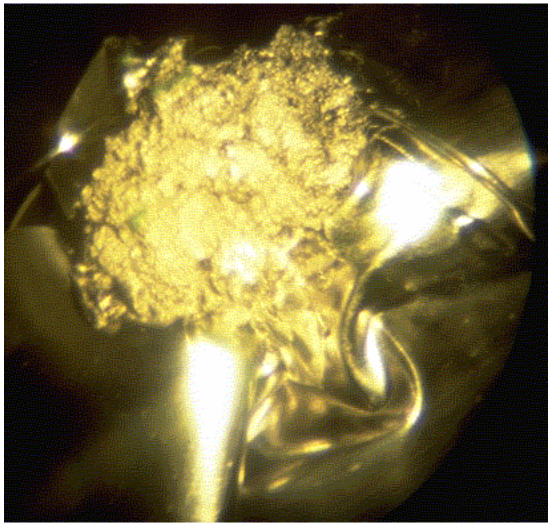
Yields & Target-lifetime ?

UC2+2C ISOLDE target and Ta-Oven at 2100º
CERN-PS-booster: 30 Tp ~ 1 Mcycles



Stress induced plastic deformation
Target material sintering ?

High Temperature … Targets
- highest possible Temperature for fast RIB diffusion out of material matrix
- Minimize material damages related to high operation temperature
- Are material damages annealed at high temperatures ?
- Effect of irradiation (dpa) and annealing on material properties ?

High Temperature targets
High Power Targetry for RIBs facilities

- Brief introduction on ISOL R&D
  - Heat transport
- Material studies
  - Properties under irradiation of metals and graphite
  - Oxides and carbides at high temperature
  - Nano-materials and composites
  - Free surface area measurements
  - Shocks measurements
- EURISOL-DS
  - Ion-sources and effusion
  - Direct targets
  - Spallation targets for high fission yields
  - *Vacuum systems*
  - *Radioactive waste streams and RW disposal.*
- *FLUKA and n-ToF*

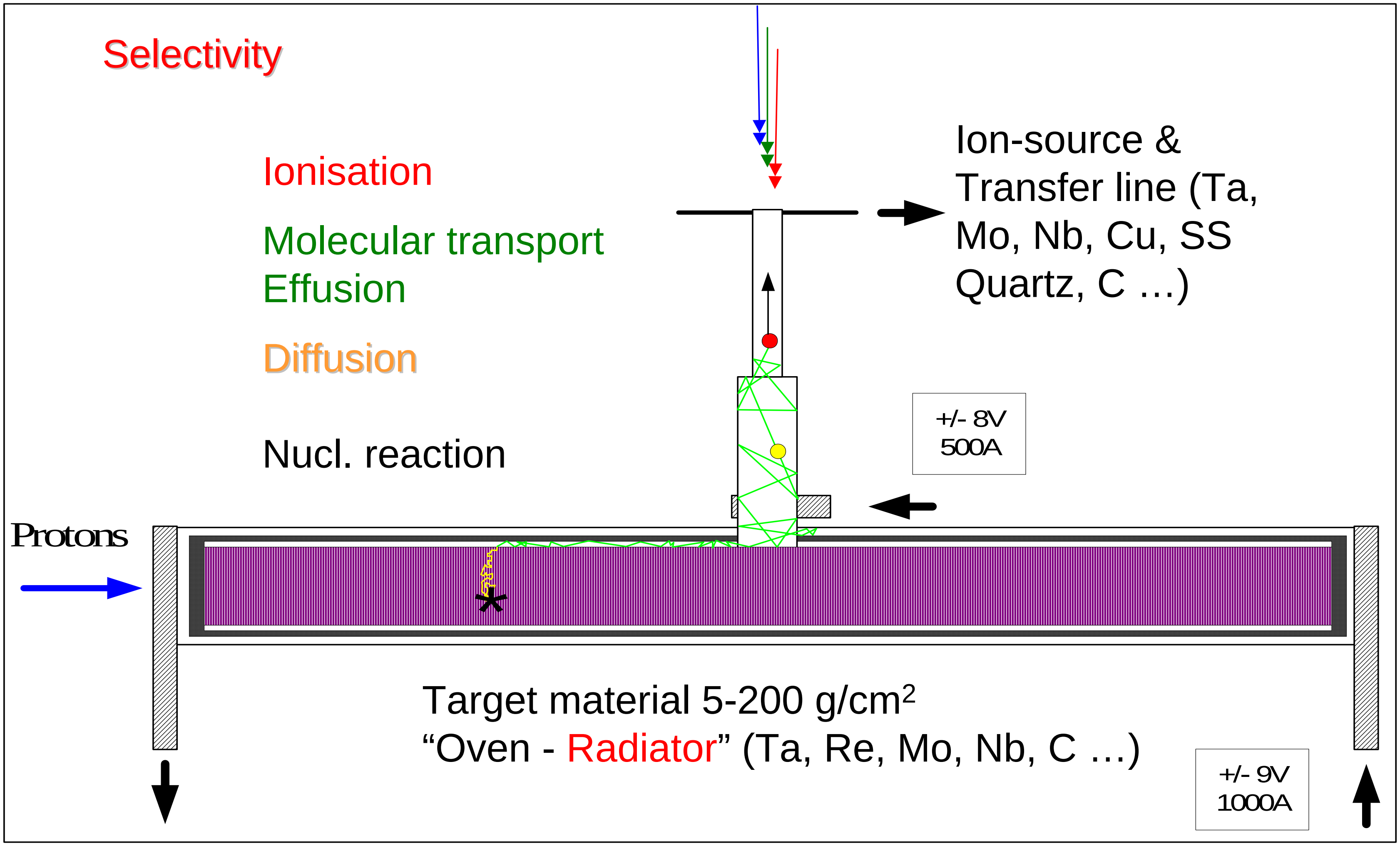
EURISOL Design Study

Tasks 2&3

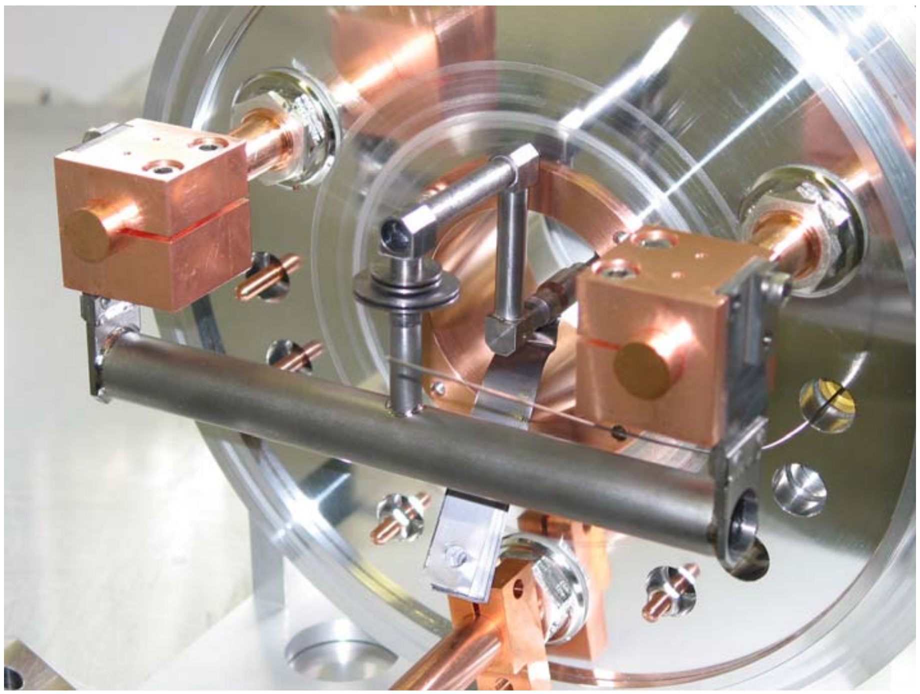
ISOL “Thick” targets

(1 GeV ~ 200 g/cm^2)

Pre-Separation, Separation
Extraction, beam optics



Target prototype:
Quartz transfer line for alkali suppression



- Independently temperature controlled transfer line with quartz insert for alkaline suppression.
- On-line test results:
  - Temp. from 600º to 1000º
  - Cs and Rb reduced by 4 orders of magnitude
- Zn minimally delayed (RILIS)

E. Bouquerel, R. Catheral, D. Carminati

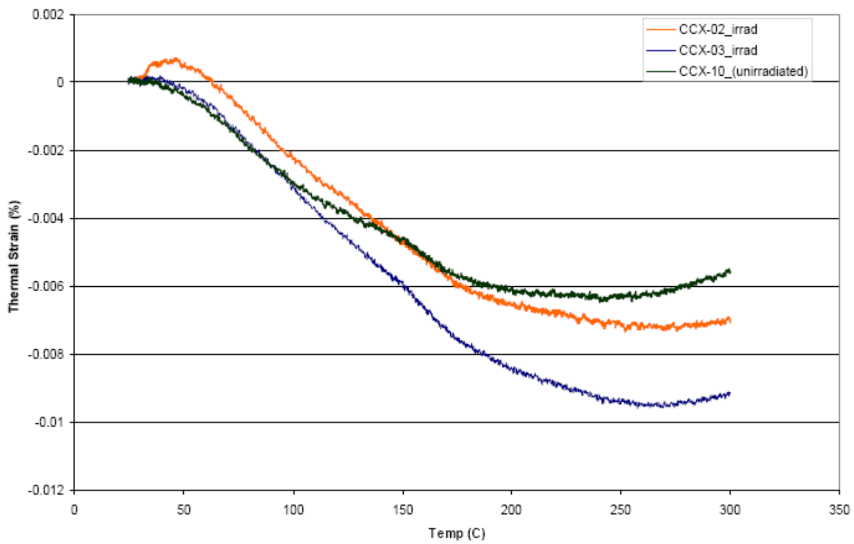
Heat flow

- High Temperature
  - Close to material limits (close to melting point)
    - Loss of plasticity (soft solids)
    - High vapor pressure
- Transport mechanism
  - Heat deposition by ionization and nuclear reactions
  - Conduction ÷ Temperature gradient and conductivity
  - Convection and phase transition in molten metal targets and forced cooling circuits
  - Radiation within and out of the target container is the dominating process at high temperature ÷ T^4 and emissivity

C-composite

Th-expansion

Ref: N.Simos et.at BNL



Th-conductivity

Ref: J.P. Bonal et C.H. Wu Nucl. Mat. 277 (2000)

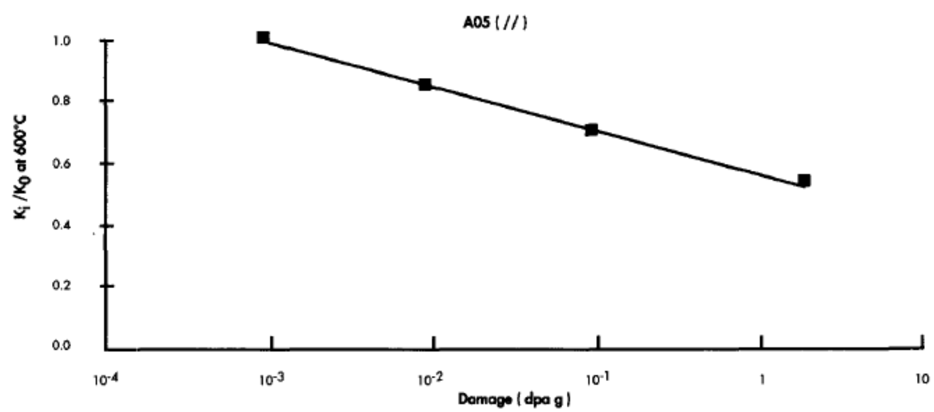
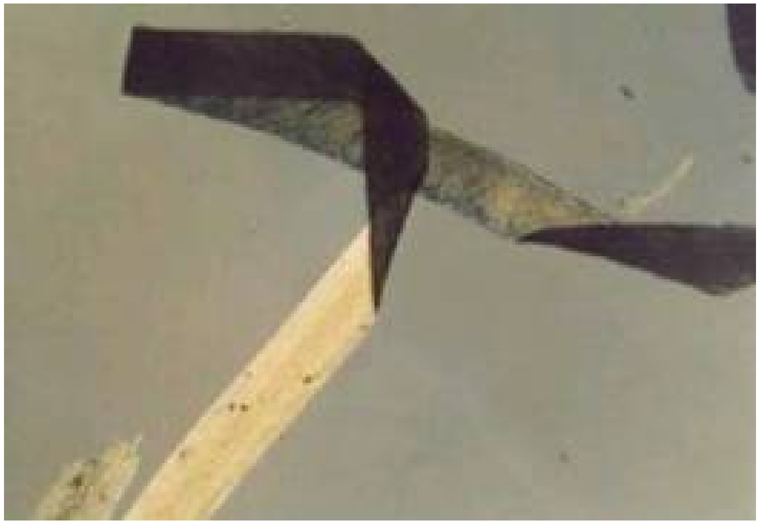


Fig. 4. Thermal conductivity A 05(||) normalized at 600°C as a function of neutron damage.

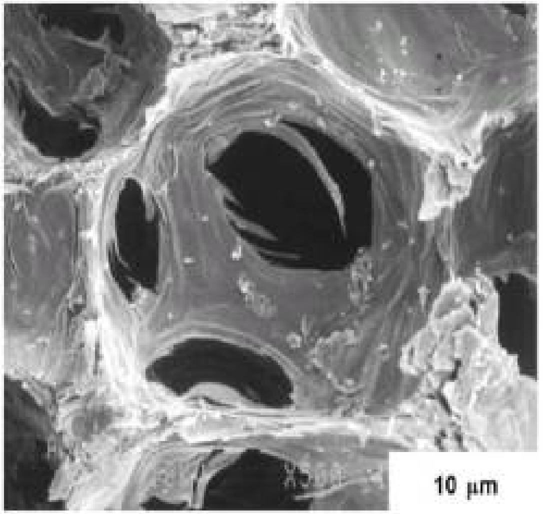
Do we need to measure these properties during irradiation at high temperature under realistic conditions ?

Materials



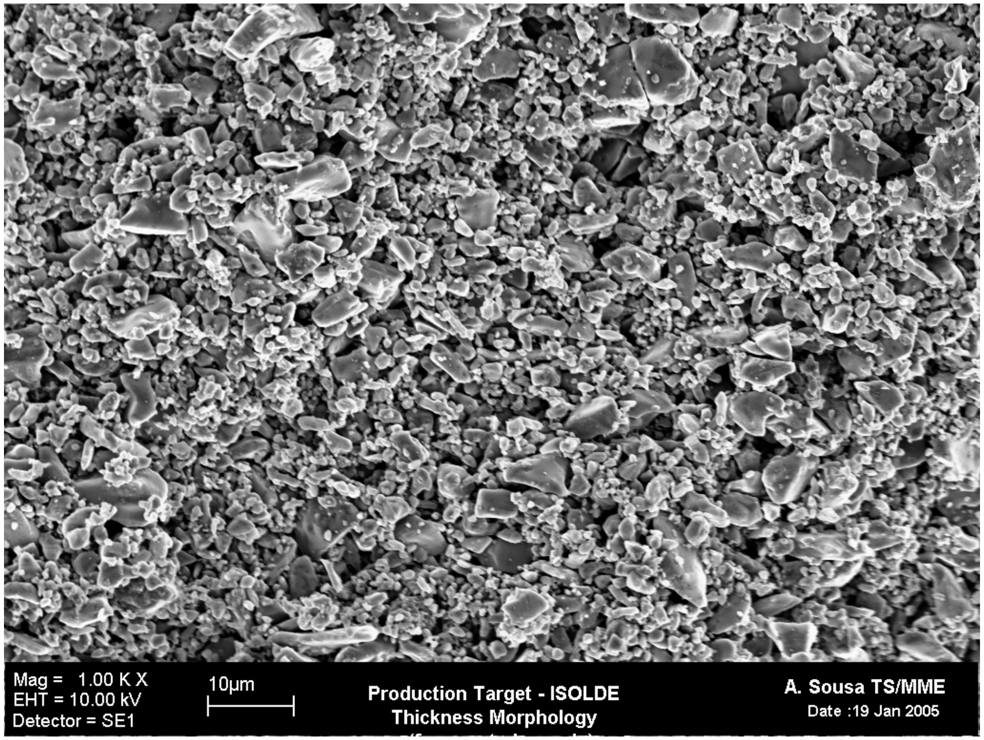
Fiber of carbon nanotubes
(Heat transfer properties)

