In-target yields for Radioactive Ion Beam (RIB) production with EURISOL

J.-C. David
with

- D. Doré, B. Rapp, D. Ridikas → Benchmarking
- S. Chabod, N. Thiollière, D. Ridikas → Direct target
- D. Ene, D. Ridikas → Fission target

EURISOL-DS project
Goals

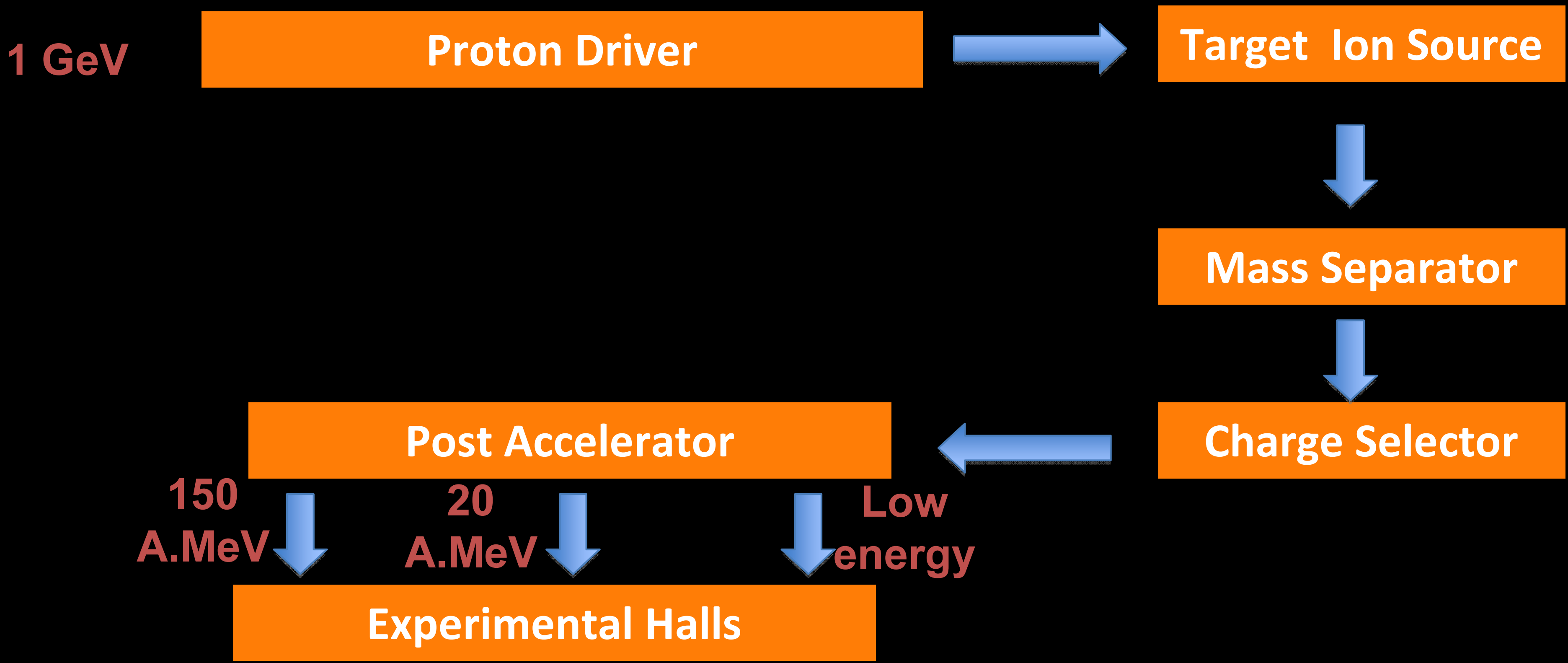
- NuPECC recommends the construction of 2 ‘next generation’ RIB facilities.
  - An in-flight machine: a major upgrade of the current GSI facility: FAIR
  - A new ISOL machine: EURISOL

- EURISOL Design Study: Design and prototyping of the most specific and challenging parts of EURISOL

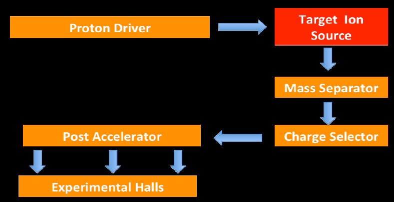
- Highest Intensities (*100 compared to existing facilities) → More exotic nuclei

- Nuclei of interest: Li, Be, Ne, Mg, Ar, Ni, Ga, Kr, Sn, Hg, Fr

EURISOL-DS project
Facility
(Idea)

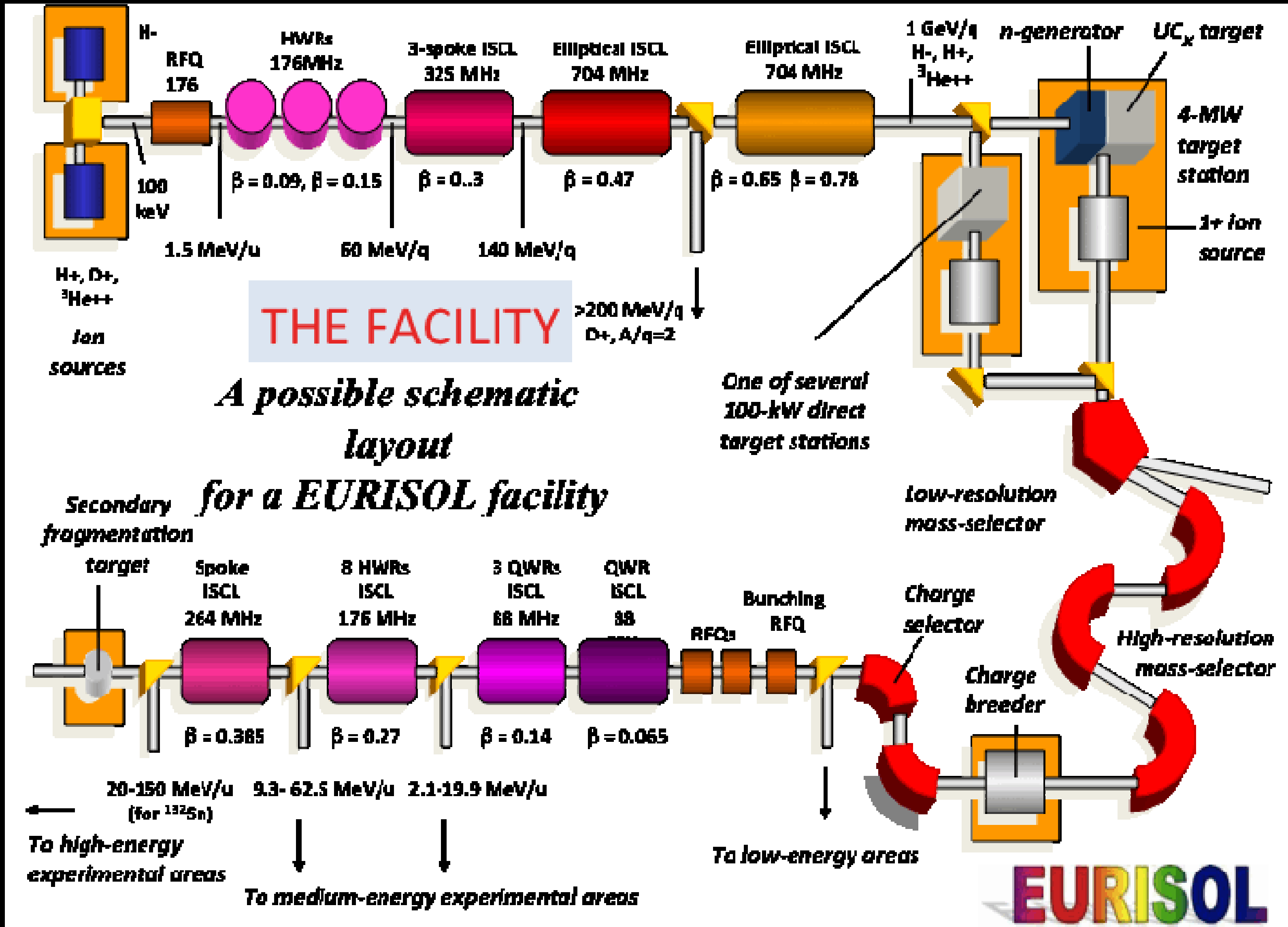


irfu cea saclay

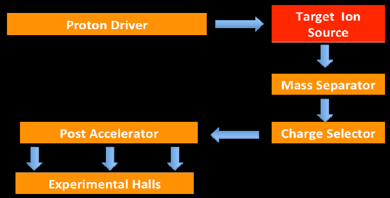


EURISOL-DS project Facility (Schematic view)

