THE SPES PROJECT AT LNL

Direct Target R&D

Effusion-diffusion calculations

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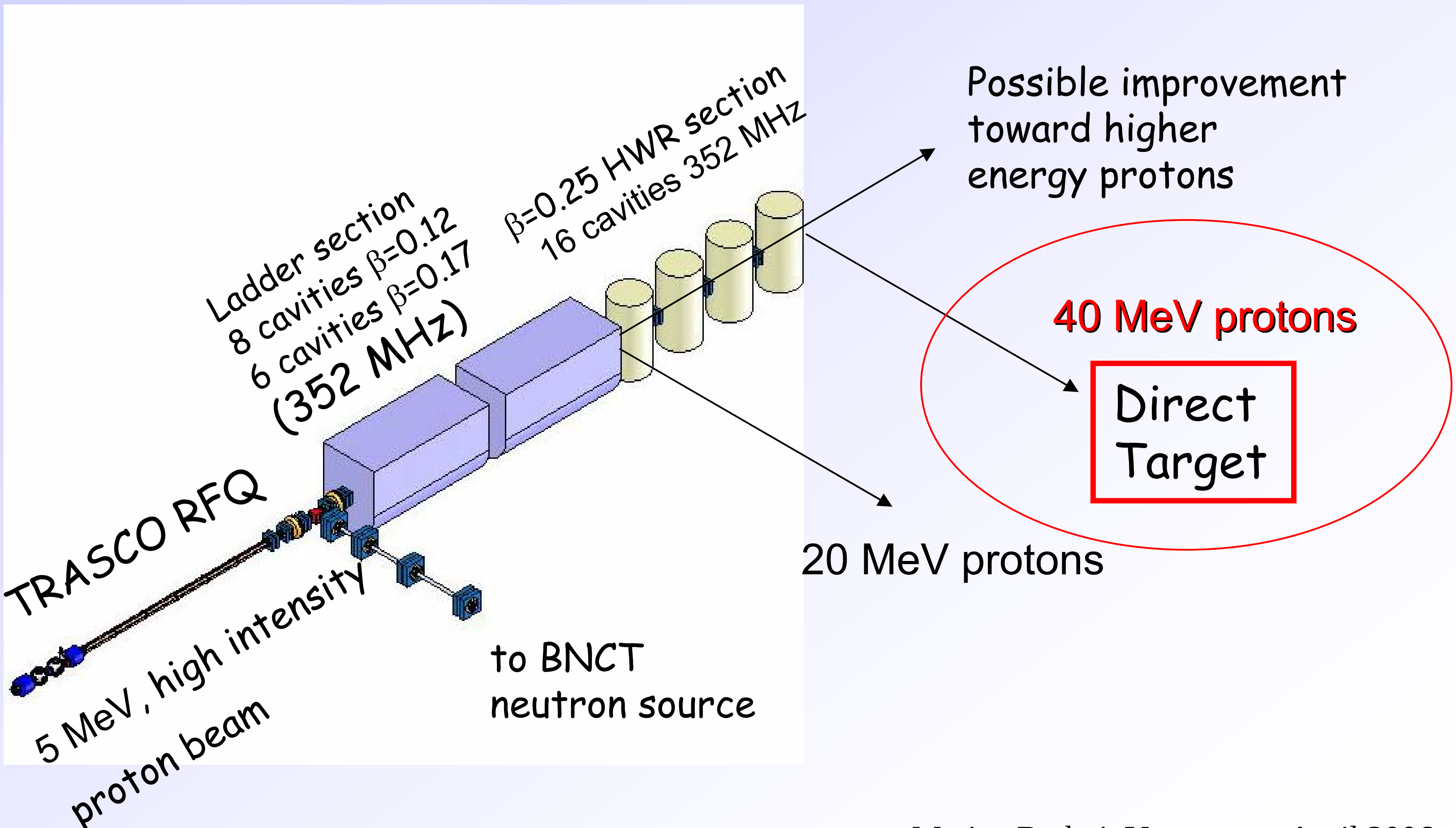
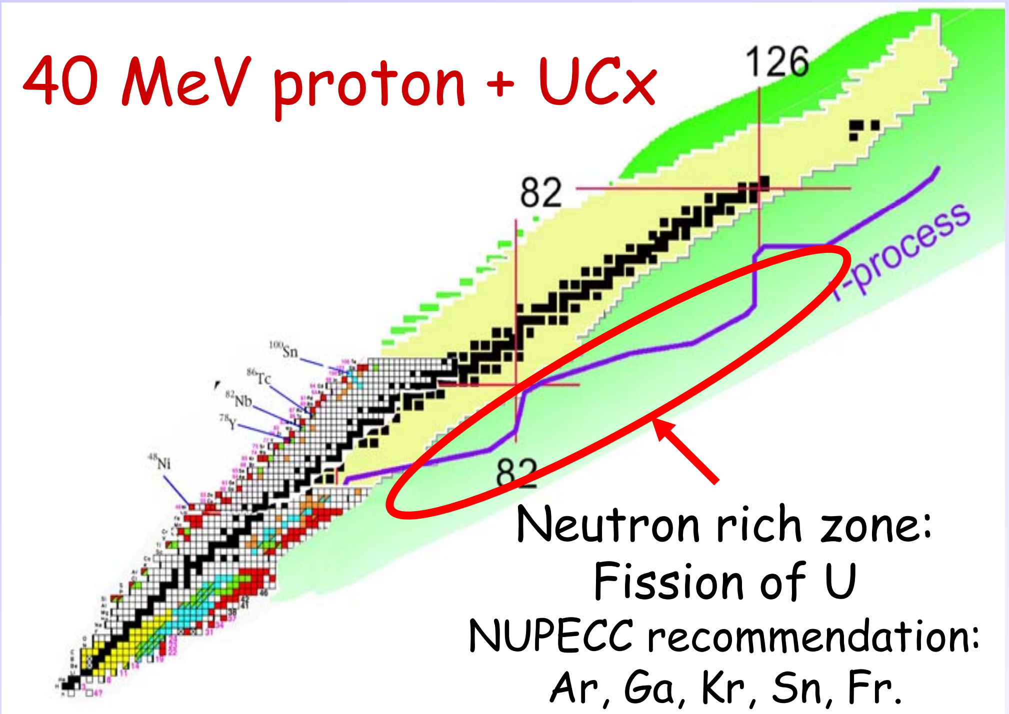
Overview

