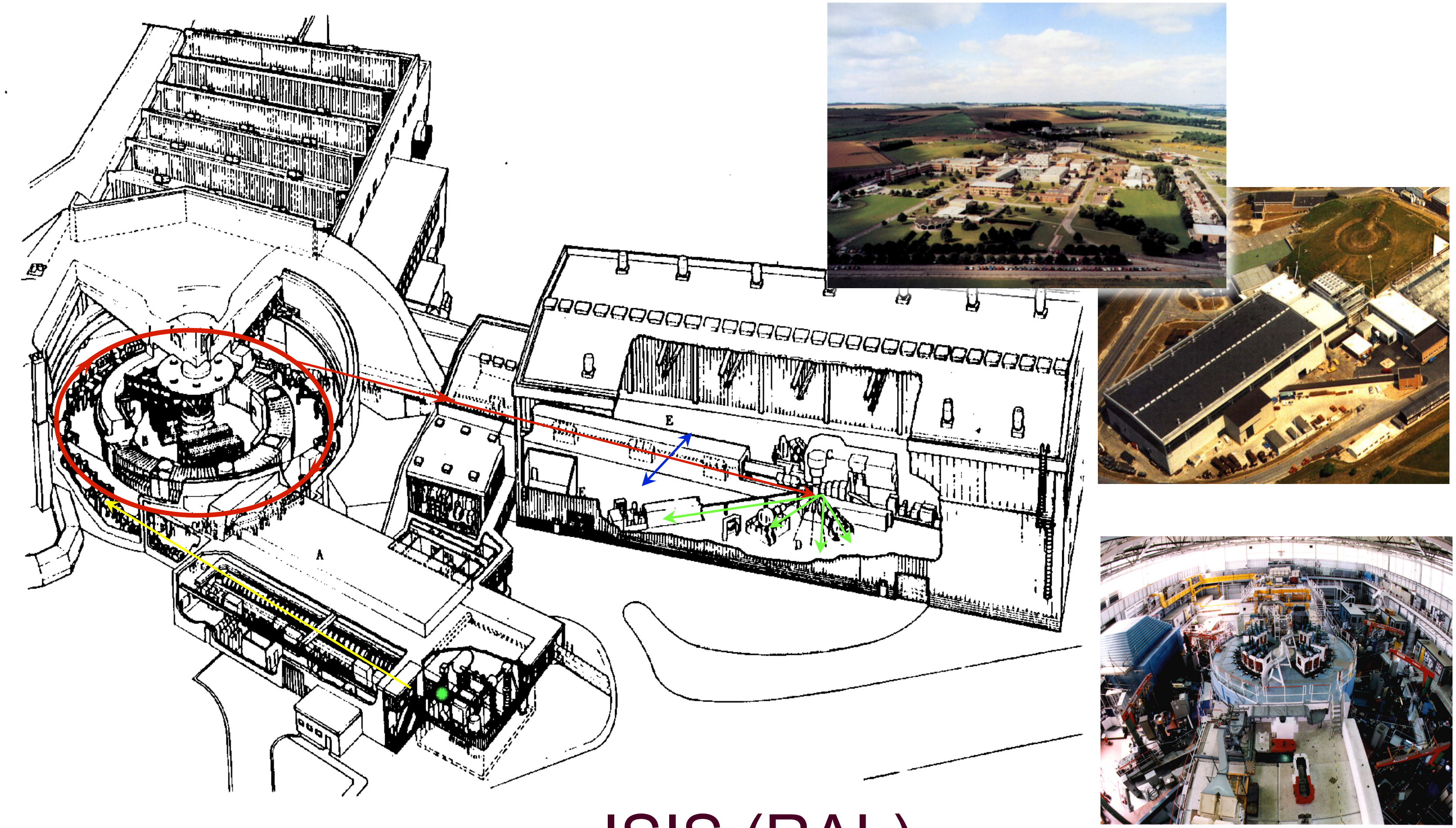


SINQ target

575 MeV, 1.8 mA continuous



SINQ - Target



ISIS (RAL)

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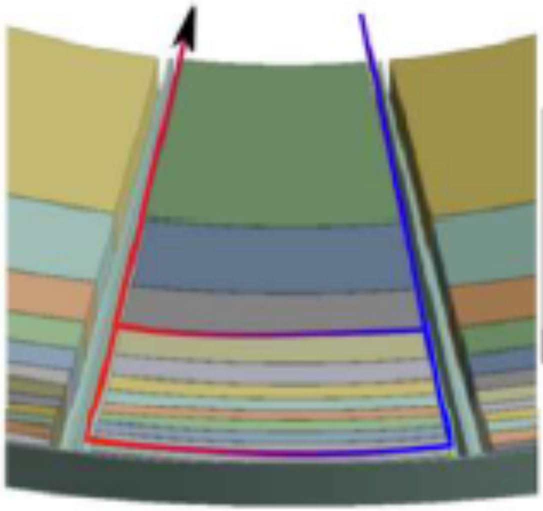
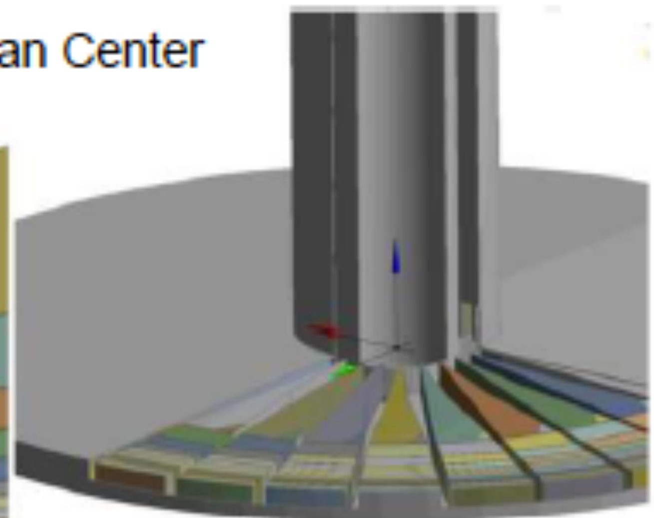
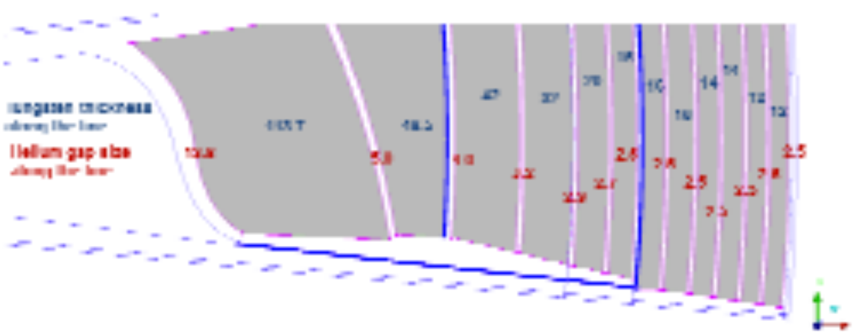
SOURCE

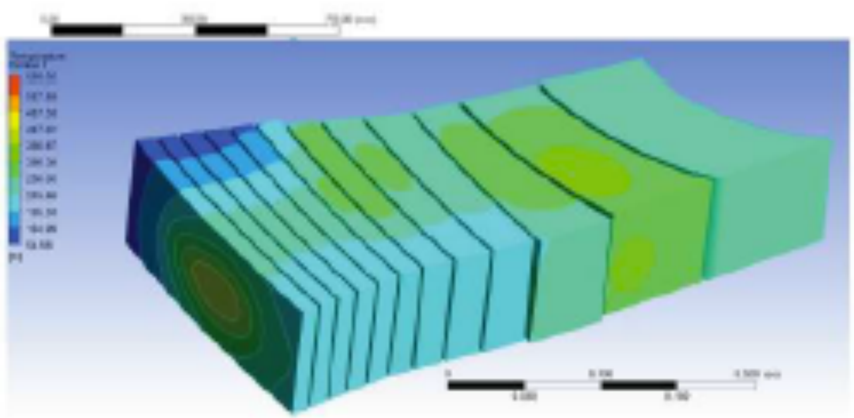
Target wheel: 33 ISIS like targets

Same radiation load as ISIS and Lujan Center









Pulsed Neutron Source

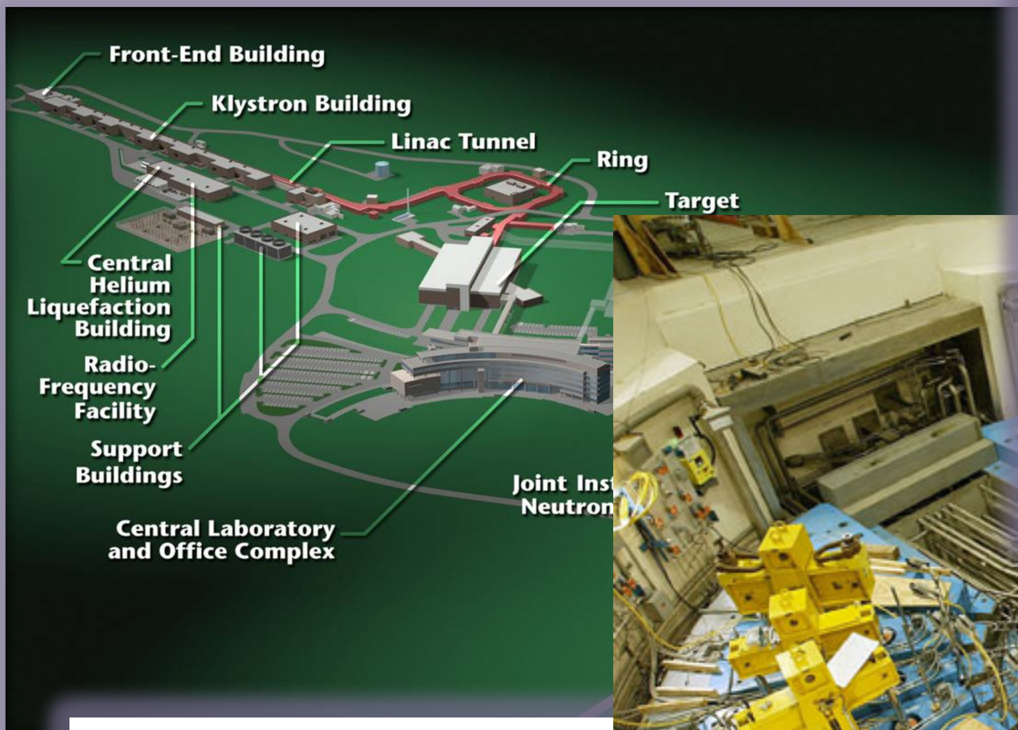
Neutron Spallation Sources

SINQ, PSI, near Villigen, CH

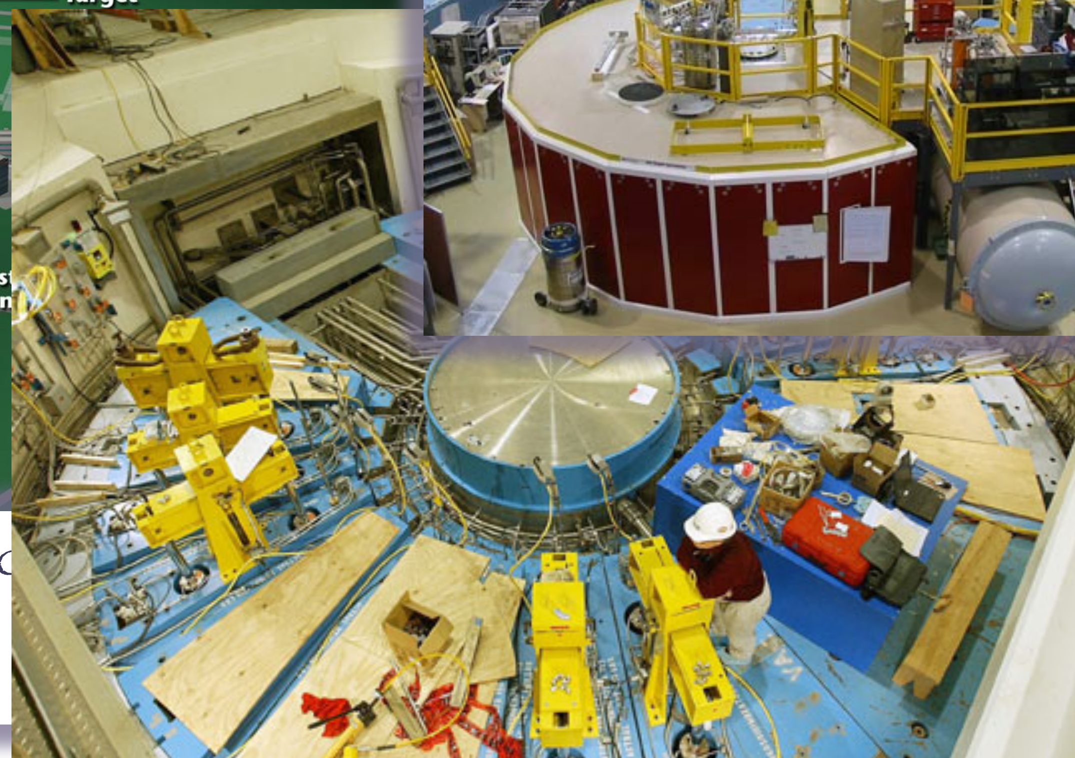
ISIS, RAL, near Oxford, UK

SNS, ORNL, near nowhere, USA

Spallation Sources



1 MW Spallation Neutr
Source in Oak Ridge
NL (compl. 2006)

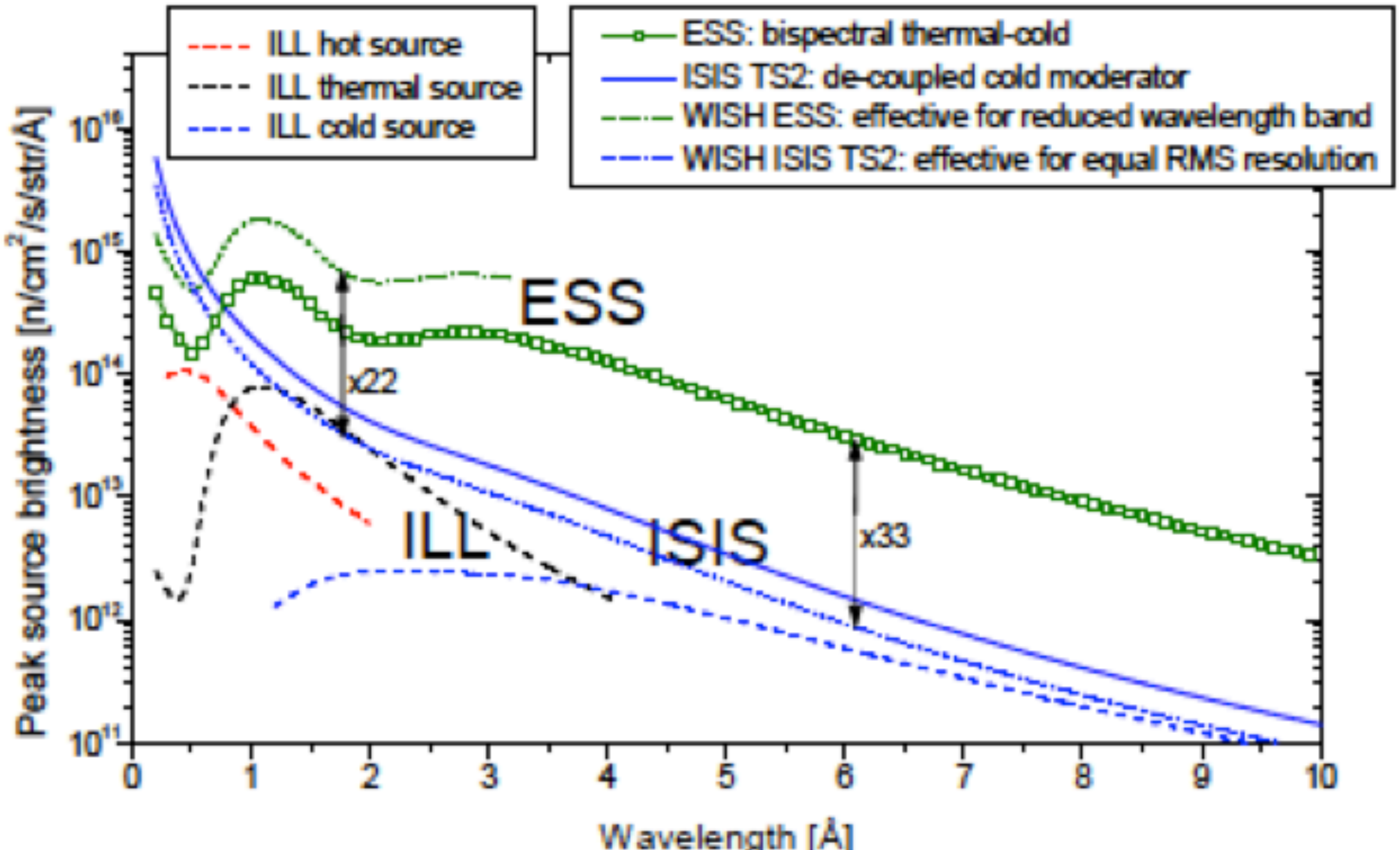


SNS Oak Ridge USA

OECD: «high power spallation source in global region »


SNS Oak Ridge
OPERATIONAL 2006
J-PARC Tokai
OPERATIONAL 2008
J-PARC
ESS in Lund
Site Decision in May 2009!