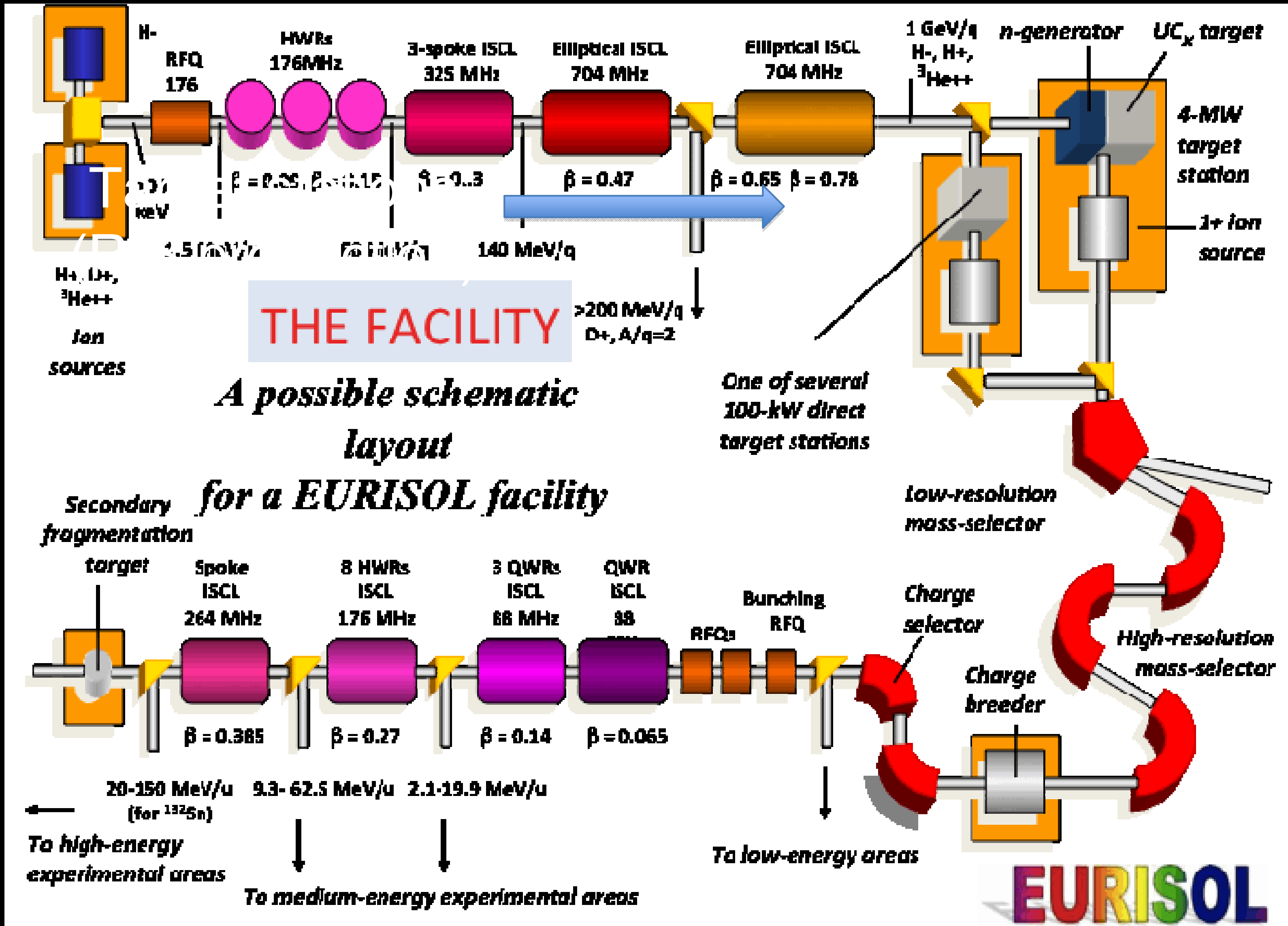
Layout 2005



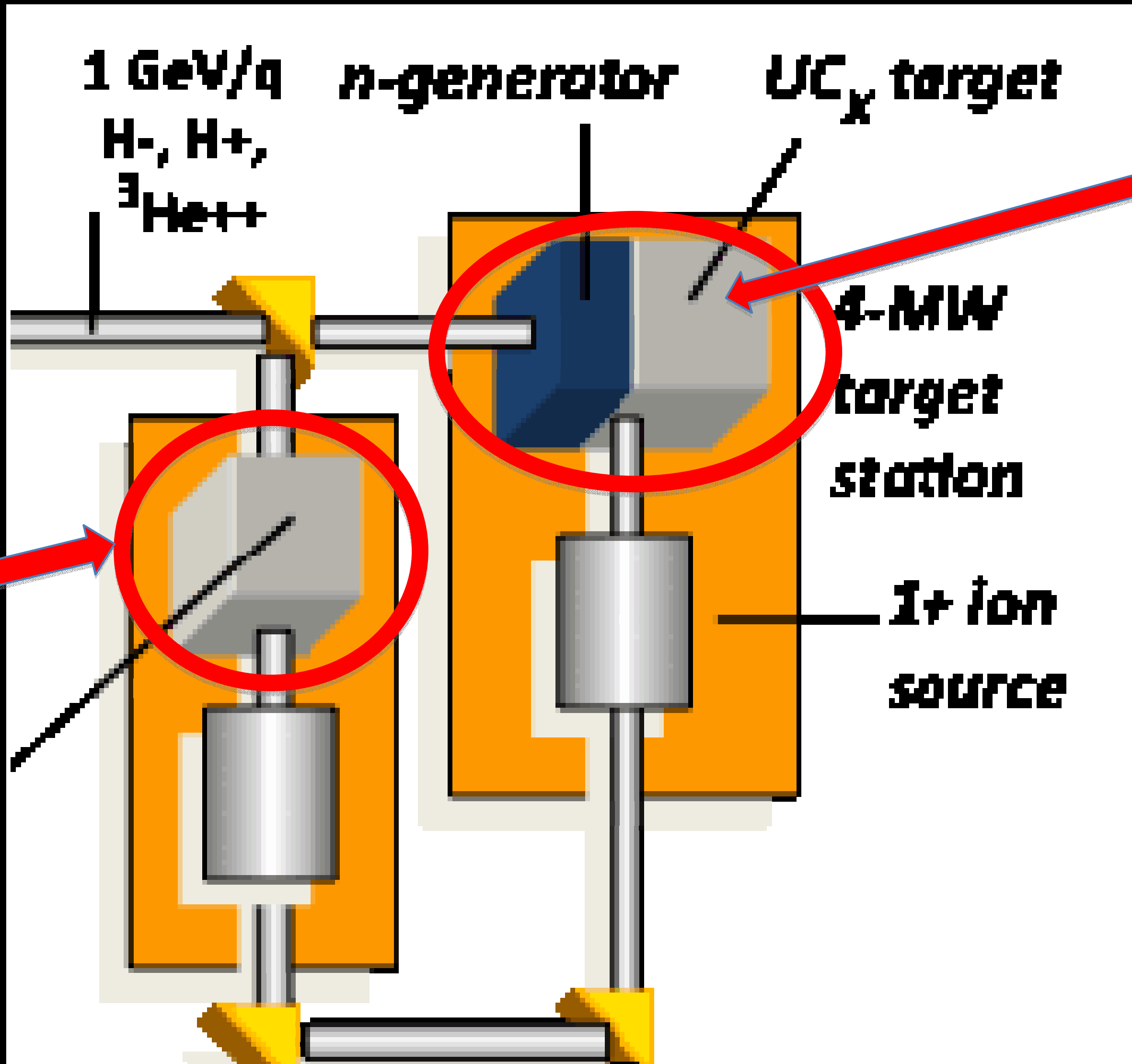
A new Layout foreseen Summer 2009



EURISOL-DS project Facility (Schematic view)