Carbides C-fibers
Composites



Graphitic foam
ORNL

CERN-TS-MME

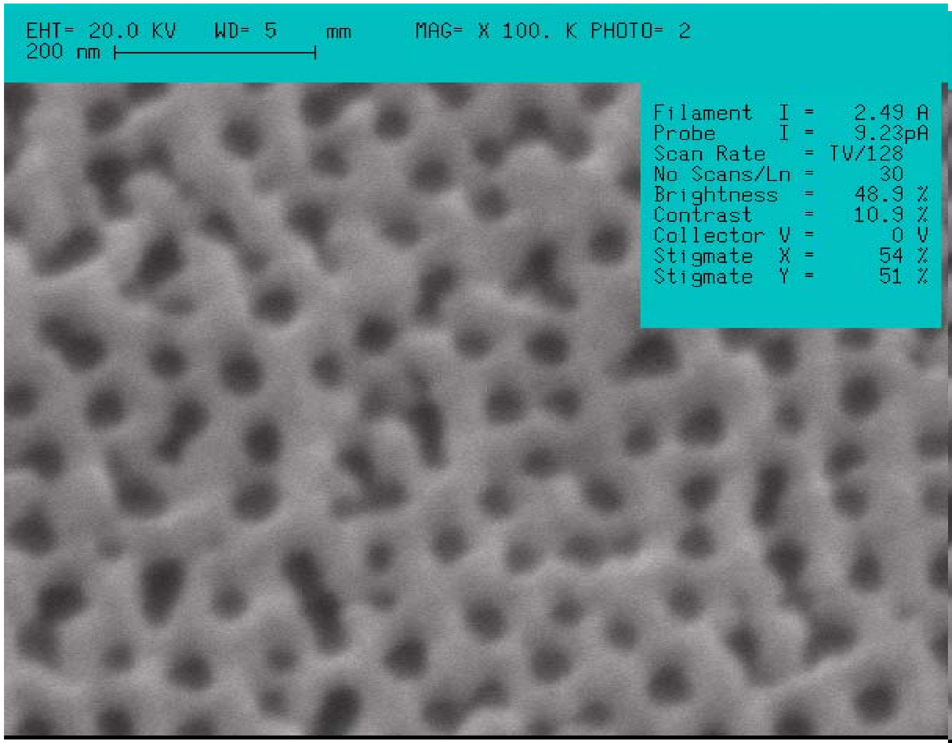


SiC-pressed powder

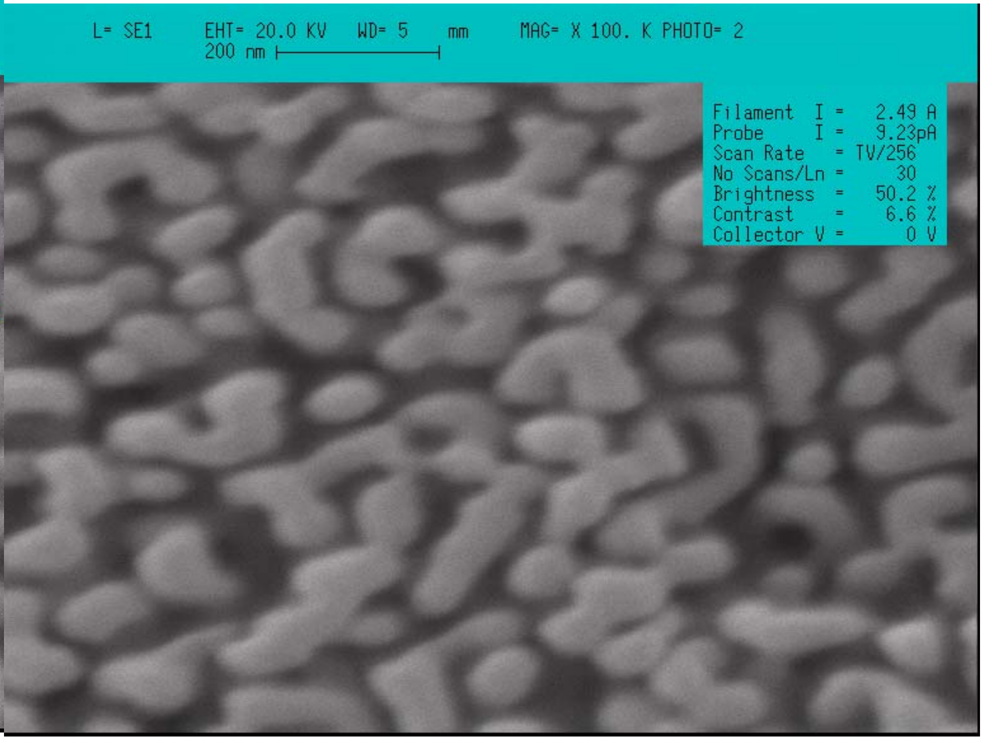
Super material design vs target life time

Nanostructure Al_2O_3

14h, 970 ºC

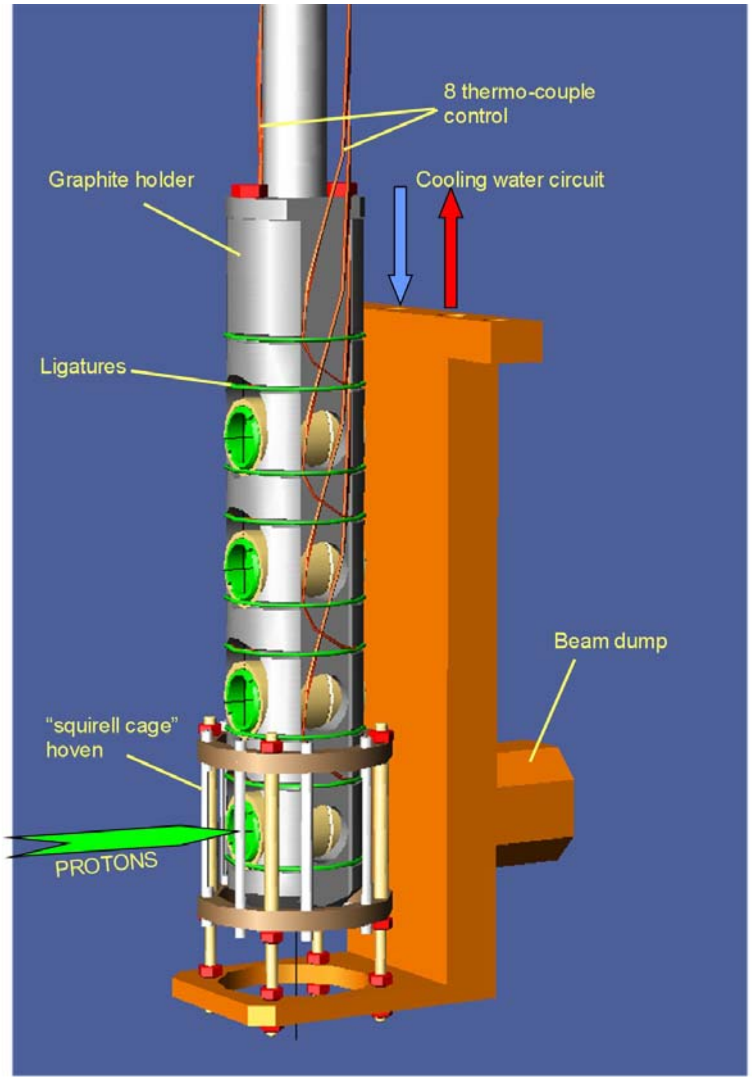


17h, 1250 ºC



T. Stora

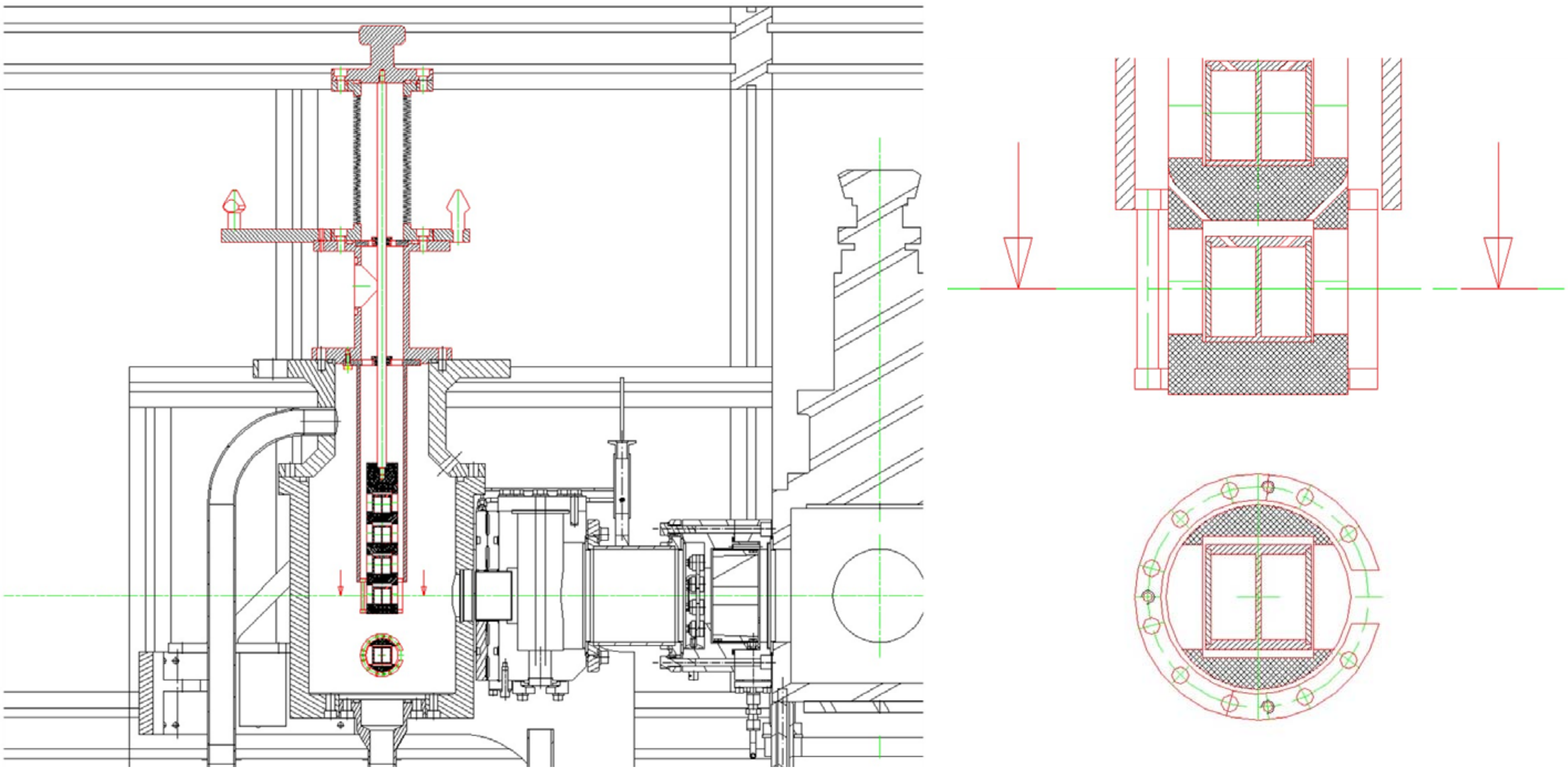
EURISOL-DS irradiation studies at PSI



- Development of multi-sample holder for the irradiation of prospective target materials for the EURISOL at the PSI-LISOR facility
- Testing mechanical and diffusion properties of various samples

S. Marzari, R. Catheral, T. Stora, E. Bouquerel

Prototype of sample holder



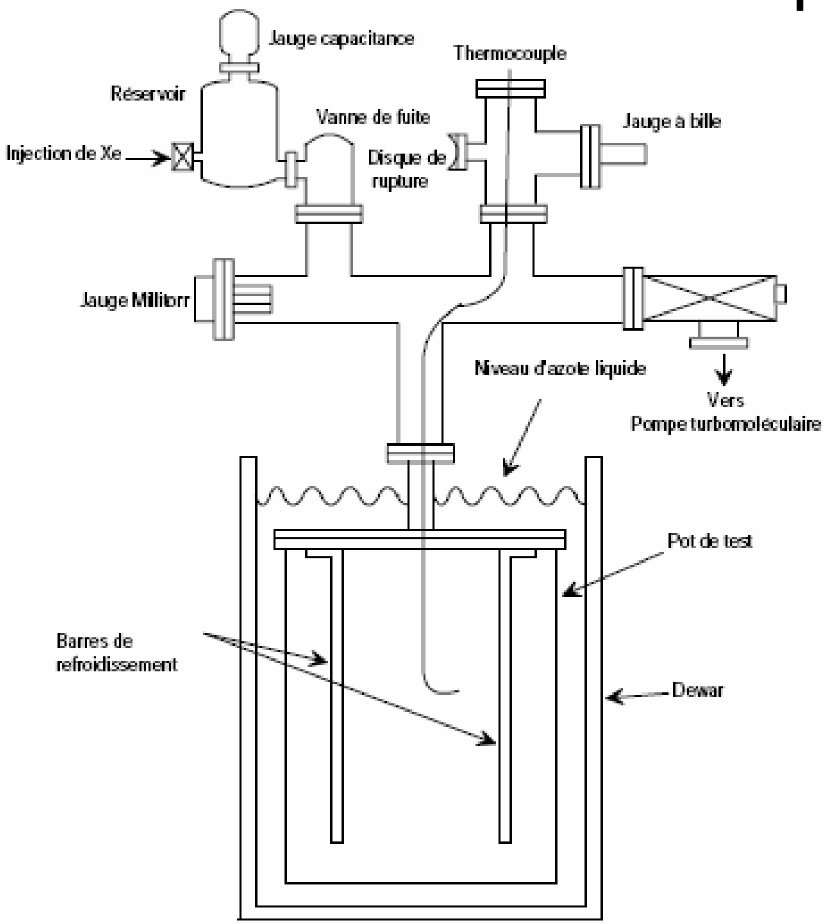
dpa estimation for Tantalum

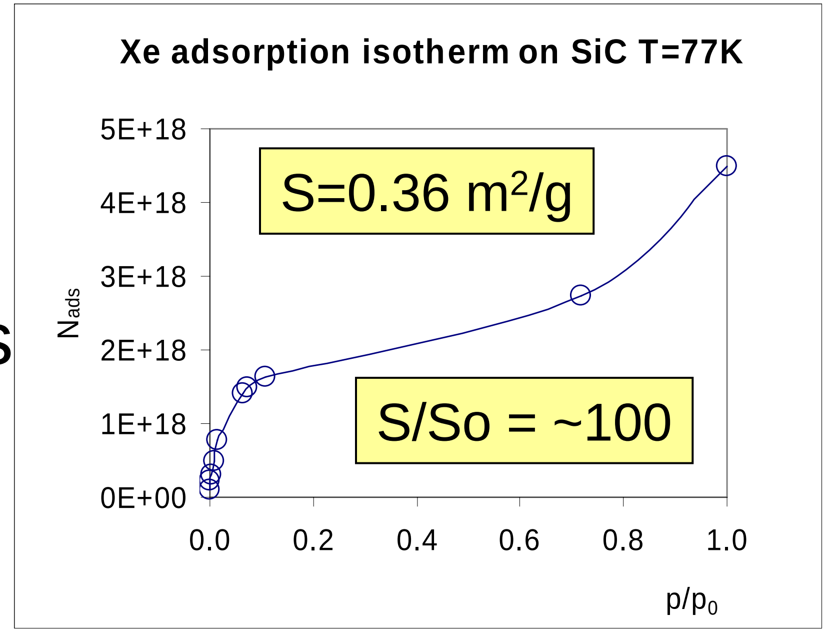
Parameters	Units	**PSI**	**Eurisol**
Time	weeks	2	3
I_{beam}	μA	50	100
σ_{beam}	mm	1.5	7
E_{beam}	GeV	0.072	1
σ_{dpa}	barns	2360	7460
dpa		7.4	3.4

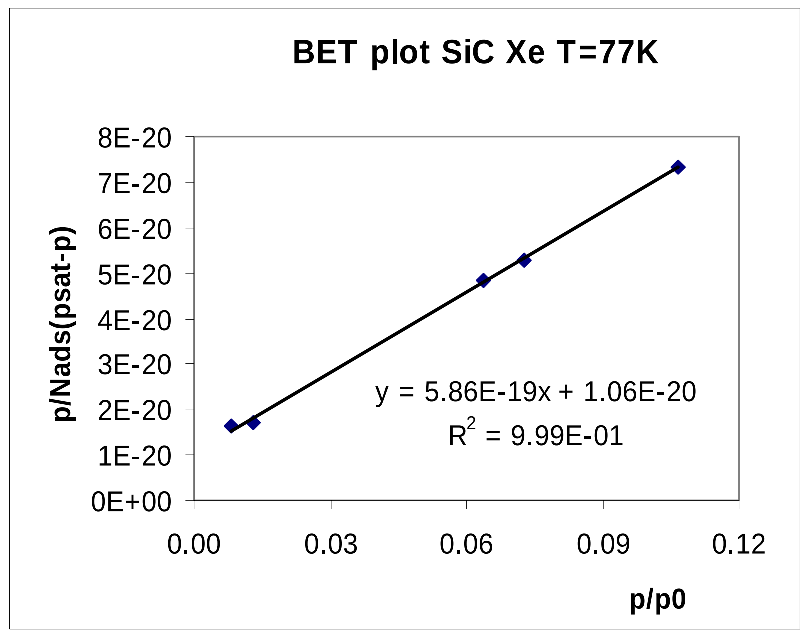
σ_{dpa} from J Nucl Mat 336, 201 (2005)

BET isotherm for specific surface ratio determination

i.e. SiC pills

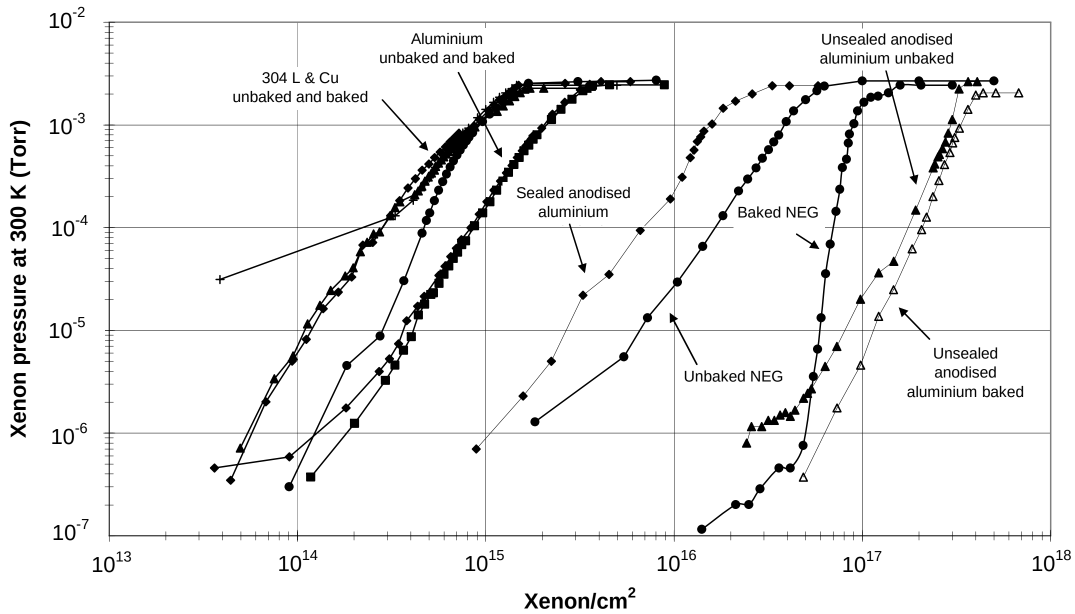






Other relevant materials for accelerators

Matériau	Non-etuvé	Etuvé
Cuivre Cu-DPH décapé	1,4	1,9 à 150°
Acier inoxydable 304 L dégazé	1,3	1,5 à 300°
Aluminium dégraissé	3,5	3,5 à 150°
Aluminium anodisé 12 V colmaté	7,1	7,3 à 150°
Aluminium anodisé 12 V	537,5	556,0 à 150°
NEG St 707	70,3	156,3 à 350°

