ADVANCES IN NEUTRON CONVERTERS FOR RIB FACILITIES

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Advances in RIB Production
Facilities

ISOL RIB Facilities (and plans)

- **Facilities for up to a few 10 kW**

  »

  ISOLDE, IGISOL, LISOL, HRIBF, HIE-ISOLDE, EXCIT, ALTO, SARAF
  ISAC, SPIRAL-1, SPES, iTHEMBA Labs, BRIF (Bejing)

  »

  CARIBU (fission source)

- **Developments and plans for systems for >100 kW beam power**

  »

  SPIRAL2 (200kW), KoRIA (200 kW), ARIEL, MYRRHA, EURISOL (4MW)

  »

  CARIF (reactor-based)

High Power Converters

Neutron Converters

EURISOL	SPIRAL2	SARAF
KoRIA	iTHEMBA Labs	BRIF

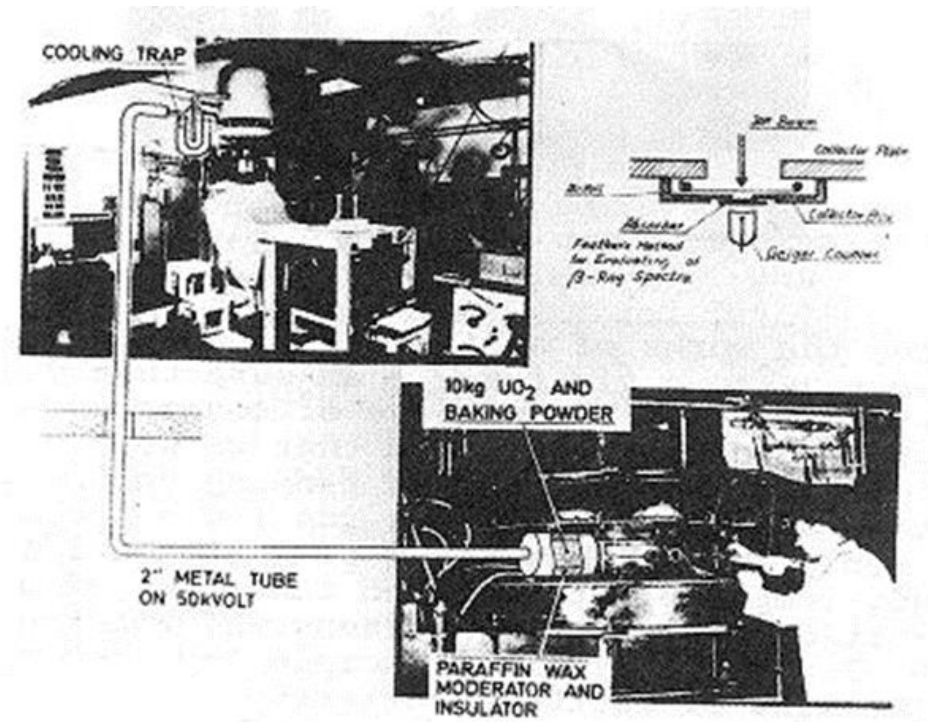
Gamma Converters

ALTO ARIEL

Increase the production of neutron-rich isotopes

Dissipate the heat associated with the high-power primary beam

The History



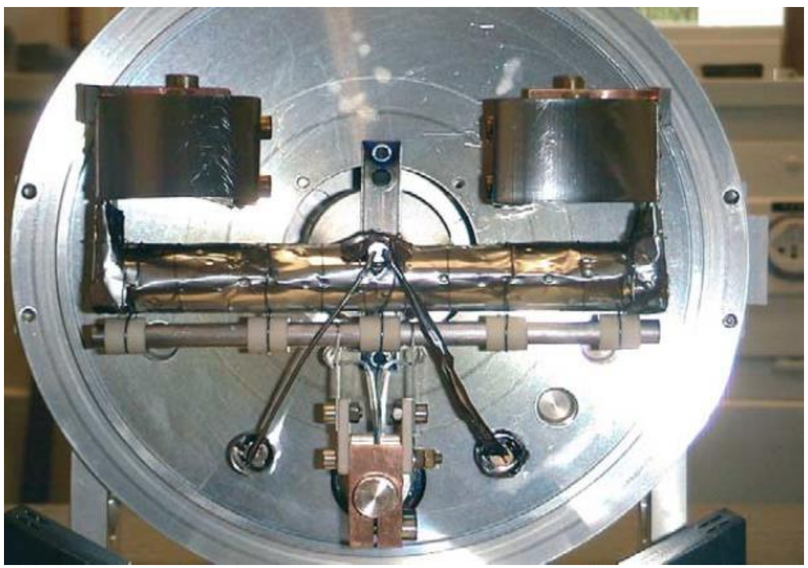
Niels Bohr Institute
O.Kofoed-Hansen
K.O. Nielsen
Dan. Mat.Fys.Medd. 26, no. 7 (1951)

Kofoed-Hansen and Nielsen invented the isotope separator on-line (ISOL) concept to address fundamental lepton interactions namely the beta neutrino angular correlation.
Two stage target technique in which the deuteron driver beam produced neutrons in a primary converter target to be used in a secondary target to produce gaseous fission products that in turn were ionized and accelerated.

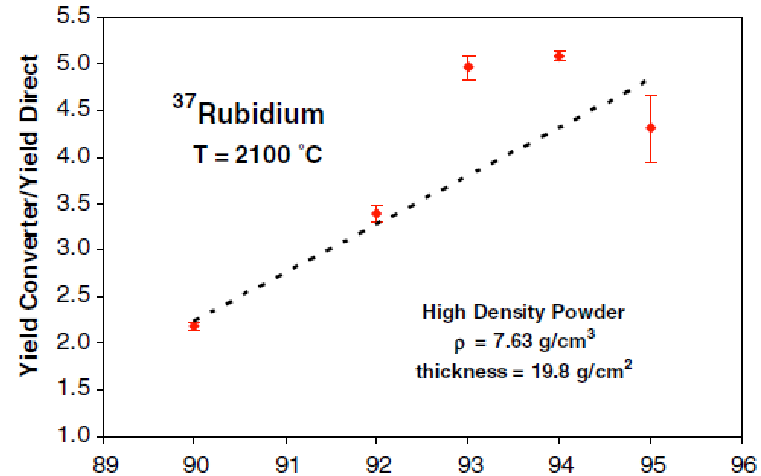
The History

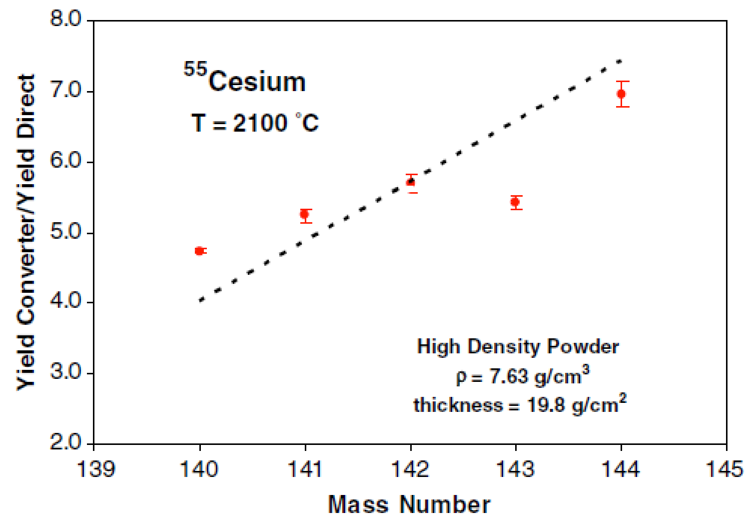
The power of the charged driver beam can be dissipated in a primary target and the produced neutrons used to generate beams of fission products in an ISOL target and ion-source unit with known technology without overheating it.

J. Nolen; Proc. 3° Int. Conf. RNB (1993), USA



R. Catherall et al.;Nuclear Instruments and Methods in Physics Research B 204 (2003) 235–239





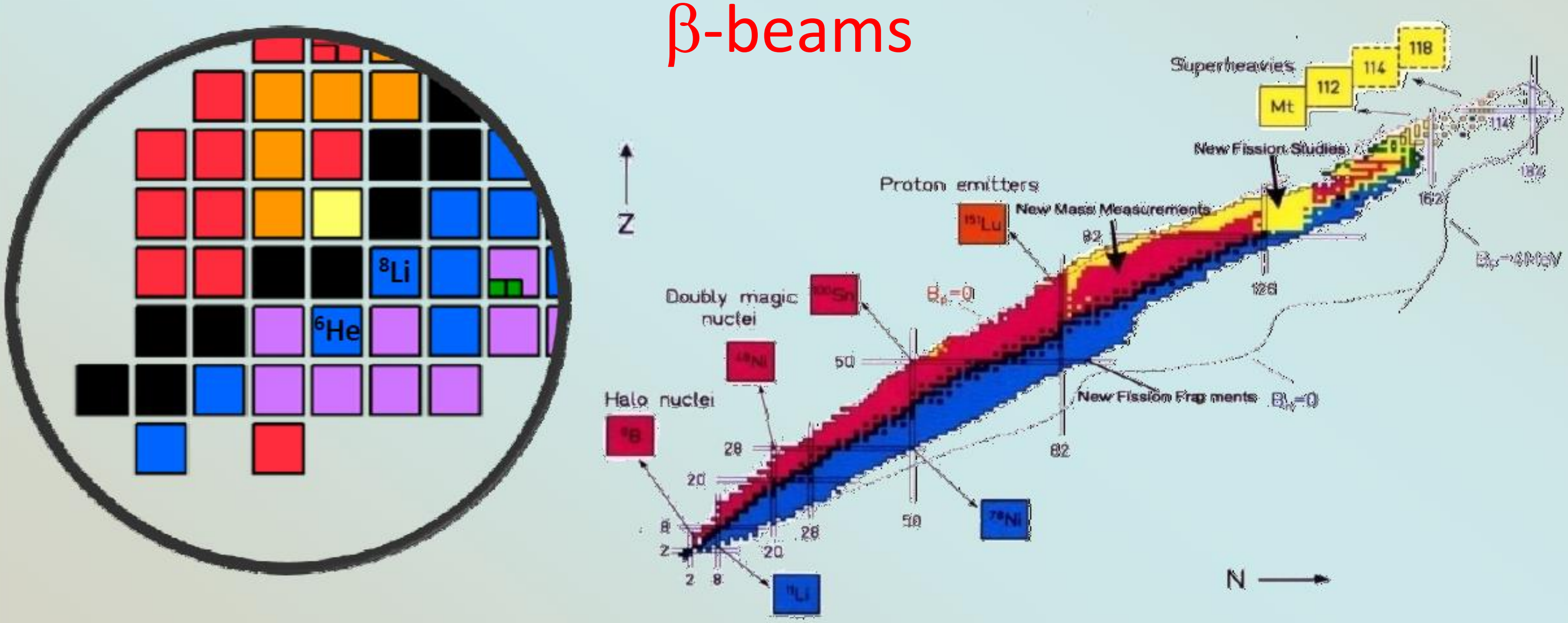
L.B. Tecchio et al.;Eur. Phys. J. A 19, 341–345 (2004)