EURISOL-DS project
Facility
(Schematic view)



Fission Target

Direct Target

3 Stations planned
(100 kW)

Benchmarking

Direct Target

Nuclei produced via **spallation reactions**

→ **Residue production benchmarked**

Fission Target

Nuclei produced via **neutrons inducing fission**

→ **Neutron production benchmarked**

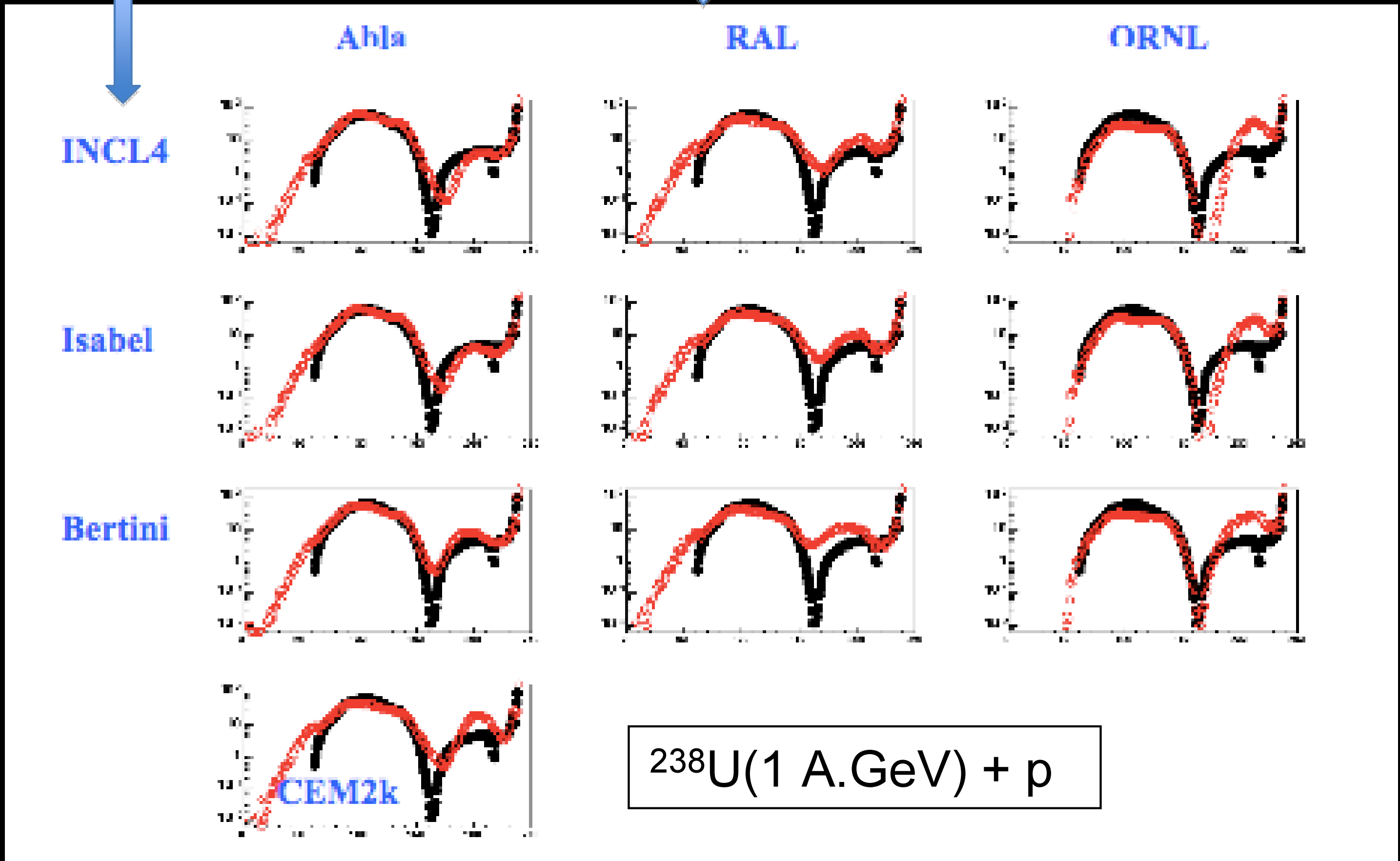
- Transport code used: MCNPX2.5.0
- Why? 10 spallation model combinations available

(FLUKA has also been benchmarked within EURISOL – CERN-AB-Note-2006-006)

Benchmarking Residue

MCNPX: 10 models

Cascade / Deexcitation



Data on thin and thick target were used…

Benchmarking Residue

Thin targets

- A, Z and (A,Z) distributions: U, Pb, Au, Fe (1→ 0.3 A.GeV) (GSI)
- Excitation functions: Pb, U, Th (40 MeV → 2.6 GeV) (R. Michel – Y. Titarenko)

Thick targets

- In-target mass distributions of noble gas (ISOLDE)
  (UCx (1.4 GeV) / ThCx (1 GeV) – L=20cm;ϕ=1.8cm)
- Axial specific activities in a lead cylinder (Dubna)
  (Pb (660 MeV) – L=30.8 cm; ϕ=8cm)

Conclusion: INCL4/Abla, Isabel/Abla and CEM2k(running time) are the best choices

Benchmarking
Neutron

Thin targets

• Neutron spectra: U, Pb, W, Fe, C, Be (800 MeV) at Los Alamos

Thick targets

• Neutron spectra: Pb and Fe at Saturne

Conclusion: All models have more or less the same quite good quality for neutron production

Direct Target
Which ones?

Target material	Al_2O_3	SiC	Pb (molten)	Ta	UC_3
ρ [g.cm^{-3}]	2.0	3.2	11.4	12.5	2.418
R [mm]	9.0 – 12.7 – 18.0 – 25.5				
L [cm]	50 – 75 – 100 – 125	32 – 48 – 64 – 80	9 – 18 – 27 – 36	8 – 16 – 24 – 32	40 – 60 – 80 – 100
Beam particles	Protons				
P [kW]	100				
E [GeV]	0.5 – 1.0 – 1.5 – 2.0				
σ [mm]	$R/3$				

- 4 types of material:
  oxides (Al_2O_3), carbides (SiC-UC_3), molten metals (Pb) and refractory metals (Ta)
- 4 radii
- 4 lengths
- 4 proton energies

→ 320 configurations were calculated (*2 → INCL4/Abla and CEM2k)!!!