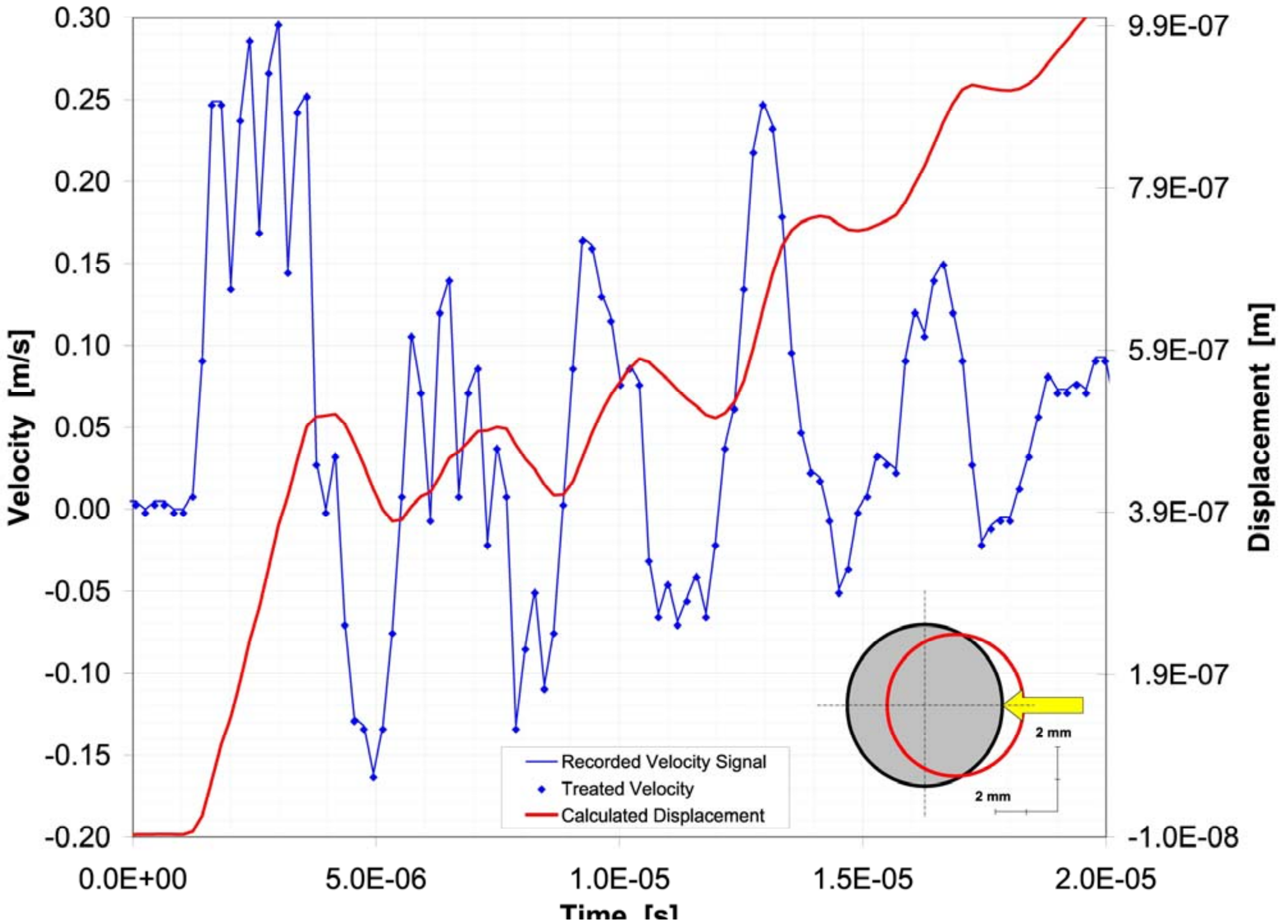


S. Fernandez, T.Stora, E. Noah

CNGS target test at ISOLDE

ISOLDE PS-booster p-beam
4 bunches of 8 TP within 2.4 μs

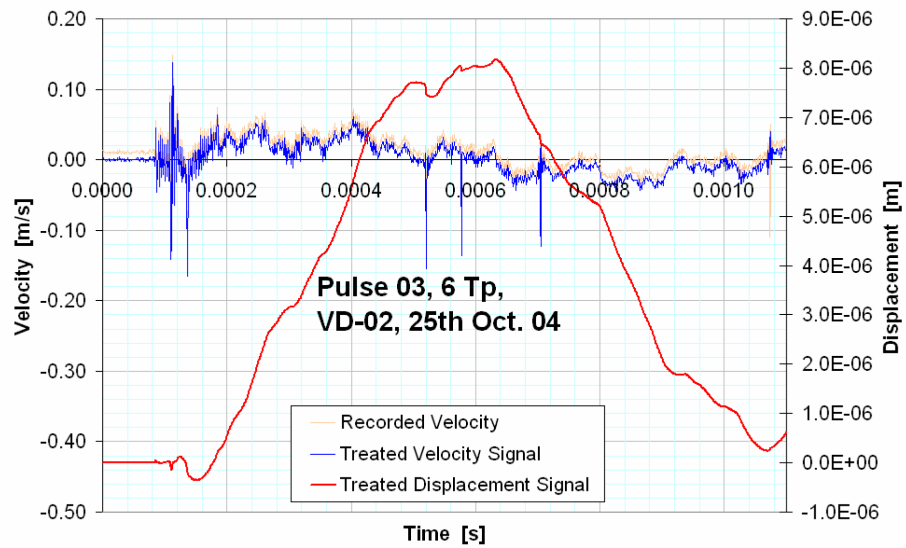
Ref: R.Wilfinger et al.

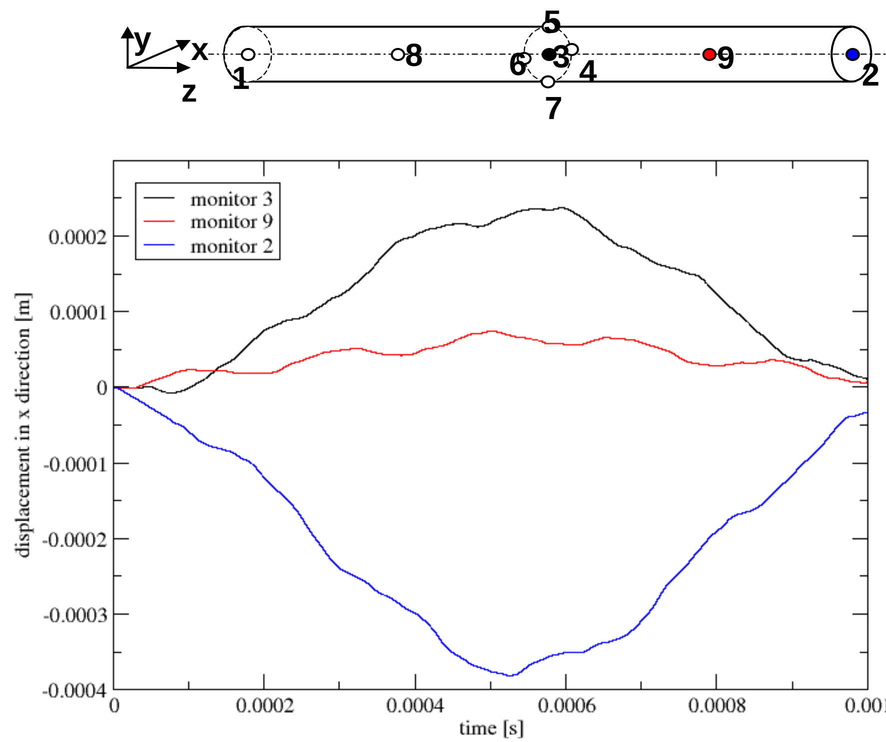


Qualitative Comparison

experiment matching simulation

Ref: R. Wilfinger
PhD thesis TUV

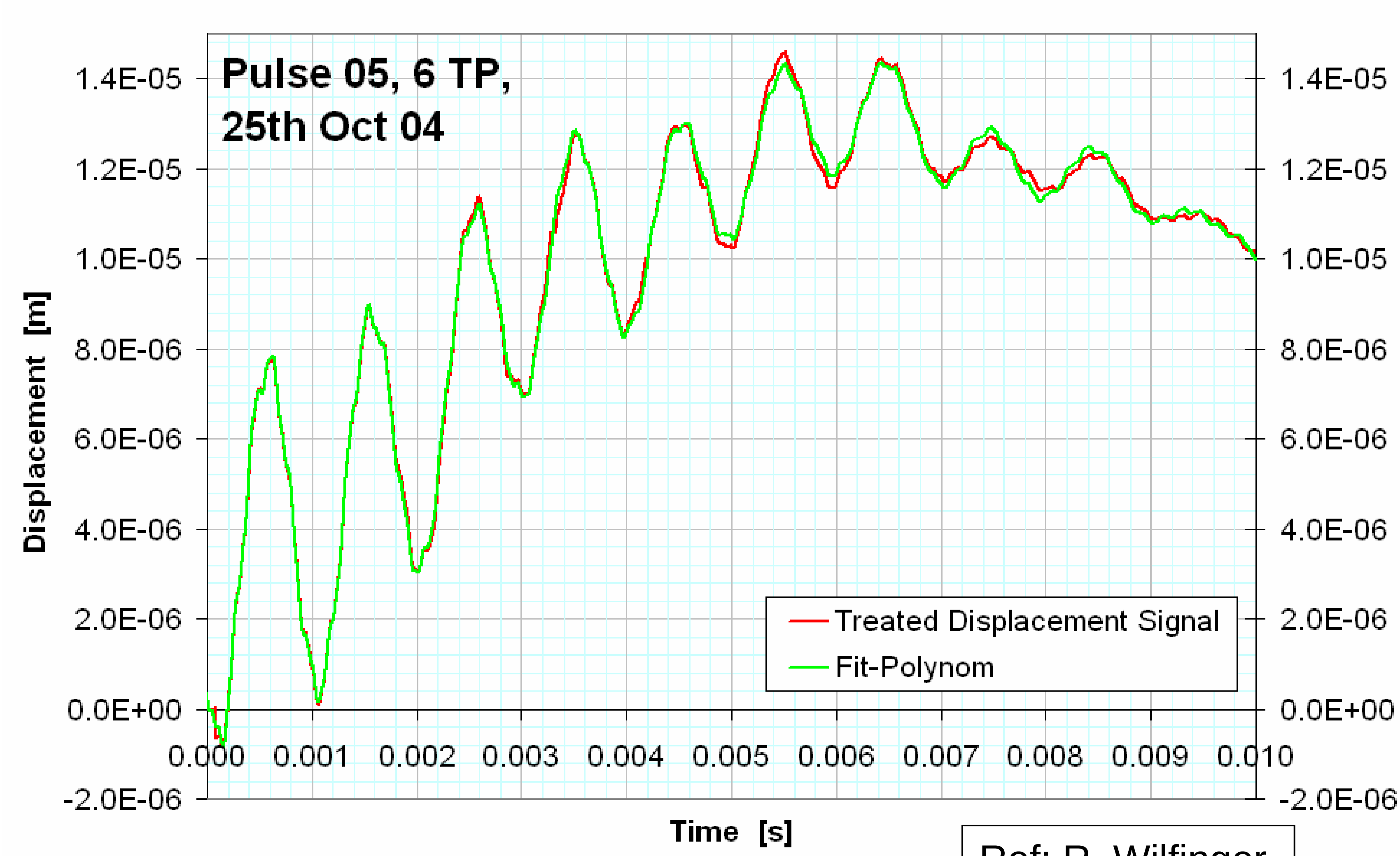




6×10^{12} 450 GeV p.o.t.,
CNGS 1st segment
TT40, 25th Oct.

3.5×10^{13} p.o.t.
CNGS 2nd segment
L. Massidda and F. Mura, CRS4

Damping constants of each eigen-modes



Ref: R. Wilfinger
PhD thesis TUV

P-beam time structure

- TRIUMF (1 month)
  - Cyclotron micro bunching structure close to DC
- ISOLDE (1 Week – 1 Mcycle)
  - Up to 3.2×10^{13} 1.4 GeV protons within 2 μs
    - Instant power averages over a p-pulse: 3.6 GW
    - Average power of the PS-Booster p-beam to ISOLDE: 3 kW
- EURISOL DS direct target (? – 4 Mcycle/day)
  - 1 ms pulses at a 20-50 Hz repetition rate:
    - Instant power: 4 MW + effect of the linac time structure (orders of mag. lower power than at ISOLDE)
    - Average power: 80-200 kW
- EURISOL-DS high power converter: 4 MW
  - Average power ~ 4 kW (~3 kW fission)

EURISOL

- 4 years EU project published end 2003
- Conclusion: RIB yields enhancement predicted (vs. 1999 data) by factors of 2 to 4 orders of magnitude !

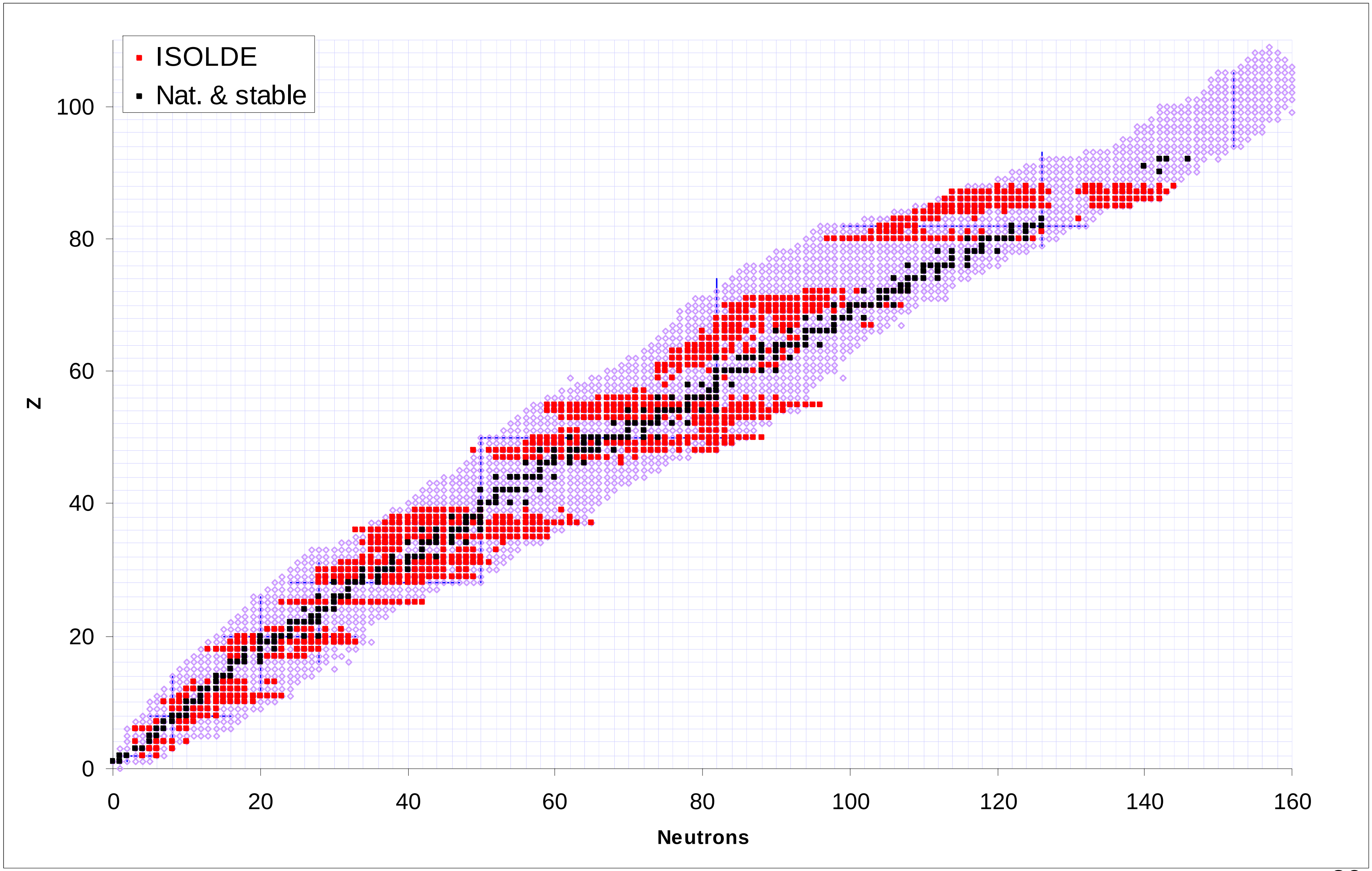
http://www.eurisol.org/

EURISOL-DS *targetry challenges*

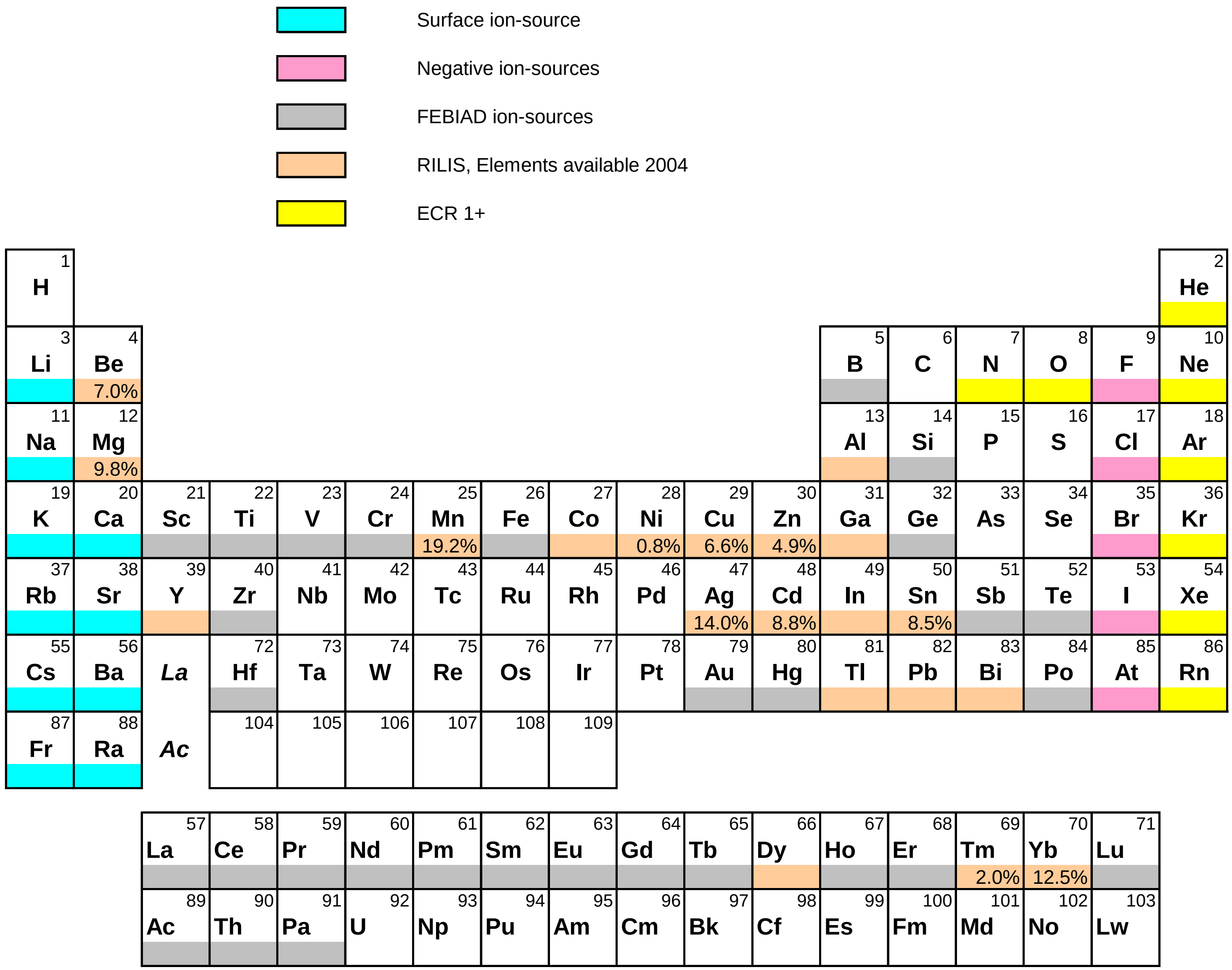
EURISOL-DS shall address R&D challenges towards beams of 2-4 orders of magnitude higher intensity than 1999 yields.