SARAF at Soreq

Light RIB at SARAF

High yield production of ^{6}He (807 ms) and ^{8}Li (838 ms) RIB

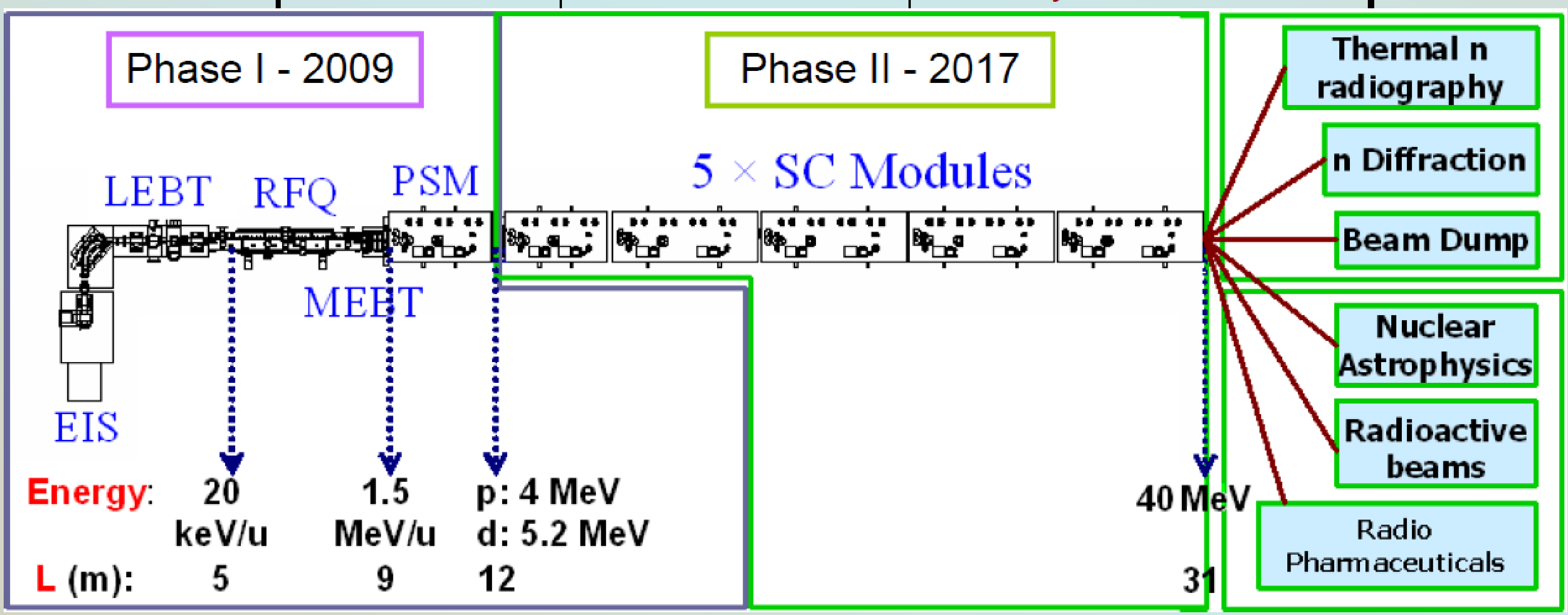
β-beams

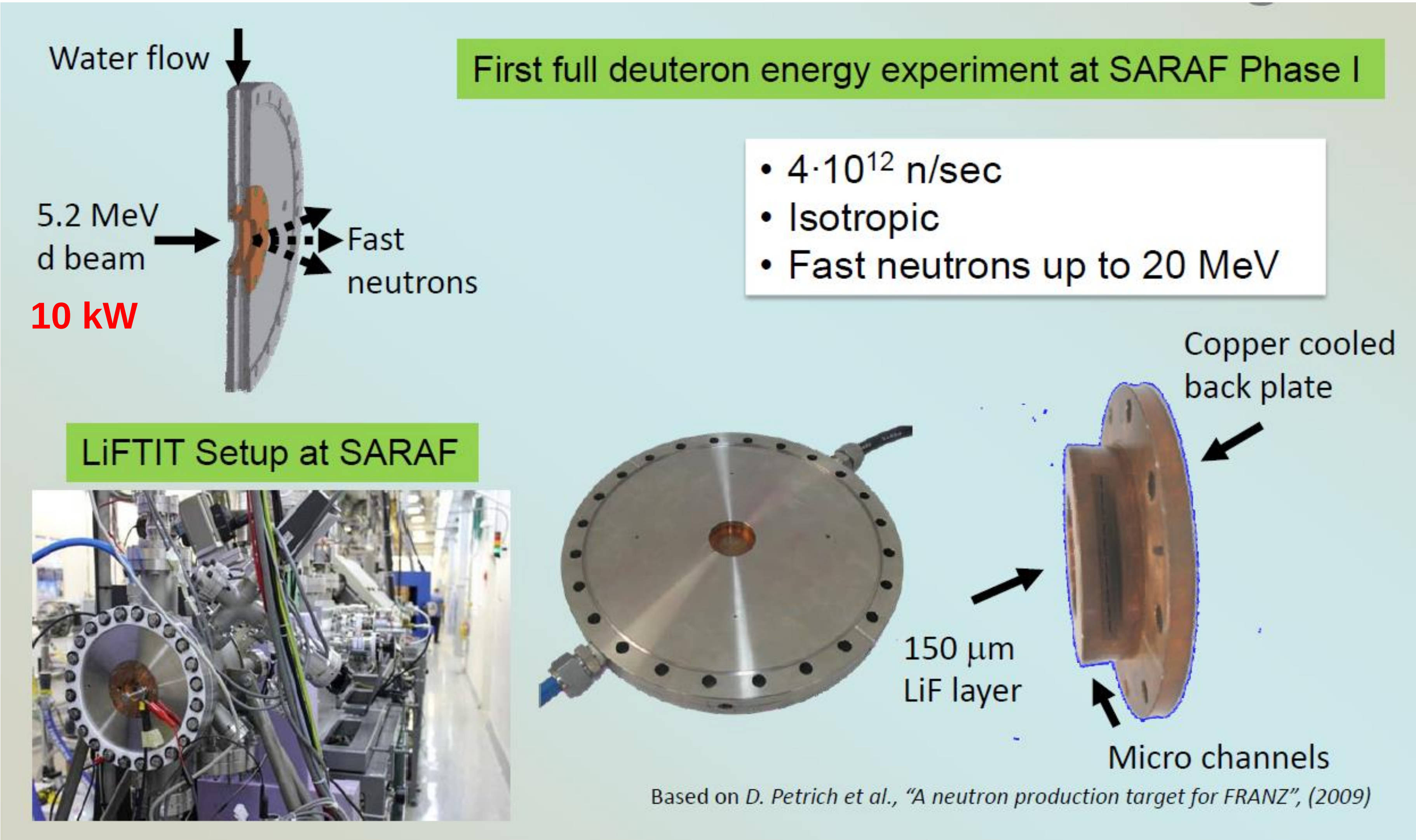


SARAF

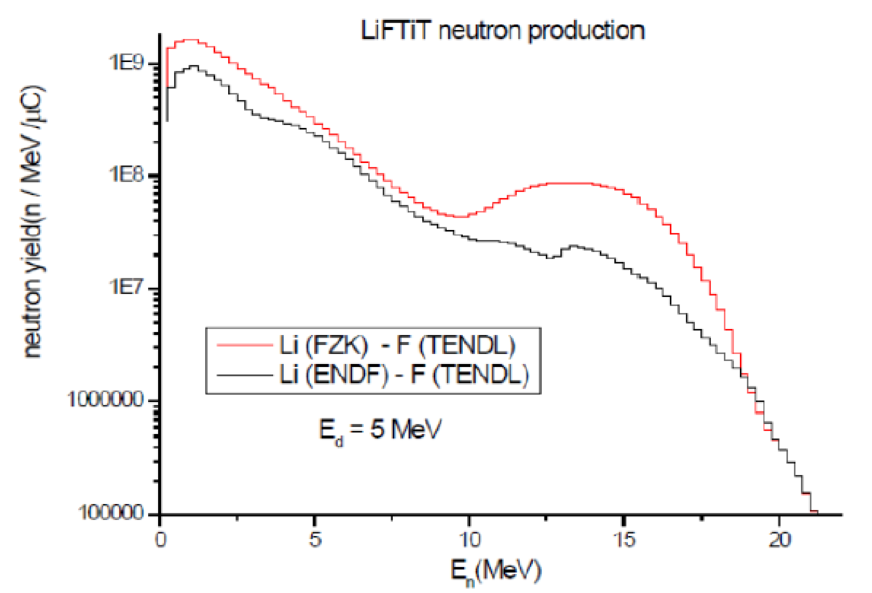
SARAF Accelerator Complex

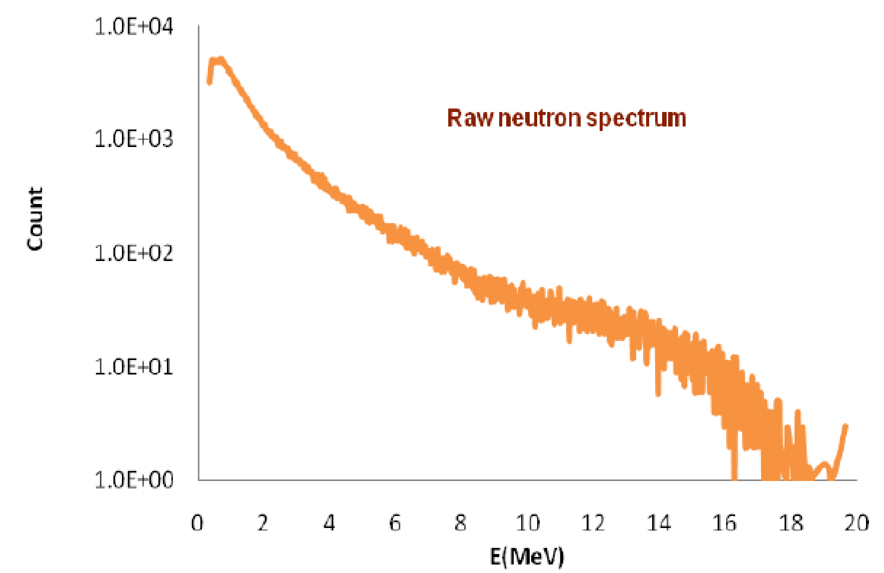
Parameter	Value	Comment
Ion Species	Protons/Deuterons	M/q ≤ 2
Energy Range	1.5 MeV/u – 40 MeV	
Current Range	0.04 – 5 mA	Continuous Wave (CW)
Operation	6000 hours/year	
Reliability	90%	
Maintenance	Hands-On	Very low beam loss




Water flow
First full deuteron energy experiment at SARAF Phase I
• 4·10^12 n/sec
• Isotropic
• Fast neutrons up to 20 MeV
5.2 MeV
d beam
10 kW
Fast
neutrons
Copper cooled
back plate
LiFTIT Setup at SARAF
150 μm
LiF layer
Micro channels
Based on D. Petrich et al., "A neutron production target for FRANZ", (2009)

SARAF LiFTiT





LiFTiT fast neutron spectra from MCUNED [J.Sanz, 2011]

Fast neutron measurement from the LiFTiT target for a 5 MeV d beam, using a NE-213 liquid scintillator. The results are preliminary and still require a response function de-convolution to get a proper spectrum.

SARAF LiLiT (Liquid Lithium Target)

- The basis for most of the R&D at SARAF
- Liquid target enables utilization of the SARAF high power beam

At SARAF Phase I:

$^{7}Li(p,n)^{7}Be$ E_{th}=1.88 MeV

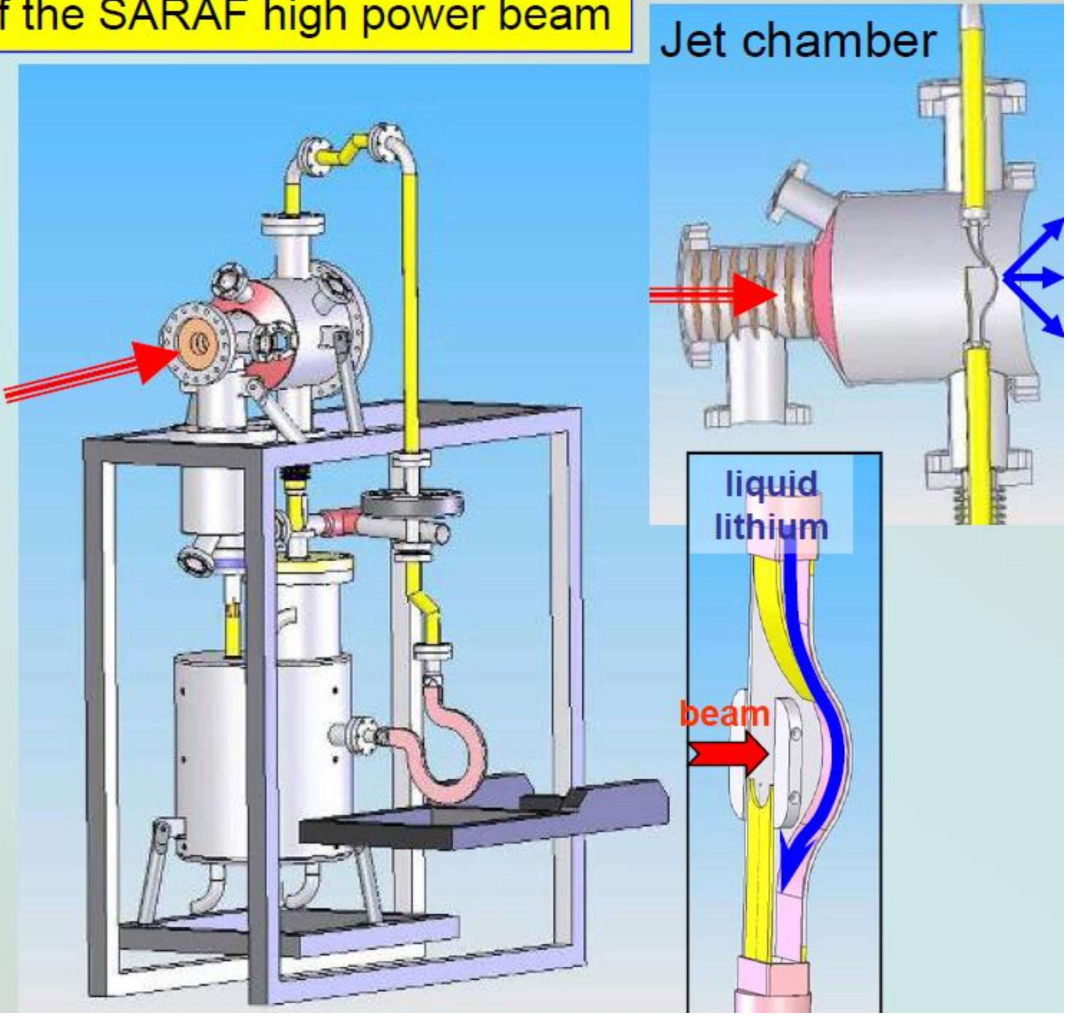
- Proton energy: ~2 MeV
- Proton current: <3.5 mA
- T ≈ 230⁰C
- T_{max} ≈ 350⁰C
- Jet: 18 mm x 1.5 mm
- Lithium velocity: 20 m/s
- Wall assisted lithium jet

D. Kijel, A. Arnshtam et al. 2008

At SARAF Phase II:

An upgrade of LiLiT will be used with a deuteron beam to produce faster neutrons and higher flux

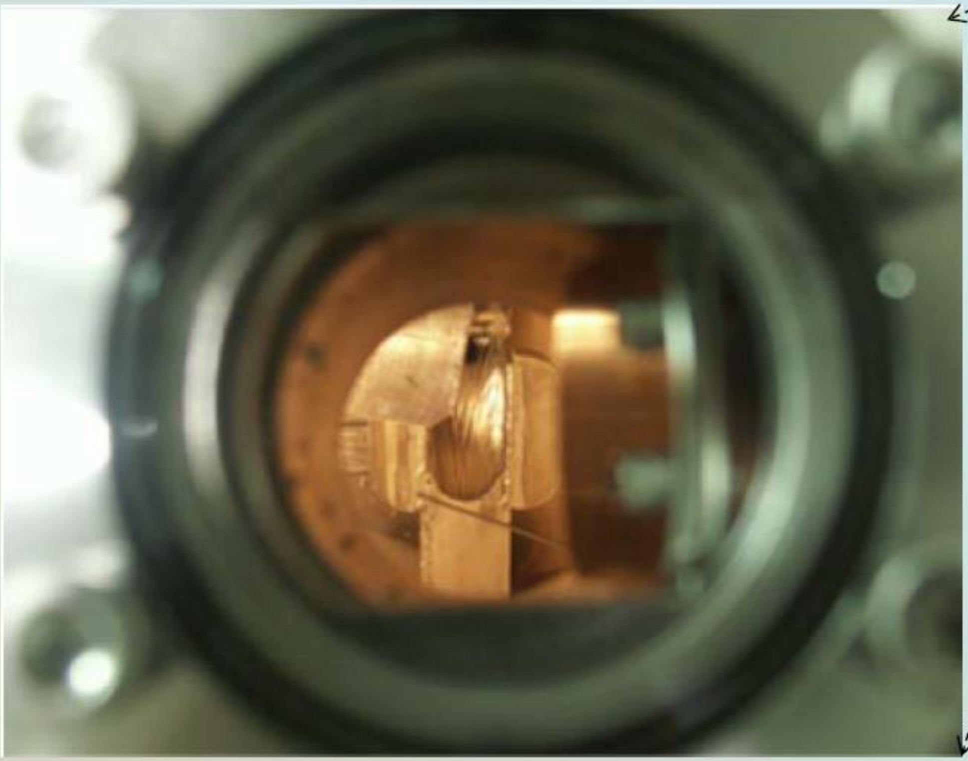
80 kW

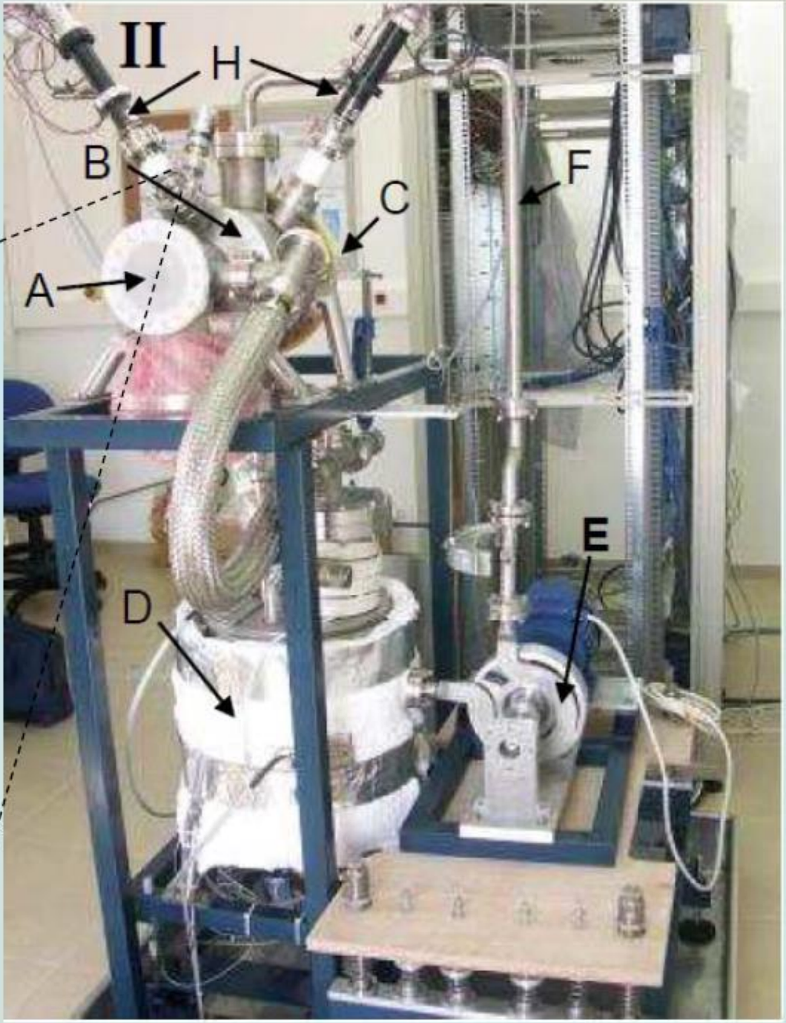


SARAF LiLiT (Liquid Lithium Target)

LiLiT Phase I as built and assembled at Soreq

Lithium flow on the LiLiT concave nozzle. Picture taken from target chamber view port while during lithium circulation





SPIRAL2 – phase 2

SPIRAL2 Project:

40 MeV deuterons 5 mA 200 kW (1,25 mA, 50 kW)

2,4 kg Ucx target

Main Goal: 10^{14} Fission/s induced by neutron

Neutron Converter: 10^{12} n/cm^2 s

Rotating wheel (400-600 turns/min) with graphite as converter material

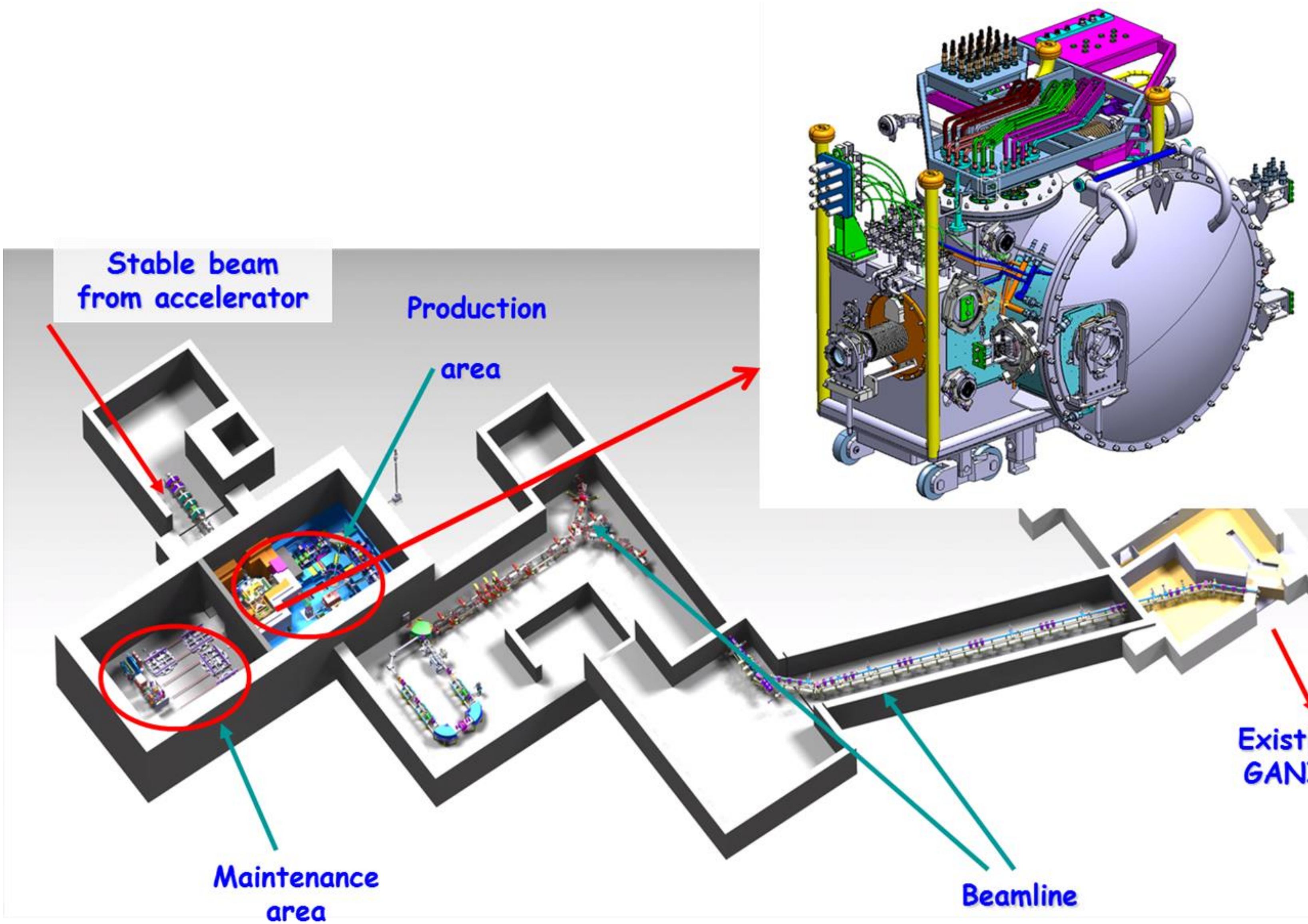
Working temperature up to 1850 °C

Radiation cooling

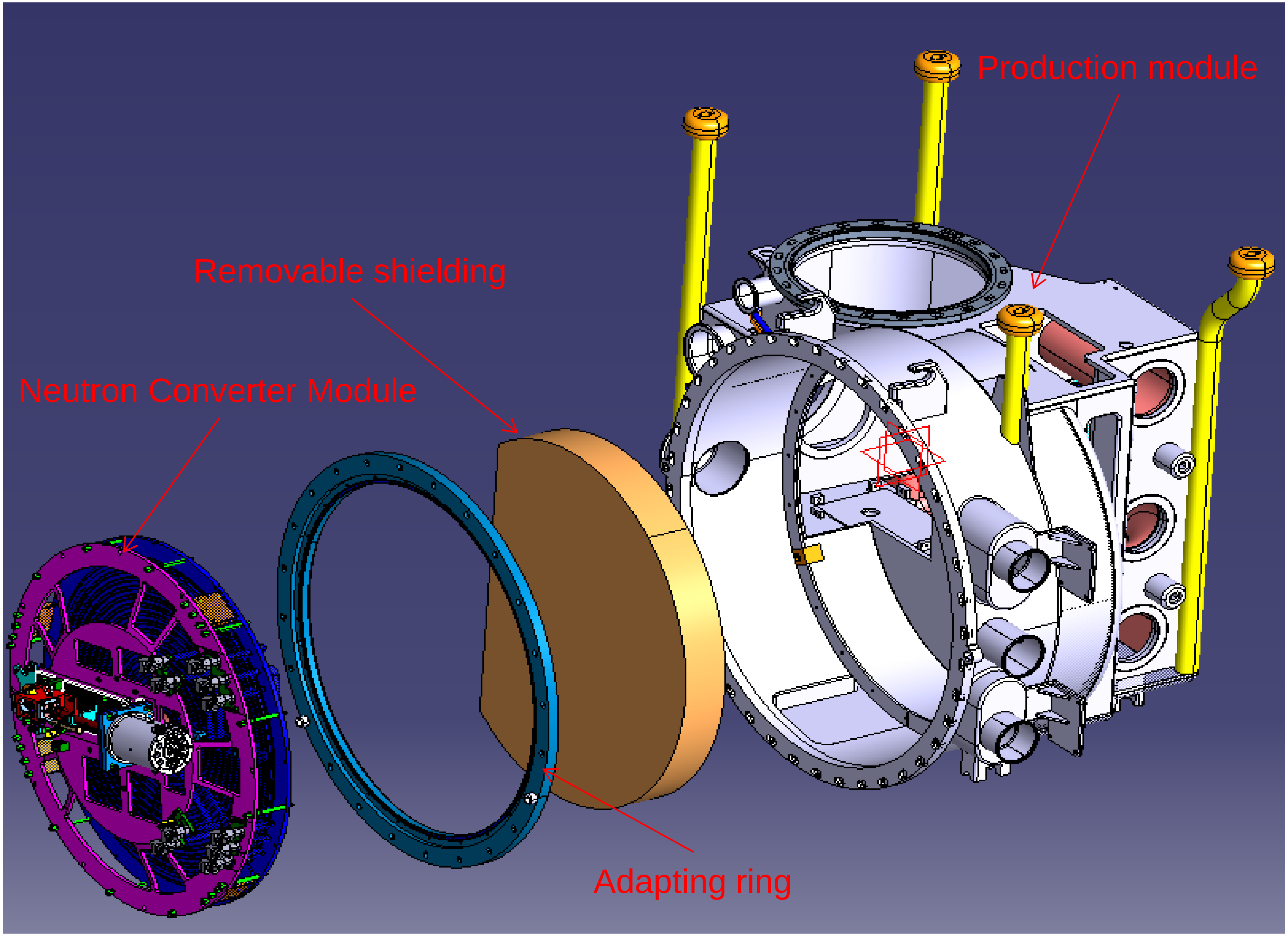
50 kW Prototype planned for the first period of operation

Neutron converter has been conceived to operate as "nuclear device"

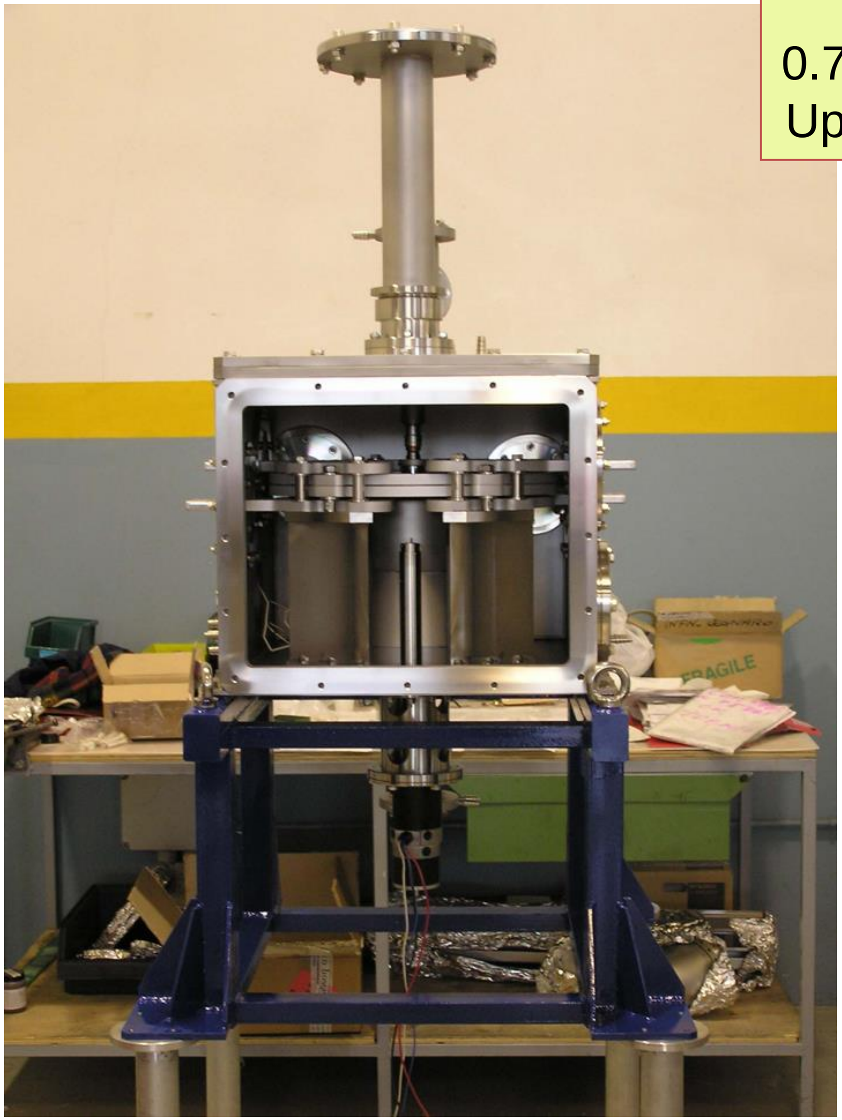
Overview of the Building – Phase 2



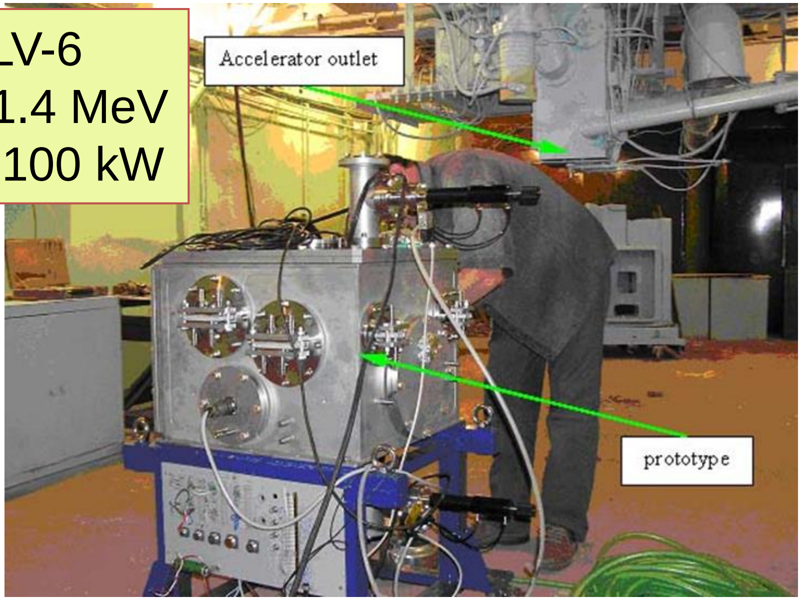
The Production Module

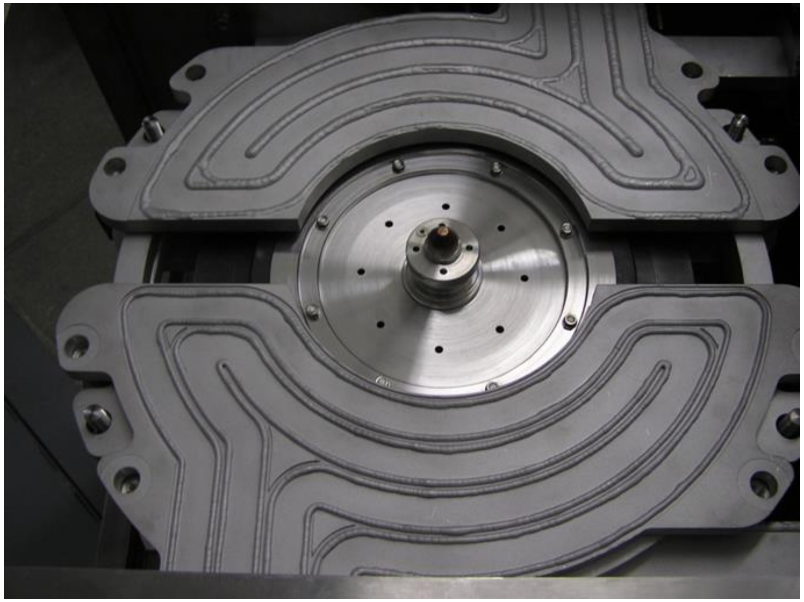


SPIRAL2 – R&D on Graphite Converter

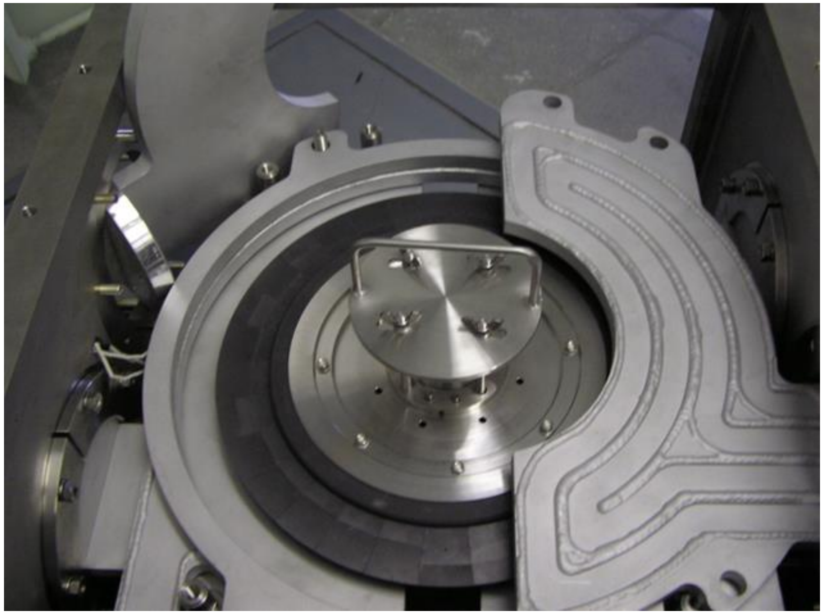


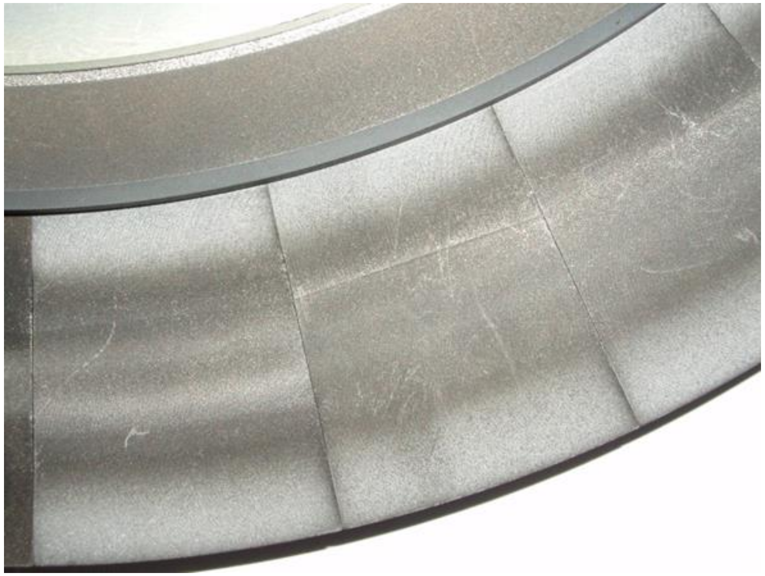
ELV-6
0.7 – 1.4 MeV
Up to 100 kW

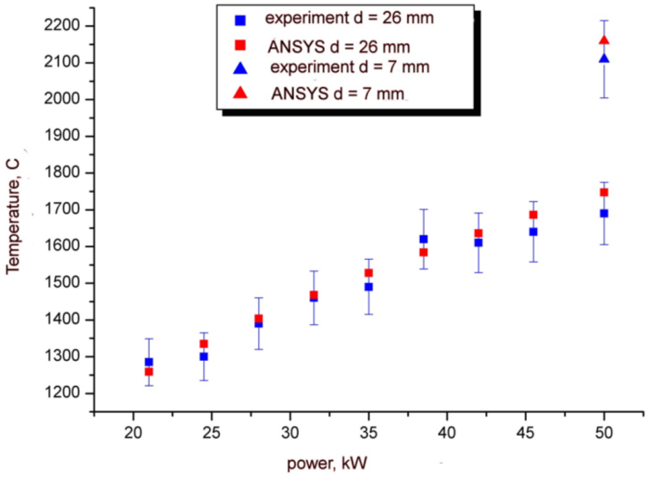




SPIRAL2 – R&D on Graphite Converter

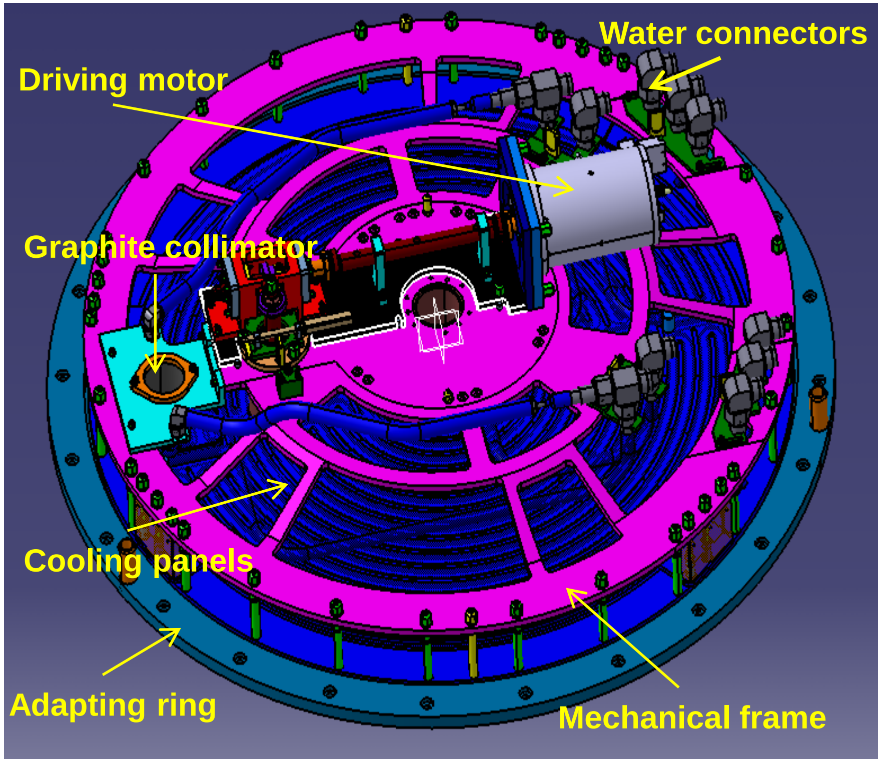






40 days test at full power (50 kW) and 70 hours at 70 kW.