Direct Target Strategy

• Codes: MCNPX2.5.0 (INCL4/Abla – CEM2k) + Cinder'90 (decays and low energy neutrons) (5.10^6 protons run)

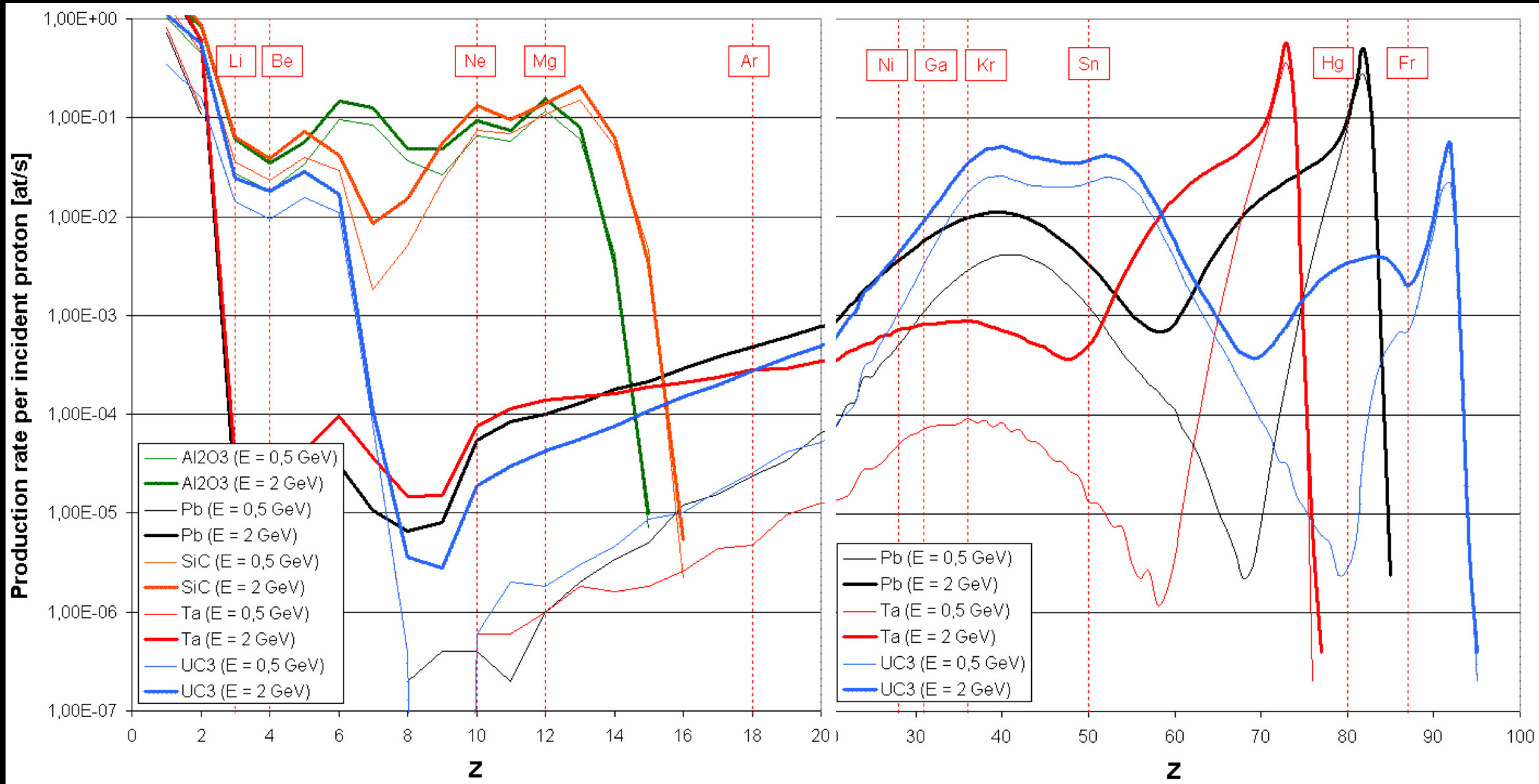
• Yields calculated, but also an attempt to optimize… → strategy and basic ideas

- Material, Size, beam Energy to be defined: step by step
- Energy costs more than Intensity → production_rate/energy (nuclei/incident_proton/s/MeV)
- In-target yield increases with $L*R^2$, BUT effusion/diffusion efficiencies decrease with L / R

Direct Target
Results

Charge distribution

E = 0.5 or 2 GeV
R = 18 mm (fixed)
L / Mass = 2 kg



Which target for which ion? → First information

Direct Target Results

Z and A distributions lead to premilinary selection

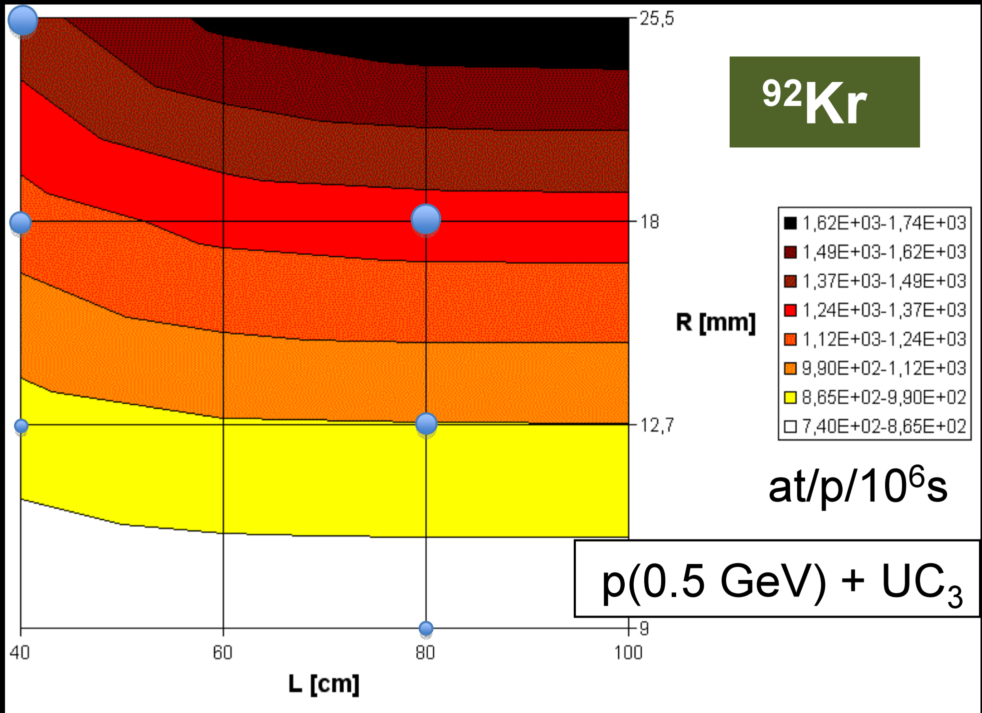
Ion	Target
Z	Best material
≈ 7	Al_2O_3
≈ 15	SiC
$30 \leq Z \leq 55$	UC_3
$65 \leq Z \leq 70$	Ta
$75 \leq Z \leq 80$	Pb
$Z \geq 85$	UC_3

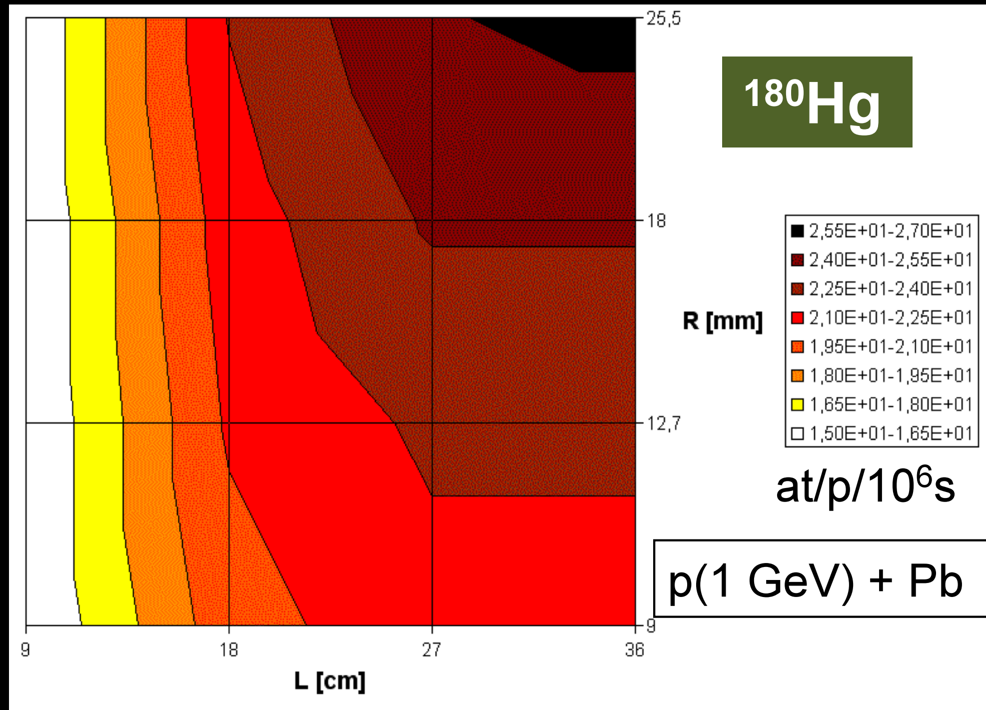
Ion	Target
A	Best material
≈ 15	Al_2O_3
≈ 30	SiC
$160 \leq A \leq 180$	Ta
$185 \leq A \leq 210$	Pb
$A \geq 215$	UC_3