Beam Performance – cold neutrons



Data sources:

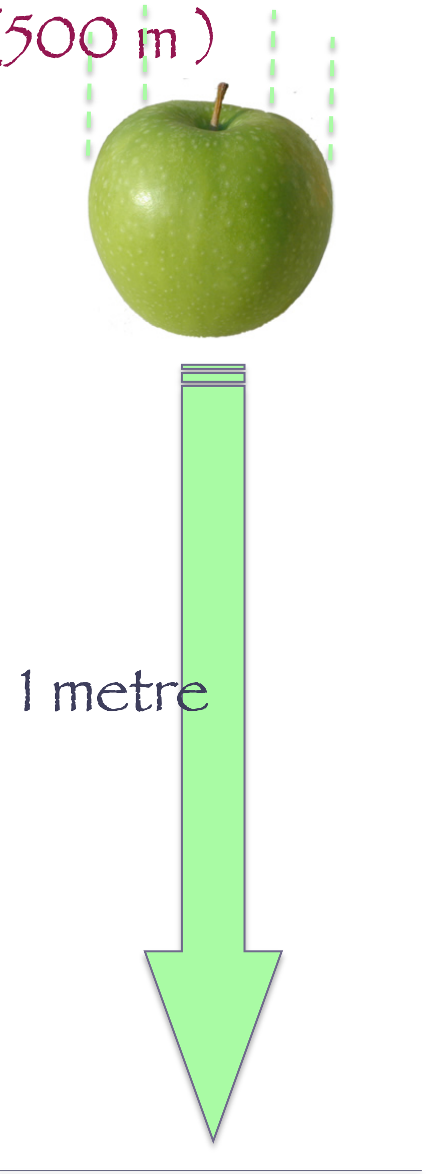
- ILL Yellow book
- ISIS cold (solid methane) moderator, generously estimated (up to 5 times ILL!) on the basis of benchmark experiments at Los Alamos cold moderator (liquid H_2). No published ISIS data available.

European Spallation Source

Sweden

ESS – some numbers

- Superconducting Proton Linear Accelerator (500 m)
  - 2.5 GeV Proton Energy
- 50mA (2mA) peak (average) proton current
  - 357 kJ/pulse
- 2.86 msec pulse length
  - 14 Hz pulse frequency
- 71.4 msec periods between pulses
  - 5MW proton beam power
- Single Target Station
  - Rotating Tungsten, helium cooled
- 22 instruments
  - High reliability, low losses



The view to the South-East in 2025

The ESS Headlines

- ESS will be the world's best source of slow neutrons by 2025
- ESS will produce its first neutrons in 2019
- ESS will cost 1479 M€$_{2008}$ to construct

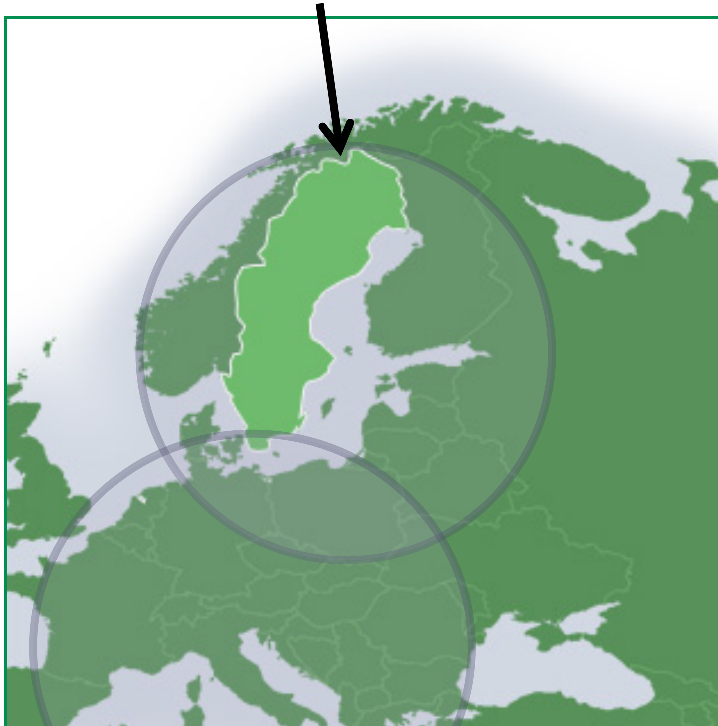
ESS will be different

- Sustainability & Environmental Responsibility
- Harness Innovations
- Excellent researcher support
- Person-centred
- Prepare for the future
- "More than simply neutrons"

EUROPEAN SPALLATION SOURCE

ESS Partners

Sweden, Denmark and Norway
50% of construction costs



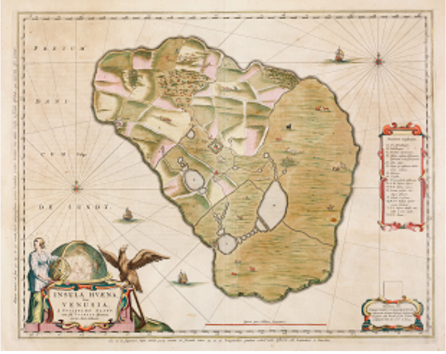
17 Partners today

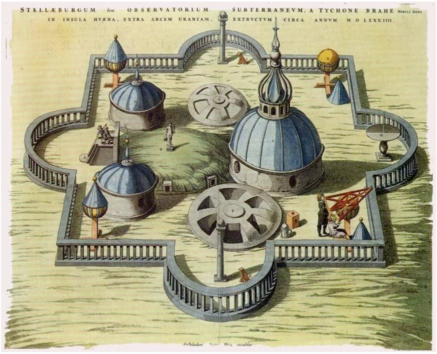
Spain, France, Germany, Italy, UK, Switzerland, Hungary, Czech Republic, Poland, Netherlands, Estonia, Latvia, Lithuania & Iceland
the remaining 50%

1.5 Billion Euros: Biggest investment in Science ever in Scandinavia?

In modern time, definitely YES!

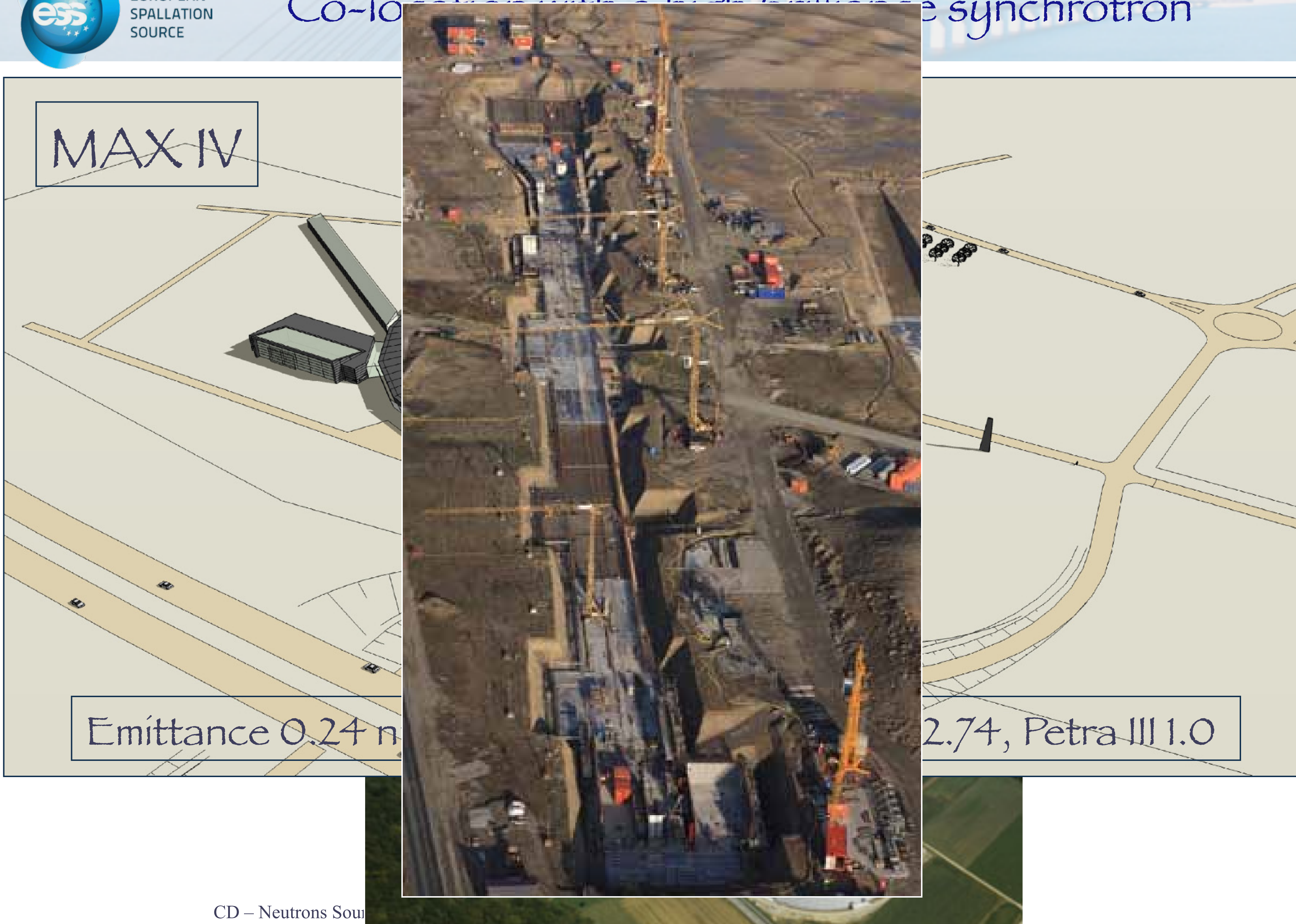
However, Tycho Brahe's Stjärneborg costed the Danish king 1% of the state budget in 1580.





Or you could for 1.5 Billion Euros pay the US bankers bonuses for 24 days!

Co-lo … e synchrotron

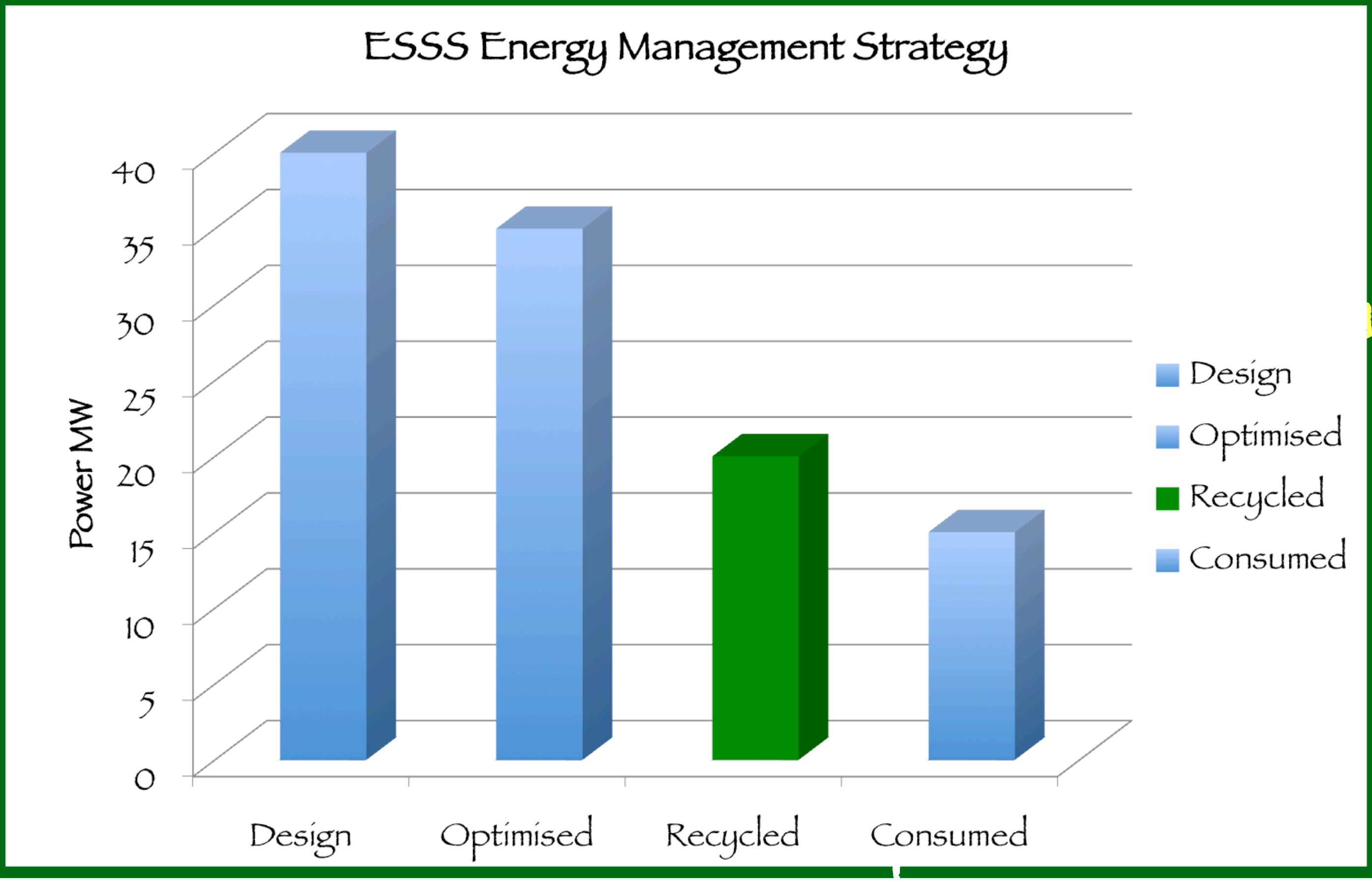



Cost of solar heater RMB 5,000
Cost of electric heater RMB 2,000
Extra cost for solar heater
RMB 3,000 yuan
For a house with three people showering and using
full 180 litre tank in one day
costs about RMB1.5
One year 365 × 1.5 = RMB 547.5
So it takes about 5.5 years to get back extra cost
and then heating costs you nothing!

R

Re

ESS Energy Management Strategy



Aim to reduce operations costs by ~9 M€ p.a.