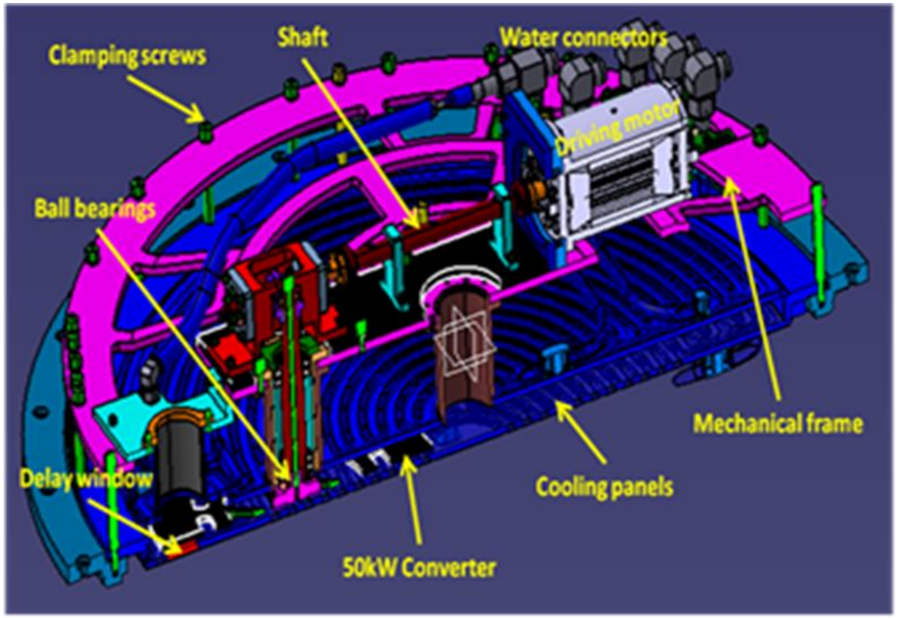
The Neutron Converter Module



NCM diameter = 1390mm

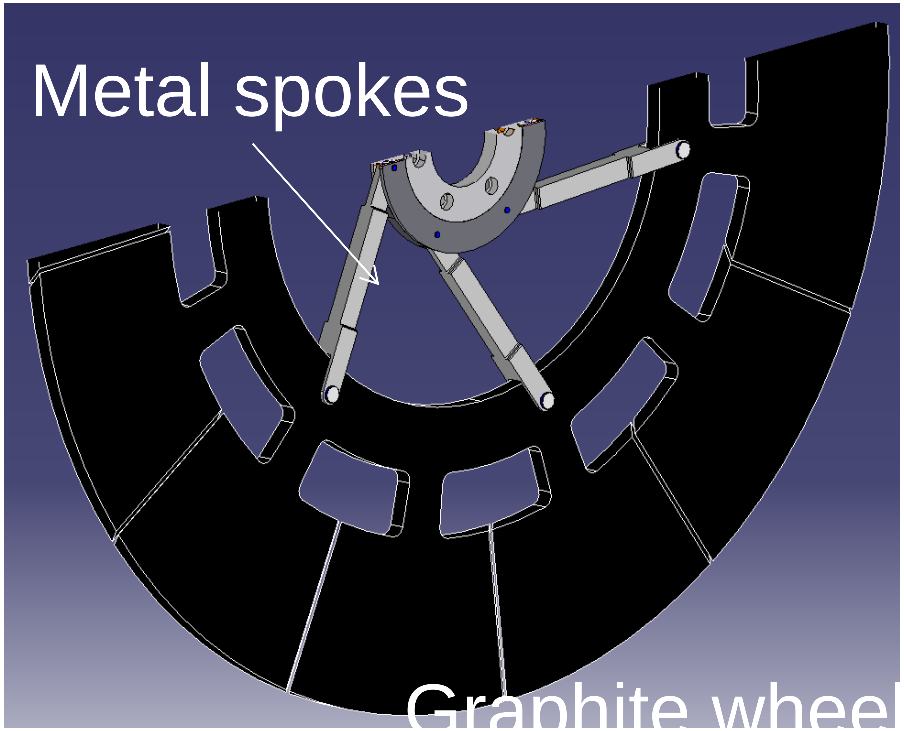
Total weight = 850 kg

For both 50 kW and 200 kW converters



Fully remote controlled by telemanipulators

The 50 kW Graphite Wheel

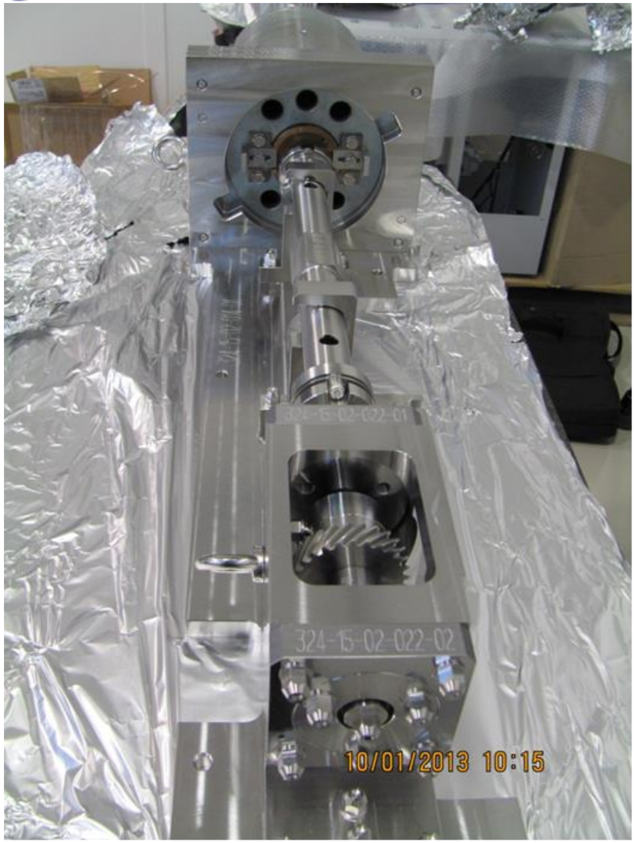


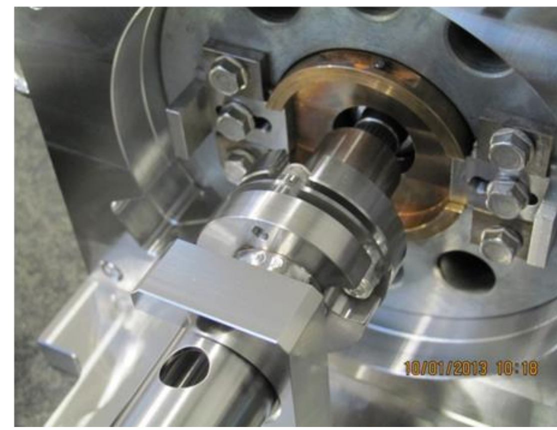
Graphite as converter material: ϕ = 520mm ; 12 sectors
thickness = 8mm

200 kW converter : ϕ = 1200mm

Stopping length 40 MeV deuteron = 5,6mm

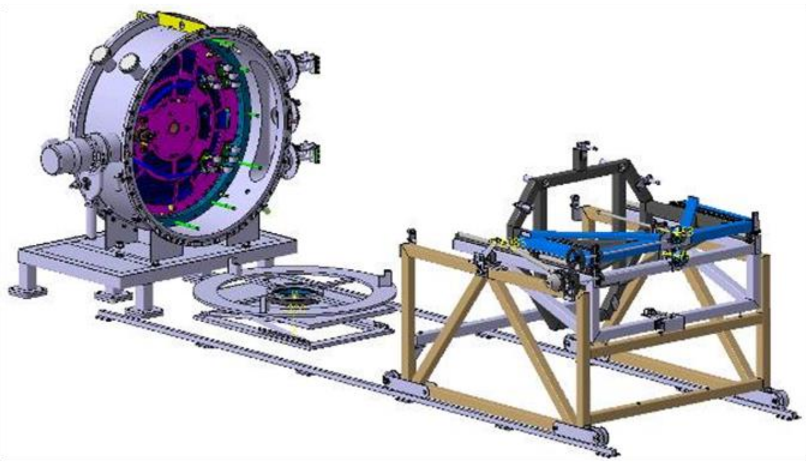
The 50 kW Rotation System

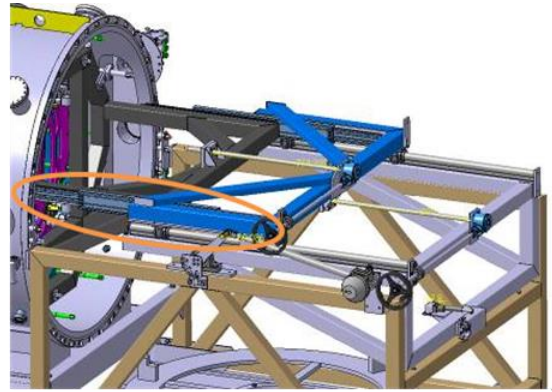


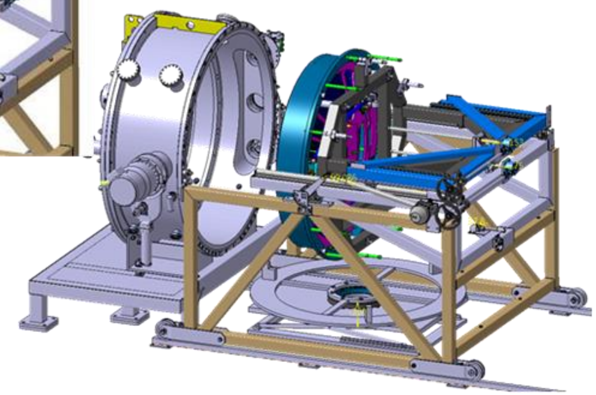


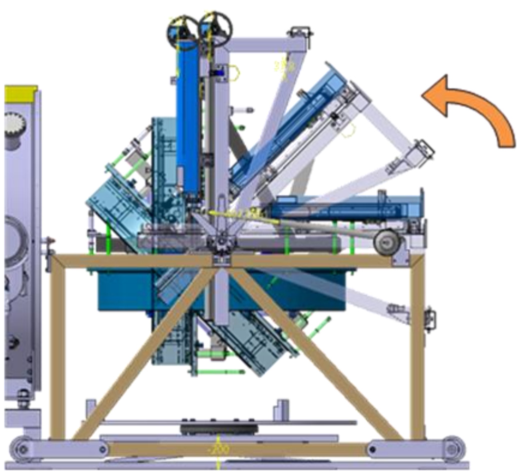
Designed to be remote controlled by telemanipulators

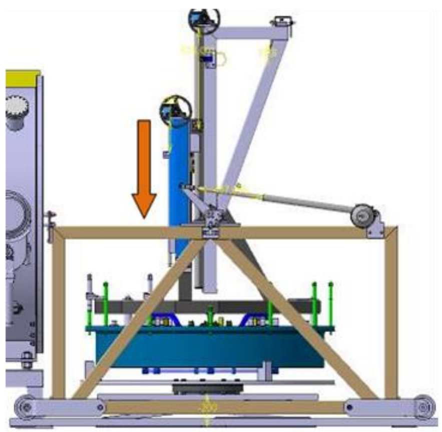
Tool for Remote Maintenance

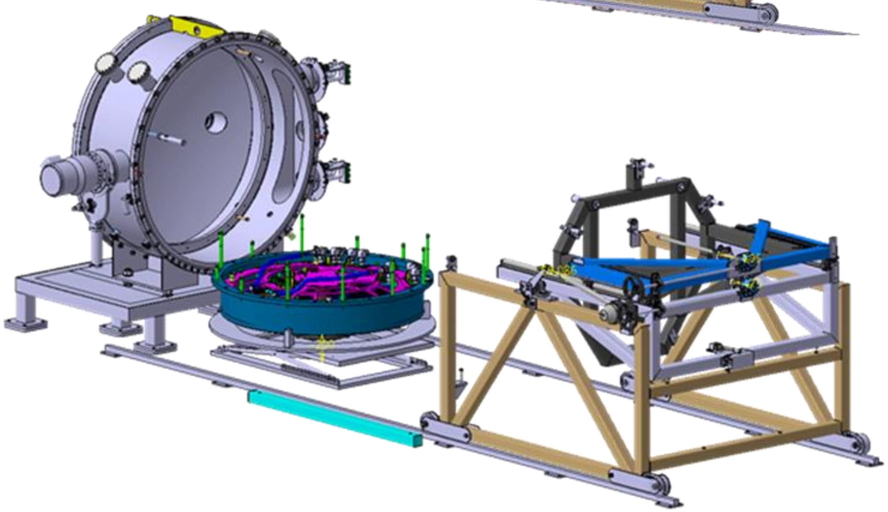






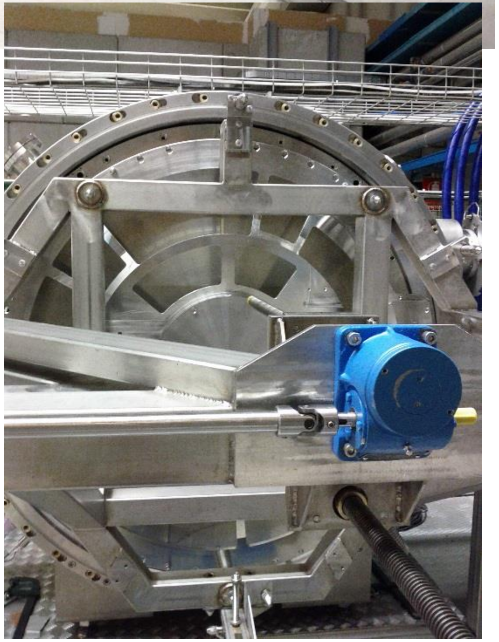






INFN LNL
Istituto Nazionale di Fisica Nucleare

Tool for Remote Maintenance



Positioning with a precision of 1/10 mm

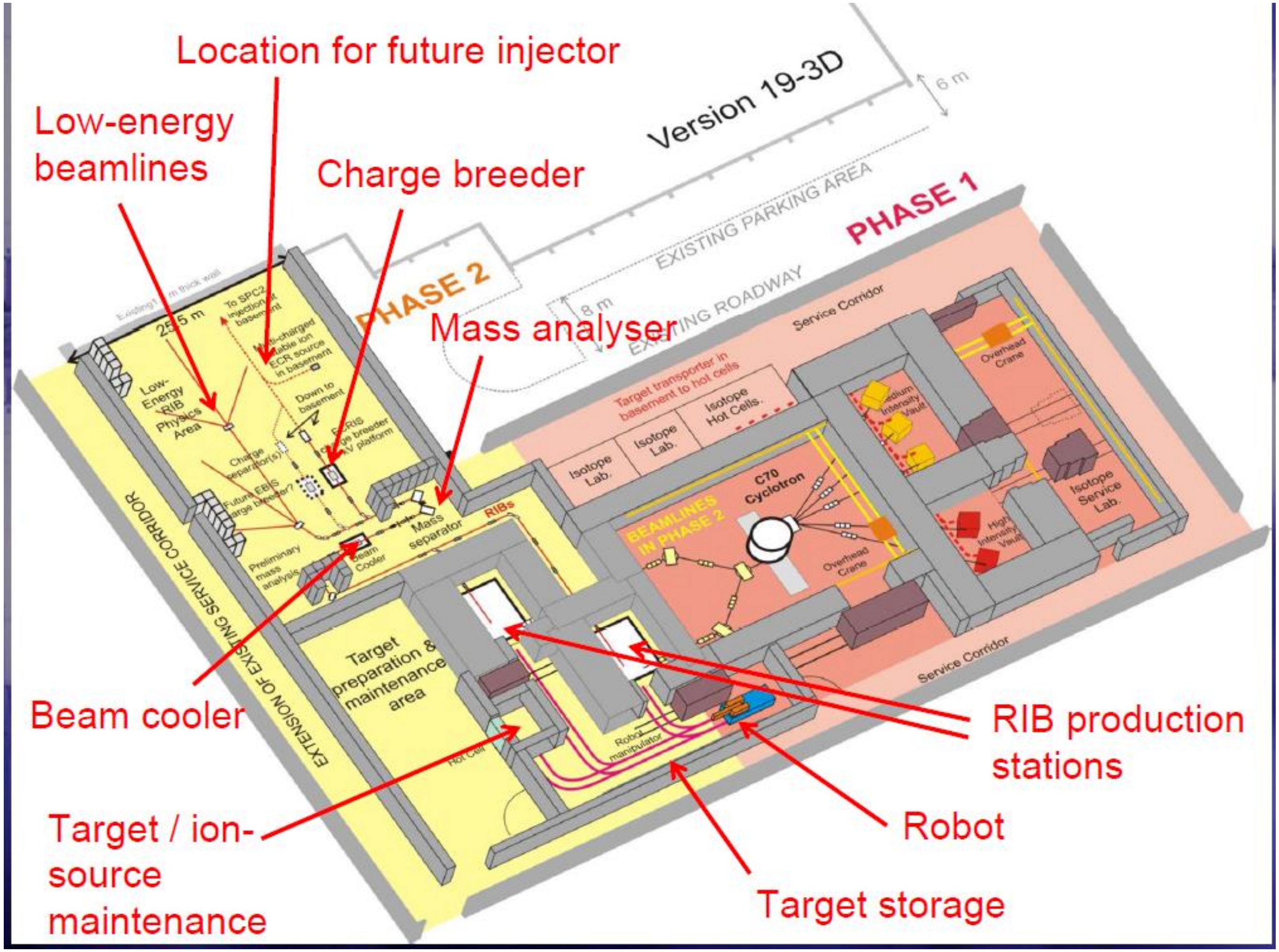
Status SPIRAL2 Phase2

- NCM delivered at LNL
- Mechanical test have been performed
- Prototype of maintenance tool is in operation at LNL
- Acceptance tests planned for November 2014
- Delivering at GANIL at December 2014

iThemba LABS (South Africa)