- Number of files to be analyzed will be reduced
- Then, R and L to be defined…

Direct Target Results

L and R determination (2 examples)





- : volume = 203.57 cm^3
- : volume = 2 * 203.57 cm^3
- : volume = 4 * 203.57 cm^3

1- optimization depends on isotope

2- only a set of possibilities

3- extraction efficiencies needed to optimize

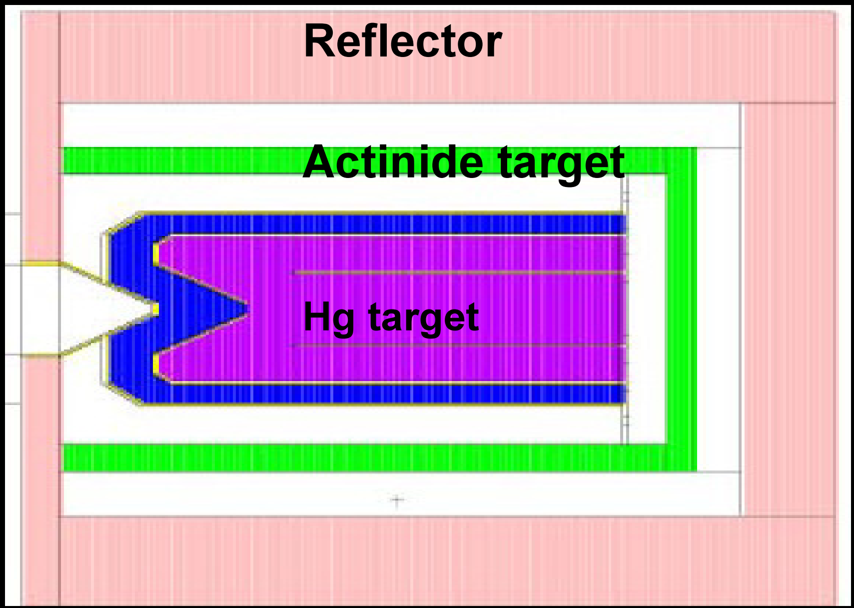
Direct Target
Results

Nevertheless, here are some in-target production yields obtained:

Isotope	Material	Beam energy (GeV)	In-target rate (at/s)
^{11}Li	Al_2O_3	1	$1.8\ 10^{9}$
^{7}Be	SiC	0.5	$1.0\ 10^{13}$
^{11}Be	Al_2O_3	1	$1.2\ 10^{11}$
^{12}Be	Al_2O_3	1	$3.0\ 10^{10}$
^{18}Ne	SiC	1	$8.3\ 10^{10}$
^{25}Ne	SiC	1	$3.2\ 10^{9}$
^{20}Mg	SiC	1	$2.4\ 10^{10}$
^{72}Ni	UC_3	0.5	$7.6\ 10^{10}$
^{81}Ga	UC_3	0.5	$1.9\ 10^{10}$
^{92}Kr	UC_3	0.5	$8.9\ 10^{11}$
^{132}Sn	UC_3	0.5	$2.9\ 10^{11}$
^{206}Hg	Pb	0.5	$2.9\ 10^{11}$
^{180}Hg	Pb	1	$1.5\ 10^{10}$
^{205}Fr	UC_3	1	$1.8\ 10^{9}$

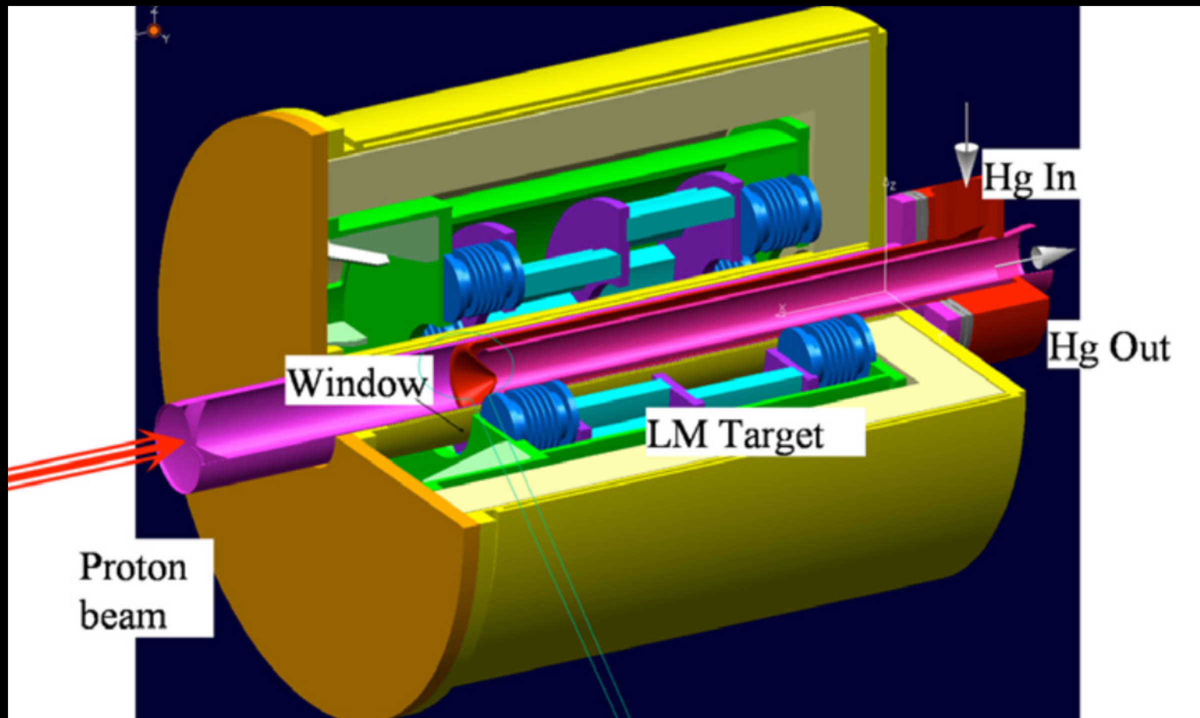
Model: INCL4/Abla

Fission Target
Which ones?