- Design of "oven + heat-transport system" target containers dissipating a direct GeV p-beam ~dc-power of > 100 kW to produce spallation generated RIBs.
- Computational optimization of the wall material and target geometry of a chosen element from a "*target vessel, heat transport, transfer line & ion-source*" system to optimize the release efficiency.
- Improve ion-source efficiencies and beam purity.
- Design high power density spallation n-sources (10 MW/l)
- Design actinide targets intercepting efficiently the neutrons generated by high power density n- sources.
- Design ion extraction mechanism for 4 MW units

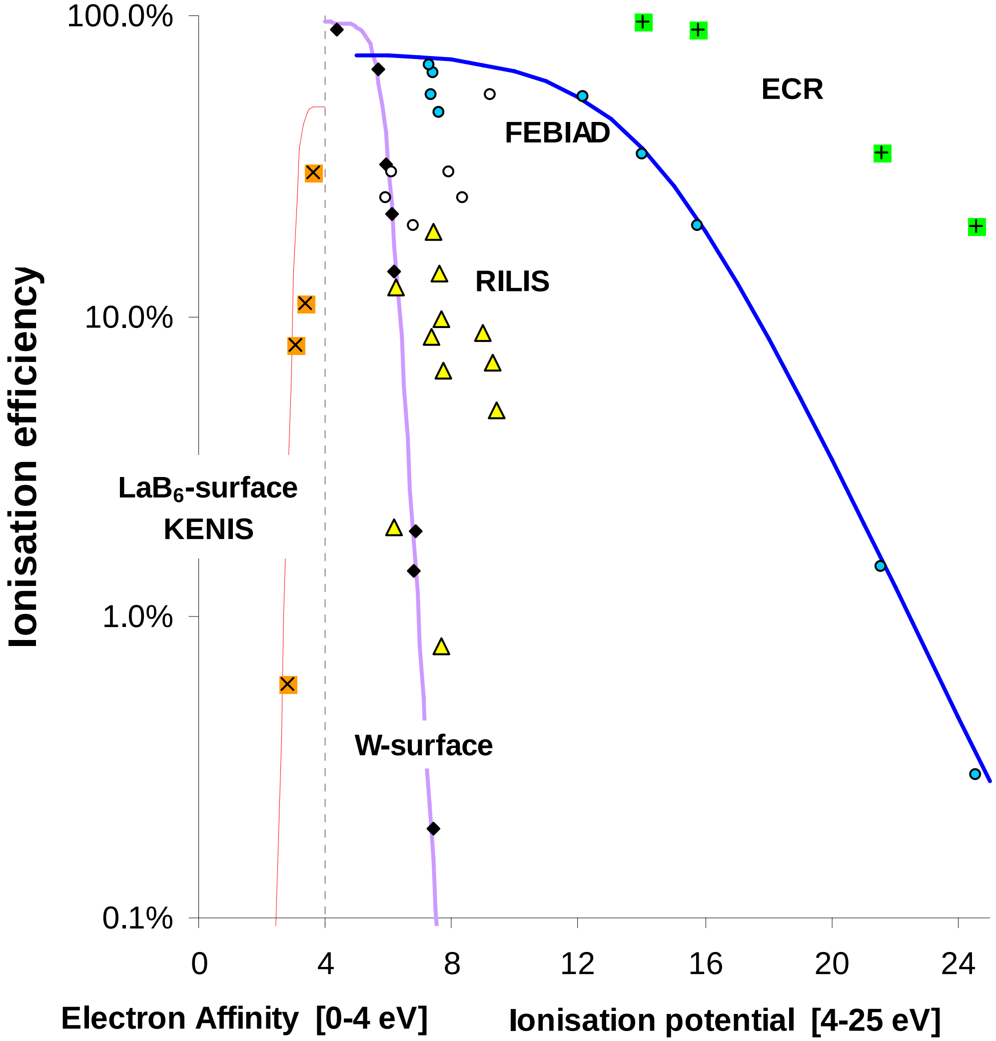
ISOLDE yields: ~750 RIBs produced (1963-2004)

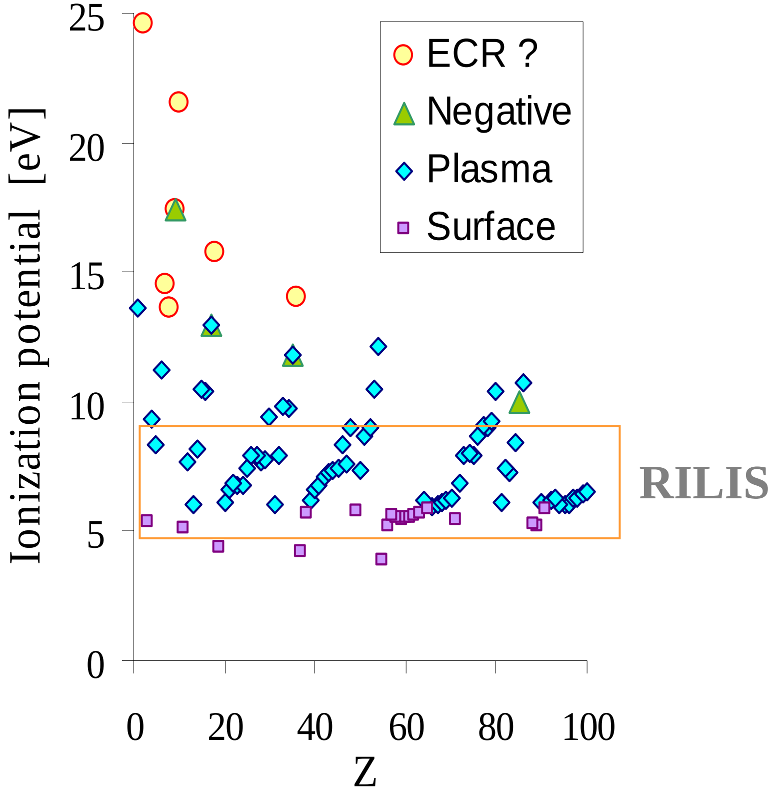


Chemically selective RIB Ion-sources



RIB-Ion-sources efficiencies





Estimation of the radio-elements yield in a 50 g/cm^2 Uc_x target

Production rate / ion currents

		Plasma MK5	plasma MK7	Surface ion-source
	puA	62%	3%	18%
ISOLDE	682.1E-3	426.1E-3	19.0E-3	119.8E-3
100 kW direct	34.1E+0	21.3E+0	950.0E-3	6.0E+0
4 MW conv.	1.4E+3	852.3E+0	38.0E+0	239.7E+0

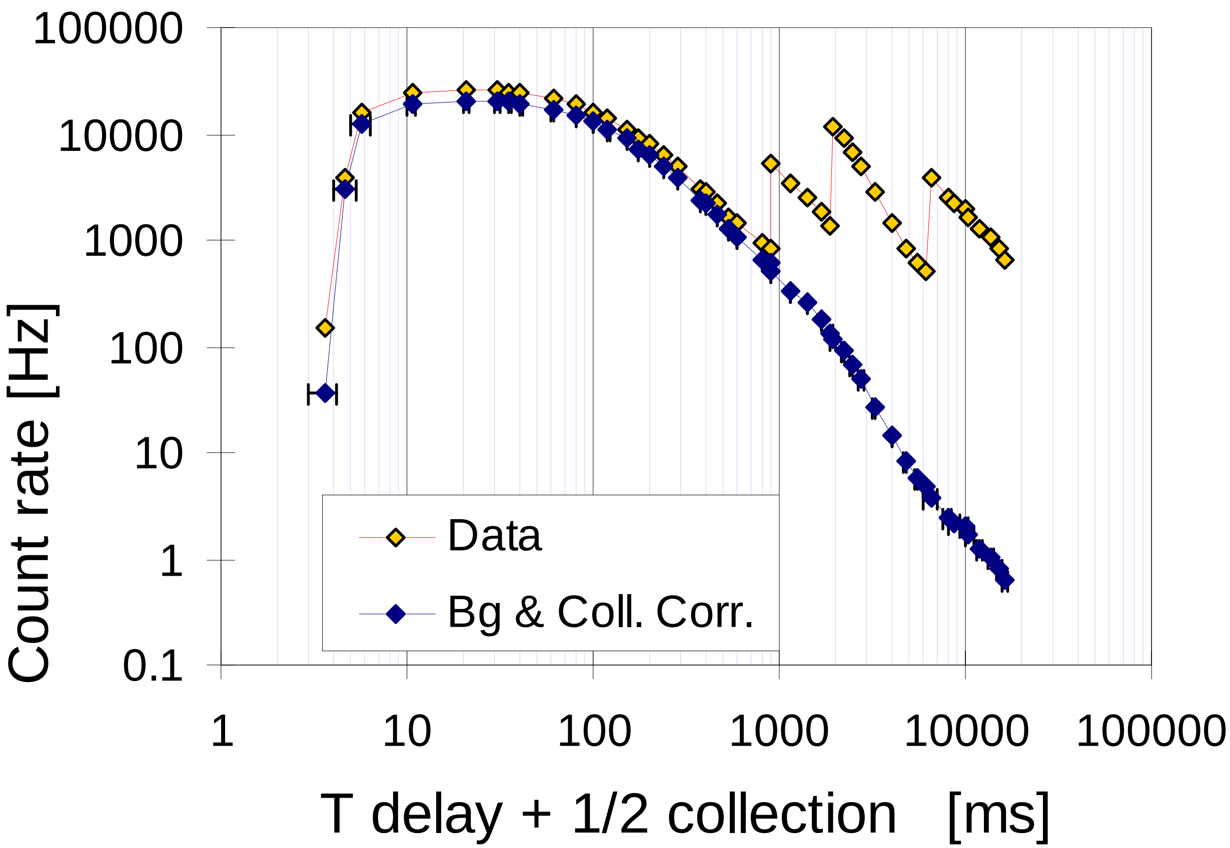
Chemical impurities

	Atoms/s	At/day	At/month
ISOLDE	4.3E+12	367.9E+15	11.0E+18
100 kW direct	212.9E+12	18.4E+18	551.8E+18
4 MW conv.	8.5E+15	735.7E+18	22.1E+21

Conclusion: Ion-source R&D mandatory to keep high efficiency while handling larger ion-currents

Release efficiency

effusion, diffusion



^{25}Na (59.6s)

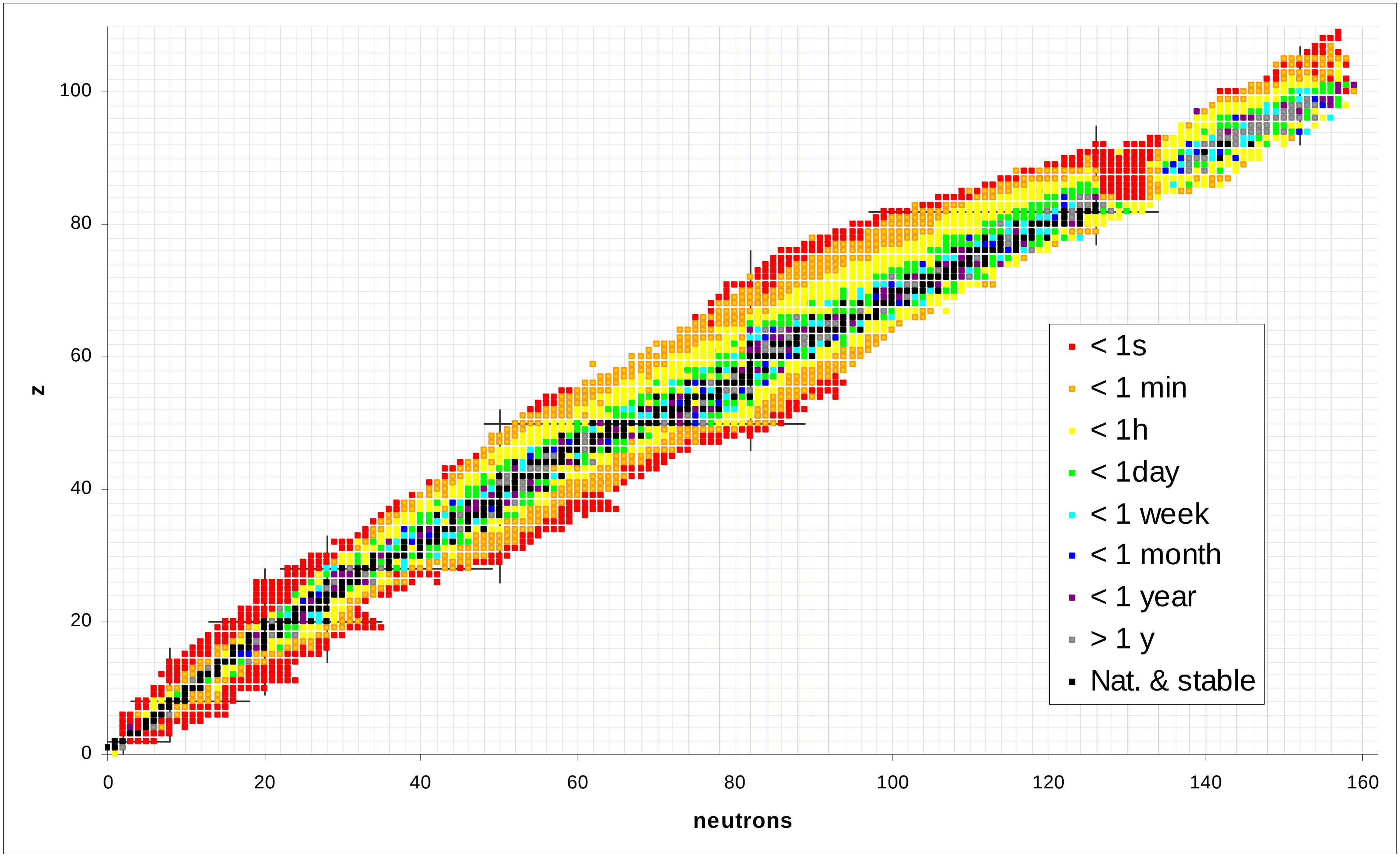
UC-118 2100°C

^{32}Na (13.5 ms)

^{33}Na (8.2 ms)

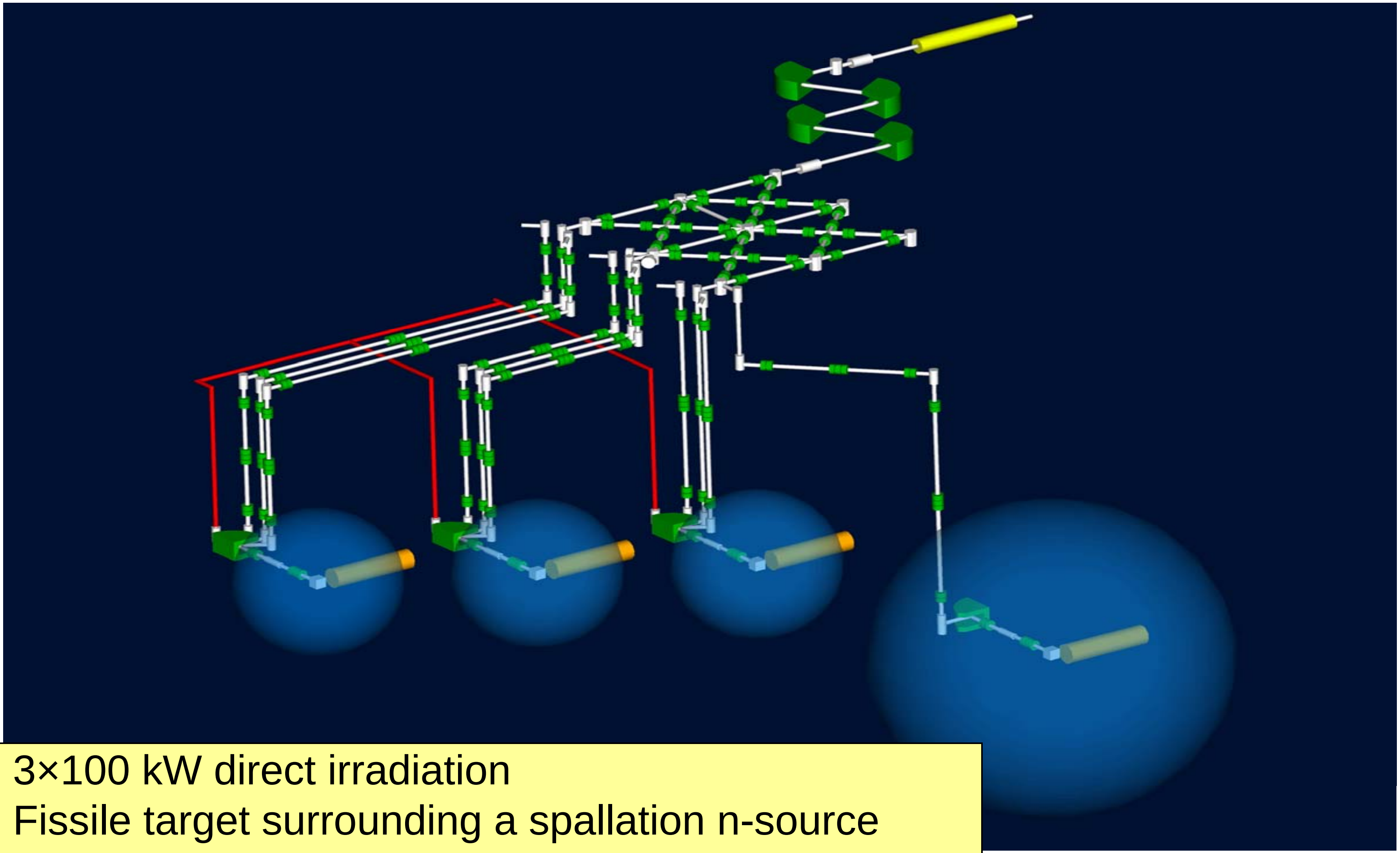
…..