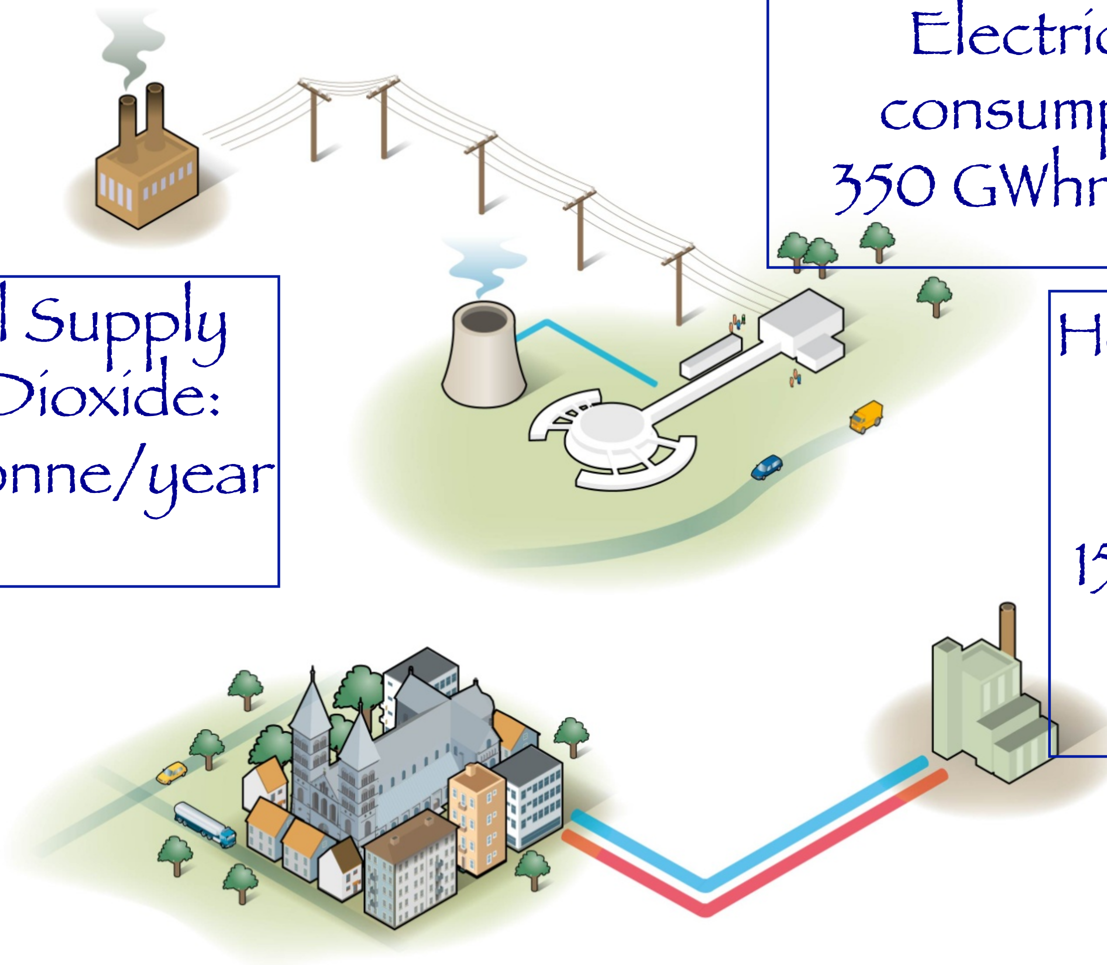
tem

Waste heat re-use

This is how it is usually done

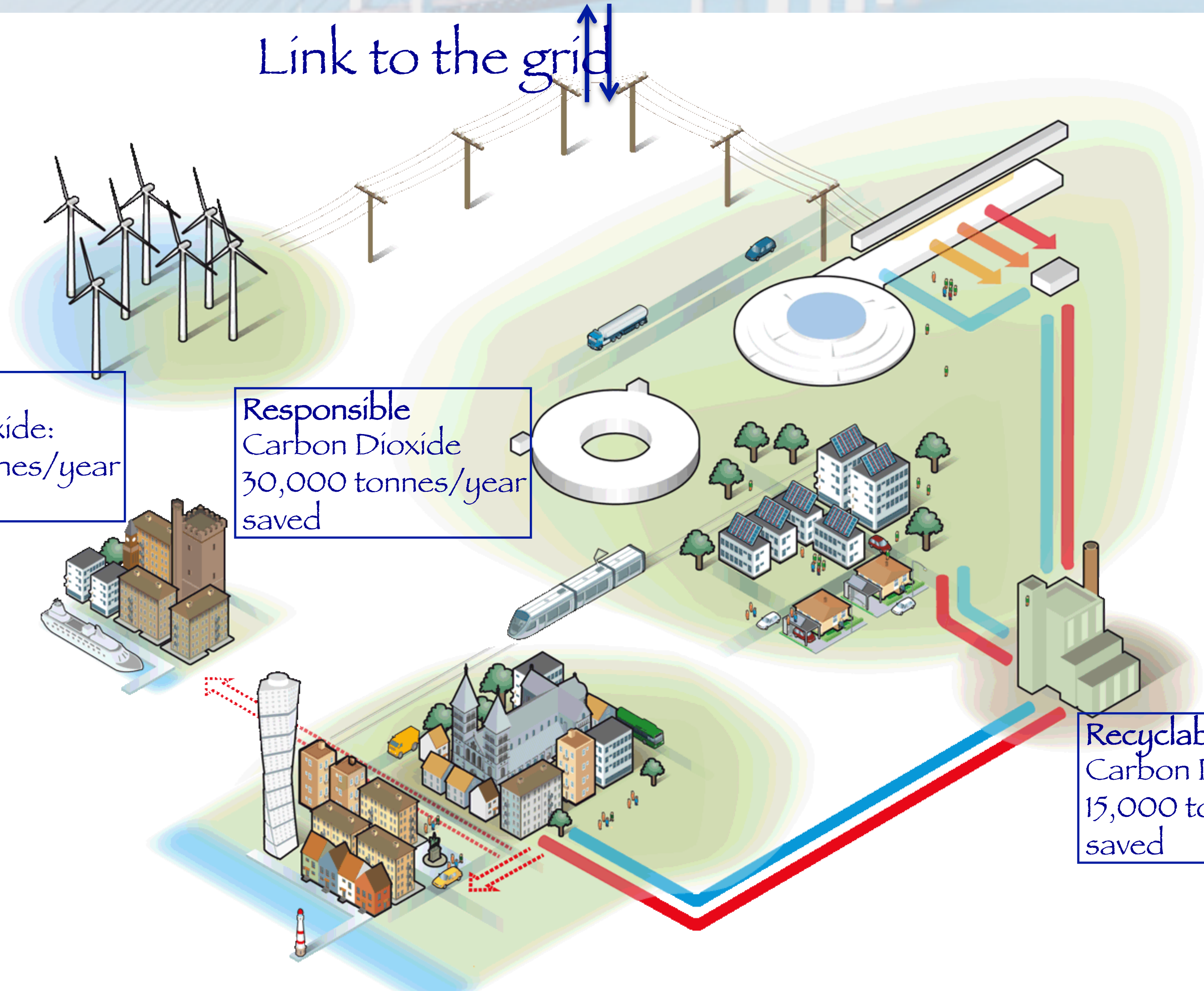
Electricity consumption:
350 GWhr/year

Electrical Supply Carbon Dioxide:
150,000 tonne/year



Heating Supply Carbon Dioxide:
15,000 tonne/year

This is how ESS will do it in 2020



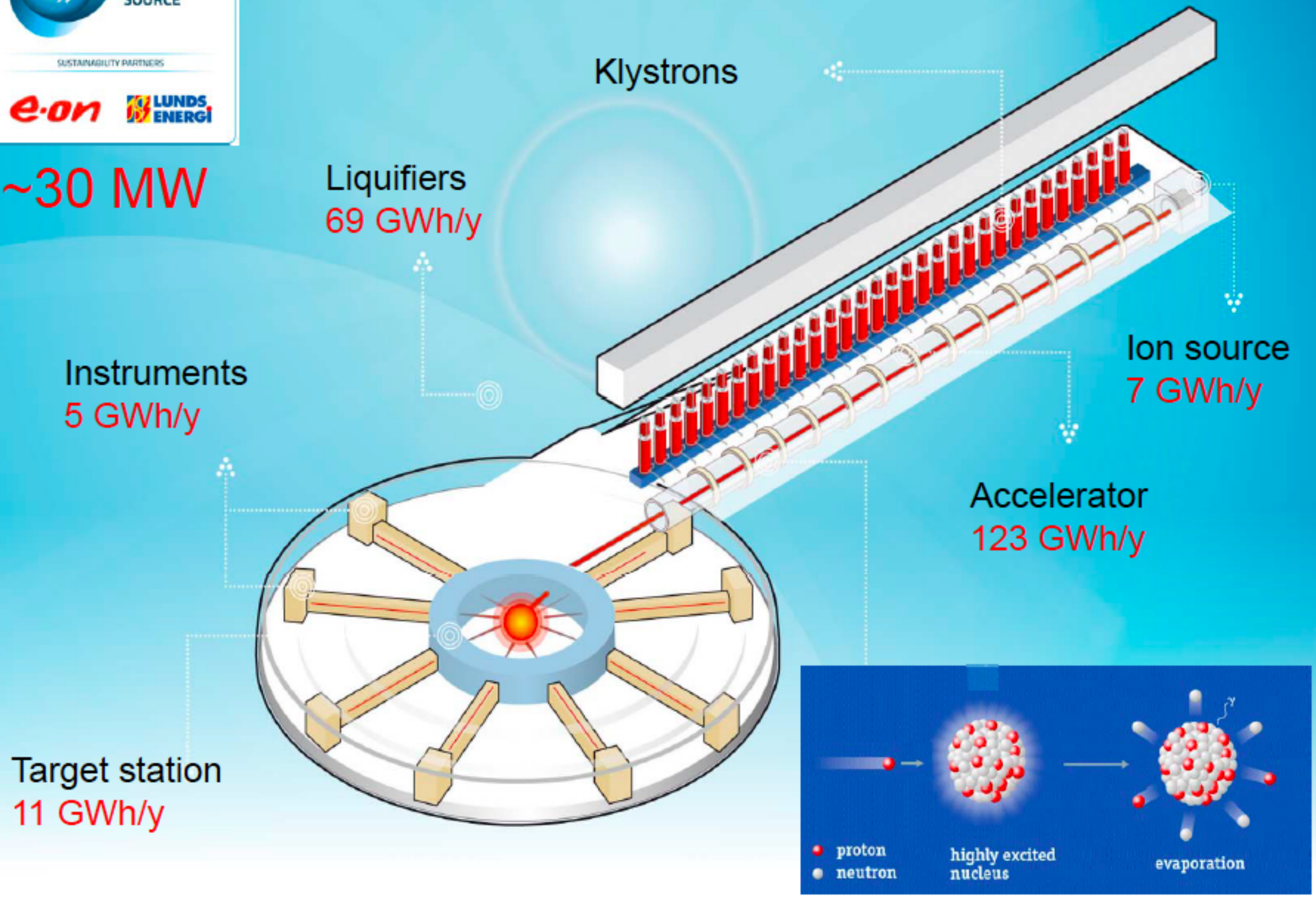
Renewable
Carbon Dioxide:
120,000 tonnes/year saved

Responsible
Carbon Dioxide
30,000 tonnes/year saved

Recyclable
Carbon Dioxide:
15,000 tonnes/year saved

ESS Layout and Energy Usage

~30 MW



J-PARC

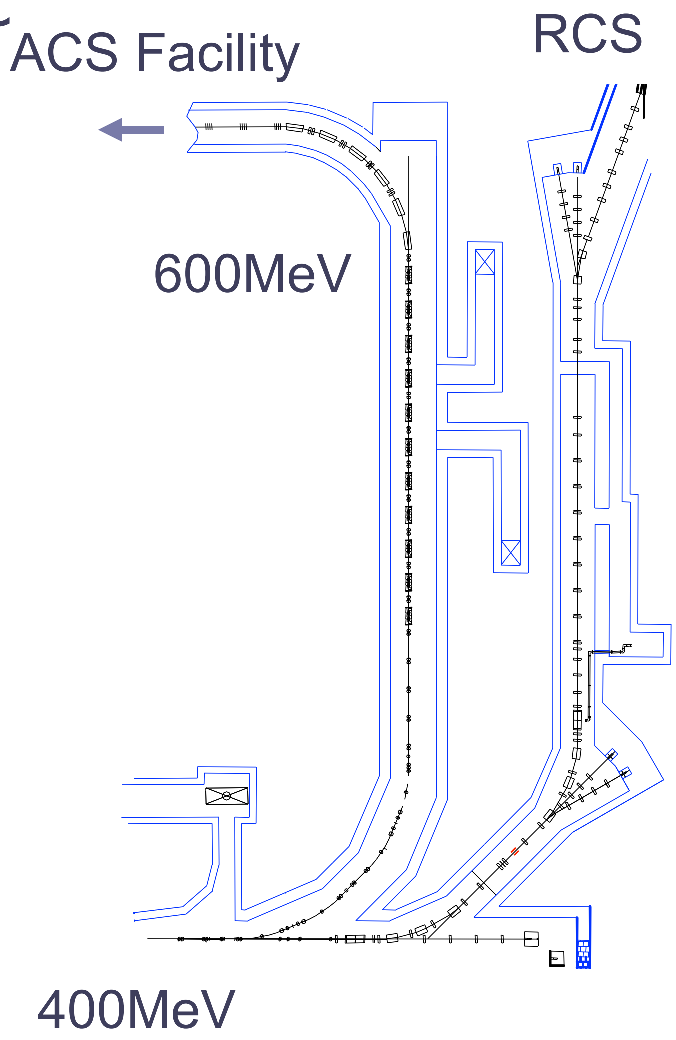
Japan

J-PARC - PARAMETERS

Preliminary design of SC proton linac

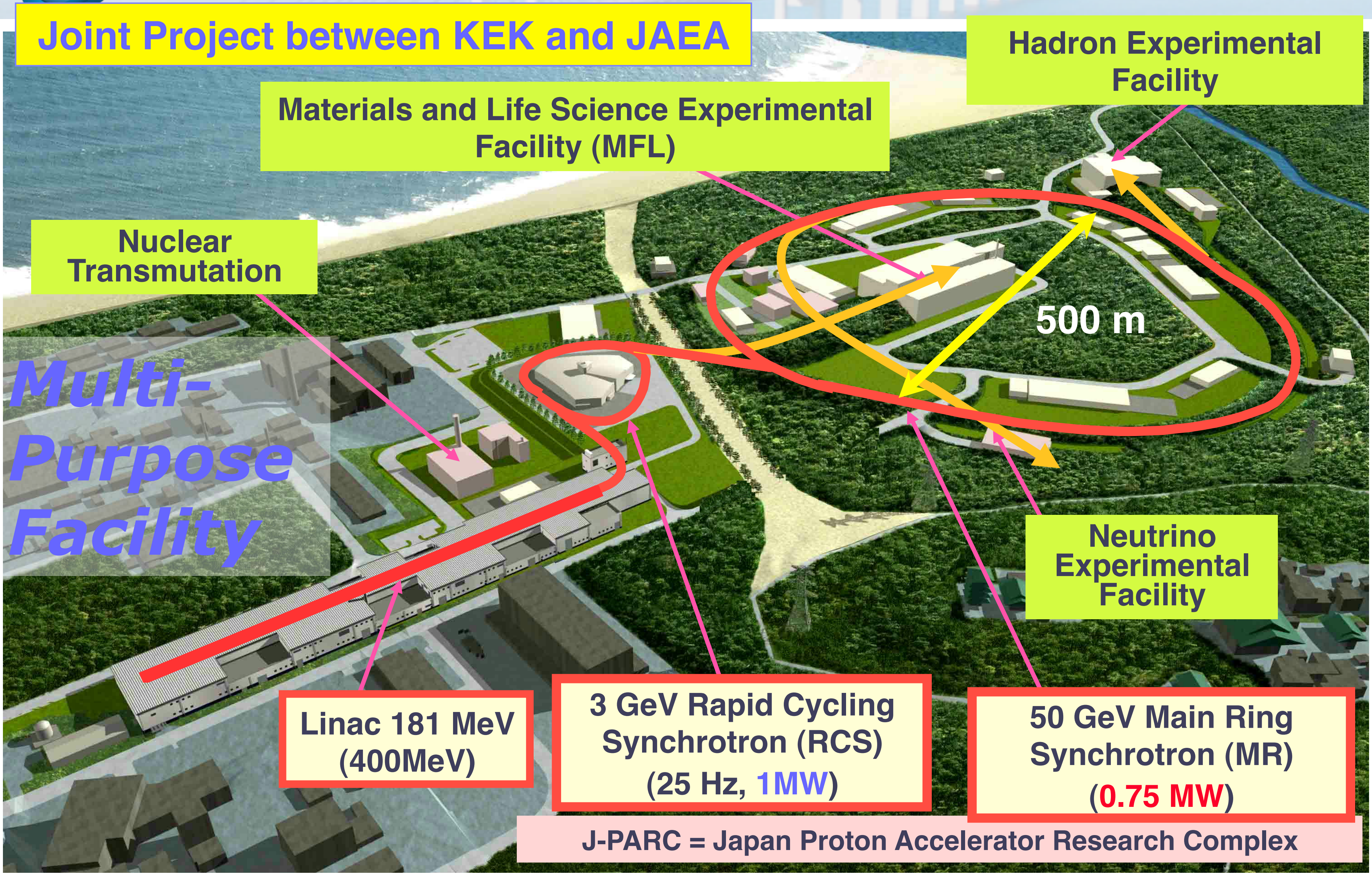
Design Parameters

Energy	400-600 MeV
Frequency	972 MHz
β	0.71-0.79
No. of Cell	9 cell/cavity
No. of Cavity	2 cavity/cryomodule
No. of Cryomodule	11 cryomodules
Length	57.7 m
Surface Peak Field	30 MV/m
Accelerating Field	9.7-11.1MV/m
Synchronous Phase	-30 deg
No. of Klystron	11 klystrons
Total RF Power	10 MW
Loaded Q	~500,000