Schematic view of the MMW target:
neutron convector + fission target

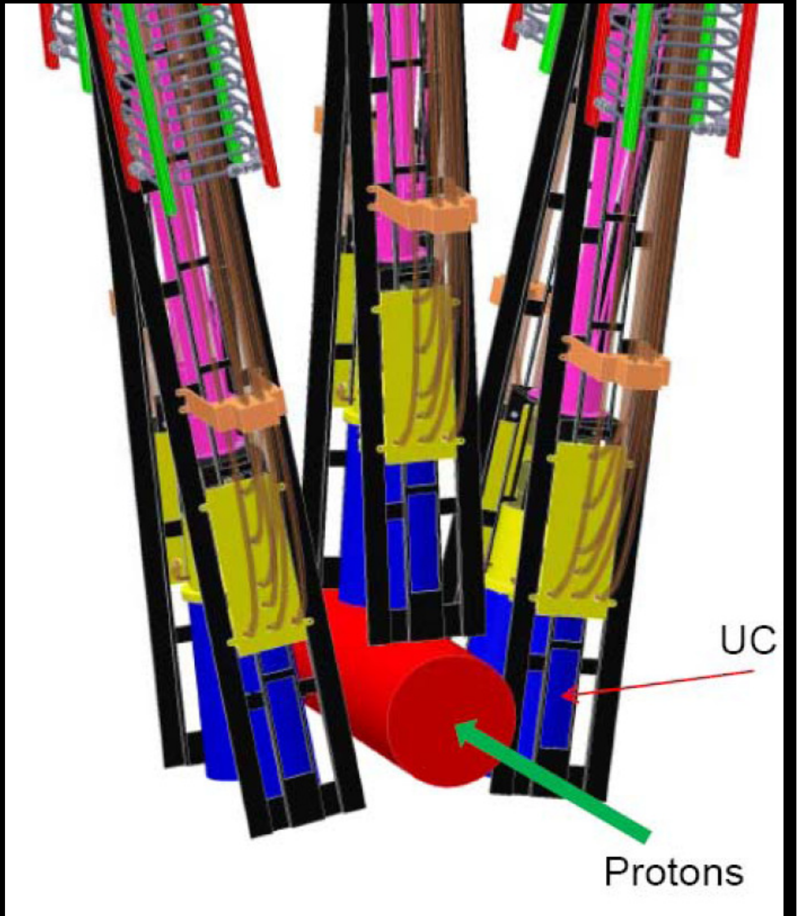
And the real life…



Transport play an important role and different materials are used

Geometry must be fixed!

Fission Target
Which ones?



The 6 fission targets around the Hg convector

Target (only one – ~15g)

181cm^3

(h=20cm, r_{ext}=1.75cm, r_{int}=0.4cm)

graphite + U/Th

ρ=1.88 g/cm^3

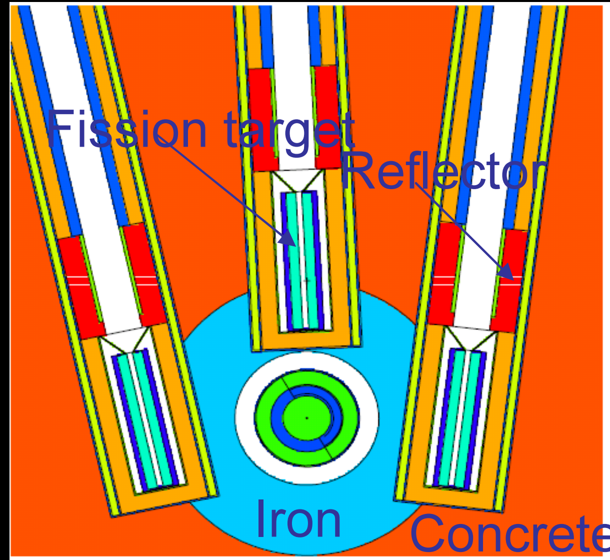
M_U/M_C=1/20

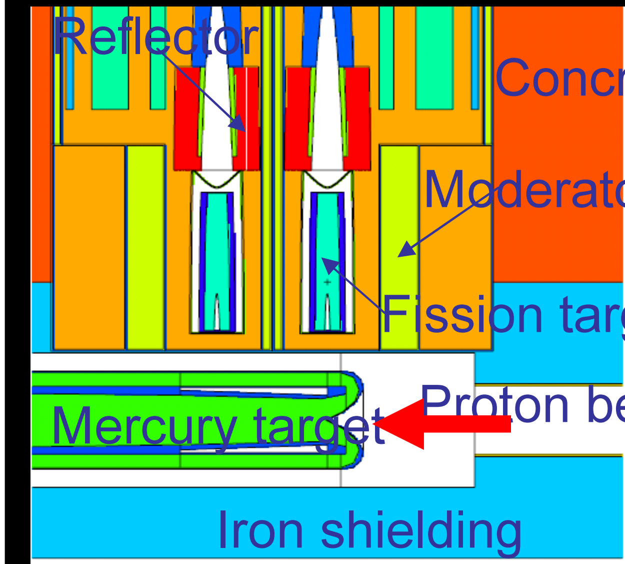
6 fissile materials tested

^{235}U(99.99%)
^{235}U (20%)
^{235}U (3%)
U_{nat}(0.072% ^{235}U)
U_{dep}(0.02% ^{235}U)
^{232}Th

Moderator: H_2O, Fe(^{232}Th)

Reflector: BeO, Fe(^{232}Th)





MCNPX geometry

Fission Target Strategy

$$\text{Yield} = Y^{T}_{fis} \cdot \tau^{T}_{fis} + Y^{F}_{fis} \cdot \tau^{F}_{fis} + Y^{H}_{fis} \cdot \tau^{H}_{fis}$$

- 3 regions ($E_{min} \rightarrow E_{max}$):
  - Thermal (0 → 5 keV)
  - Fast (5 keV → 5 MeV)
  - High energy (5MeV → 1 GeV)

- Y_{fis}: fission yields (T.R. England and B.F. Rider, LA-UR-94-3106, ENDF-349)

- $\tau_{fis} = N \int_{E_{min}}^{E_{max}} \sigma_{fis}(E) \cdot \phi(E) \cdot dE$; Fission rates by MCNPX2.5.0 (CEM2k)

Fission Target Results

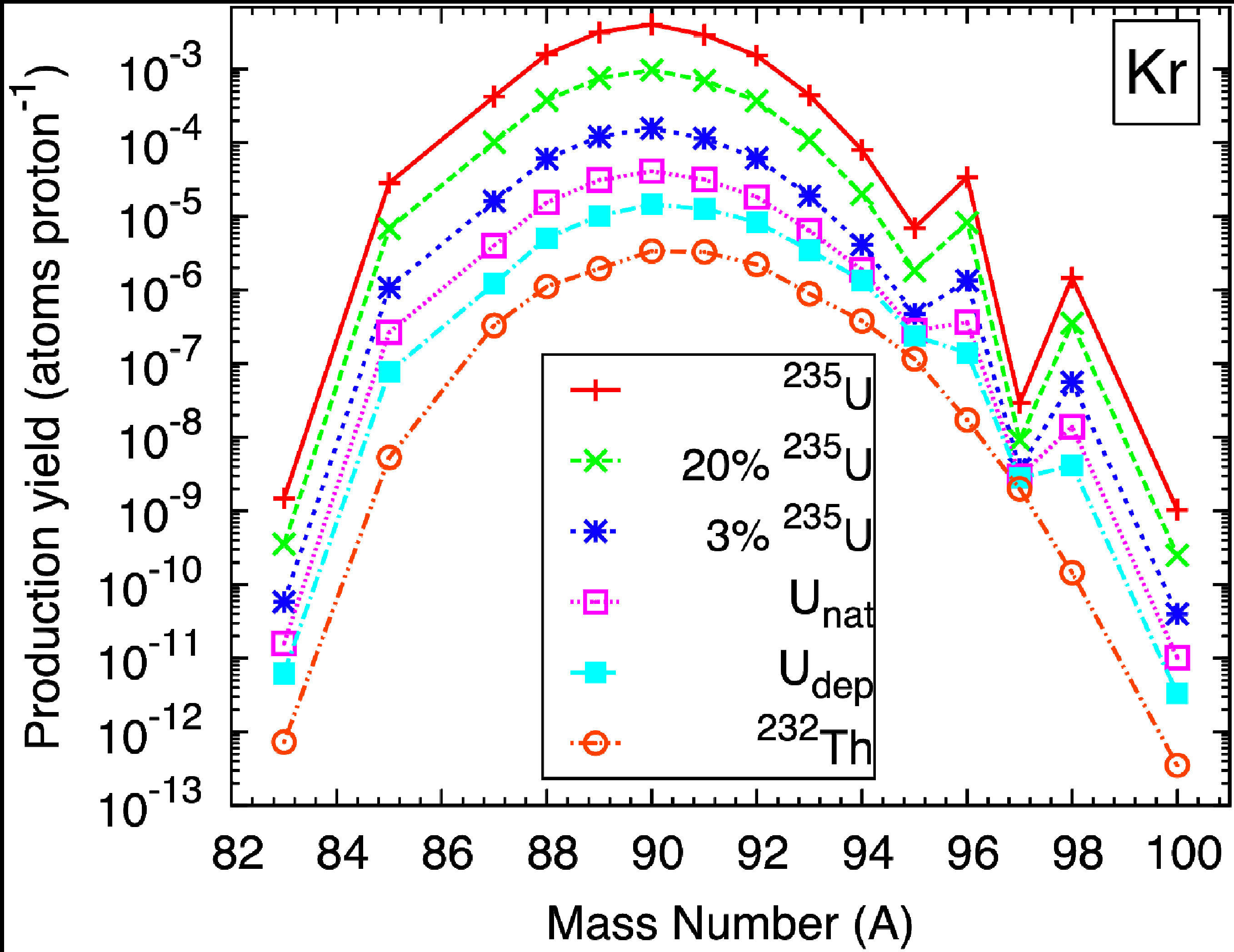
Fission rates (given for 1mA)