Half lives



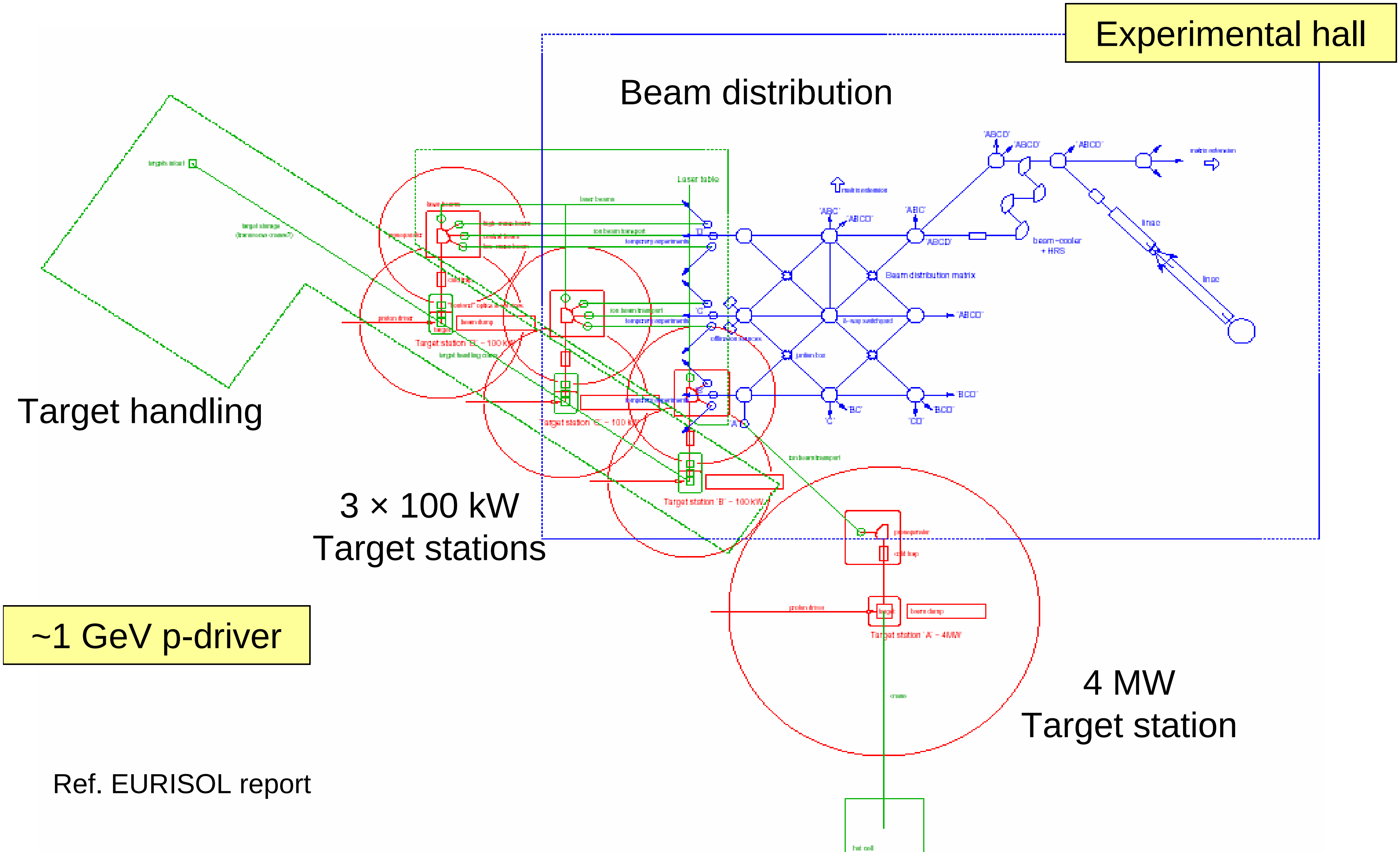
100
80
60
40
20
0
z
0
20
40
60
80
100
120
140
160
neutrons
< 1s
< 1 min
< 1h
< 1day
< 1 week
< 1 month
< 1 year
> 1 y
Nat. & stable

EURISOL target stations



- 3×100 kW direct irradiation
- Fissile target surrounding a spallation n-source
  - >100 kW Solid converters
  - 4 MW Hg-jet or Hg pool

Top view



Ref. EURISOL report

100 kw direct irradiation

- Target Materials: > **25**
  - Thickness, Heat transport, dose rate
  - Diffusion and Effusion delays
- Chemical nature of the target: **6**
- Oven Materials: **4**
- Elements to be produced: > **70**
- Transfer line: **4**
  - Drift fields
- Ion source: **5**
  - Stabilisation of the production (Std. eff., life time, reproduce on-line the best off-line results).
  - Radiation Hardness.
  - Selectivity vs. isobars.
- Maintenance, vacuum vessel, pumps, radioactive Waste handling.

100
Target and
Ion-source
systems

One
Standard
Front-end ***?***

TEST cases 100 kW direct

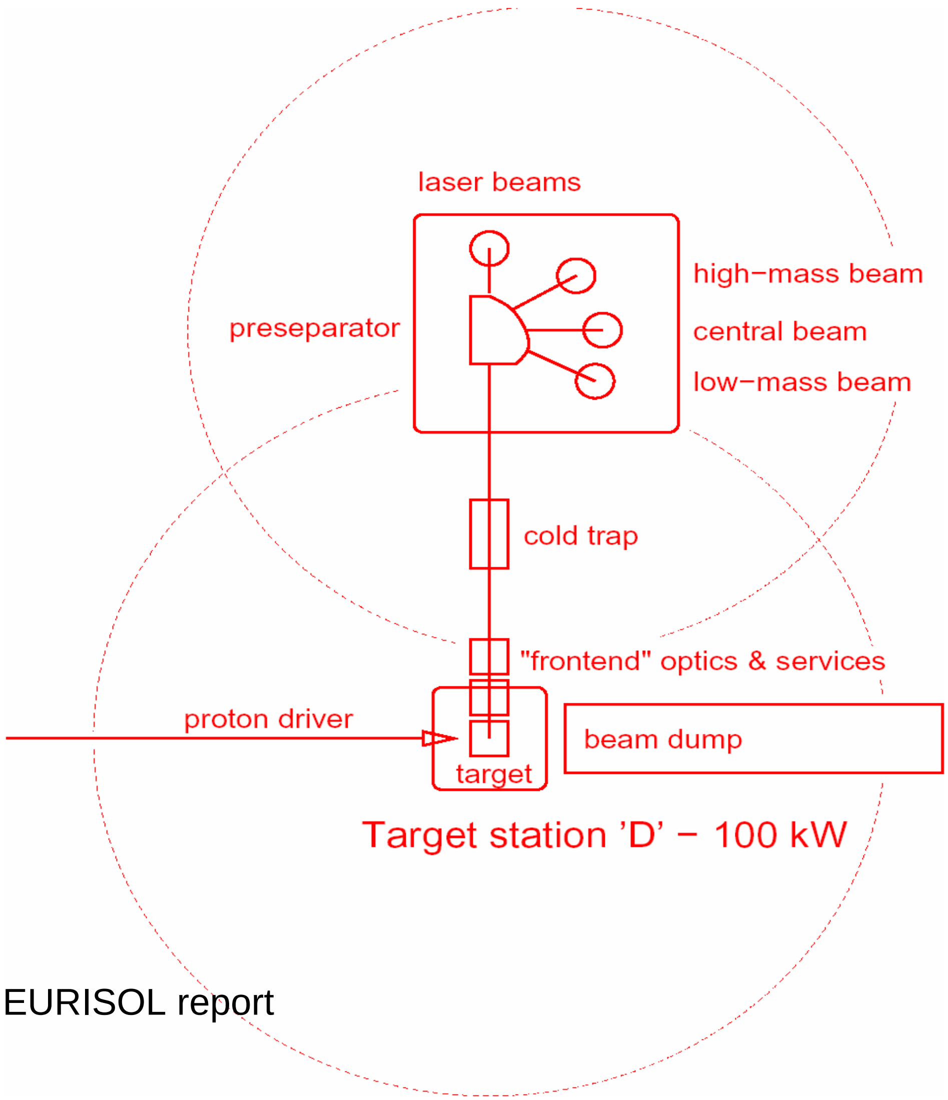
- *Targets*
  - Actinide target (carbide)
    - UC_2+C, ThC_2+C
    - W-converter, Moderator & Reflector
  - Metal foil target (solid)
    - Ta, Nb
  - Oxide powder of fiber
    - BeO + converter
    - Insulating materials low dE/dx
    - Low density
  - Molten metal (Liquid)
    - Vapor condensation
- *Ion-sources*
  - Mono ECR
  - RILIS, Surface
  - FEBIAD
- *Elements*
  - He, Li, Be, Hg …

4 Targets
4 Ion-sources
1 Front-end

Synergy with β-beam

Spin off is expected on:
- Similar target materials
- Elements from the same chemical group

Confinement of the activity, RIB-selection



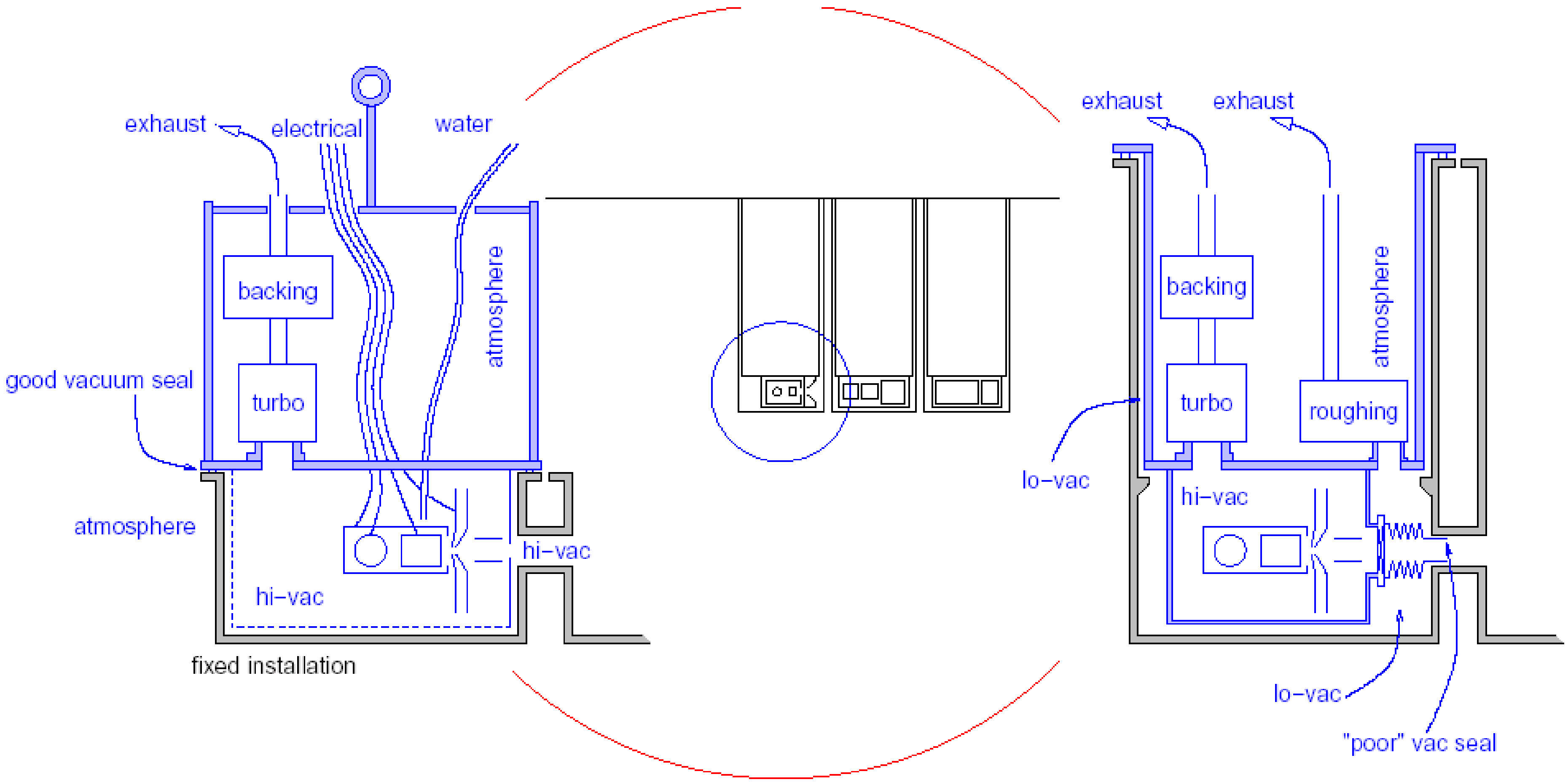
Mass separator

Confinement of radioactve gases
(cold trap)

Target station
Chemically selective ion-source (RILIS)

Ref. EURISOL report

Target plugs



Ref. EURISOL report

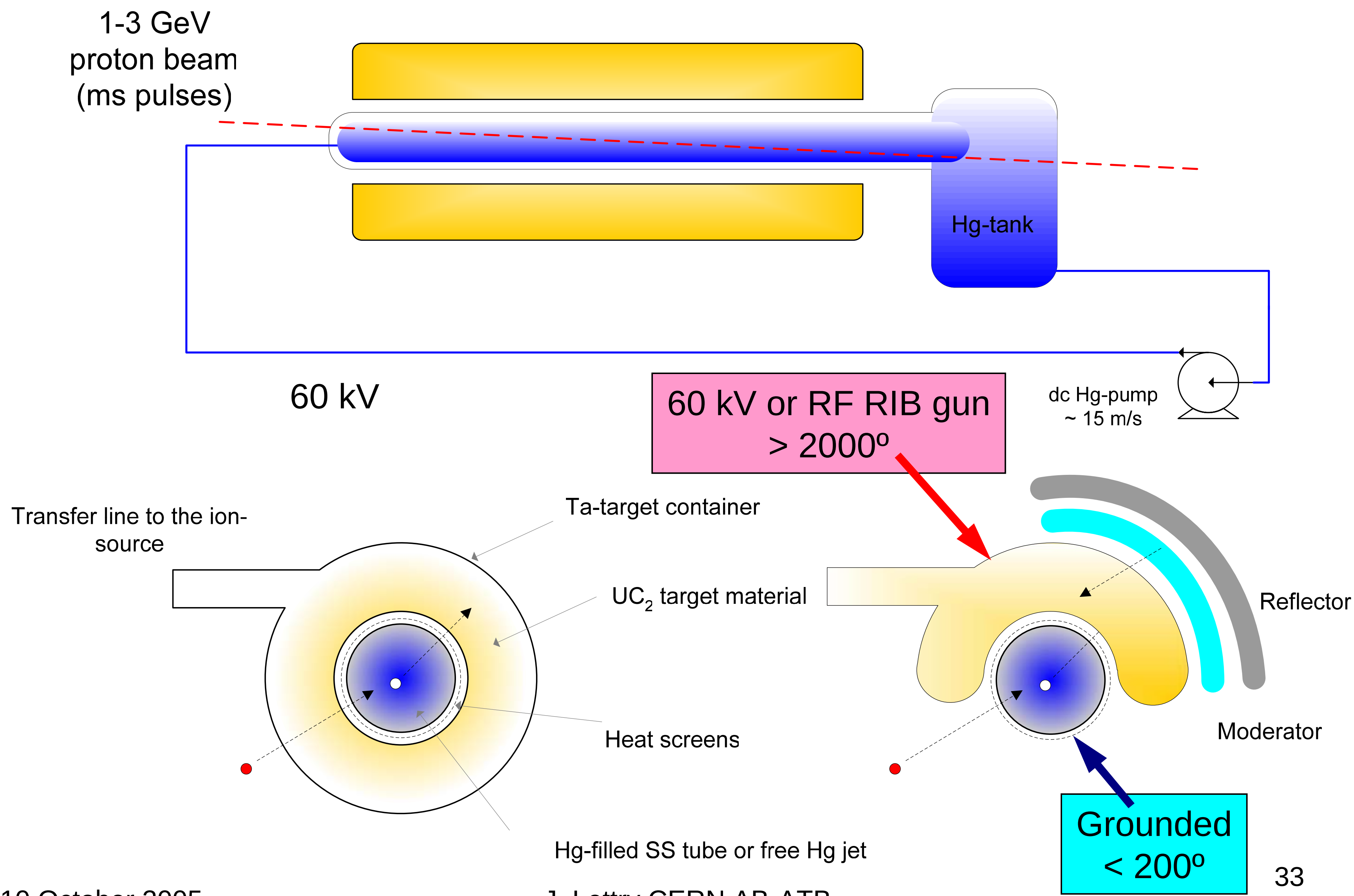
Actinide target

- Cylindrical, donut or C-shaped optimized vs. n-flux … and target exchange.
- Target material: Test of the release properties of high density UC_2 vs. UC_2+C powder
- Thermal equilibrium issue: the target is kept at 2200ºC while its inner or close by placed Hg-n-spallation source Has to evacuate ~1 MW.