Phase II 2017-2020

IBA 70-MeV H⁻ cyclotron.



iThemba LABS (South Africa)

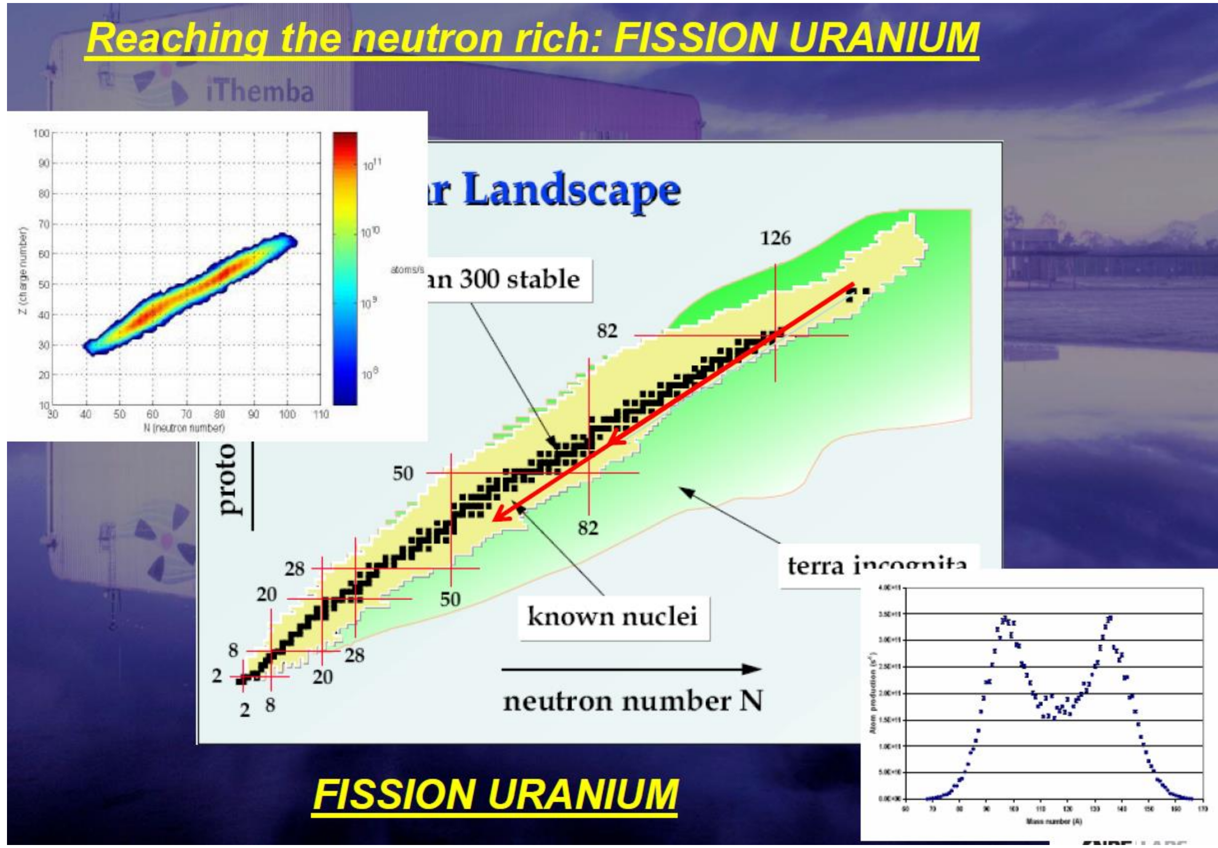
Rotating BeO converter

2000 rpm , 1600 °C

400 µA, 70 MeV protons

28 kW

Enriched
oxygen-18 water ($H_2{}^{18}O$).



Converter R&D in progress

EURISOL

Most ambitiuos project of a RIB facility

1 GeV proton beam, 4 mA current (4 MW)

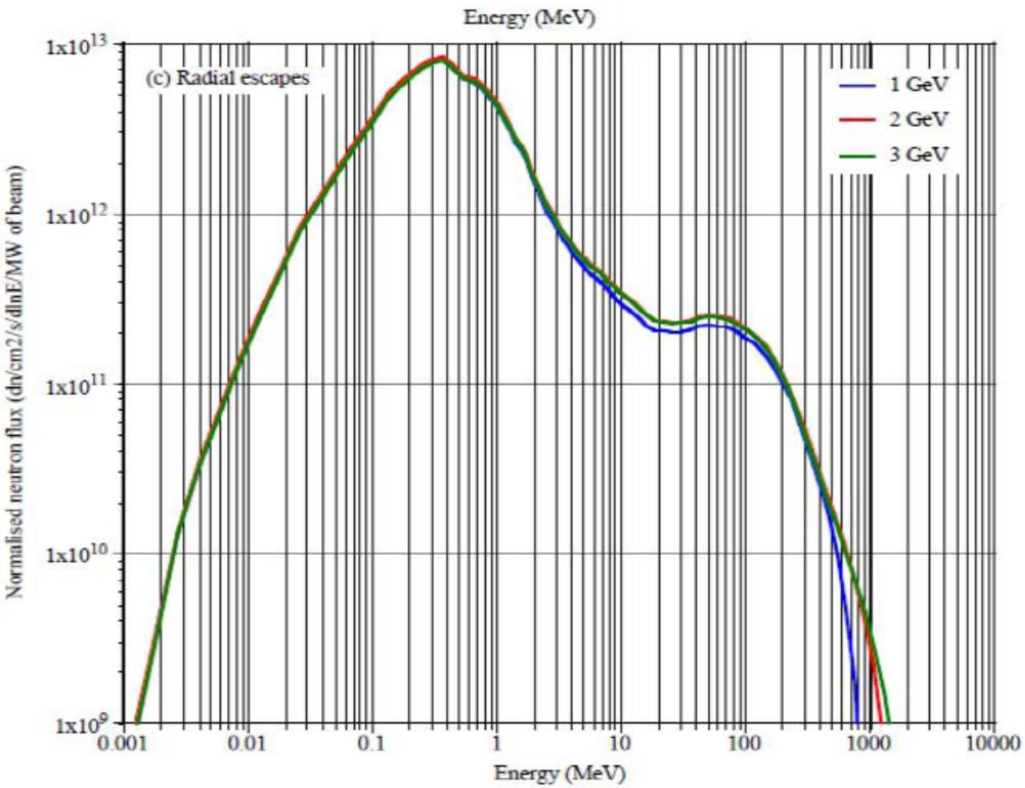
Liquid Hg as converter (inspired by SNS at ORNL)

$>10^{15}$ $n_{th}/cm^2/s$

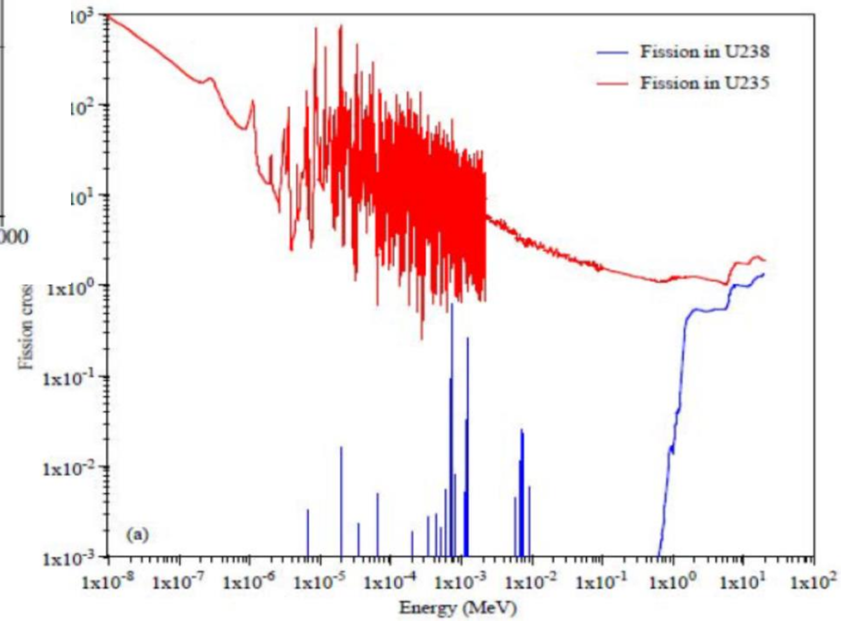
Production rate 2,4 x 10^{15} ions/s

by thermal neutrons inducing fission on ^{235}U thick target

EURISOL

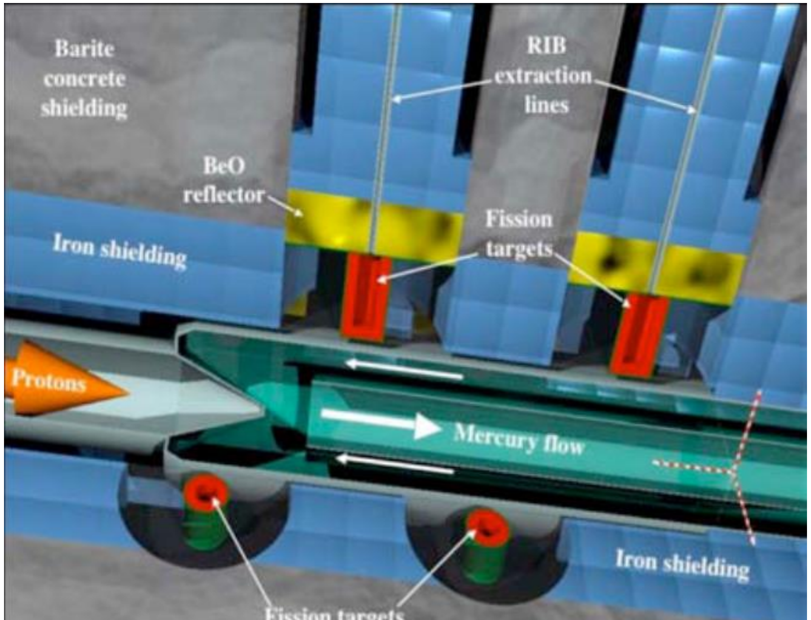


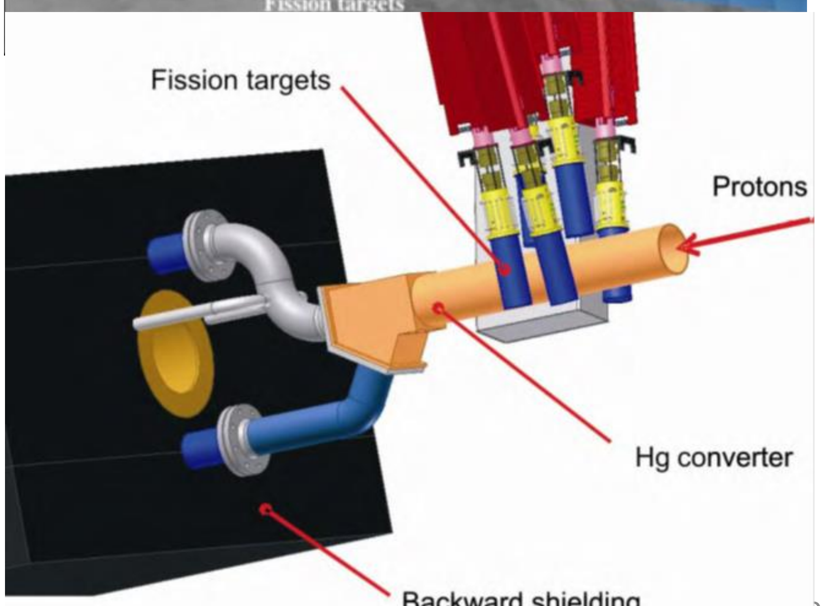
Neutron spectra for 1, 2, 3 GeV proton beam on Liquid Hg