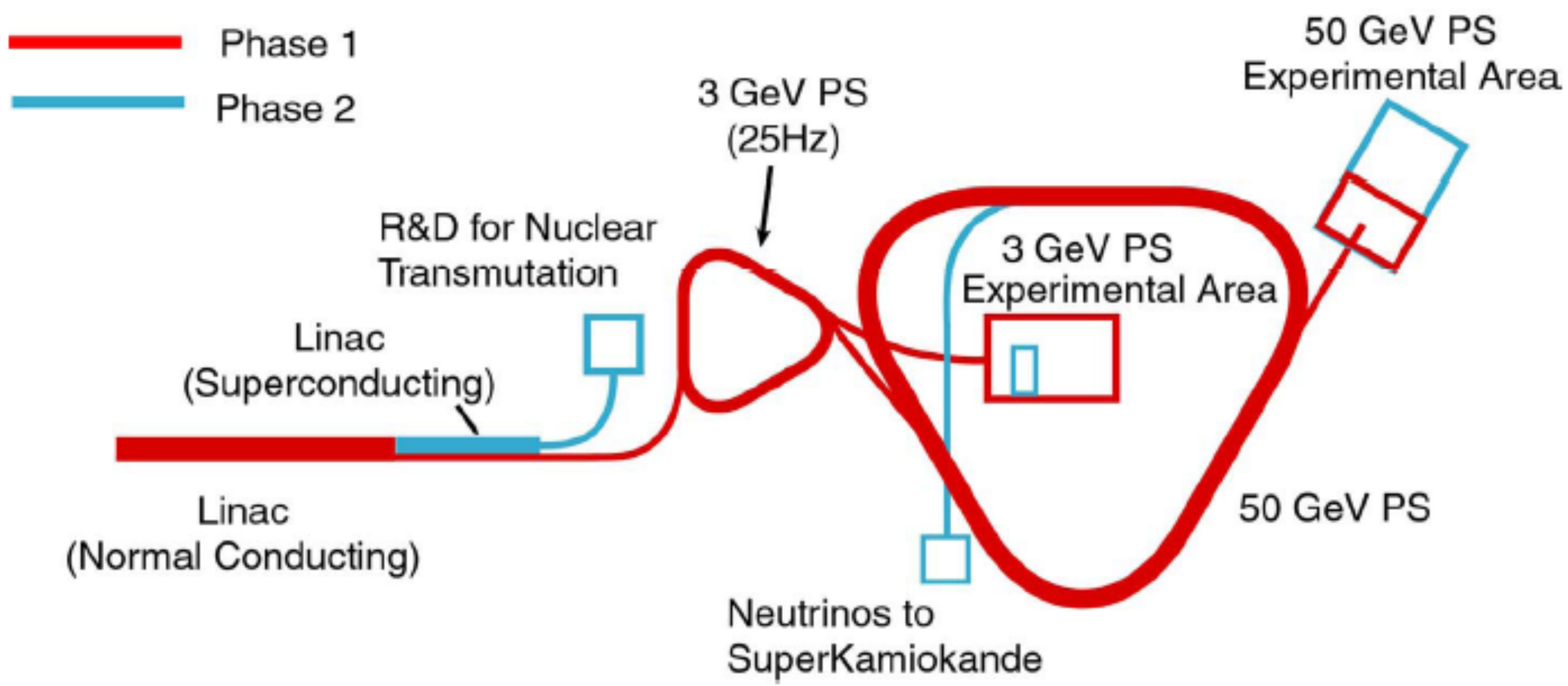


Amplitude and phase stability (±1% & 1deg) in pulsed operation

J-PARC

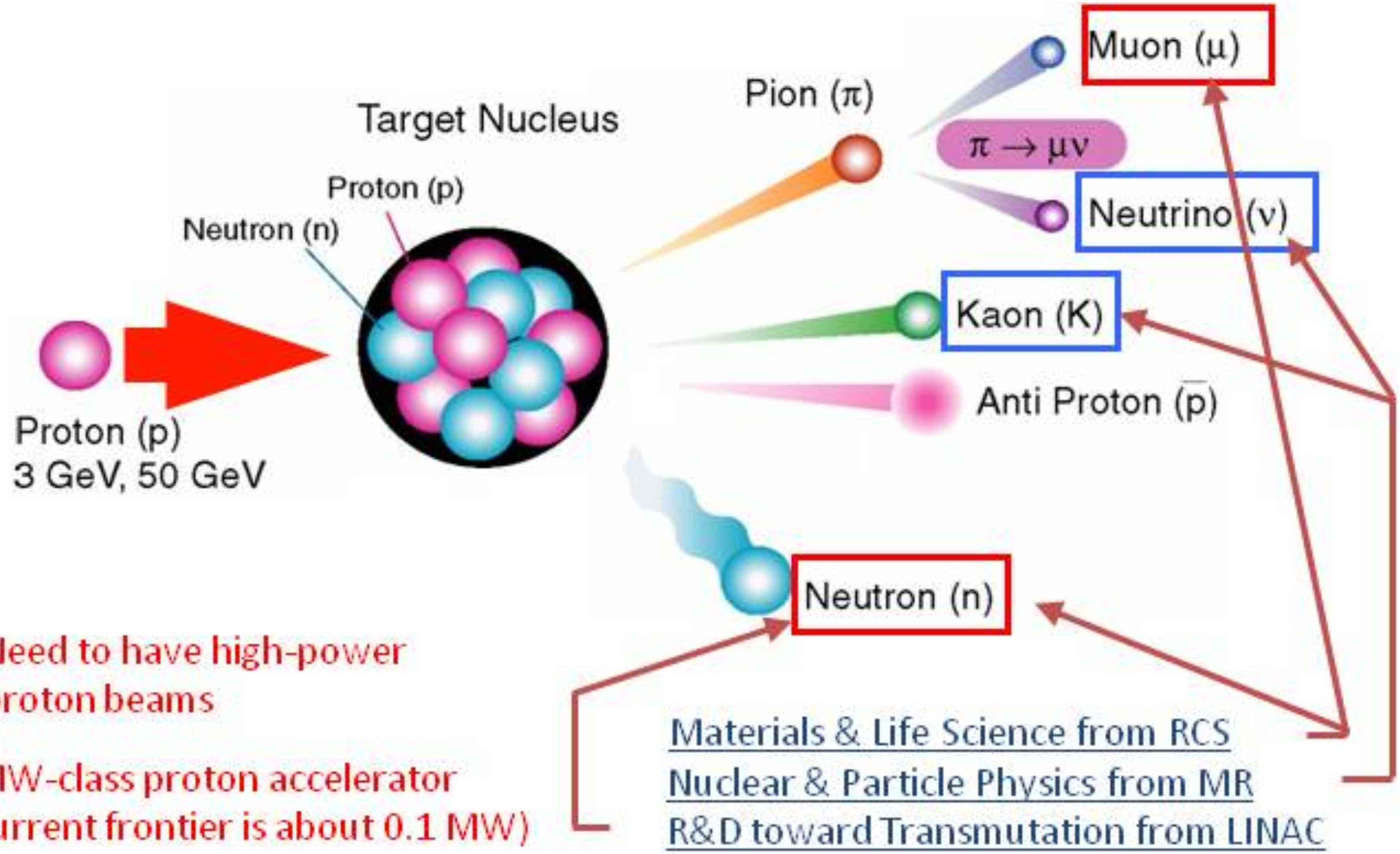

Joint Project between KEK and JAEA
Hadron Experimental Facility
Materials and Life Science Experimental Facility (MFL)
Nuclear Transmutation
500 m
Multi-Purpose Facility
Neutrino Experimental Facility
Linac 181 MeV (400MeV)
3 GeV Rapid Cycling Synchrotron (RCS) (25 Hz, 1MW)
50 GeV Main Ring Synchrotron (MR) (0.75 MW)
J-PARC = Japan Proton Accelerator Research Complex

J-PARC : Accelerator Complex



- Phase 1 + Phase 2 = 189 billion Yen (= $1.89 billion if $1 = 100 Yen).
- Phase 1 = 133.5 billion Yen for 6 years (= 2/3 of 189 billion Yen).
- Construction budget does not include salaries.

Secondary particle produced at J-PARC



Need to have high-power proton beams

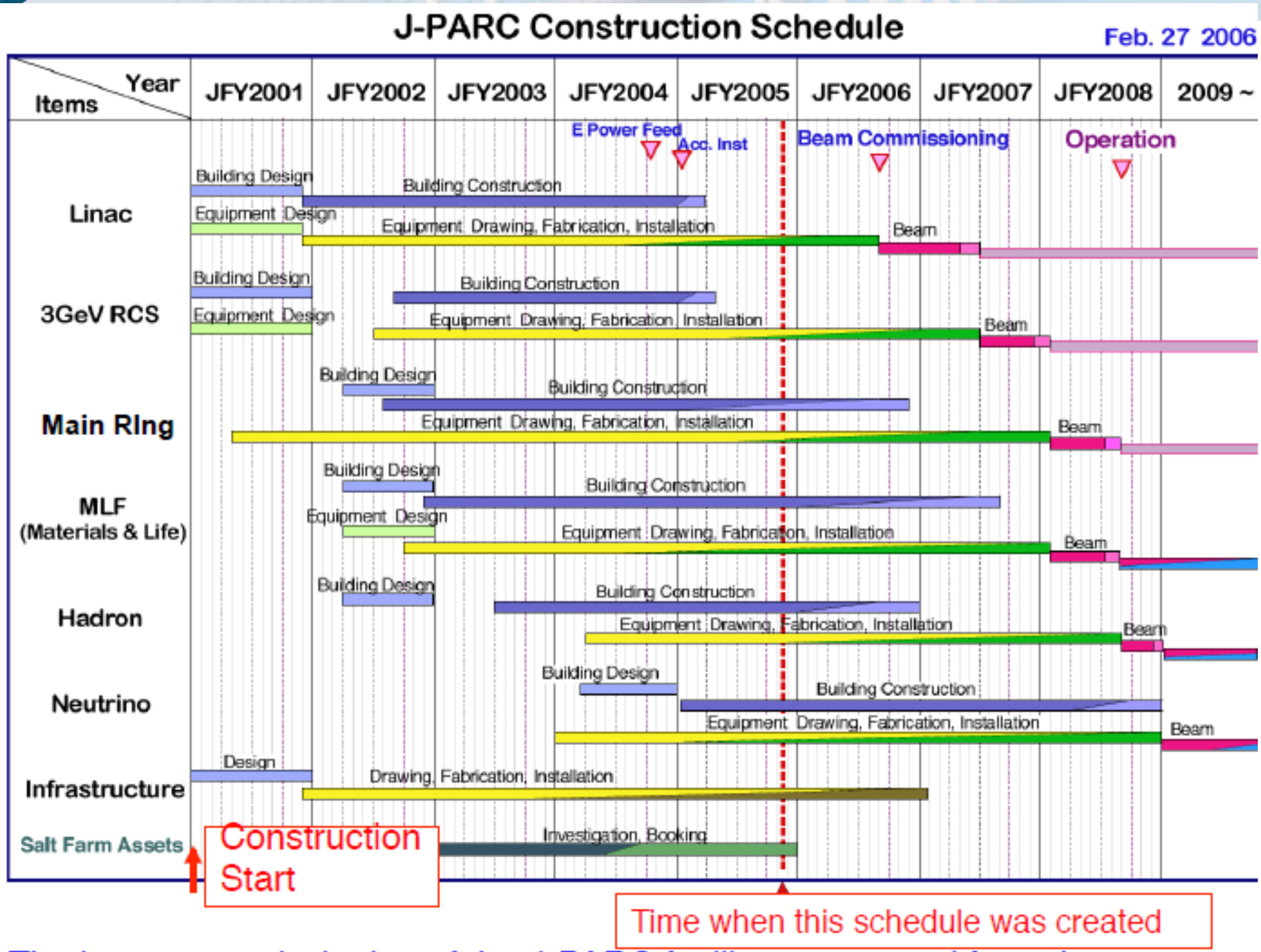
→ MW-class proton accelerator (current frontier is about 0.1 MW)

Materials & Life Science from RCS

Nuclear & Particle Physics from MR

R&D toward Transmutation from LINAC

J-PARC

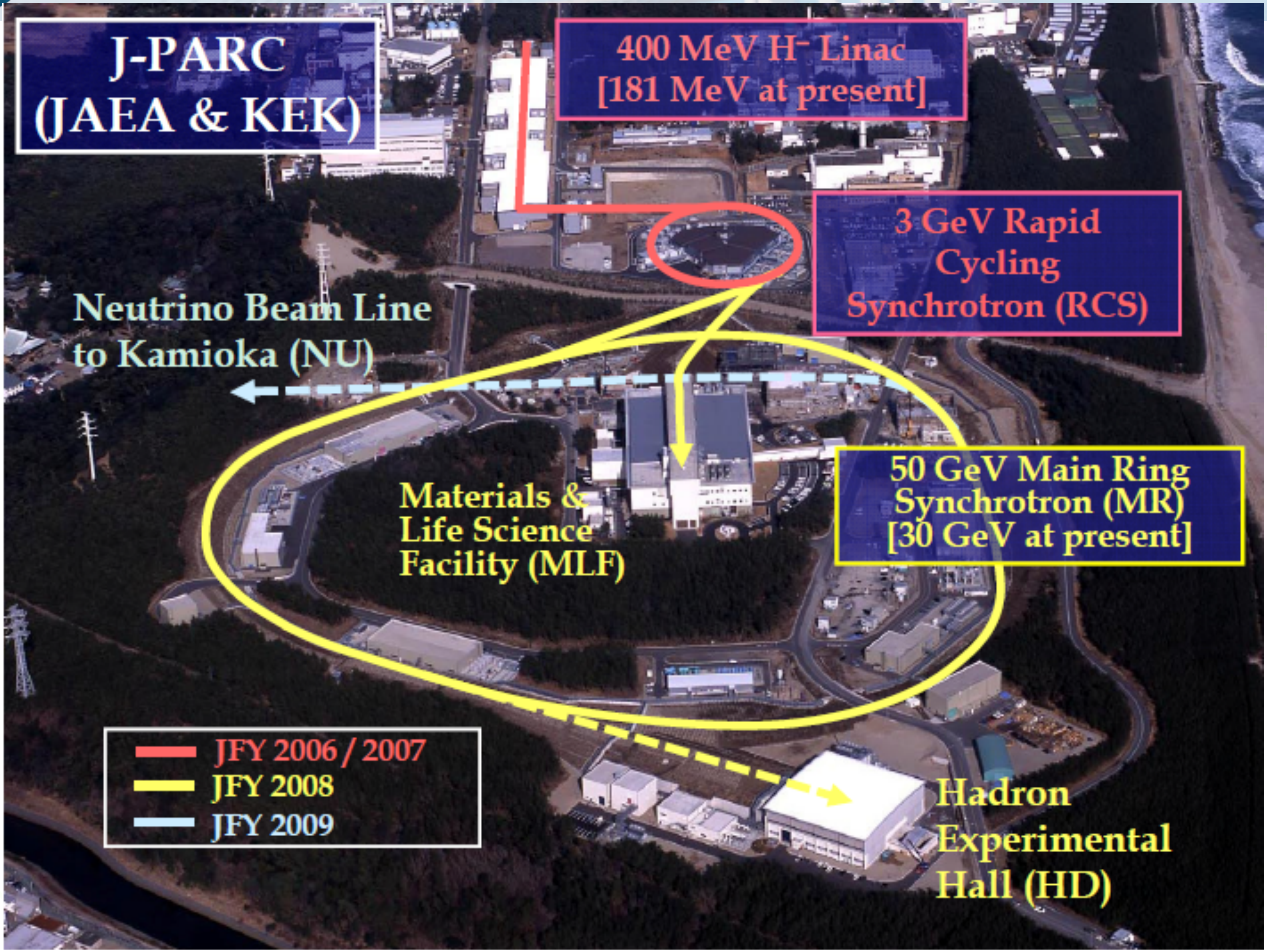

J-PARC Construction Schedule
Feb. 27 2006
Year
Items
JFY2001
JFY2002
JFY2003
JFY2004
JFY2005
JFY2006
JFY2007
JFY2008
2009 ~
E Power Feed
Acc. Inst
Beam Commissioning
Operation
Linac
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
3GeV RCS
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
Main Ring
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
MLF
(Materials & Life)
Building Design
Building Construction
Equipment Design
Equipment Drawing, Fabrication, Installation
Beam
Hadron
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Neutrino
Building Design
Building Construction
Equipment Drawing, Fabrication, Installation
Beam
Infrastructure
Design
Drawing, Fabrication, Installation
Salt Farm Assets
Investigation, Booking
Construction Start
Time when this schedule was created