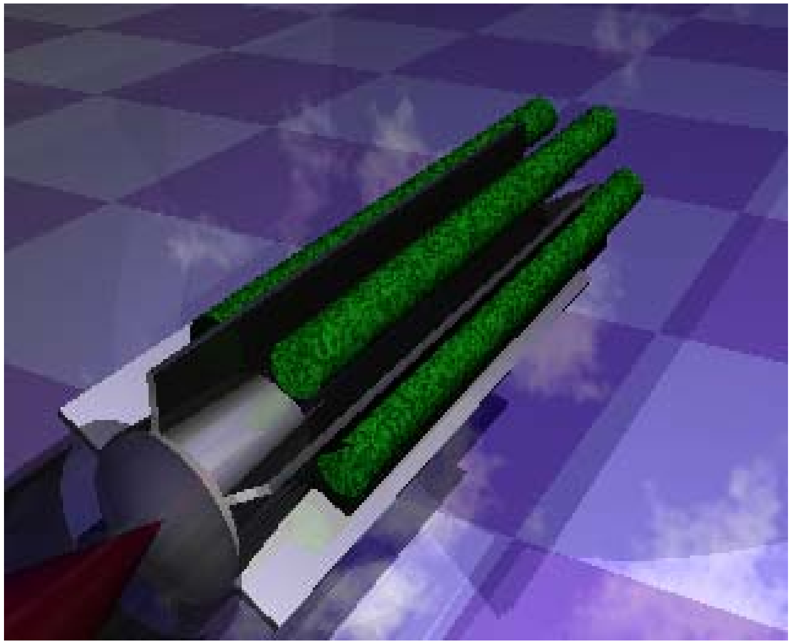
Synergy with SNS, SPIRAL II and SPES
Competitive method: high flux reactors
^{235}U-fission at MAAF

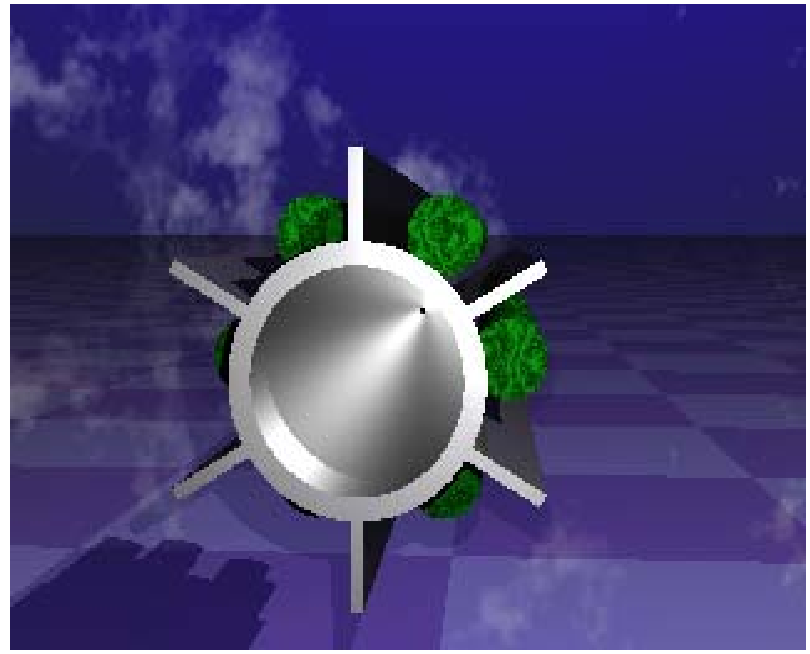
1 Target **?**
5 Ion-sources
1 Front-end

EURISOL Hg-converter and $^{238}UC_2$ target



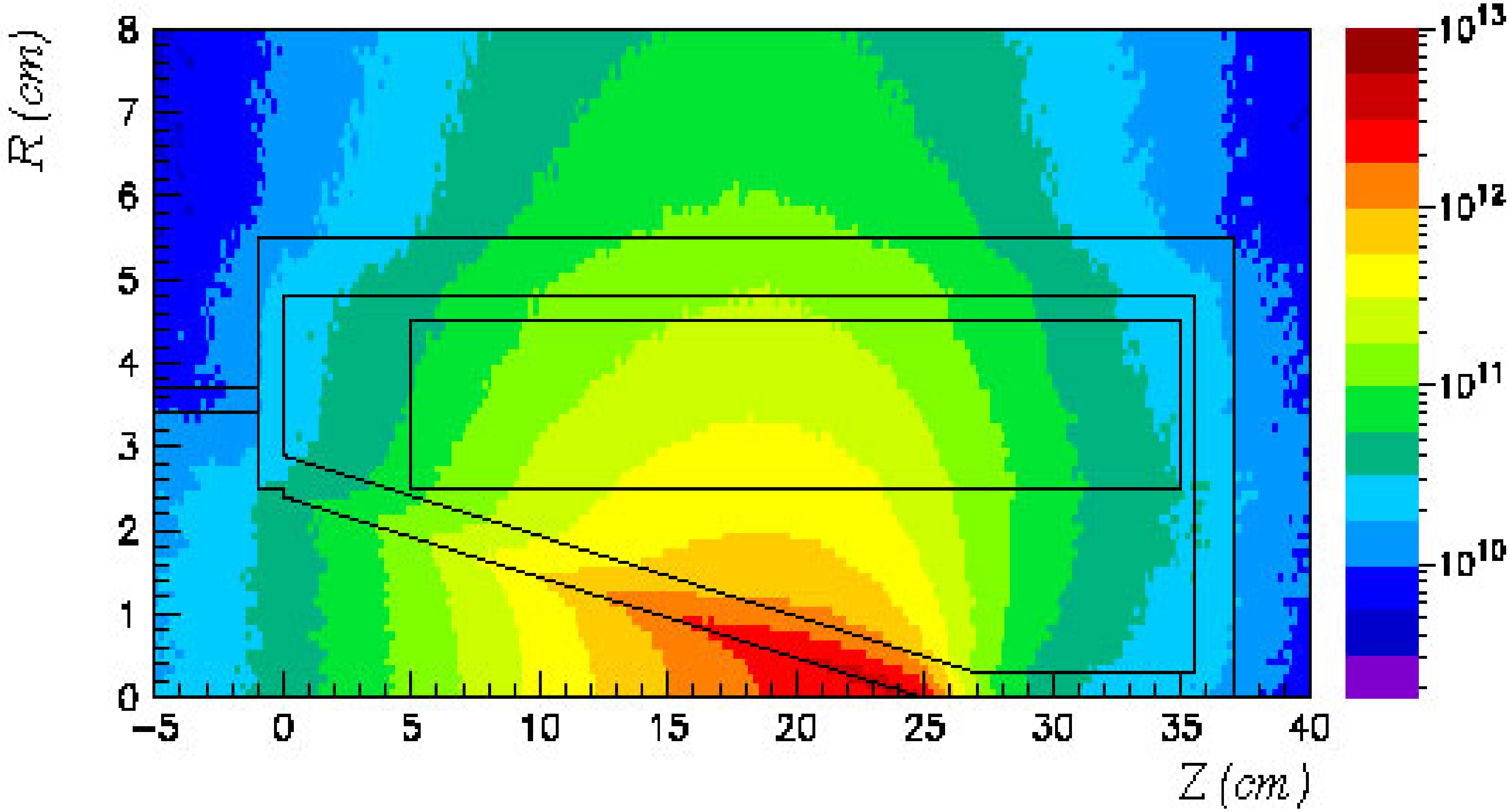
Ta n-converter and UC targets geometry





- Honeycomb structure to house the fission targets
- Fins to establish thermal contact for heat conduction from the Ta n-converter part to external vessel which is cooled.

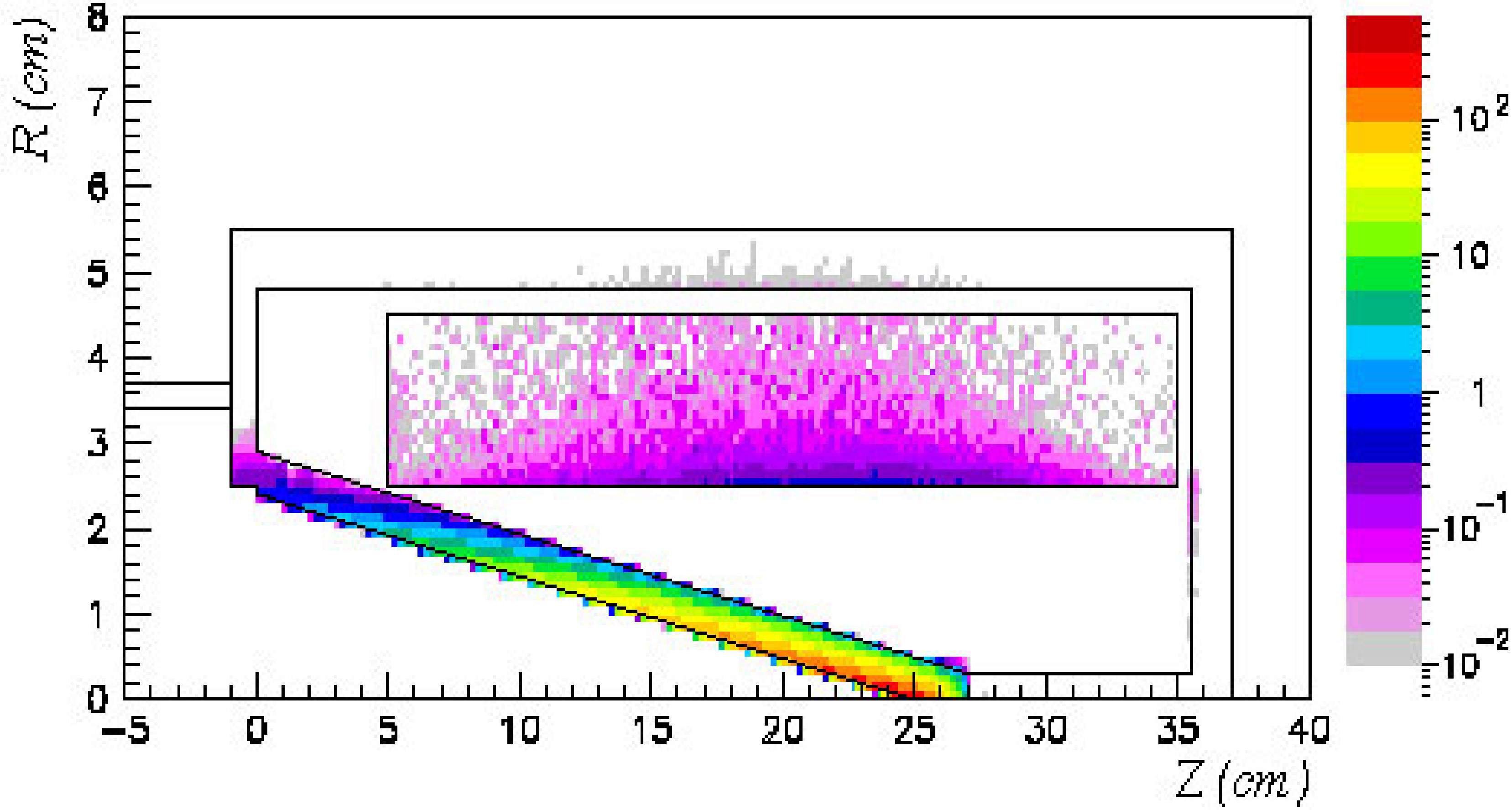
Ta n-converter and UC targets n-flux



Neutron flux distribution in (n/cm^2/s) per kW of beam for 160 MeV protons

A. Herrera, Y. Kadi

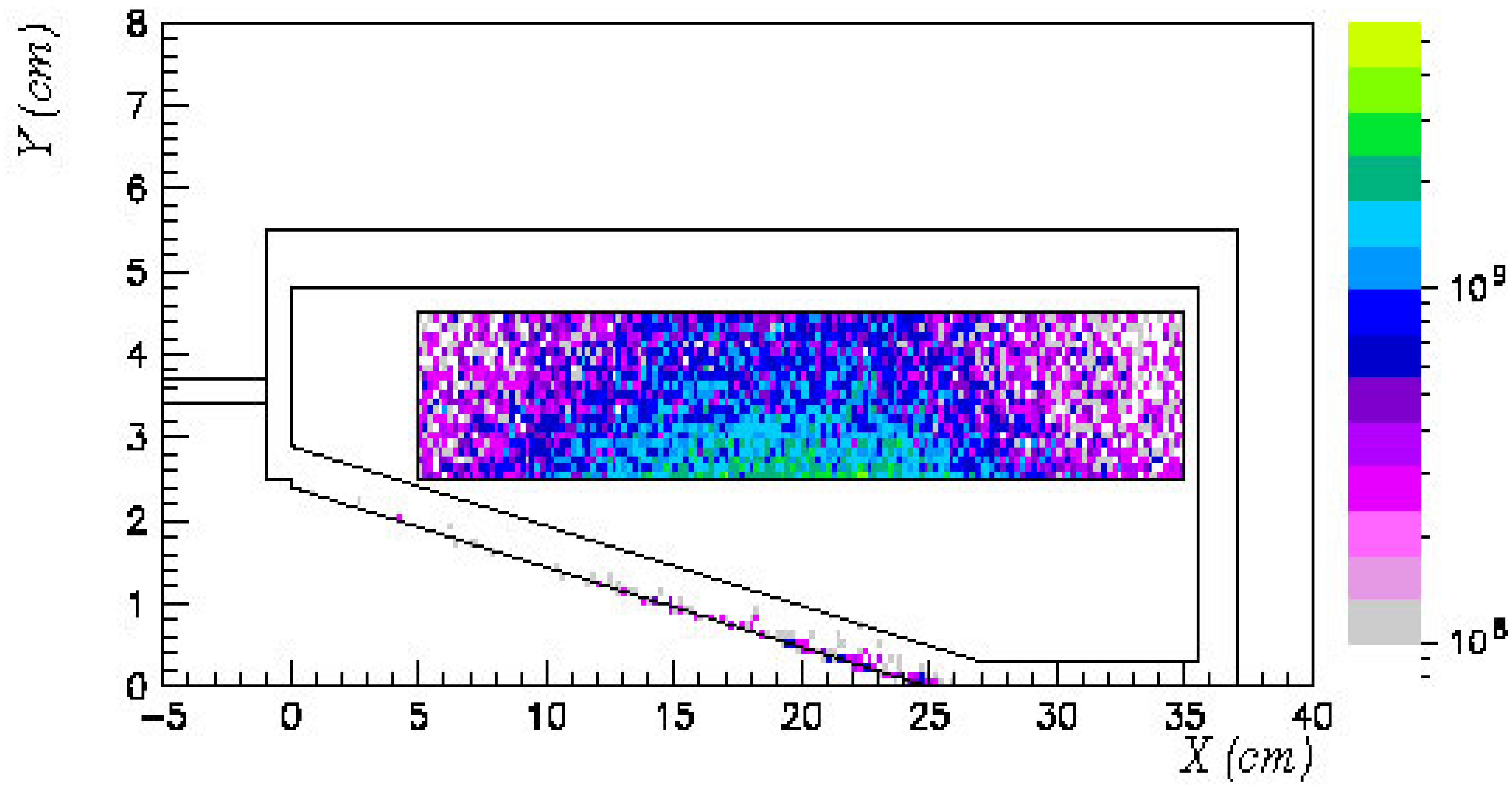
Ta n-converter and UC targets power deposition