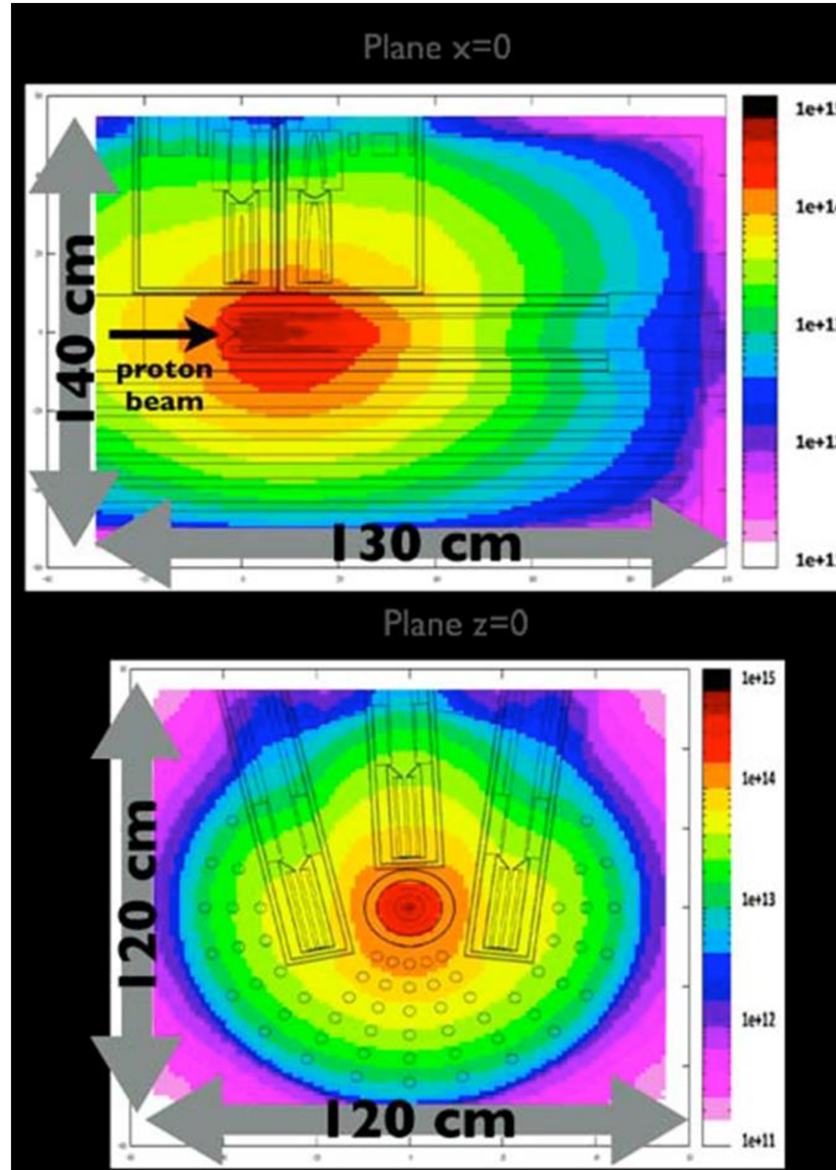


Fission cross-section for neutrons on ^{238}U and ^{235}U

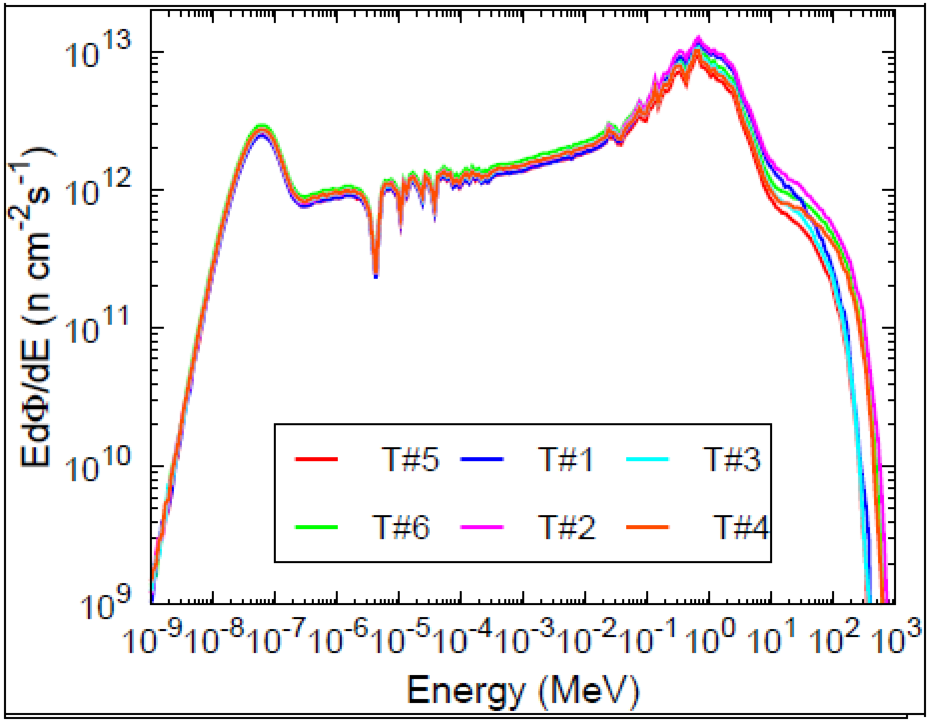
EURISOL

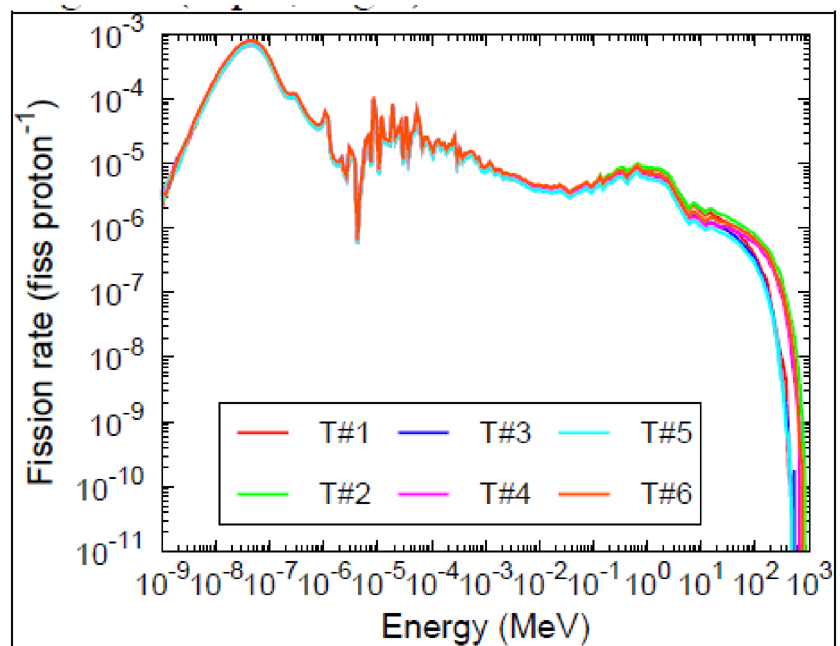

Barite concrete shielding
RIB extraction lines
BeO reflector
Iron shielding
Fission targets
Protons
Mercury flow
Iron shielding
Fission targets

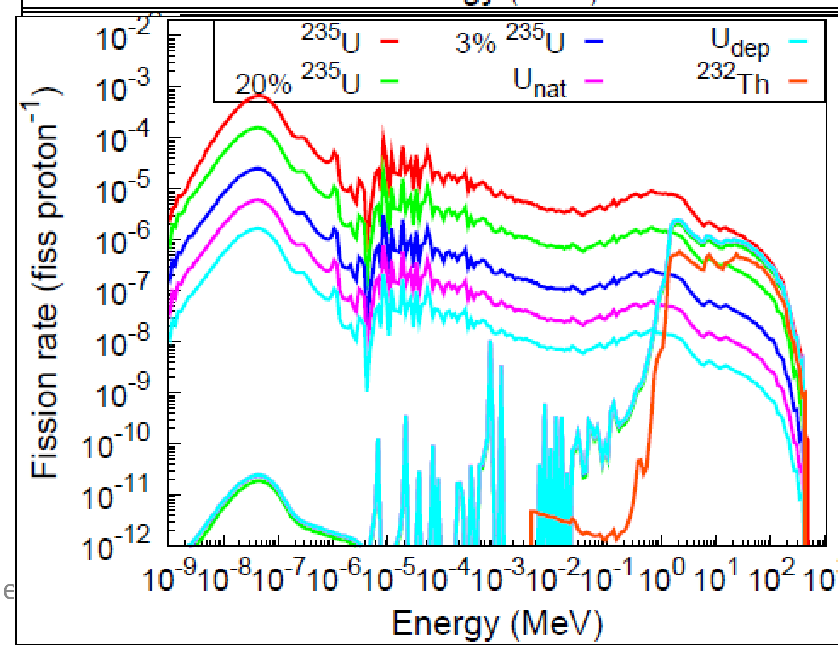

Fission targets
Protons
Hg converter
Backward shielding


Plane x=0
140 cm
proton beam
130 cm
1e+15
1e+14
1e+13
1e+12
1e+11
Plane z=0
120 cm
120 cm
1e+15
1e+14
1e+13
1e+12
1e+11

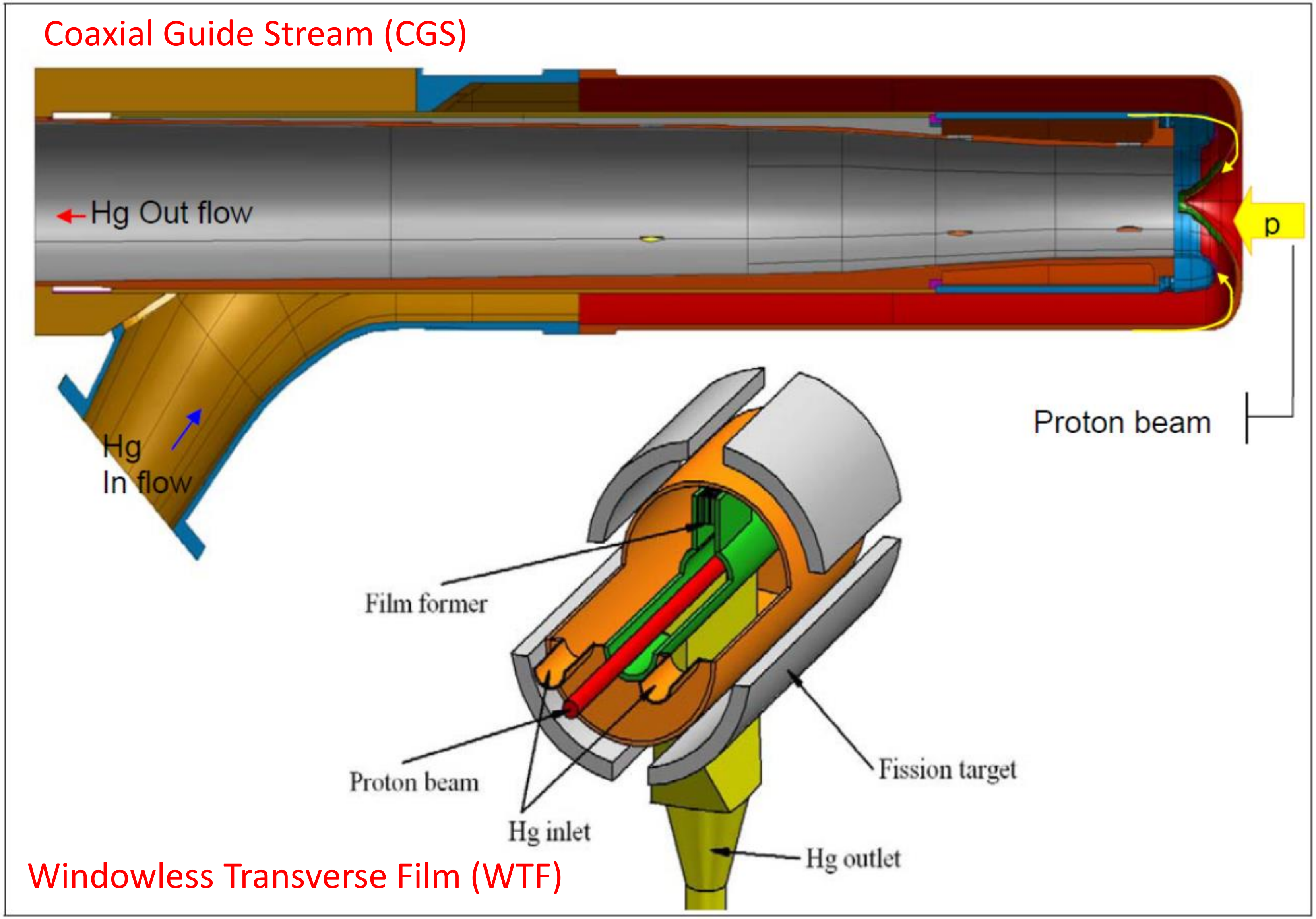
EURISOL


EdΦ/dE (n cm-2s-1)
Energy (MeV)
T#5
T#1
T#3
T#6
T#2
T#4

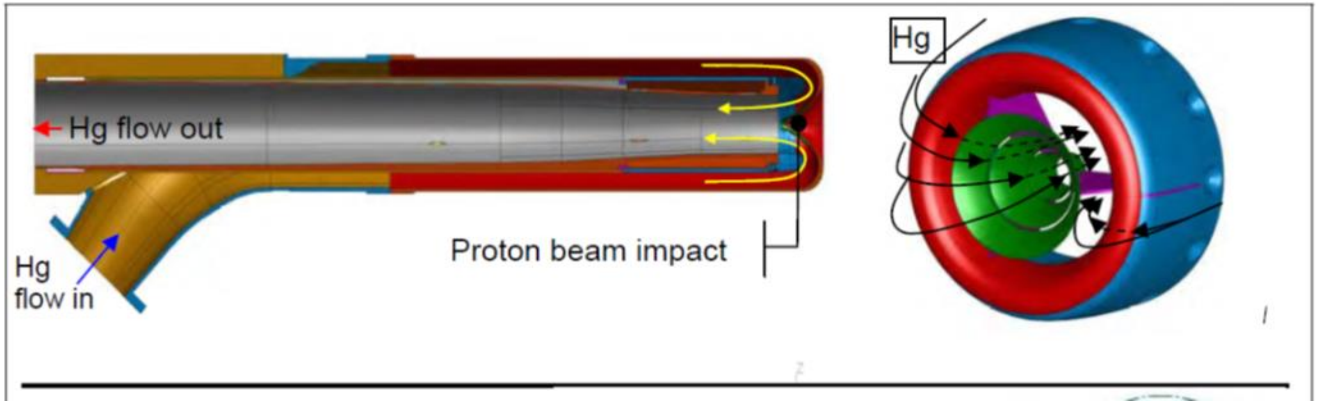

Fission rate (fiss proton-1)
Energy (MeV)
T#1
T#3
T#5
T#2
T#4
T#6

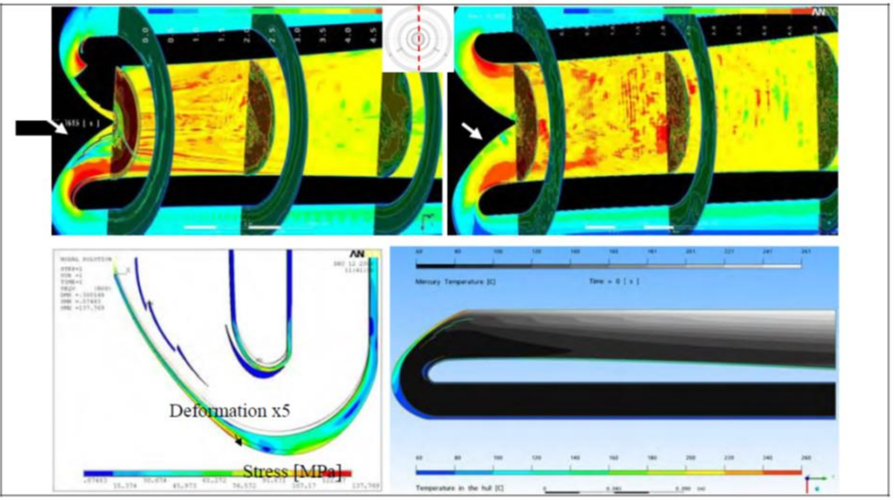

Fission rate (fiss proton-1)
Energy (MeV)
235U
3% 235U
Udep
20% 235U
Unat
232Th

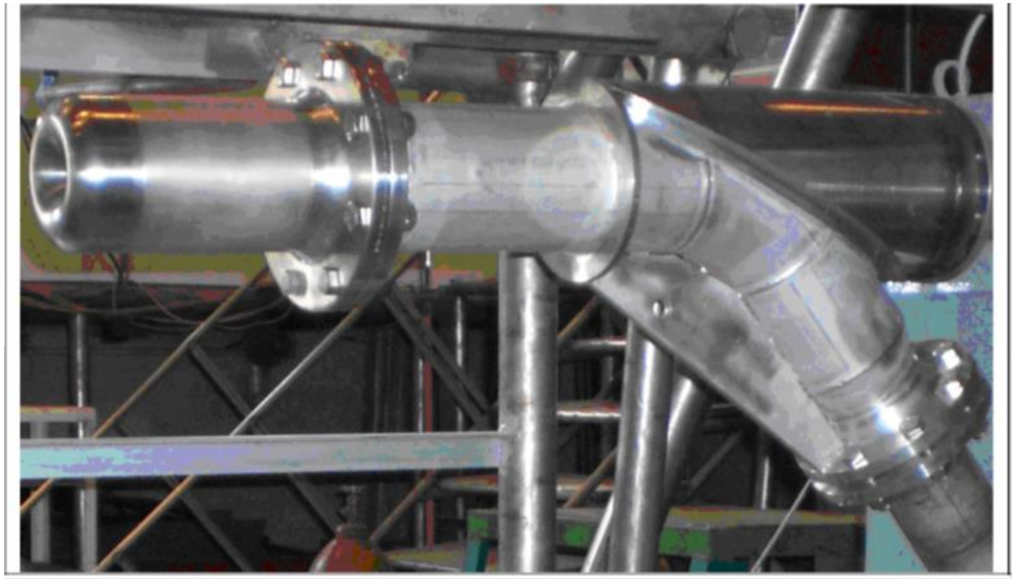
EURISOL n-Converters



EURISOL n-Converter Prototype (CGS)