Configuration	^{235}U* (fiss/s)	^{238}U (fiss/s)	Total (fiss/s)	^{235}U [%]
^{235}U	5.7689E+14		5.7689E+14	100
20% ^{235}U	1.3823E+14	1.2021E+12	1.3943E+14	99.14
3% ^{235}U	2.1712E+13	1.3931E+12	2.3106E+13	93.97
U_{nat}	5.2449E+12	1.4172E+12	6.6621E+12	78.73
U_{dep}	1.4591E+12	1.4223E+12	2.8814E+12	50.64
^{232}Th	5.2366E+11		5.2366E+11	

^{232}Th for Th case

- Objective of 10^{15} fis/s reached ($5.7689\ 10^{14} * 4 = 2.3076\ 10^{15}$)
- Highly enriched Uranium needed
- … but ^{232}Th can be useful in some cases (ex.: Ni – neutron rich side)

Fission Target Results

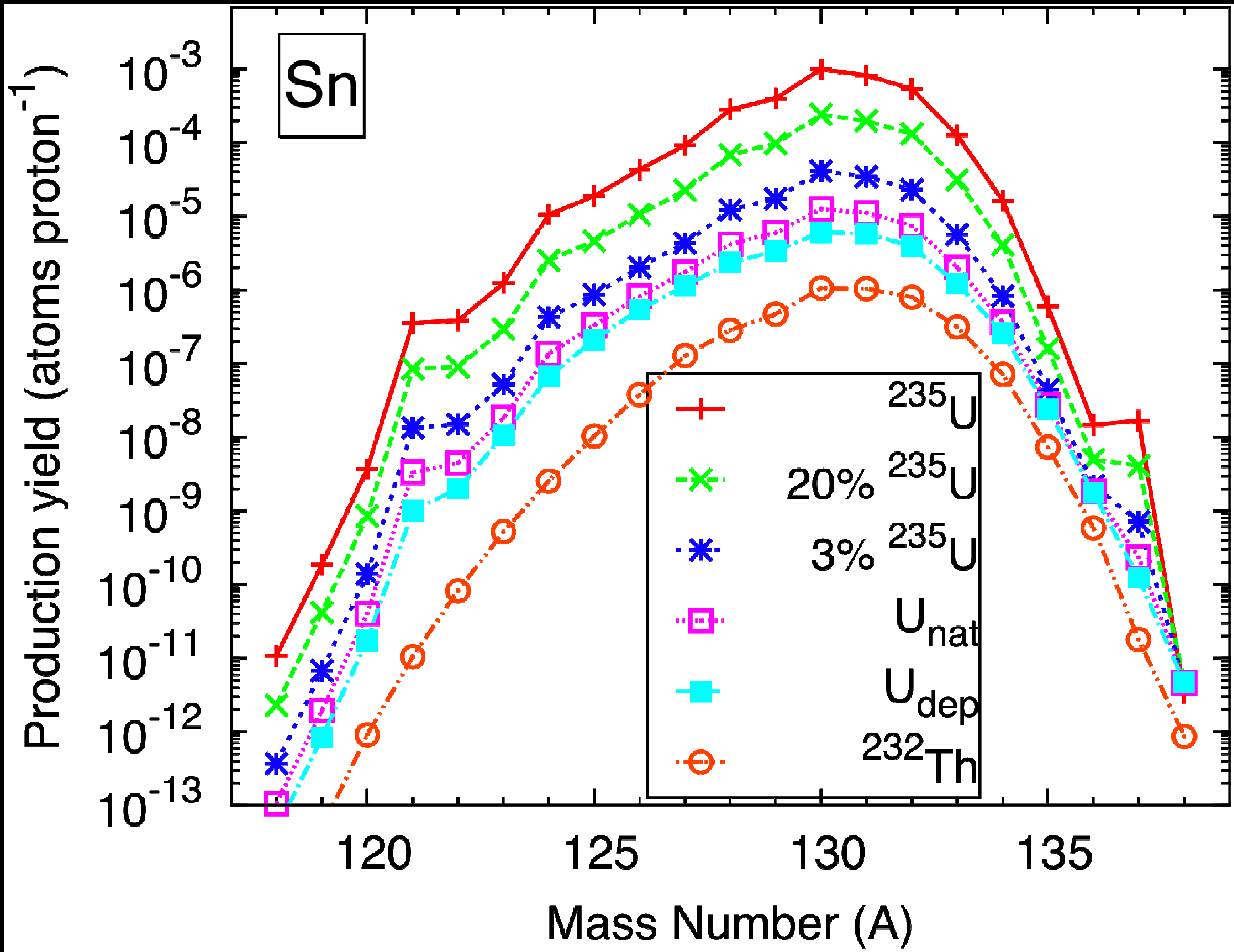


^{92}Kr

$Y_{max} = 4.0\ 10^{13}$ at/s

Fission Yields | Kr

Fission Target Results



^{132}Sn

$Y_{max} = 1.2\ 10^{13}$ at/s

Fission Yields | Sn

Conclusion

- In-target yields have been calculated for the targets possibly used in EURISOL
- Benchmarking and knowledge of the tools are needed to understand results
- Direct target: 320 configurations were studied
- Fission target: 6 target materials were tested