J-PARC

J-PARC


J-PARC Photo
Hadron
Experimental
Facility
RCS
ADS Area
MLF
Linac
MR
Neutrino
Experimental
Facility
November, 2006

J-PARC


J-PARC
(JAEA & KEK)
400 MeV H⁻ Linac
[181 MeV at present]
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line to Kamioka (NU)
Materials & Life Science Facility (MLF)
50 GeV Main Ring Synchrotron (MR)
[30 GeV at present]
Hadron Experimental Hall (HD)
JFY 2006 / 2007
JFY 2008
JFY 2009

J-PARC

History of beam commissioning

2001 Construction started.

2006 Linac beam commissioning started.

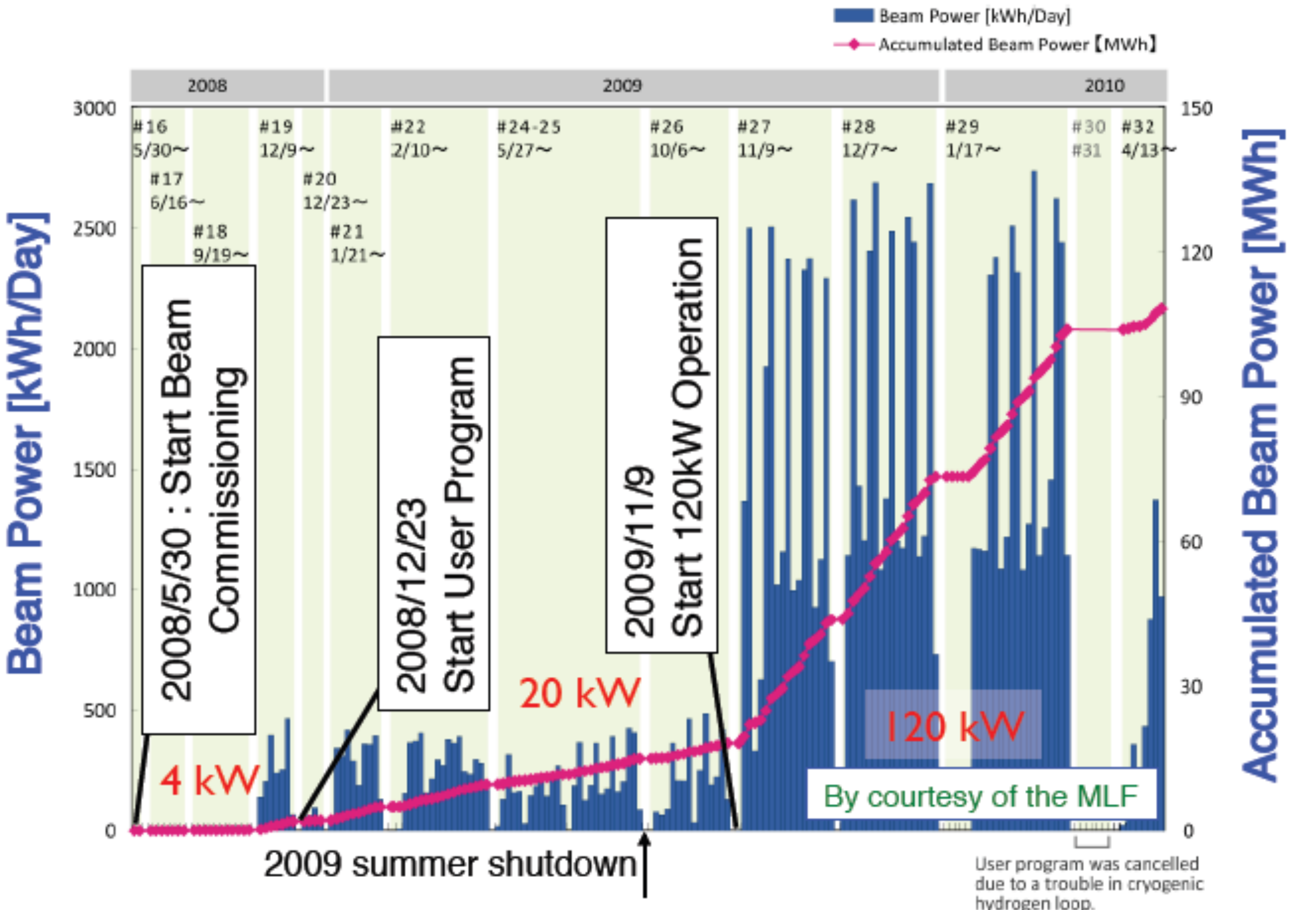
2007 Linac beam energy of 181 MeV was achieved.
RCS beam commissioning started.
RCS beam energy of 3 GeV was achieved.

2008 MR beam commissioning started.
First proton beams reached to the neutron target.
MR beam energy of 30 GeV was achieved.
First proton beams reached to the Hadron target.
User operation of MLF started.

2009 First proton beams reached to the Neutrino target.

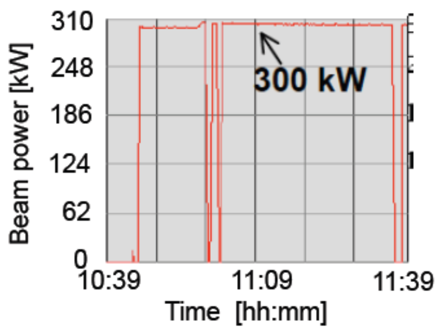
J-PARC

History of beam delivery to MLF



Dec. 2010:

300 kW during 1 hour of beam power issued from the RCS



After the recovery of Linac-RFQ, high power operation of the RCS has became possible and 120 kW operation has started for the MLF users.

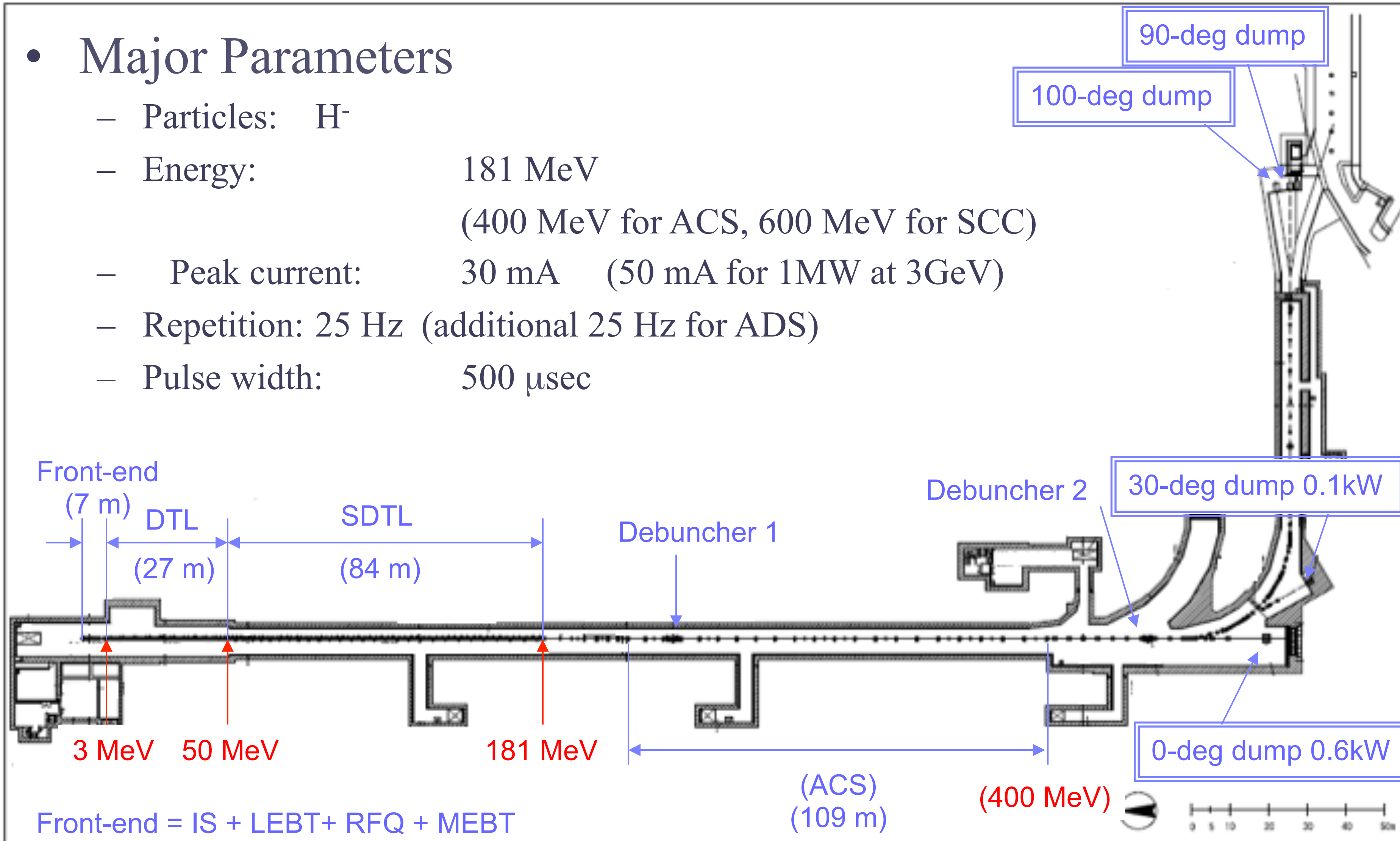
Neutron beamline : 12 beamlines are now under commissioning and open for users.

Muon beamline: The highest intensity beamline in the world with the 120 kW beam.

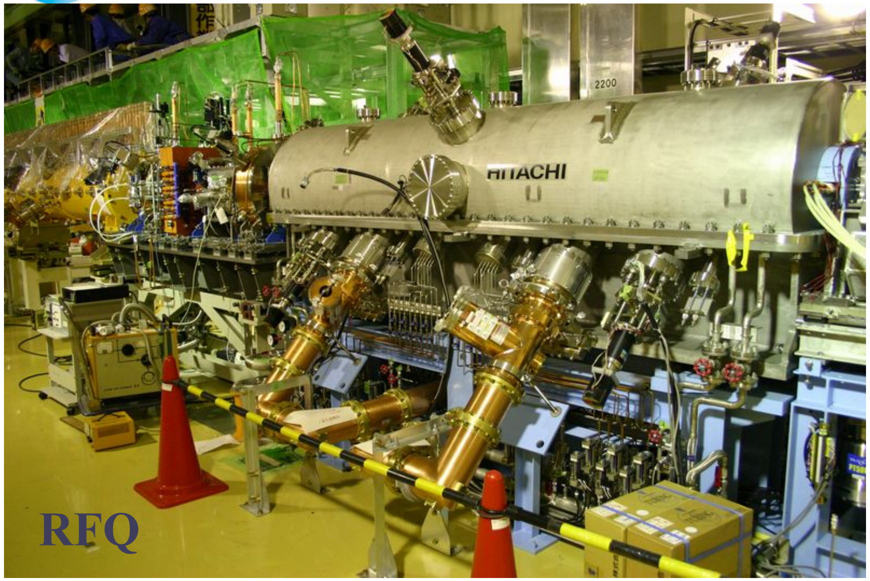
11 Mars 2011: M 9 Earthquake & consecutive Tsunami: damages to JPARC

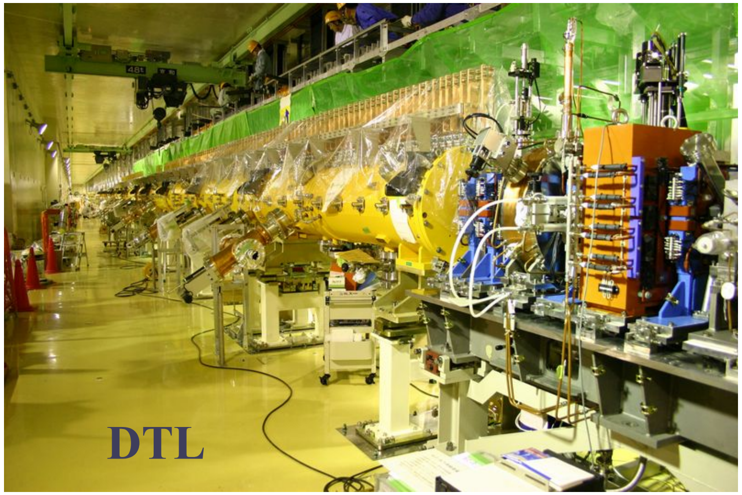
J-PARC

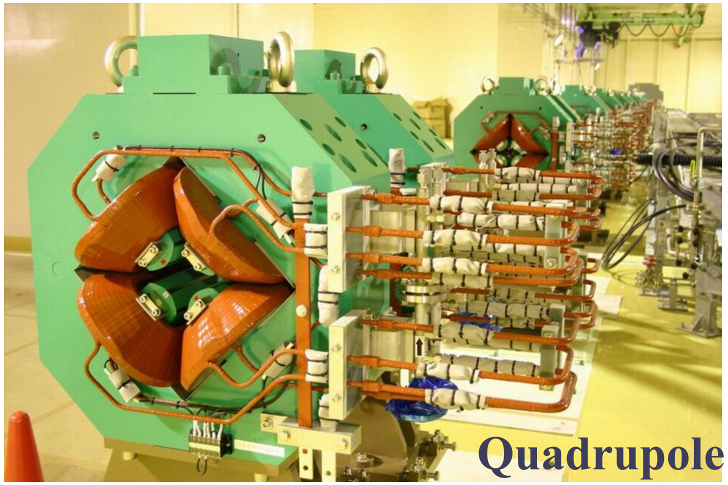
- Major Parameters
  - Particles: H^-
  - Energy: 181 MeV
    (400 MeV for ACS, 600 MeV for SCC)
  - Peak current: 30 mA (50 mA for 1MW at 3GeV)
  - Repetition: 25 Hz (additional 25 Hz for ADS)
  - Pulse width: 500 μsec