Power deposition in the tip region in (W/cm^3) per kW of beam at 160 MeV

A. Herrera, Y. Kadi

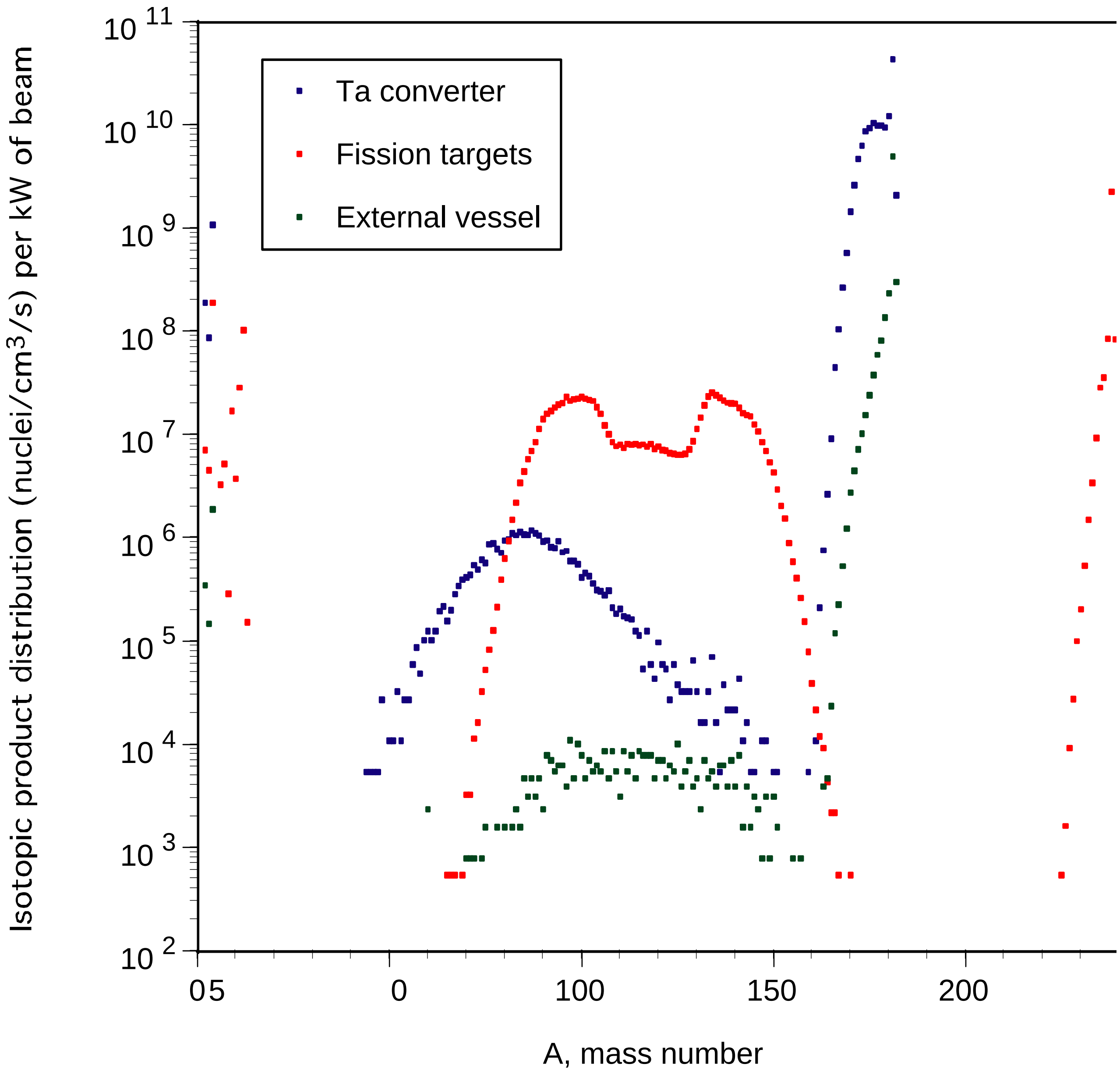
Ta n-converter and UC targets yields



Fission density in the entire target section in (fission/cm^3/s) per kW of beam

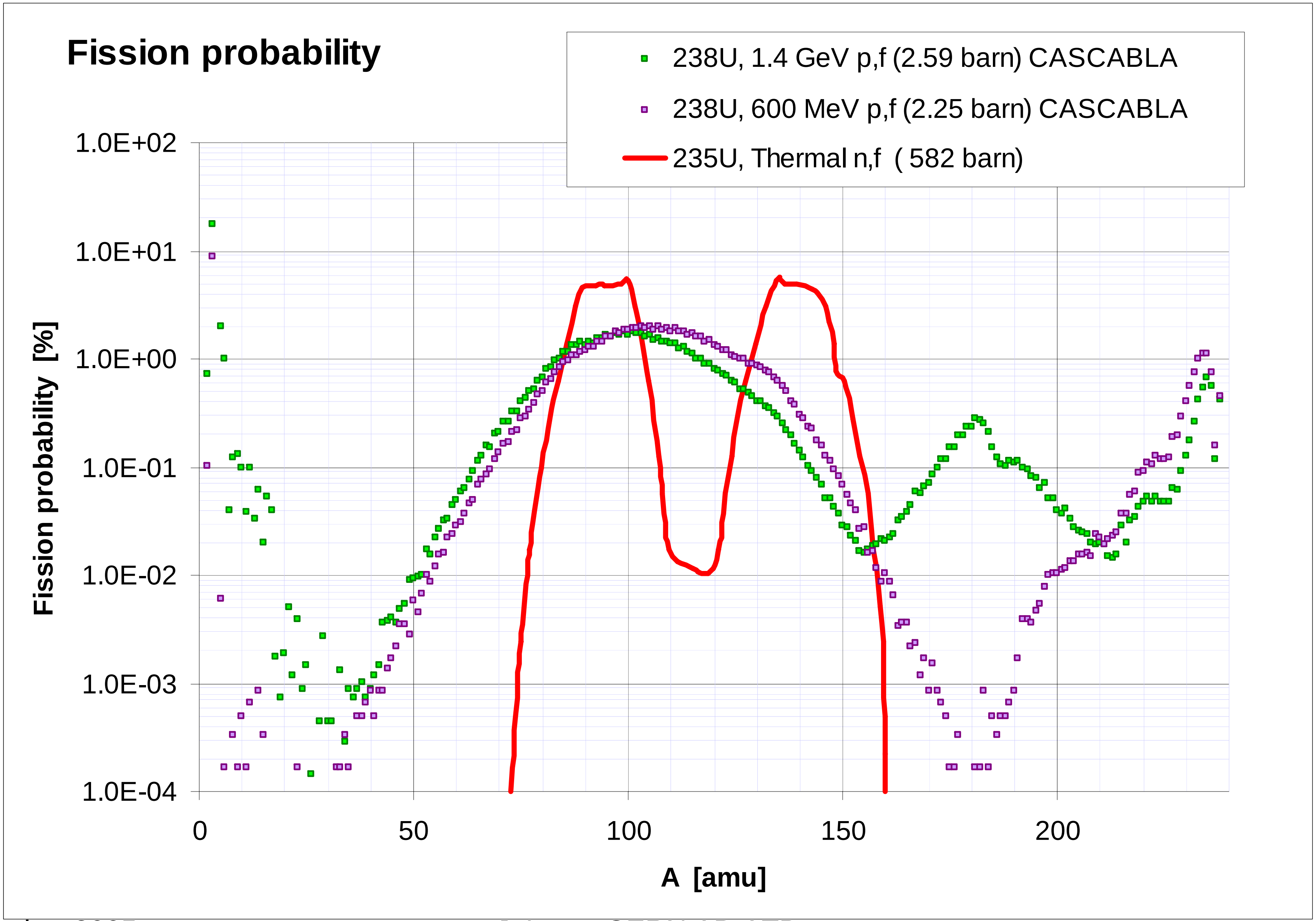
A. Herrera, Y. Kadi

Yield vs. A in (nuclei/cm^3/s) per kW of 160 MeV p-beam

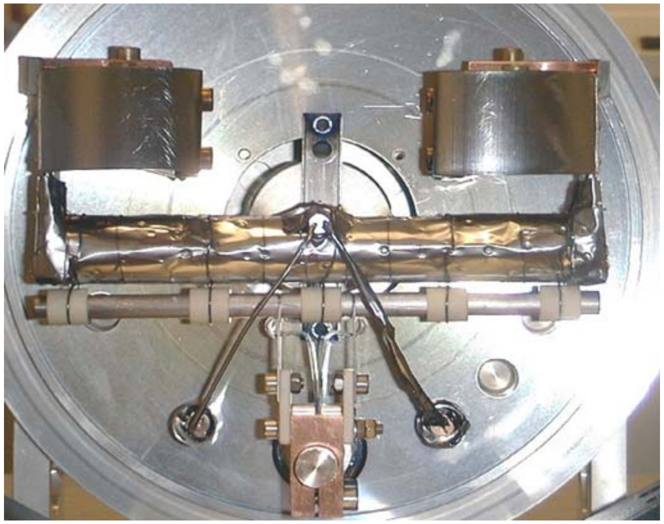


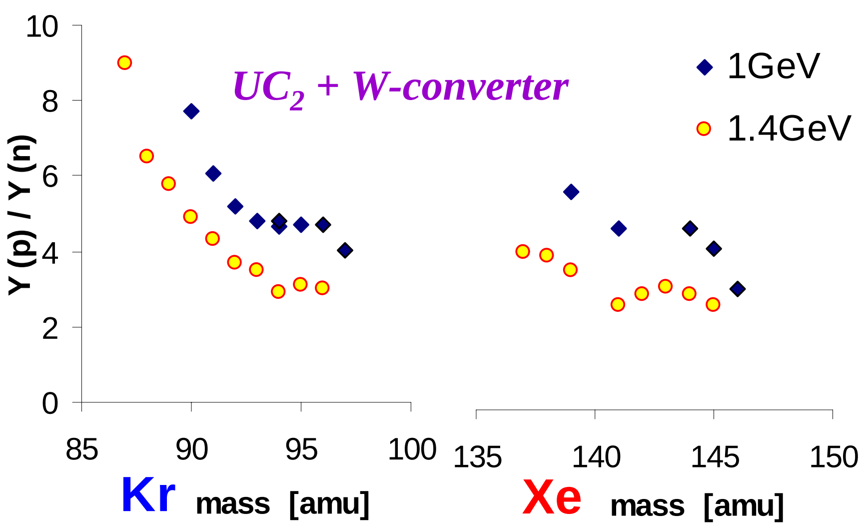
A. Herrera, Y. Kadi

p- or n-induced fission

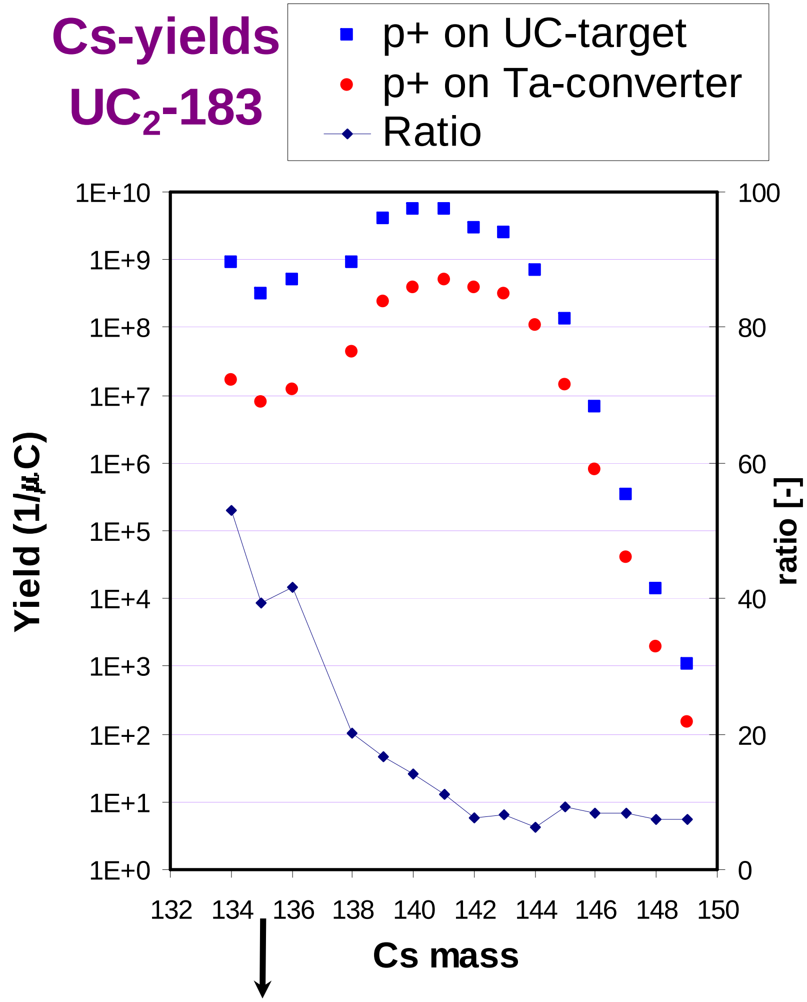


Kr, Xe and Cs yields, Ta-W converter





The yields of very n-rich isotopes obtained
via neutron induced fission of Th or U
are close to those of high energy protons.
Further R&D: Geometry and n-reflectors



Spallation Fission

EURISOL Multi-MW Hg-converter and UC target

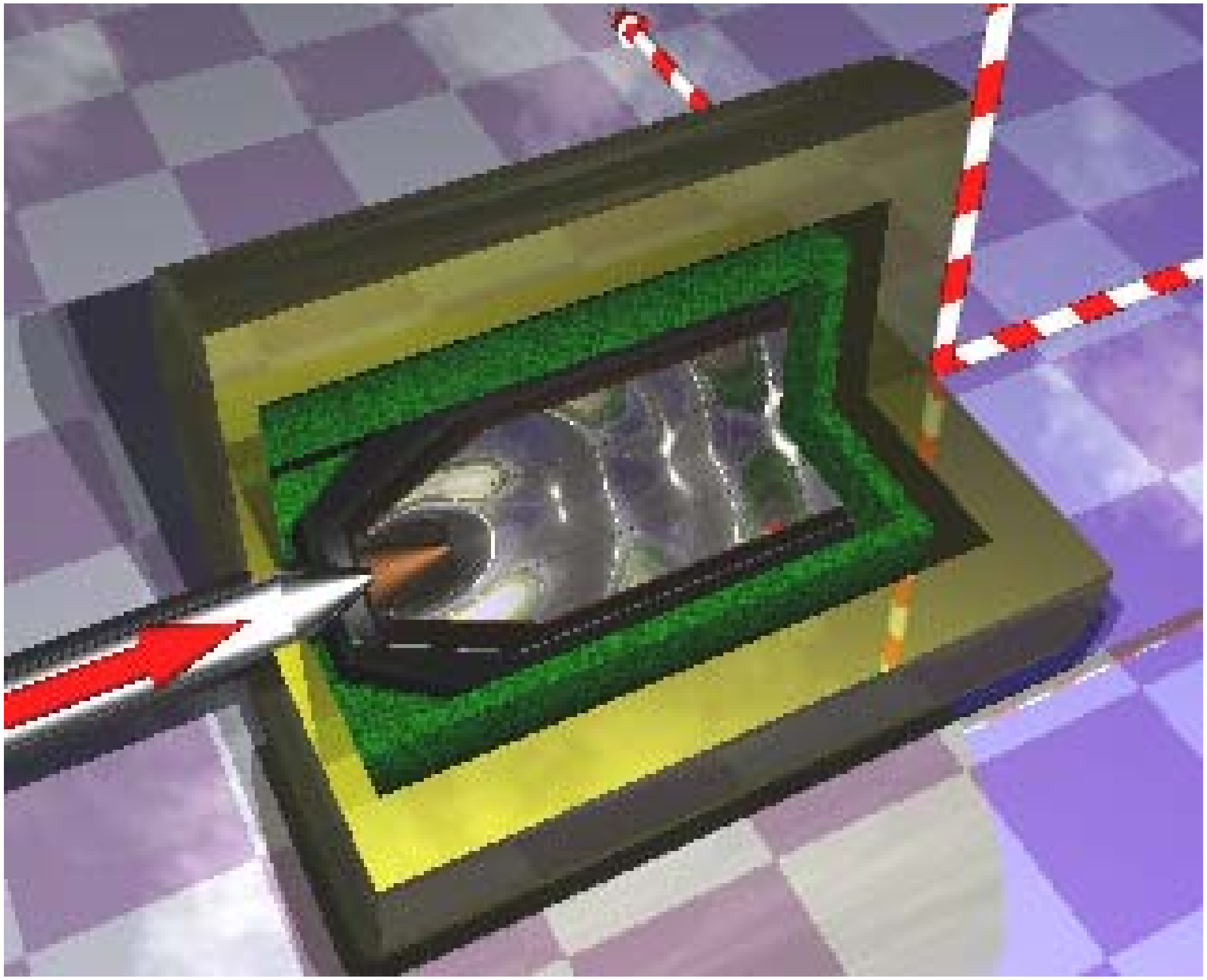
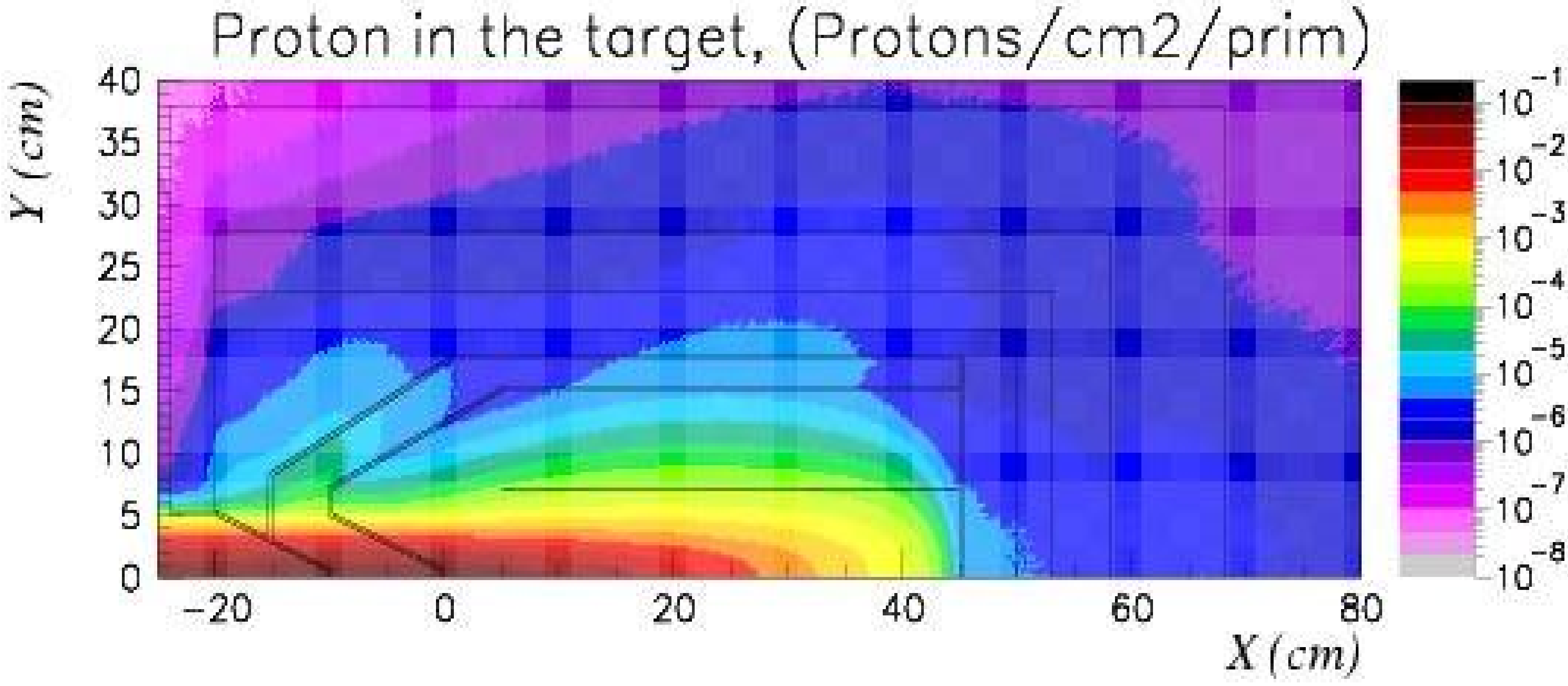


Figure 1. 3-D view of the proposed baseline design for the EURISOL 5 MW target.