10^{15} fission/s and values up to 10^{13} p/s have been obtained

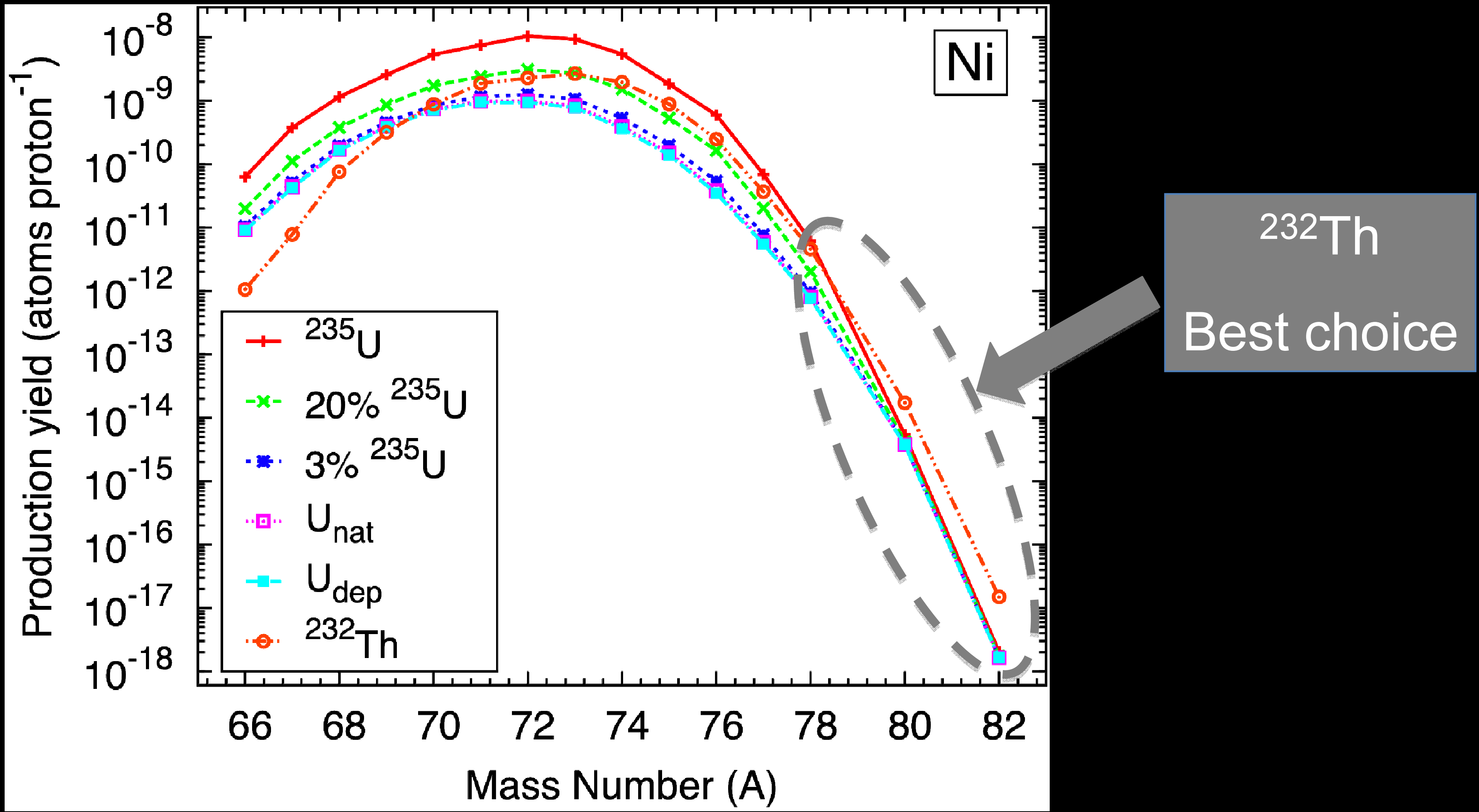
But now extraction efficiencies must be applied

References

- J.-C. David, D. Doré, B. Rapp, D. Ridikas → Benchmarking
  - J.-C. David et al., Benchmark calculations on residue production within the EURISOL DS project, Part I: thin targets, CEA Saclay internal report DAPNIA-07-04 (2007)
  - J.-C. David et al., Benchmark calculations on residue production within the EURISOL DS project, Part II: thick targets, CEA Saclay internal report DAPNIA-07-59 (2007)
  - B. Rapp et al., Benchmark calculations on particle production within the EURISOL DS project, CEA Saclay , Mar. 2006 --- http://www.eurisol.org/ (TN-06-04)
- S. Chabod, N. Thiollière, J.-C. David, D. Ridikas → Direct target
  - S. Chabod et al., Optimization of in-target yields for RIB production Part I: direct targets, CEA Saclay internal report Irfu-08-21 (2008) and paper in preparation
- D. Ene, J.-C. David, D. Ridikas → Fission target
  - D. Ene et al., Optimization of in-target yields for RIB production Part II: fission targets, CEA Saclay internal report Irfu and EPJA to be published

More information on http://www.eurisol.org/site02/index.php (Task 11)

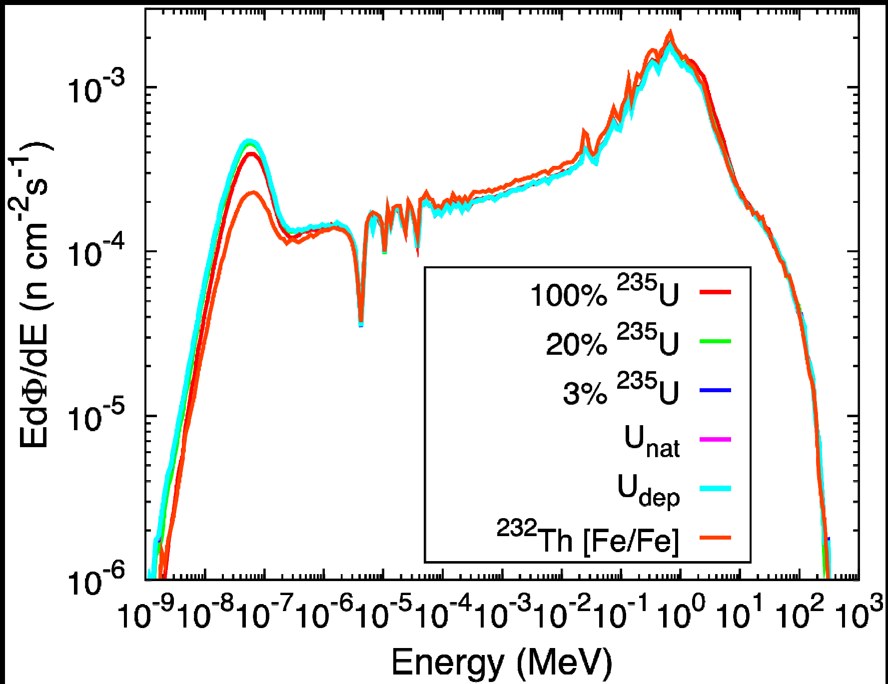
Fission Target Results



Fission Yields | Ni

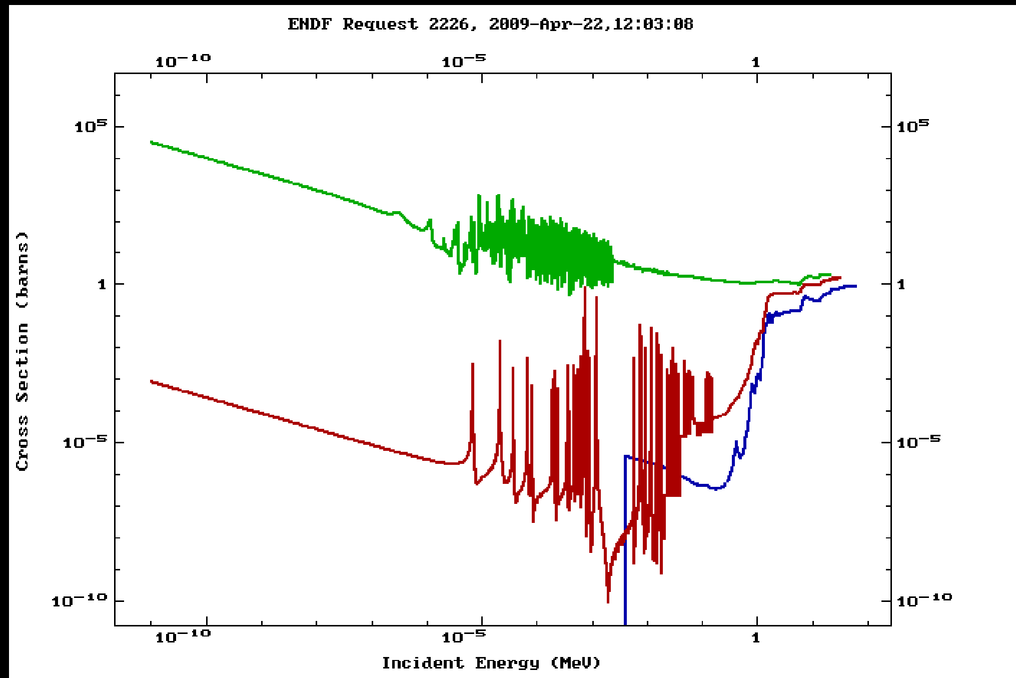
Fission Target Results

Fission rate =



Neutron flux

X



Fission cross sections