J-PARC

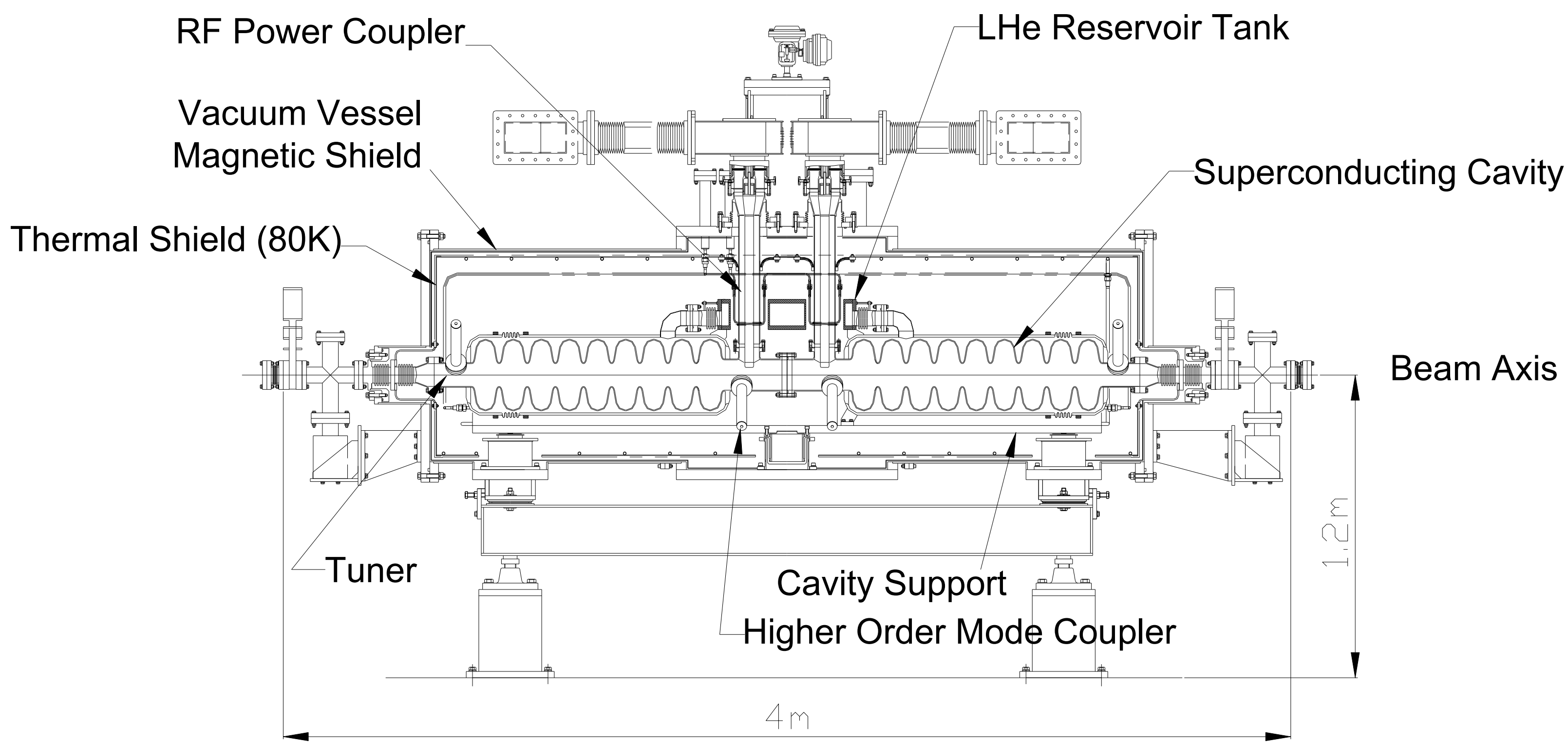




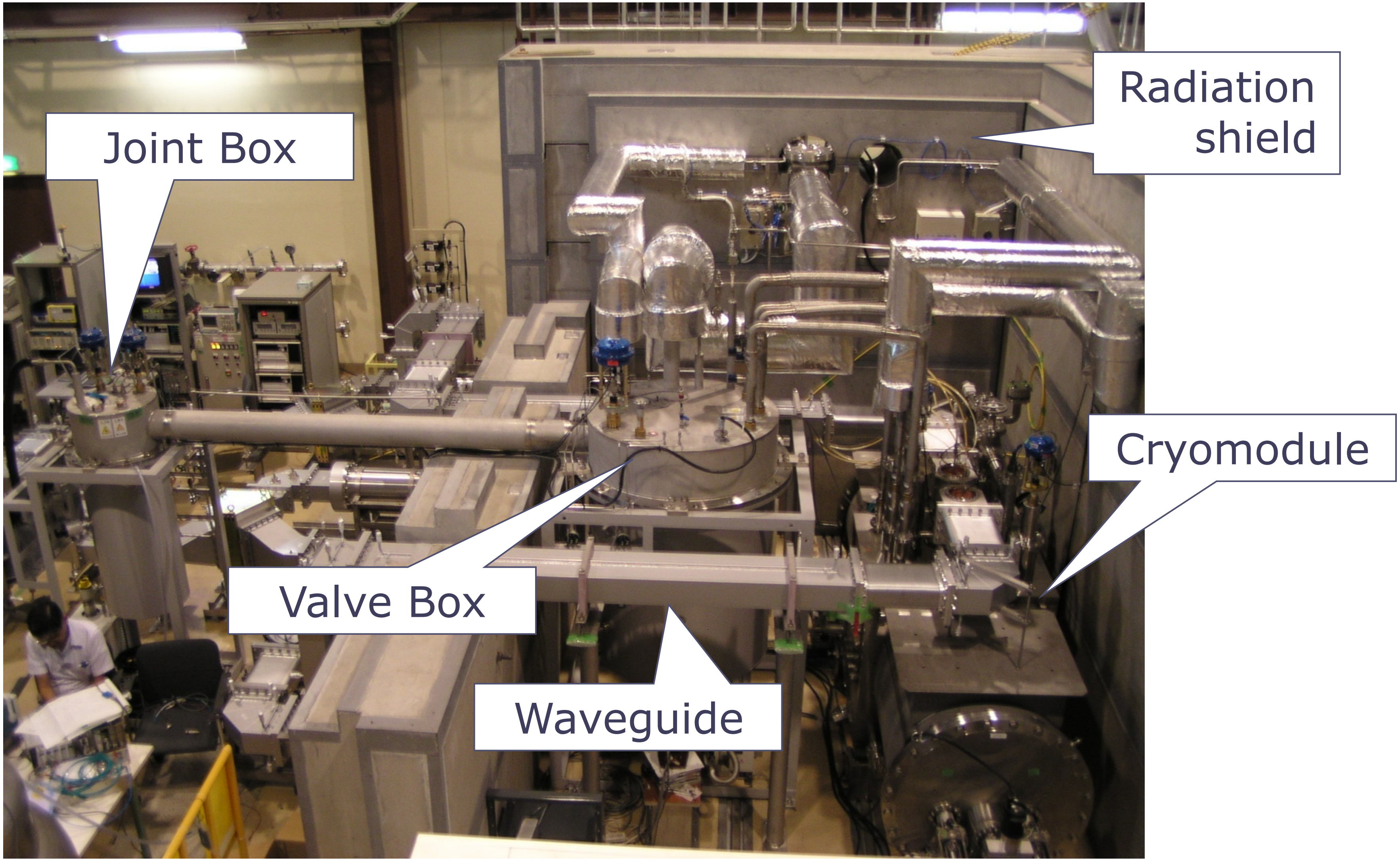


J-PARC – Linac Cryogenics

- Two 9-cell elliptical cavities of b=0.725 at 2K (972 MHz)
- Stiff structure for cavity and tuner to reduce Lorentz force detuning
- 80K thermal shield by LN_2 and 5K thermal intercept by LHe



J-PARC SC Linac : R&D on 972 MHz cryomodule

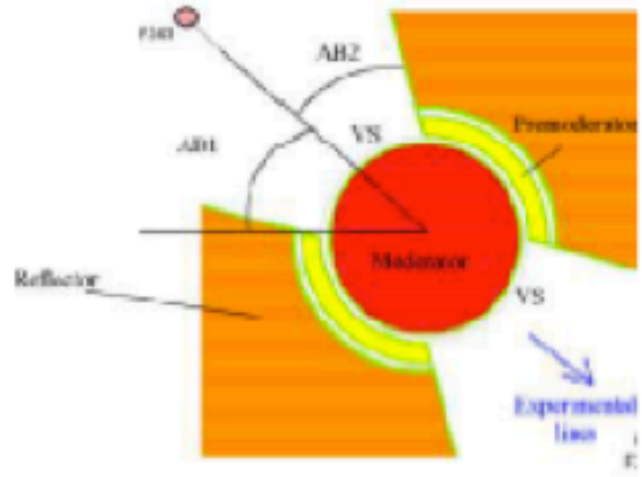


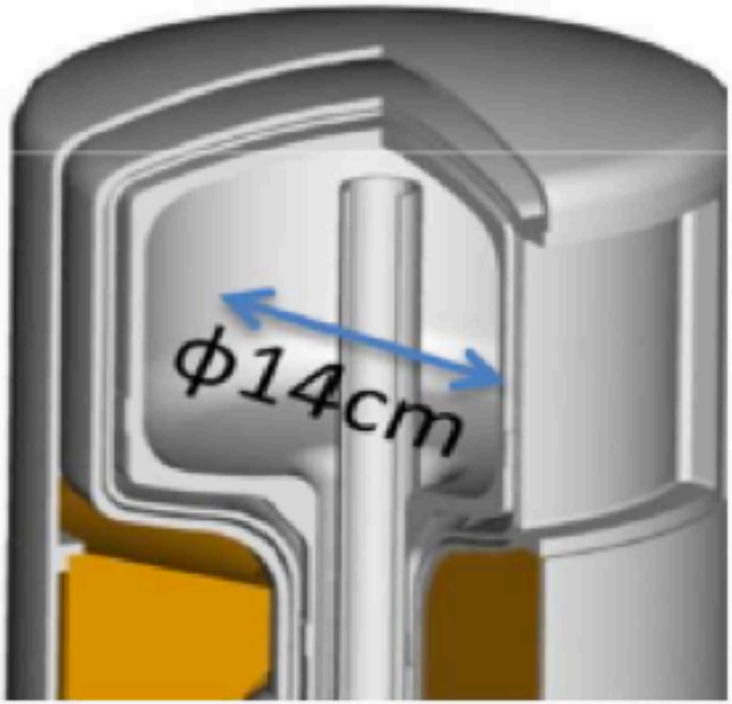
High performance cold moderator

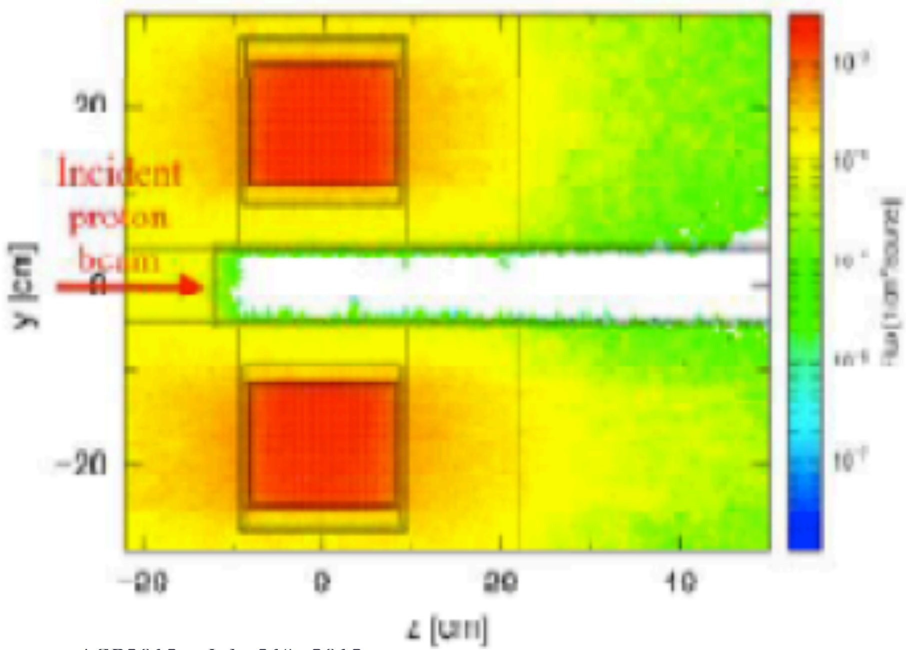
Volume moderator:

implemented at J-PARC

99 % para-H_2 tested

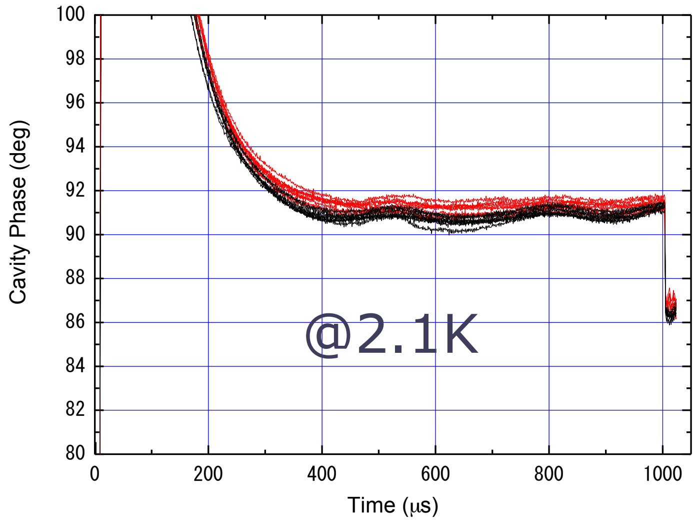


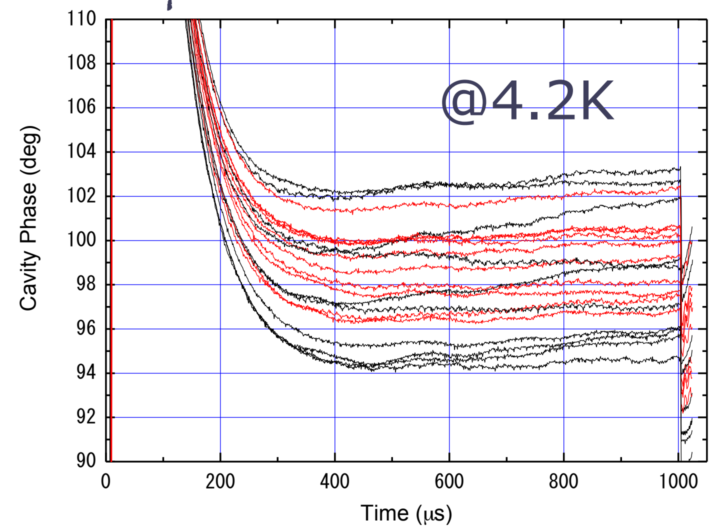




J-PARC SC Linac : R&D on 972 MHz cryomodule

Cavity Phase for several pulses during ~1min (Eacc~10MV/m, Pulse length:1ms, Repetition:25Hz)





- Phase stability < ±1 deg
- Changing slowly
  →Control of LHe vessel pressure & automatic tuning system

- Phase stability < ±5 deg
- Scattering significantly
  (Microphonics ?)
  (Bubbling of He ?)