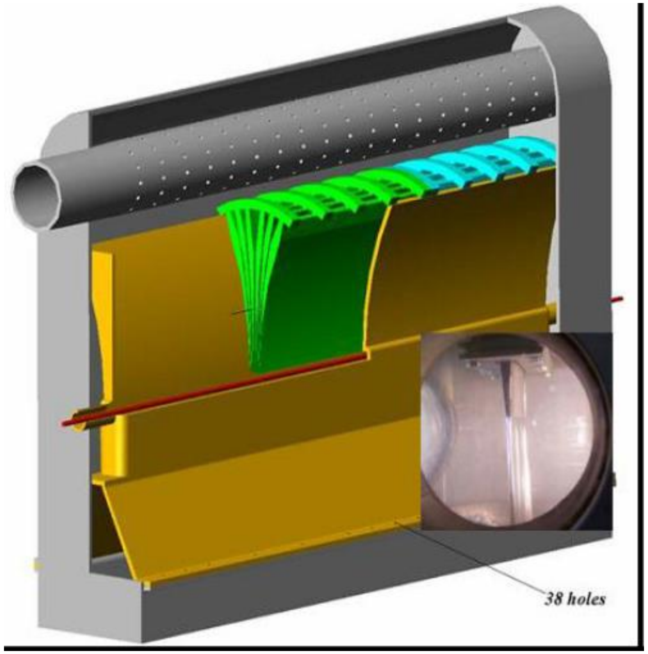


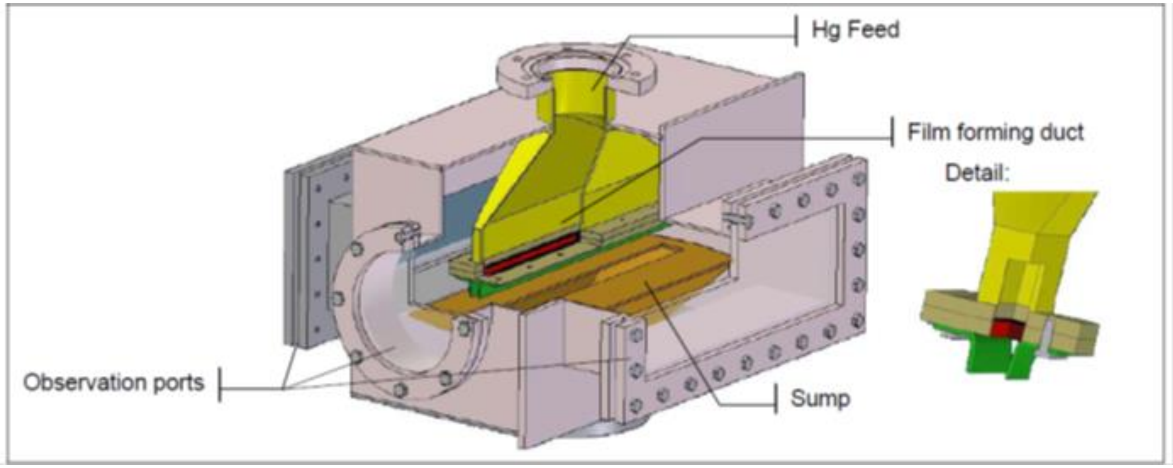




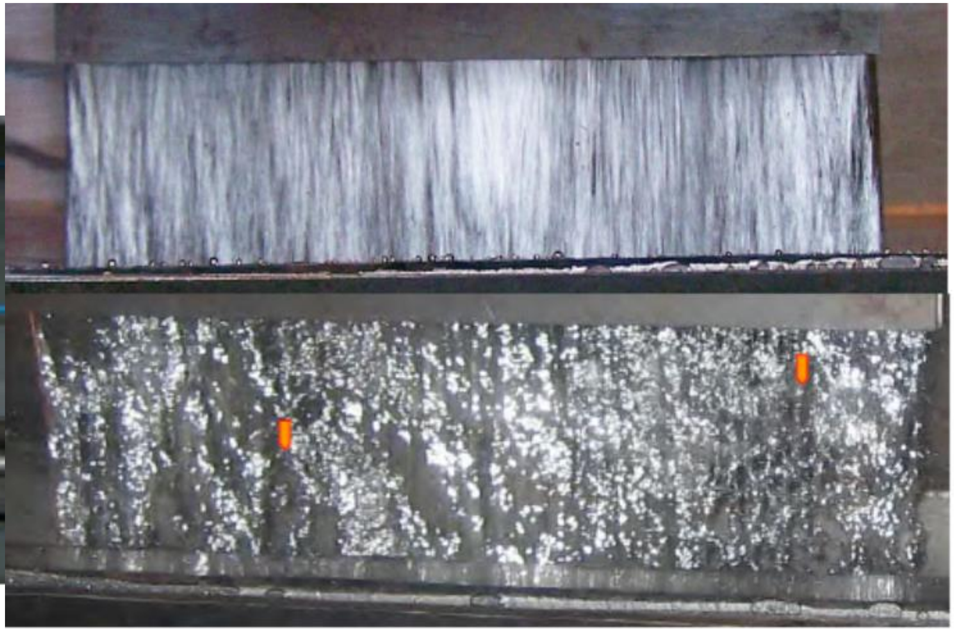
Coaxial Guide Stream (CGS) costructed at PSI and tested at IPUL

EURISOL n-Converter Prototype (WTF)

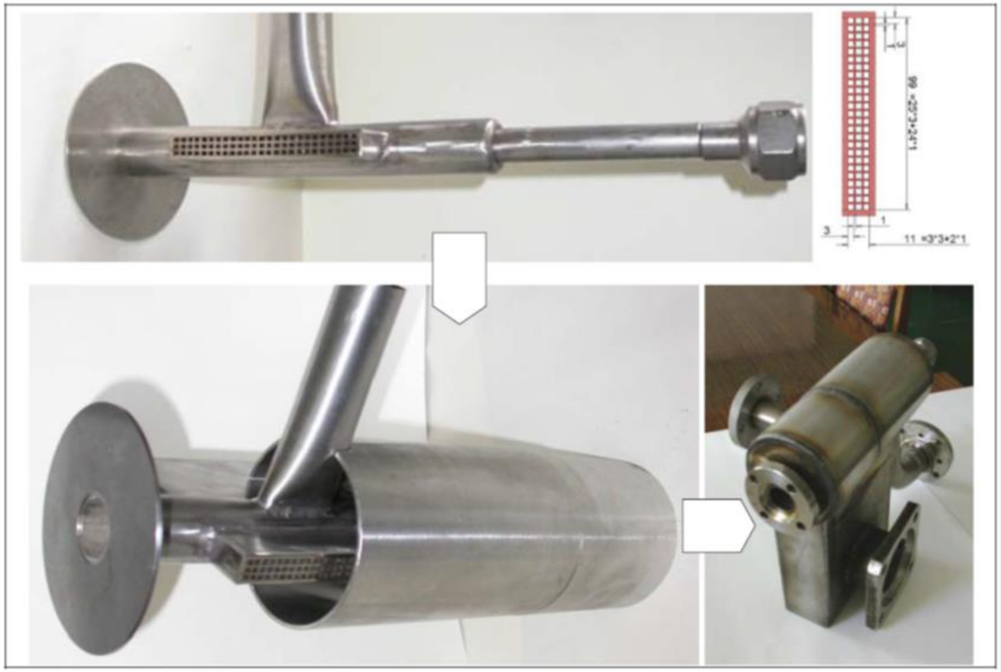


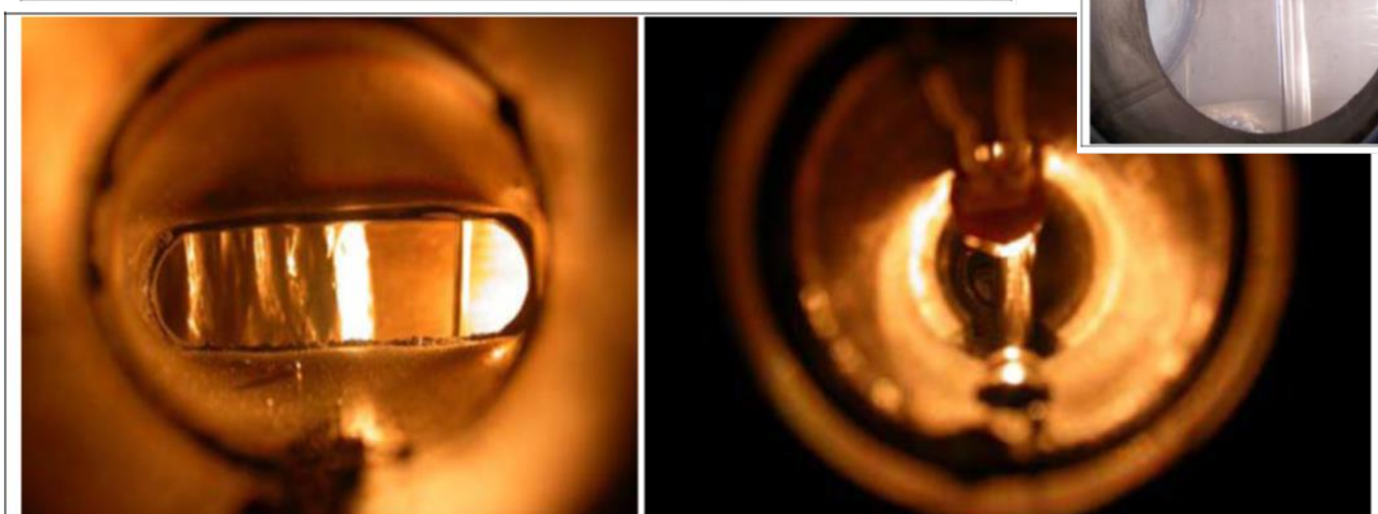


Prototype of the Windowless Tranverse Film (WTF)



EURISOL n-Converter Prototype (WTF)



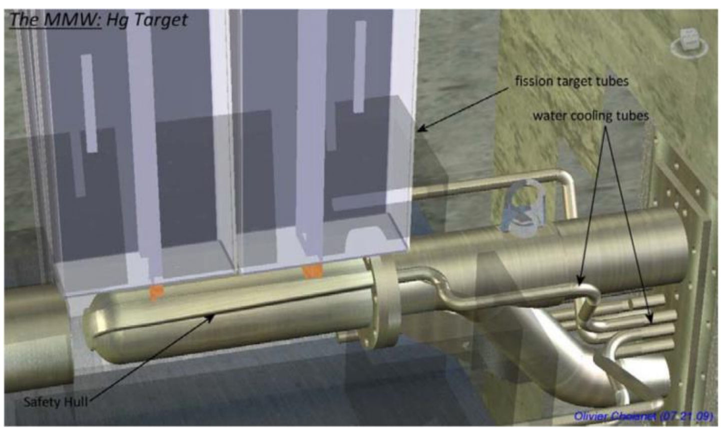


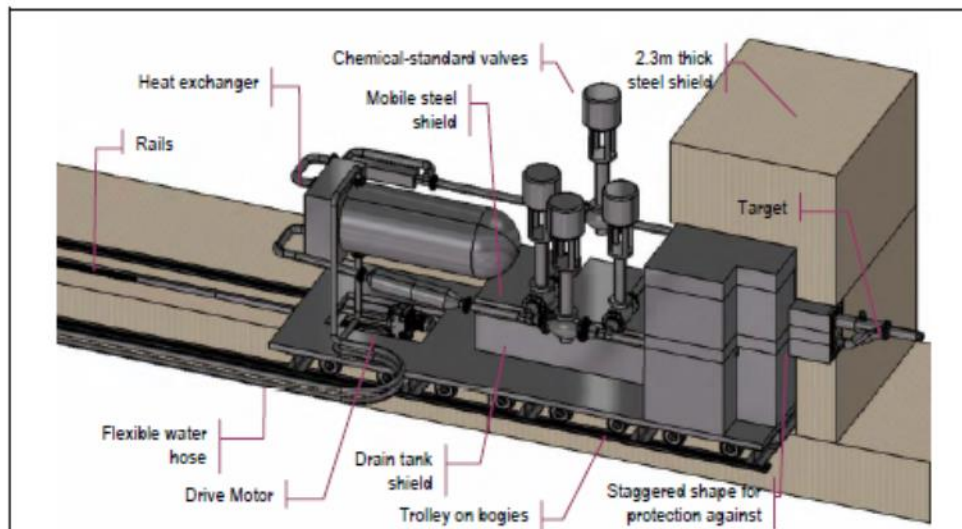
EURISOL n-Converter (CGS)

Parameter	Symbol	Units	Nval	Range
Converter Target material	Z_{conv}	-	Hg (liquid)	LBE
Secondary Target material	Z_{targ}	-	UC_x, BeO	
Beam particles	Z_{beam}	-	Proton	
Beam particle energy	E_{beam}	GeV	1	≤ 2
Beam current	I_{beam}	mA	4	2 – 5
Beam time structure	-	-	dc	ac 50Hz 1ms pulse
Gaussian beam geometry	σ_{beam}	mm	15	≤ 25, parabolic
Beam power	P_{beam}	MW	4	≤ 5
Converter length	l_{conv}	cm	45	≤ 85
Converter radius (cylinder)	r_{conv}	cm	15	8 – 20
Hg temperature	T_{conv}	°C	150 (tbc)	<< 357
Hg flow rate	Q_{conv}	ton/s	1 (tbc)	<< 3
Hg speed	V_{conv}	m/s	5 (tbc)	<< 15
Hg pressure drop	ΔP_1	bar	tbc	<< 100
Hg overpressure	ΔP_2	bar	tbc	<< 100
UC_x temperature	T_{targ}	°C	2000	500-2500

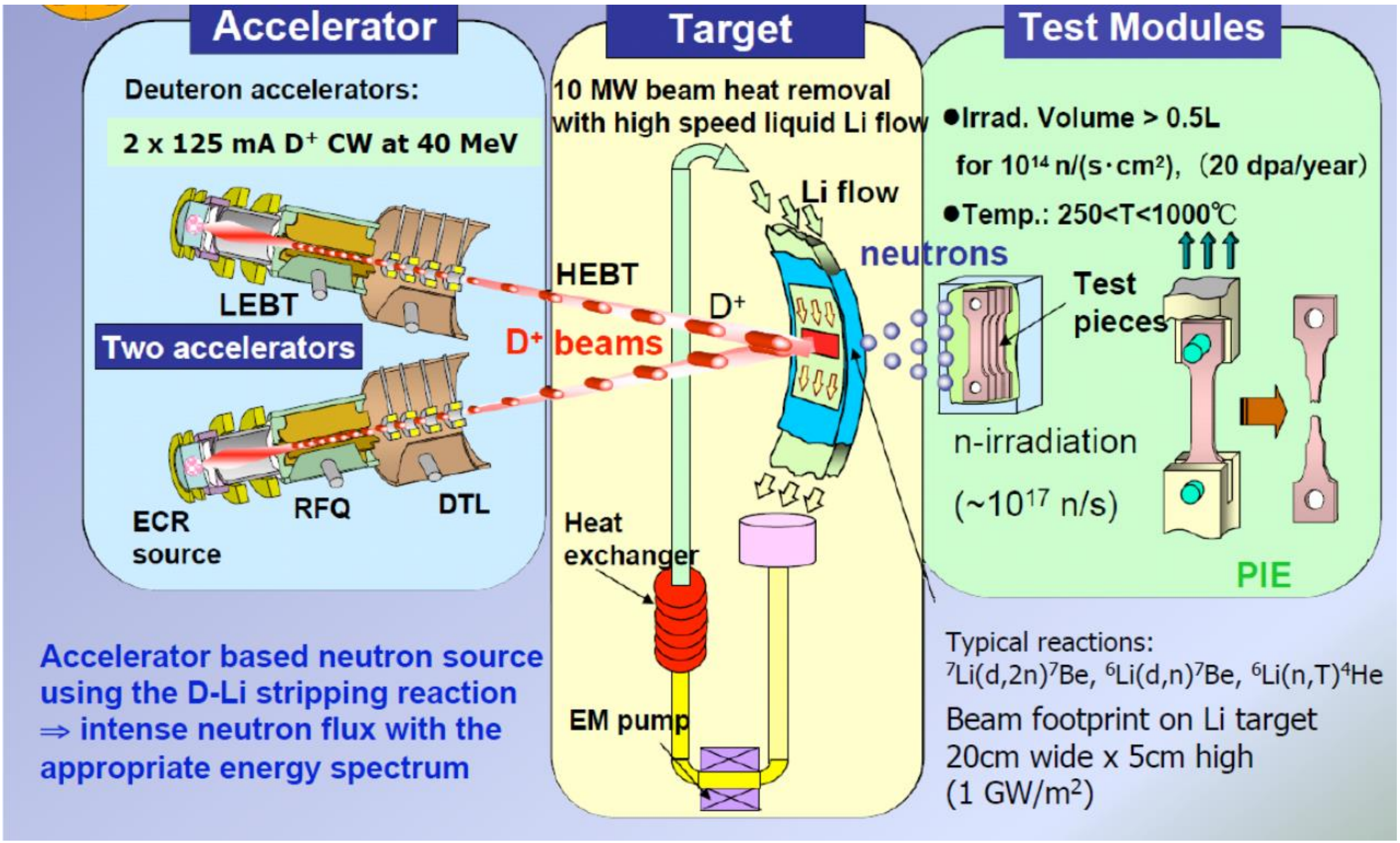
Main parameters for the Multi-MW converter and fission target system

Set up of the Hg converter





IFMIF – International Fusion Materials Irradiation Facility

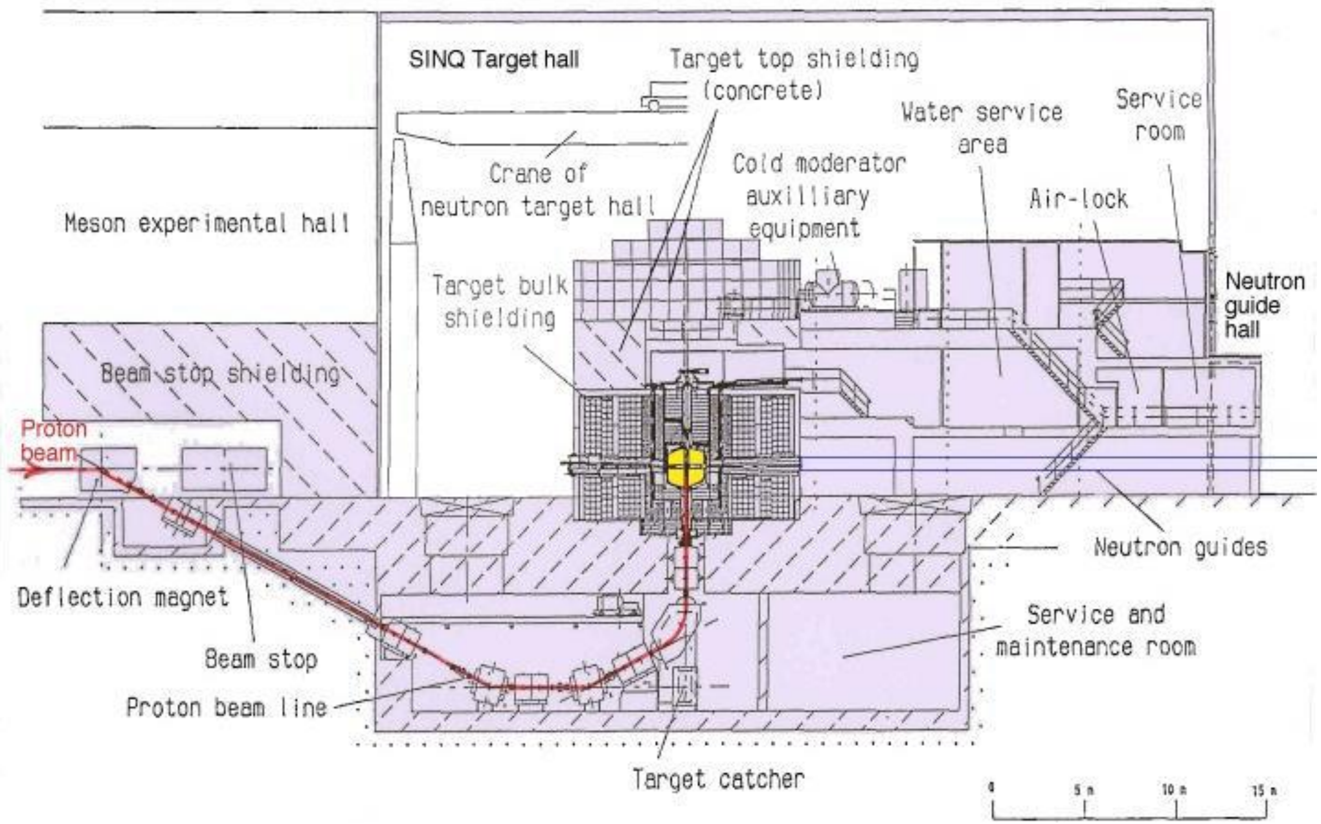


IFMIF – International Fusion Materials Irradiation Facility

Main objectives: demonstrate a stable lithium flow at nominal conditions
Remove all impurities, develop adequate diagnostics (flow measurement)

- Speed: 15 m/s
- Thickness: 25 ±1 mm
- Width: 100 mm (260 mm for IFMIF)

MEGAPIE at SINQ –Paul Scherrer Institut



An experiment to be carried out in the SINQ target location to demonstrate the safe operation of a liquid metal spallation target of about 1 MW beam power.