A. Herrera, Y. Kadi

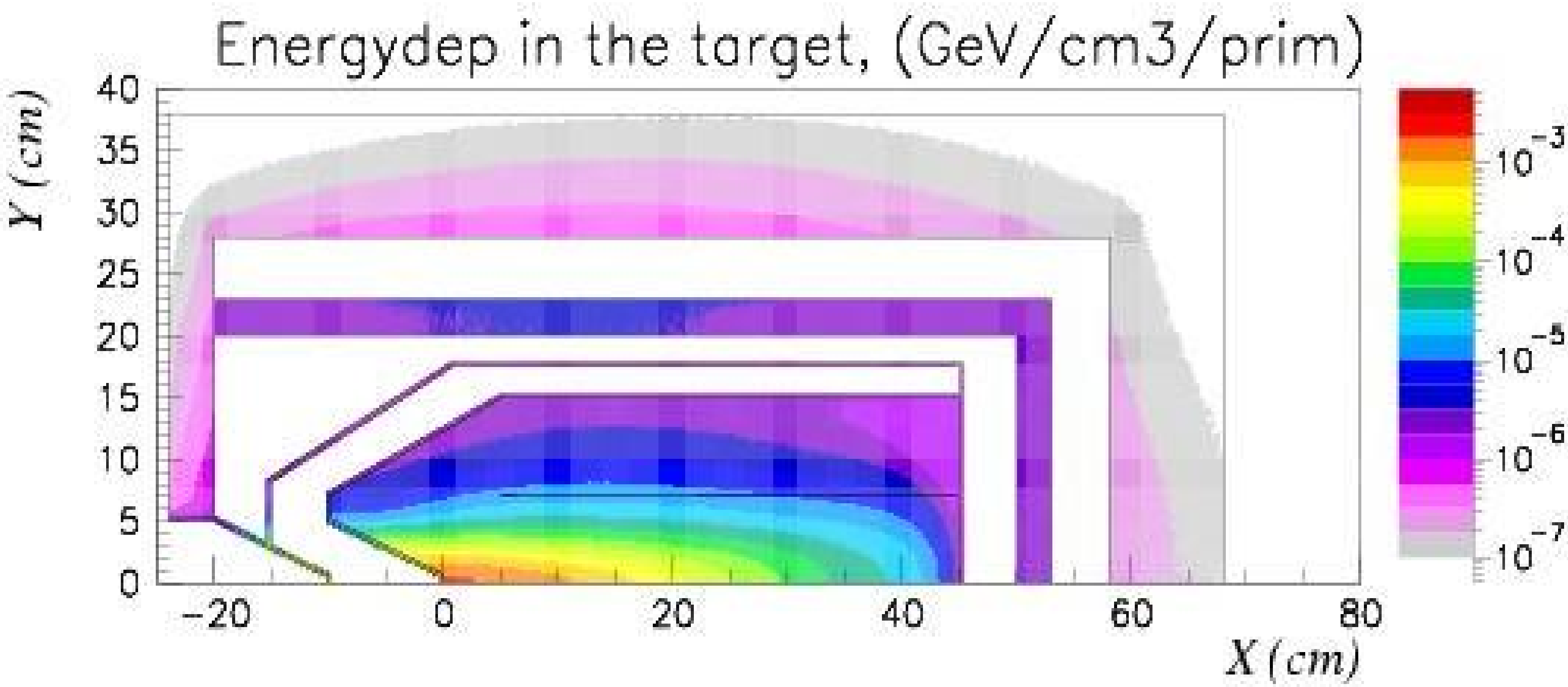
EURISOL Multi-MW Hg-converter and UC target



1 GeV Protons

A. Herrera, Y. Kadi

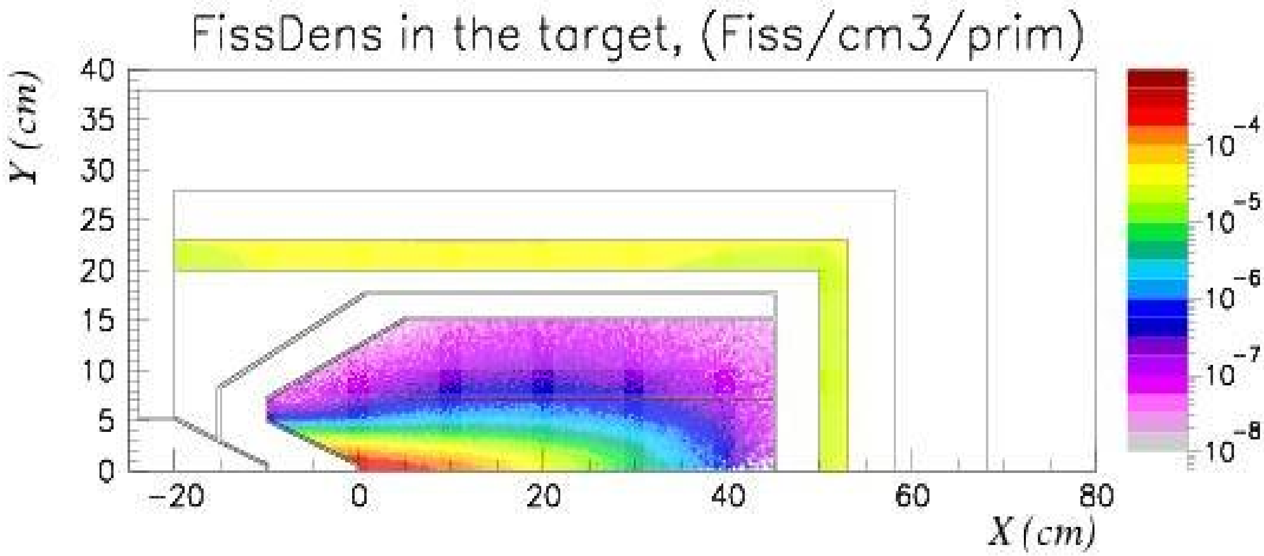
EURISOL Multi-MW Hg-converter and UC target

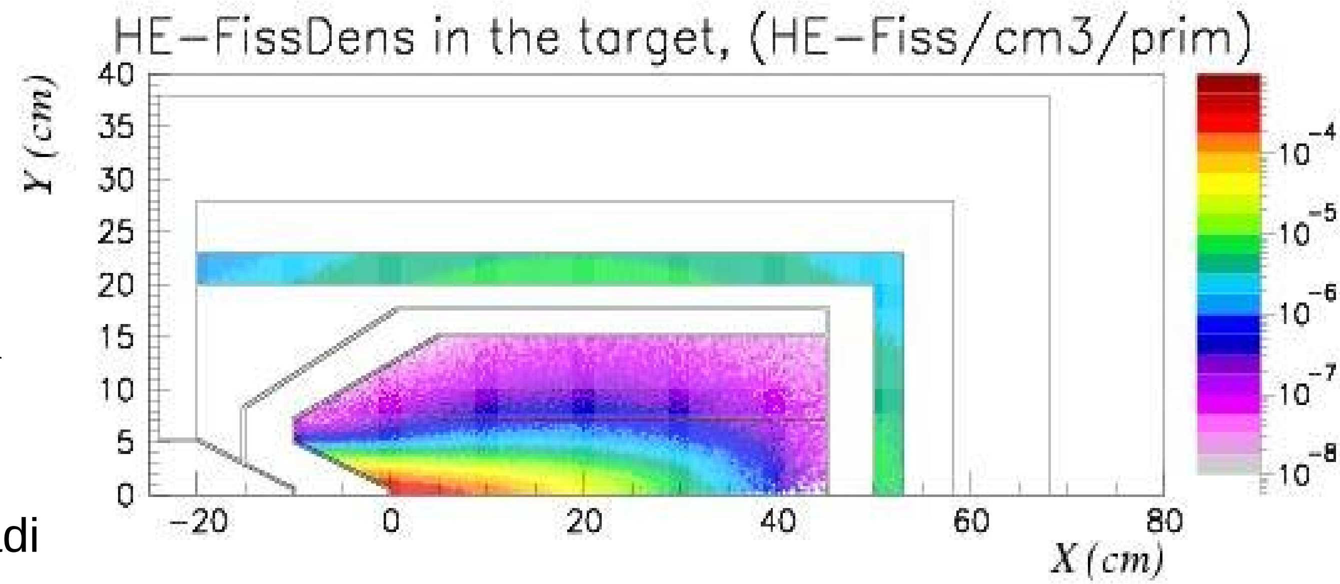


1 GeV Protons

A. Herrera, Y. Kadi

EURISOL Multi-MW Hg-converter and ^{nat}UC target





1 GeV Proton

A. Herrera, Y. Kadi

Issues or new technologies to be established

- Molten metal converters
  - Hight pressure high velocity molten metal fluid dynamics
    - Cavitation in the piping
    - Corrosion
    - Recuperation of high velocity splashes
  - Purification of the molten metal circuits
- Solid targets
  - Effect of chemical impurities (generated via radio genesis) on material properties
  - Effects of annealing and direct radiation damages
- Component reliability or life time vs. exchange time
  - Vacuum pumps
- Simulation codes
  - Beyond simple Energy deposition
  - Ion-sources plasma simulation
- Measurements
  - Optical measurement techniques in high radiation environement
  - Total surface measurement (tuning of effusion codes and ageing)
- Activation of components, inventory of specific activities vs. time
  - Radioactive waste handling
  - Internal transport, intermediate storage
  - End disposal
- Experimental areas dedicated to target tests (highest radiotoxicity)
  - Optimization of RIB-yields
- Chemistry at very high temperatures

The FLUKA release 2005.6

Full FLUKA release, including source: 26-7-2005
NEW FLUKA user guide ready to be published as CERN Yellow rep.
Licensing conditions defined and approved by CERN and INFN

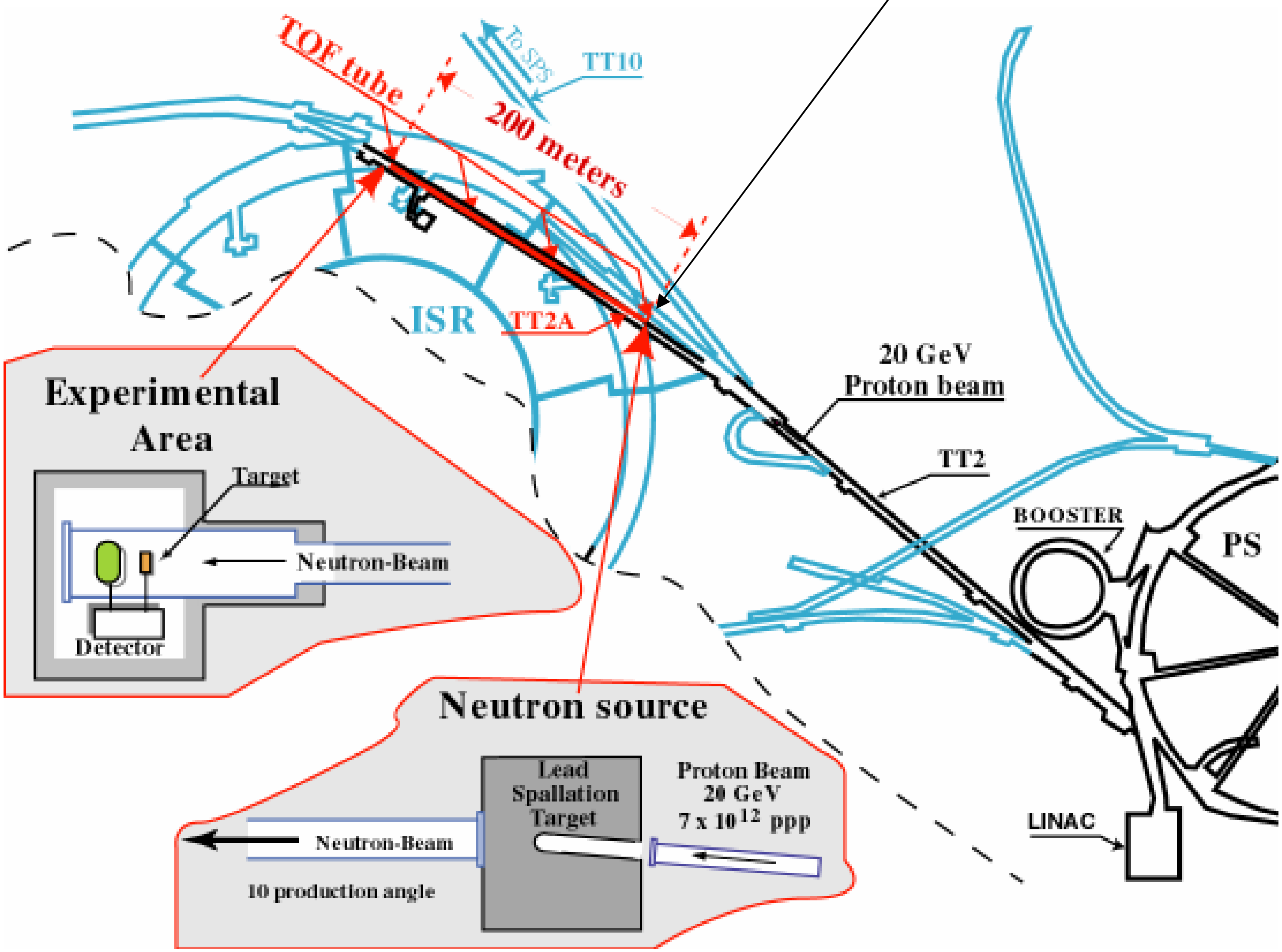
Major improvements:

- Radioactive products online evolution and associated remnant dose
- Elimination of PEMF
- Electro Magnetic dissociation of Heavy Ions
- PEANUT extension to pbar/nbar
- New photon cross sections (EPDL97, from LLNL)
- New photon coherent scattering, updated pair production and photoelectric
- Interface with DPMJET-3 (DPMJET-2.53 still available)
- Preprocessor directives in input and geometry
- Parentheses in geometry
- New 64-bit random number generator (Marsaglia)

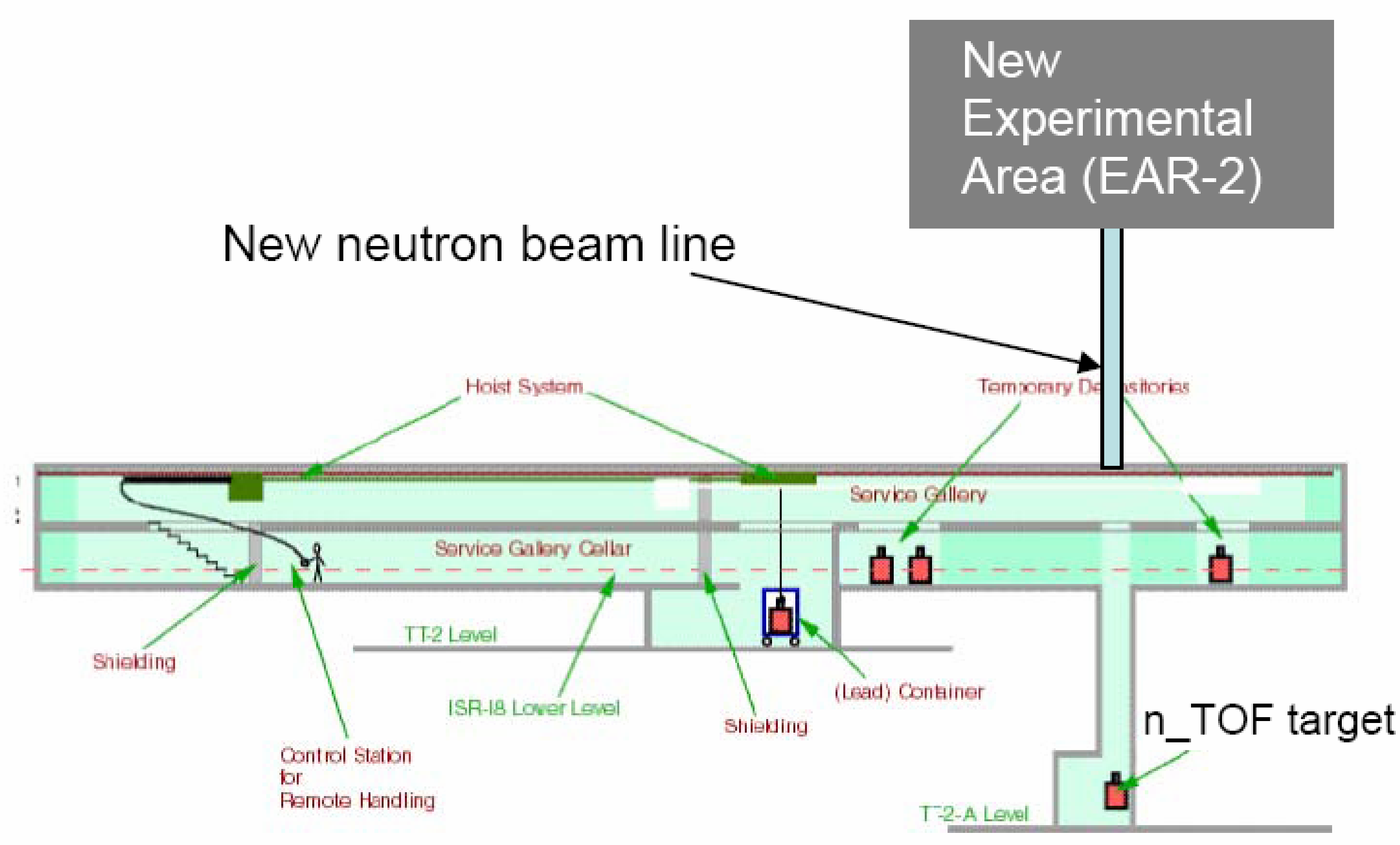
www.fluka.org

The n_TOF Facility

Location of the MERIT experiment



N_ToF_Ph2


New Experimental Area (EAR-2)
New neutron beam line
Hoist System
Service Gallery
Service Gallery Cellar
TT-2 Level
Shielding
ISR-I8 Lower Level
Shielding
(Lead) Container
Control Station for Remote Handling
n_TOF target
T-2-A Level