Phase stability of ±1deg is realized in 2K operation, impossible at 4.2 K

SNS :

Spallation Neutron Source
Oakridge, Tennessee, USA

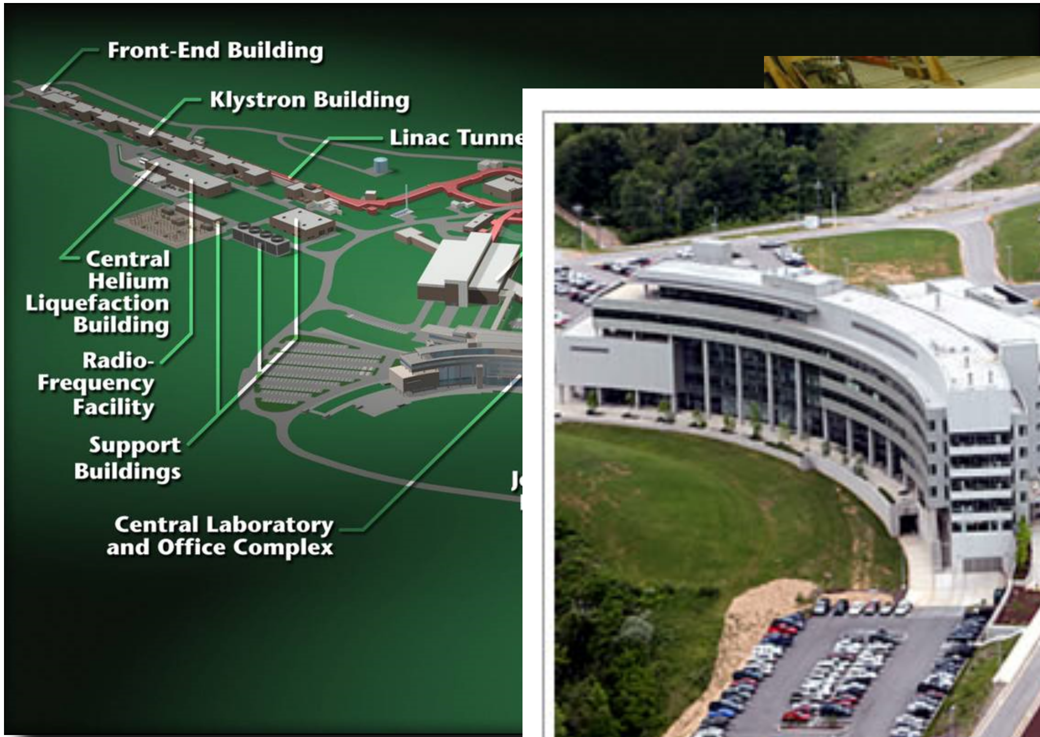
SNS : Main parameters

Spallation Neutron Source Primary Parameters

Proton beam power on target	1.4 MW
Proton beam kinetic energy on target	1.0 GeV
Average beam current on target	1.4 mA
Pulse repetition rate	60 Hz
Protons per pulse on target	1.5×10^{14} protons
Charge per pulse on target	24 µ
Energy per pulse on target	24 k
Proton pulse length on target	695 n
Ion type (Front end, Linac, HEBT)	H minus
Average linac macropulse H- current	26 m
Linac beam macropulse duty factor	6 %
Front end length	7.5 m
Linac length	331 m
HEBT length	170 m
Ring circumference	248 m
RTBT length	150 m

RTBT length	150 m
Ion type (Ring, RTBT, Target)	proton
Ring filling time	1.0 ms
Ring revolution frequency	1.058 MHz
Number of injected turns	1060
Ring filling fraction	68 %
Ring extraction beam gap	250 ns
Maximum uncontrolled beam loss	1 W/m
Target material	Hg
Number of ambient / cold moderators	1/3
Number of neutron beam shutters	18
Initial number of instruments	5

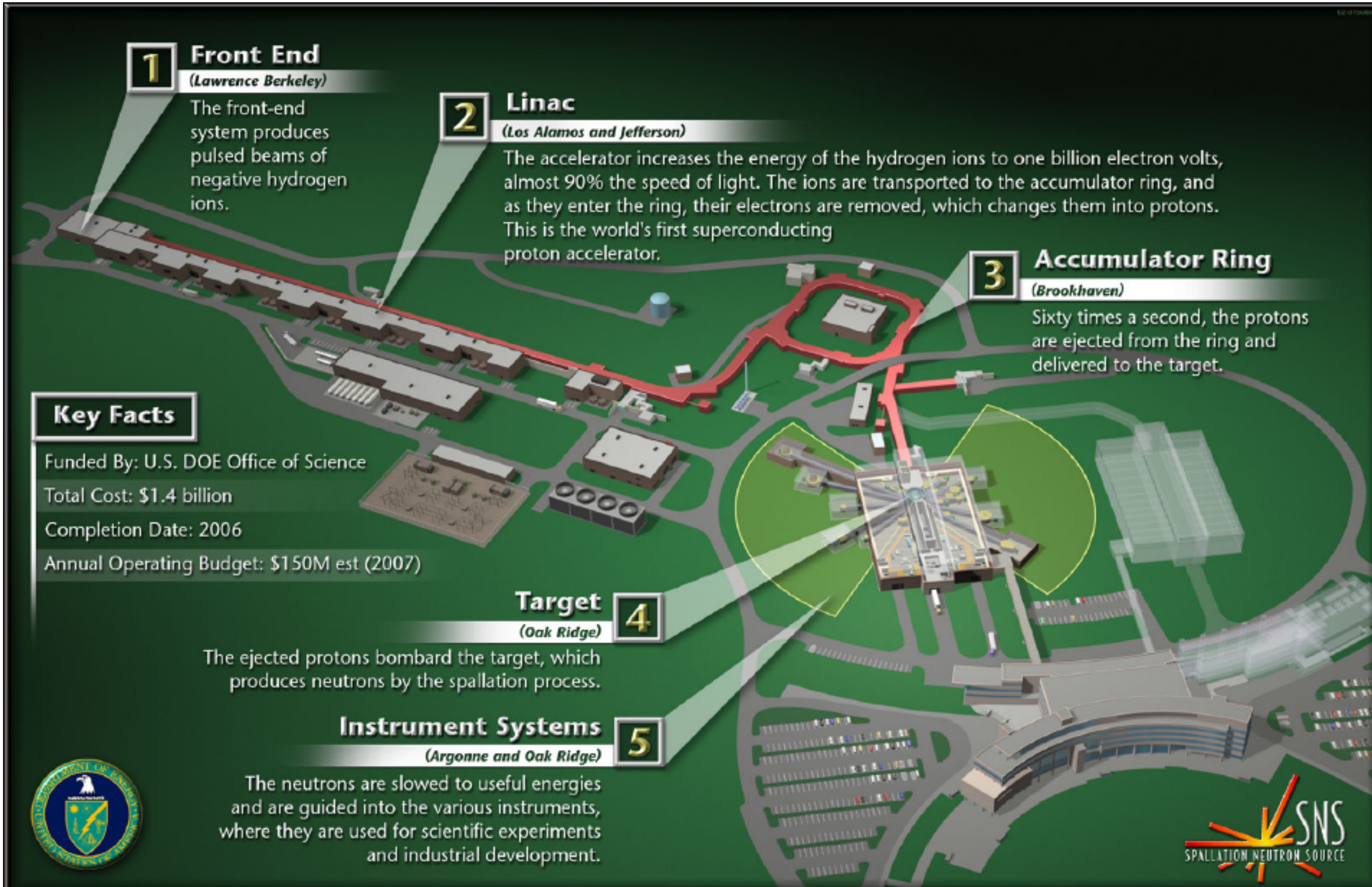
Spallation Sources



1 MW Spallation Neutr
Source in Oak Ridge
NL (compl. 2006)

SNS : the US spallation neutron source

SNS : layout


1
Front End
(Lawrence Berkeley)
The front-end system produces pulsed beams of negative hydrogen ions.
2
Linac
(Los Alamos and Jefferson)
The accelerator increases the energy of the hydrogen ions to one billion electron volts, almost 90% the speed of light. The ions are transported to the accumulator ring, and as they enter the ring, their electrons are removed, which changes them into protons. This is the world's first superconducting proton accelerator.
3
Accumulator Ring
(Brookhaven)
Sixty times a second, the protons are ejected from the ring and delivered to the target.
Key Facts
Funded By: U.S. DOE Office of Science
Total Cost: $1.4 billion
Completion Date: 2006
Annual Operating Budget: $150M est (2007)
Target
(Oak Ridge)
4
The ejected protons bombard the target, which produces neutrons by the spallation process.
Instrument Systems
(Argonne and Oak Ridge)
5
The neutrons are slowed to useful energies and are guided into the various instruments, where they are used for scientific experiments and industrial development.
SNS
SPALLATION NEUTRON SOURCE

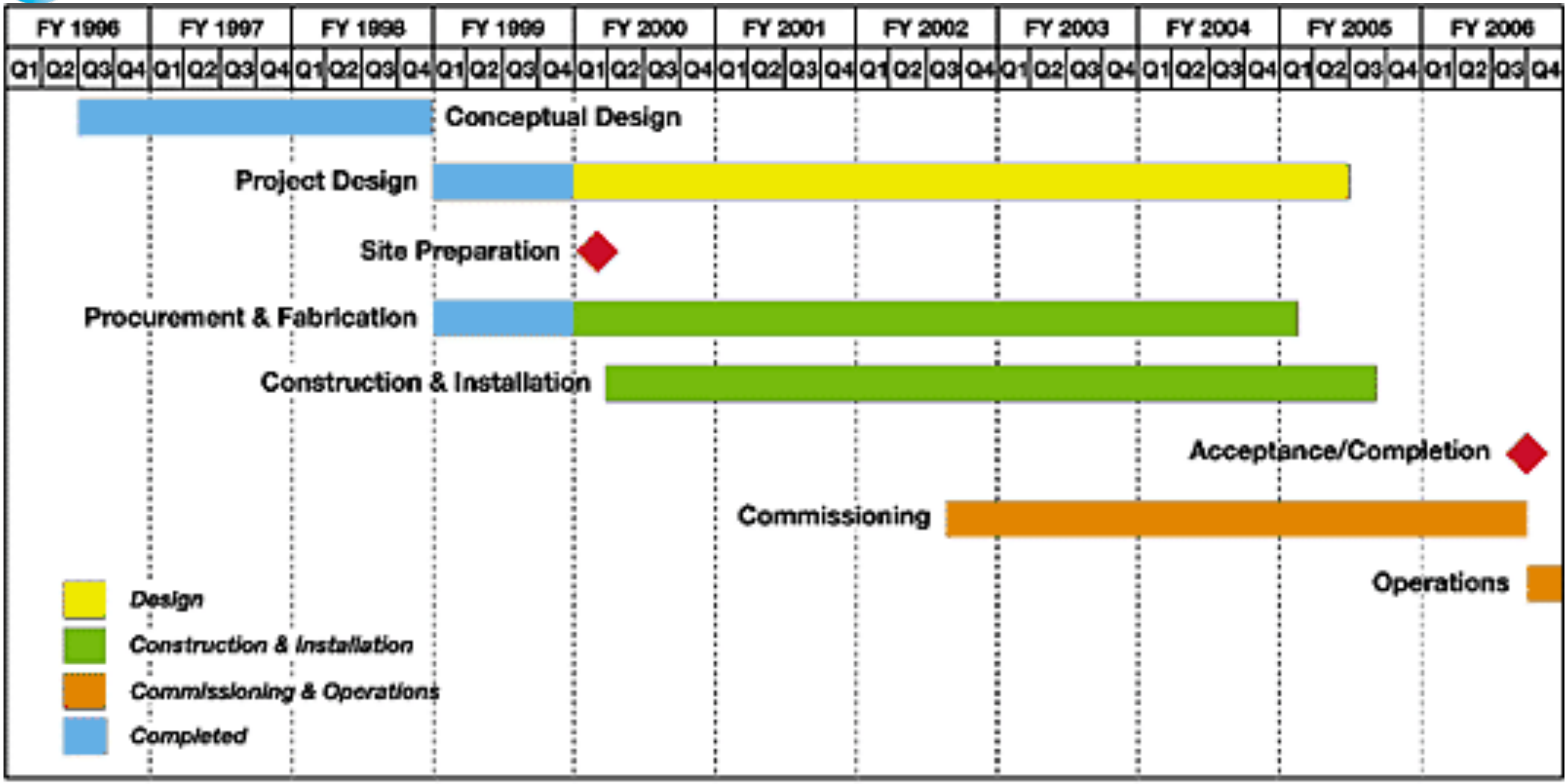
SNS : Main parameters

SNS Beam Evolution Parameters

	Front End			Linac				Ring			
	IS/LEBT	RFQ	MEBT	DTL	CCL	SCL (1)	SCL (2)	HEBT	Ring	RTBT	Unit
Output Energy	0.065	2.5	2.5	86.8	185.6	391.4	1000	1000	1000	1000	MeV
Relativistic factor □	0.0118	0.0728	0.0728	0.4026	0.5503	0.7084	0.875	0.875	0.875	0.875	
Relativistic factor □	1.00007	1.0027	1.0027	1.0924	1.1977	1.4167	2.066	2.066	2.066	2.066	
Peak current	47	38	38	38	38	38	38	38	9×10^4	9×10^4	mA
Minimum horizontal acceptance[g]			250	38	19	57	50	26	480	480	πmm mr
Output H emittance (unnorm., rms)	17	2.9	3.7	0.75	0.59	0.41	0.23	0.26	24	24	πmm mr
Minimum vertical acceptance[g]			51	42	18	55	39	26	480	400	πmm mr
Output V emittance (unnorm., rms)	17	2.9	3.7	0.75	0.59	0.41	0.23	0.26	24	24	πmm mr
Minimum longitudinal acceptance			4.7E-05	2.4E-05	7.4E-05	7.2E-05	1.8E-04		19/□		πeVs
Output longitudinal rms emittance		7.6E-07	1.0E-06	1.2E-06	1.4E-06	1.7E-06	2.3E-06		2/□		πeVs
Controlled beam loss; expected	0.05[a]	N/A	0.2[b]	N/A	N/A	N/A	N/A	5[c]	62[d]	58[e]	kW
Uncontrolled beam loss; expected	70	100[f]	2	1	1	0.2	0.2	<1	1	<1	W/m
Output H emittance (norm., rms)	0.2	0.21	0.27	0.33	0.39	0.41	0.41	0.46	44	44	πmm mr
Output V emittance (norm., rms)	0.2	0.21	0.27	0.33	0.39	0.41	0.41	0.46	44	44	πmm mr

Note a) corresponding to 27% chopped beam
b) corresponding to 5% chopped beam
c) beam loss on the transverse and momentum collimators
d) including total 4% of beam escaping foil and 0.2% beam loss on collimators
e) including 4% beam scattered on the target window
f) corresponding to 20% beam loss averaged over RFQ length
g) full acceptance without collimation

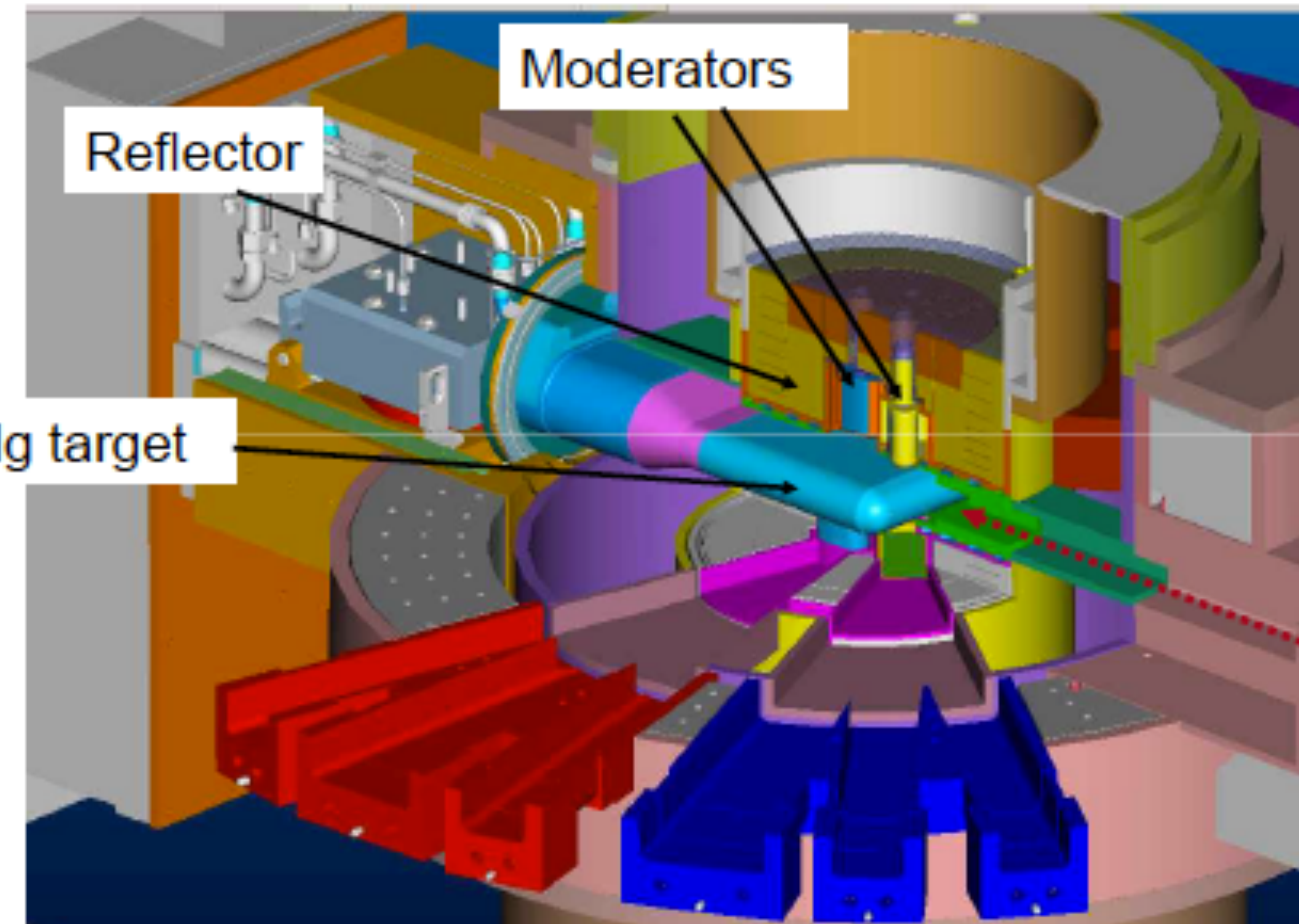
SNS : Planning



Commissioning of the accelerator at low power (10 kW) achieved in May 2006. Next phase is the power ramping up to 1. 4 MW. Present status is around 1 MW