Demonstration of feasibility for future ADS development
Increase neutron flux for SINQ

MEGAPIE at SINQ –Paul Scherrer Institut

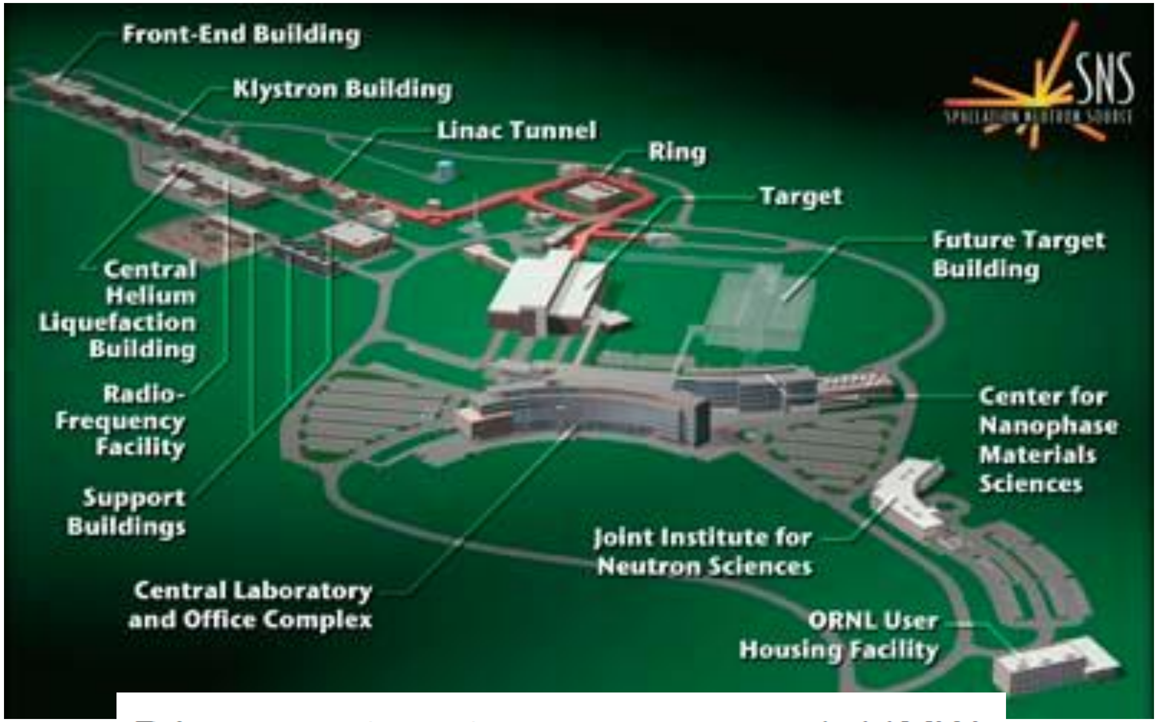
Beam energy:	575 MeV	Deposited heat:	650 kW
Beam current:	1.74 mA (design)	Cold temperature:	230 – 240°C
Length:	5.35 m	Hot temperature:	380°C
LBE volume:	~ 82 l	Design temperature:	400°C
Weight:	~ 1.5 t	Operating pressure:	0 – 3.2 bar
Wetted surface:	~ 8m²	Design pressure:	16 bar
Gas expansion volume:	~ 2 l	Total LBE flow rate:	4 l/s
Insulation Gas:	0.5 bar He	By-pass flow rate:	0.25 l/s

Lead-Bismuth eutectic (Pb 44.5%- Bi 55.5%)
Attractive neutronic and physical properties:

Heat transfer coefficient

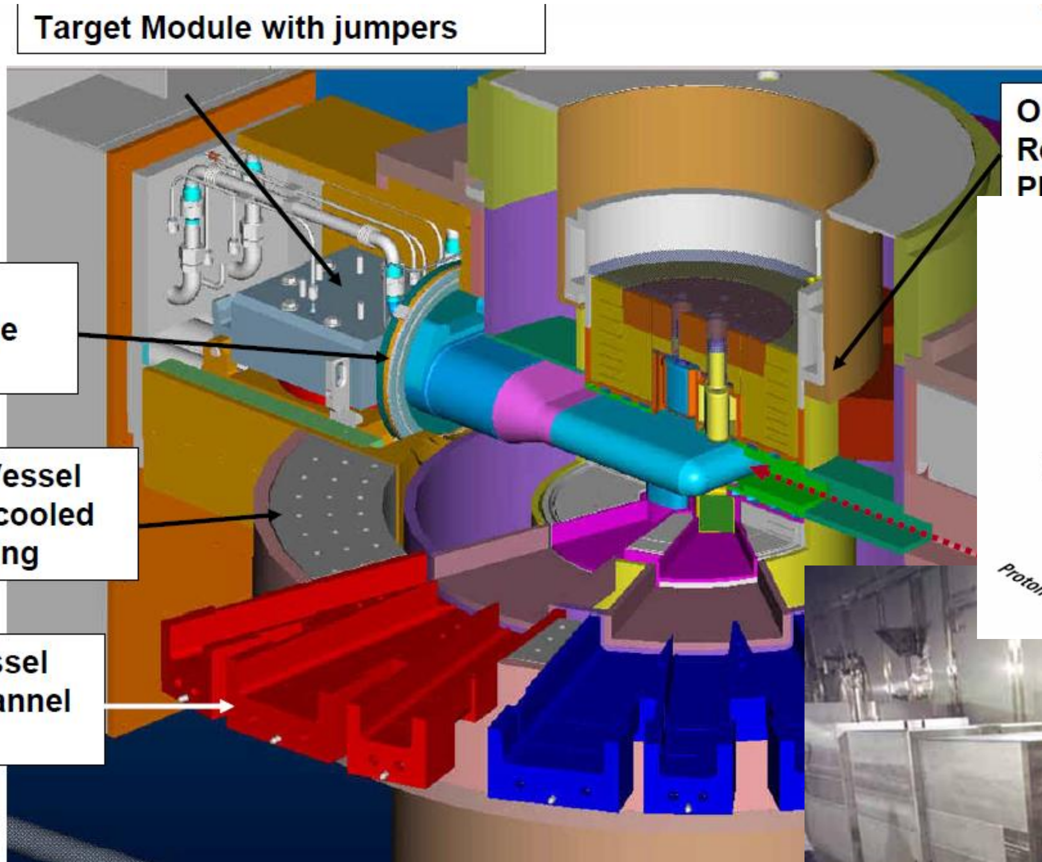
Low melting poit (125°C)

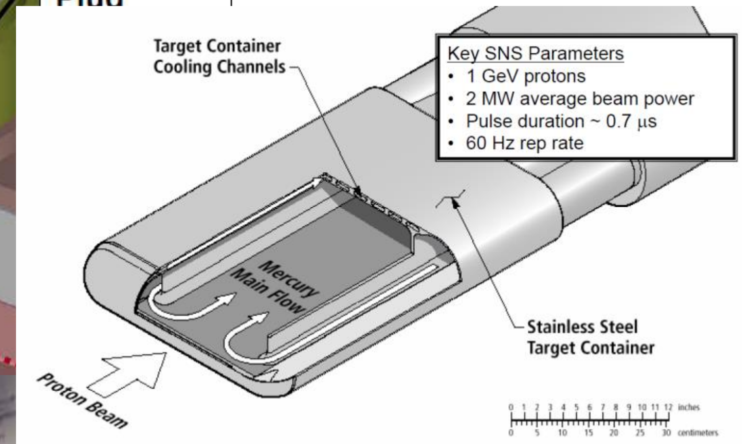
SNS – Spallation neutron Source - ORNL

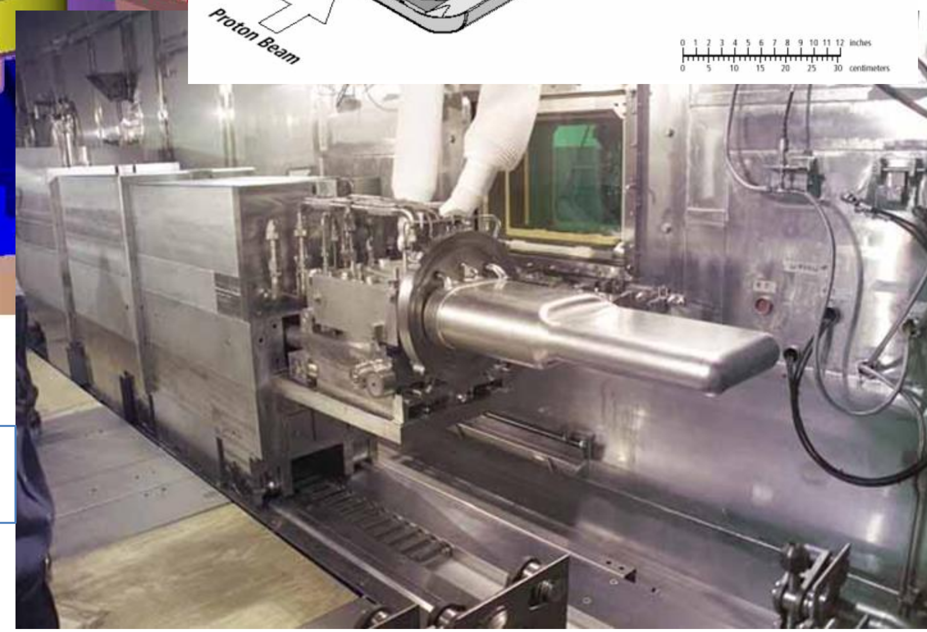


P beam on target :	1.44MW
I beam average:	1.44mA
Maximum Beam energy:	1 GeV
Duty factor:	6%
Rep. rate:	60Hz
Pulse width:	1ms

SNS – Spallation neutron Source - ORNL



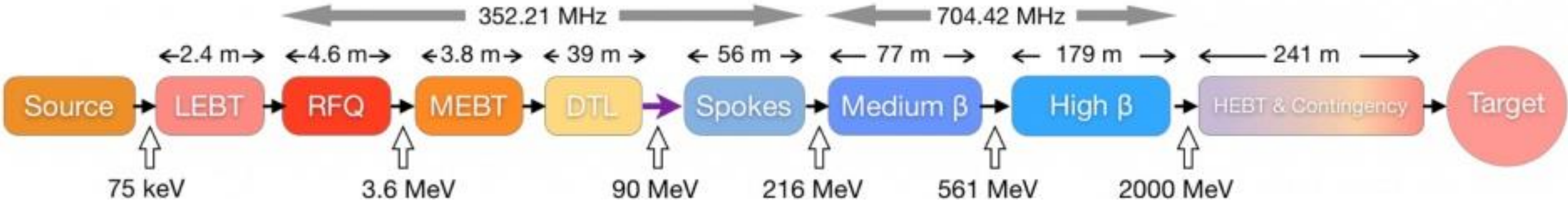




R&D on Rotating solid converter

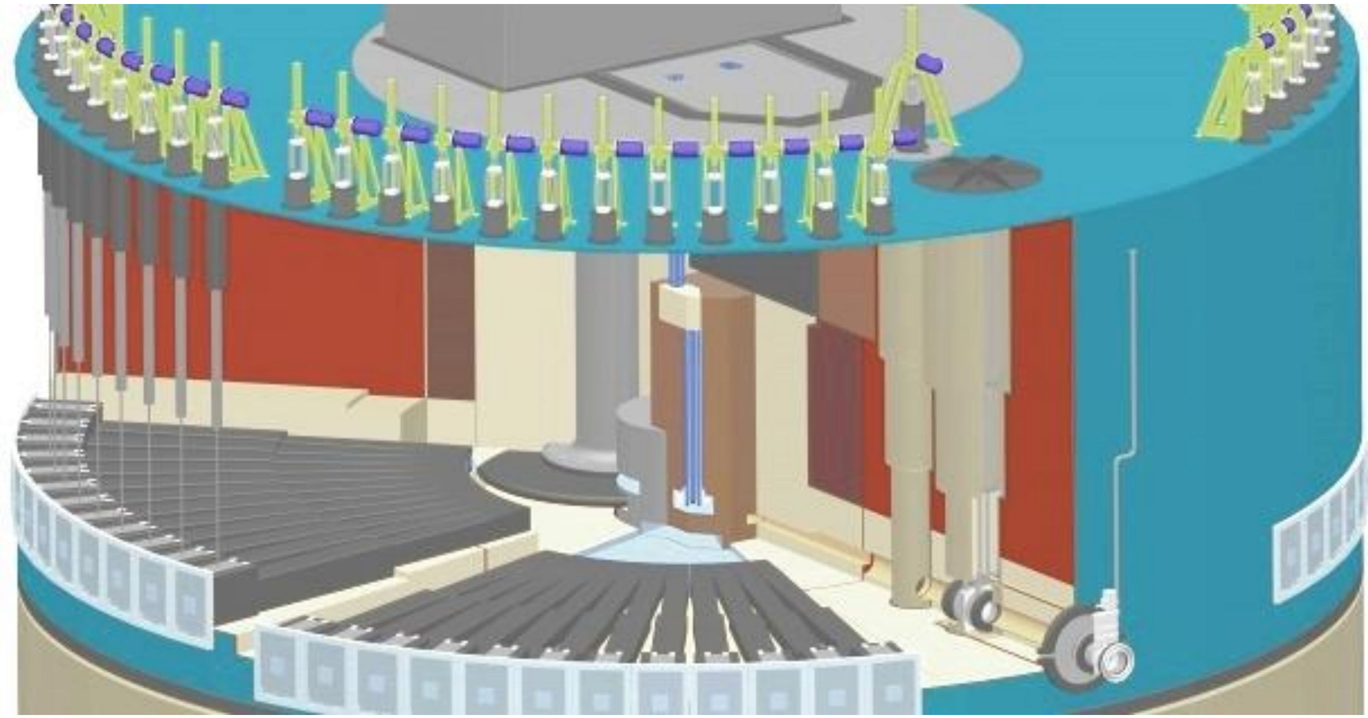
ESS – European Spallation Source

Optimus+_2013_10_31



The ESS accelerator high level requirements are to provide a 2.86 ms long proton pulse at 2 GeV at repetition rate of 14 Hz. This represents 5 MW of average beam power with a 4% duty cycle on target.

ESS – European Spallation Source



A rotating tungsten wheel is the baseline option for the target, which distributes the irradiation over a large volume of target material. Metallic liquid lead-bismuth eutectic is being retained as an comparative target for licensing purposes.

Conclusions

A few RIB facilities uses (or plan to use) neutron converters of different materials to produce radioactive ion beams (beam power up to few 10kW)

Saraf LiFTiT 10kW LiLiT(up to 80kW; plans)

iThemba rotating BeO (28kW; plans)

SPIRAL2 will be the first RIB facility operating a High Power Neutron Converter (200kW)

This is expected in 4/5 years from now!?

SPIRAL2 represent a valid technological test bench for EURISOL (scale 1:10)

Neutron Spallation Sources as precursors of high power neutron converters in the MW range in synergy with EURISOL.