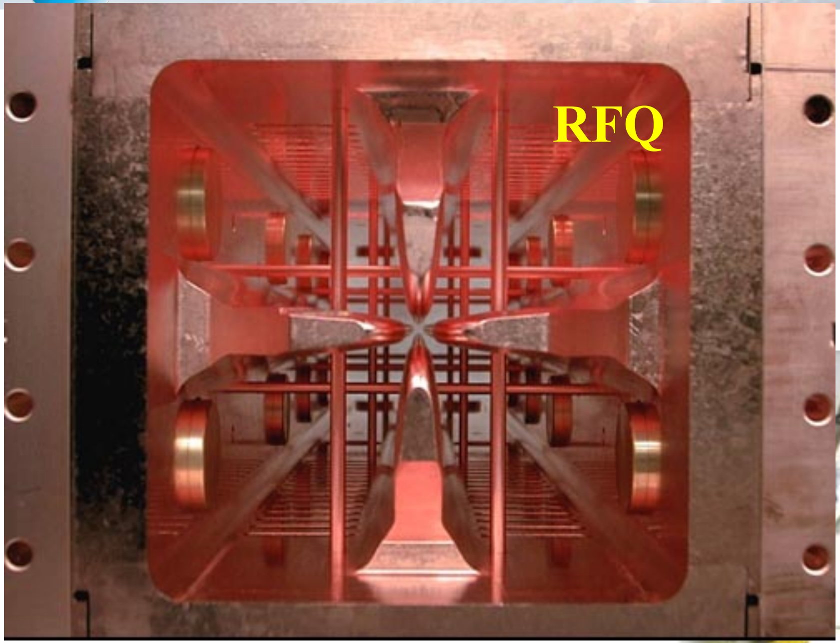
SNS : Arial view

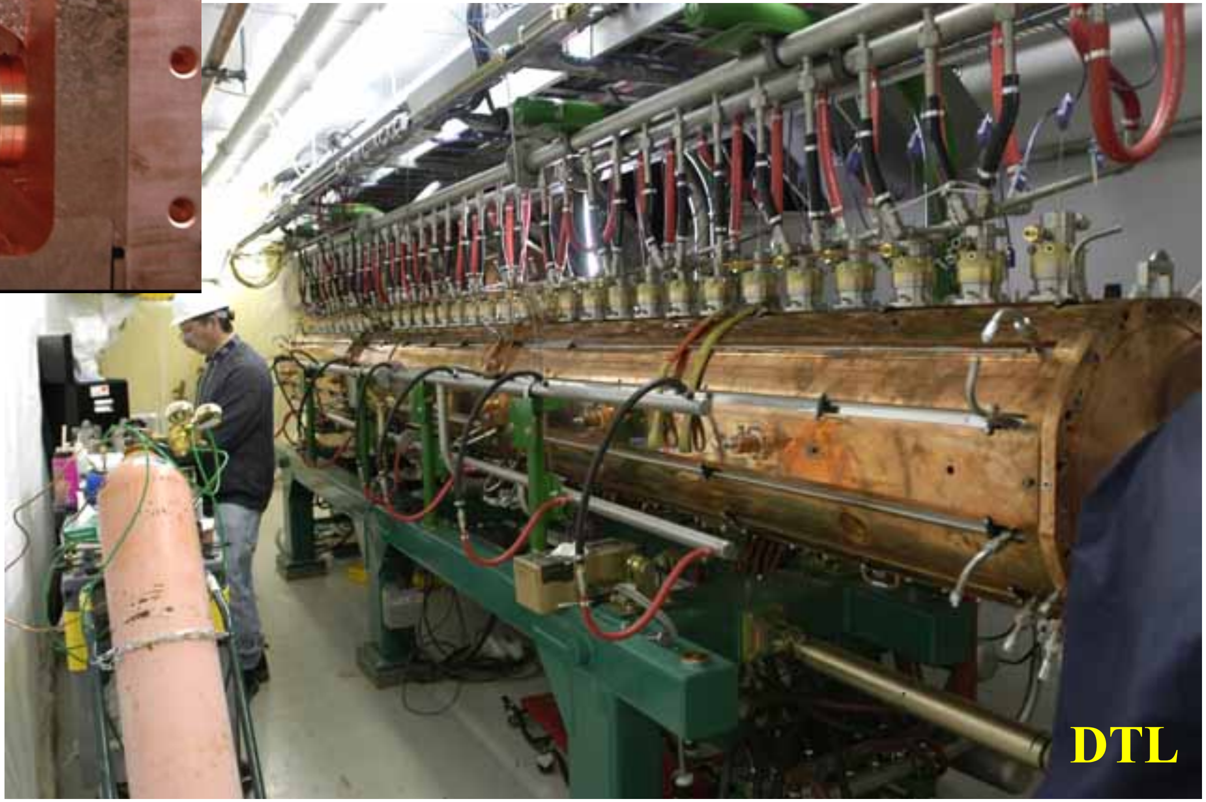
State-of-the-art target (SNS, ISIS): He atmosphere



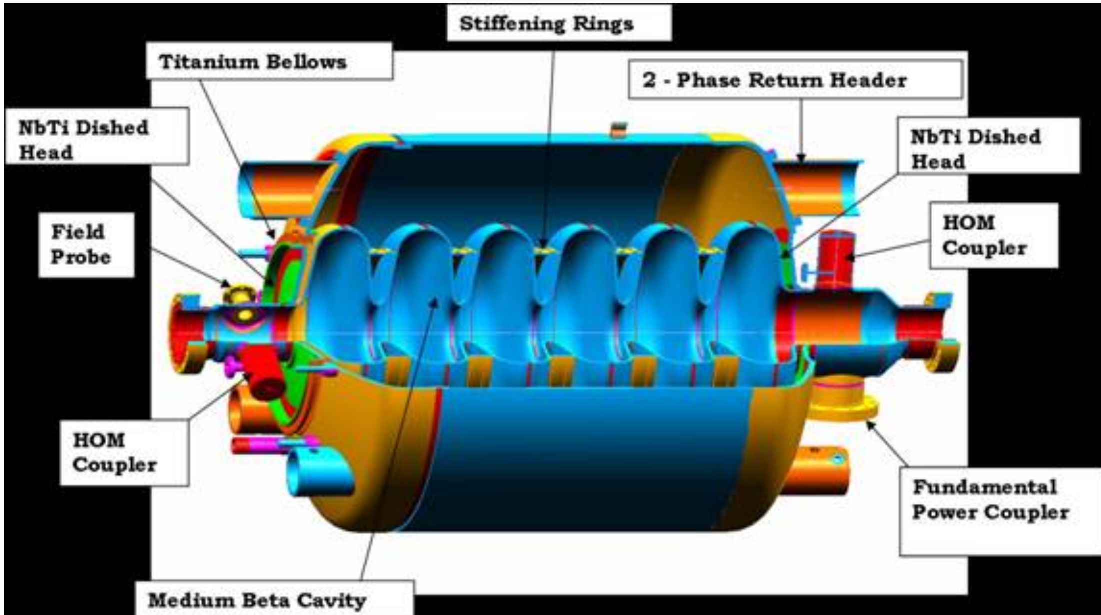
He gas:
~ 1 bar

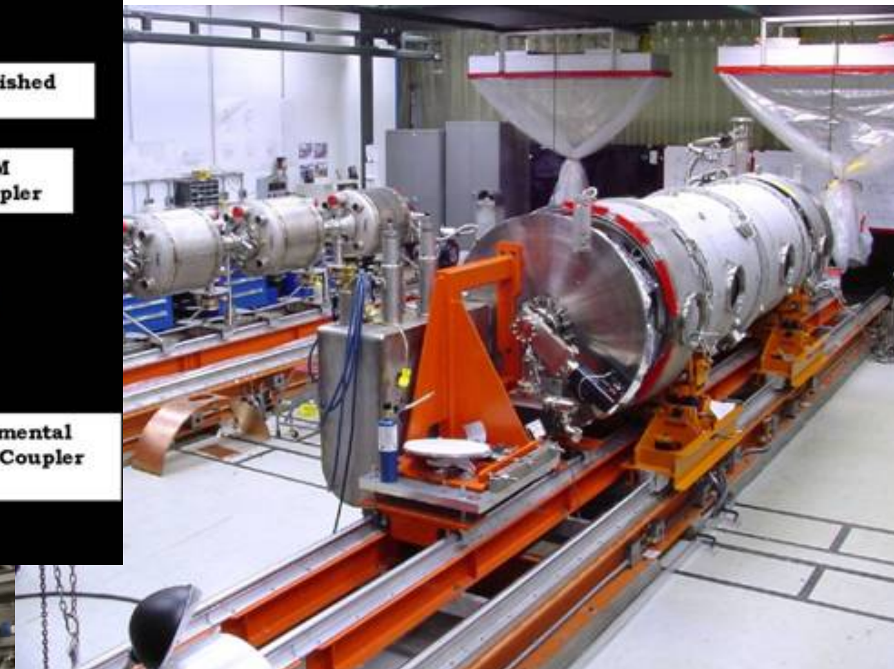
SNS : Linac



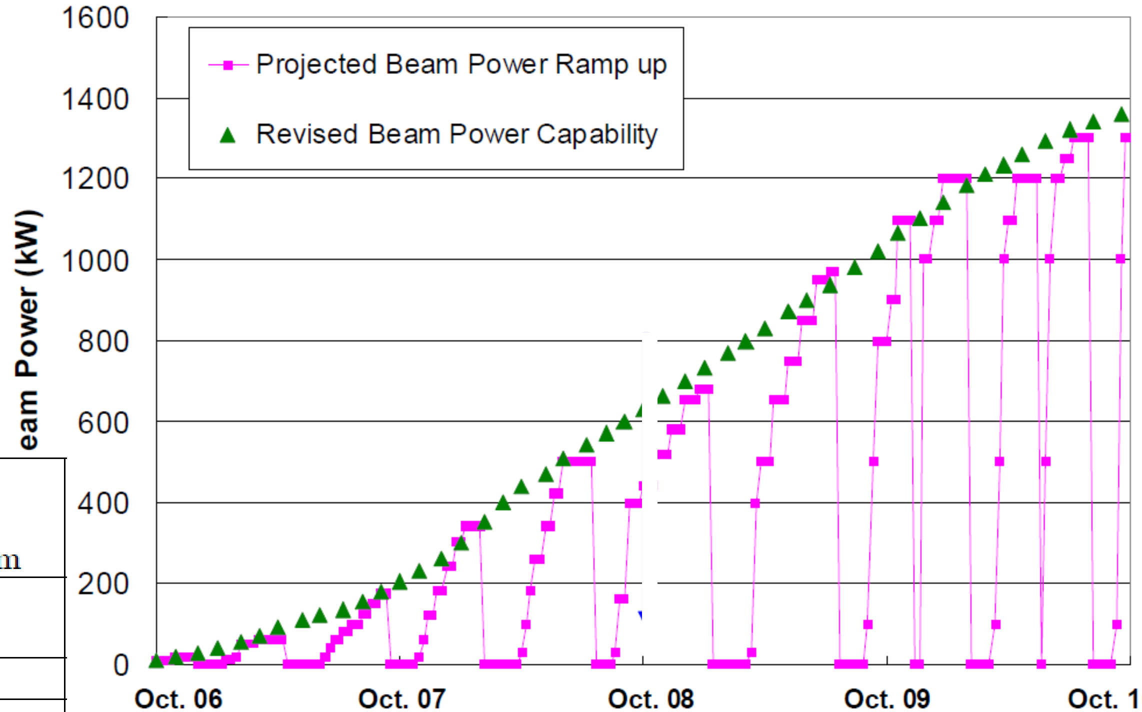


SNS : SRF Cryomodules





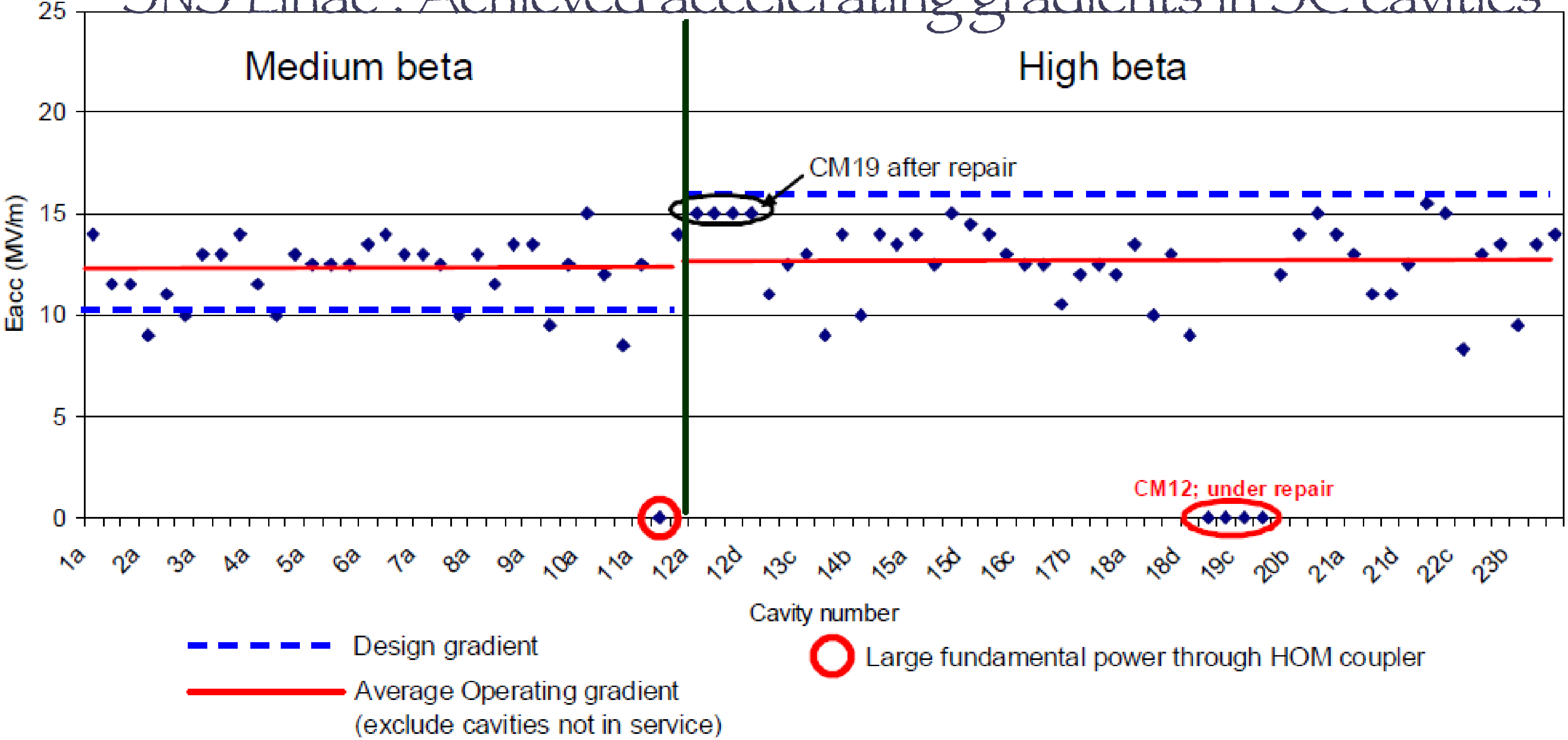
SNS : Design vs achieved parameters (oct. 2009)



Parameters	Design	Highest Production Beam
Beam Energy (GeV)	1.0	0.93 + 0.01
Peak Beam current (mA)	38	40
Average Beam Current (mA)	26	24
Beam Pulse Length (ms)	1000	670
Repetition Rate (Hz)	60	60
Beam Power on Target (MW)	1440	**1.01**
Linac Beam Duty Factor (%)	6	4.0
Beam intensity on Target (protons per pulse)	1.5 x 10^{14}	1 x 10^{14}
SCL Cavities in Service	81	80

SNS : Design vs achieved parameters (oct. 2009)

SNS Linac : Achieved accelerating gradients in SC cavities



Future : finish commissioning up to 1.4 MW.

Upgrades plans: beam power upgrade to 3 MW with increasing beam energy from 1.0 GeV to 1.3 GeV (adding 9 additional high-beta cryomodules) and by increasing beam current from 38 mA to 59 mA.