- ✓ The RNB project at LNL, a possible lay-out
- ✓ Motivation
- ✓ Development of a Direct Target to be operated with 40MeV proton beam, 8 KW (200 μA)
  - Target configuration for 10^{13} fissions/s
  - First Calculations: fission cross-section, fission yield, power deposition, thermal calculations.
  - Effusion calculations using GEANT4 and RIBO
  - Diffusion calculation using RIBO
- ✓ 1:5 scaled Prototype
- ✓ Conclusions

LNL-RIB Layout



Motivations



Such nuclei might be produced with relatively high cross-section using fusion reactions involving neutron rich projectiles as $^{78-80}$Ge, $^{90-92}$Kr, ^{132}Sn.

Why explore neutron rich nuclei?

1) **For the investigation of the nuclear shell structure since a new magic numbers might appear.**

2) **For the understanding of the nucleo-synthesis *r-process***

3) **High neutron excess reduces the nuclear fissility, therefore very high angular momentum might be sustained by neutron rich nuclei with exotic shapes**

4) **For Super heavy nuclei production with**

   Z = 114, 120, or 126
   N = 172 or 184.

Target Configuration: Comparing two philosophies

Direct Target (1 Step)

Low power proton beam (<1mA)

Crucial Parameters:

1) Cross Sections
2) EM Stopping Power (p 40% less than d @ 40 MeV)

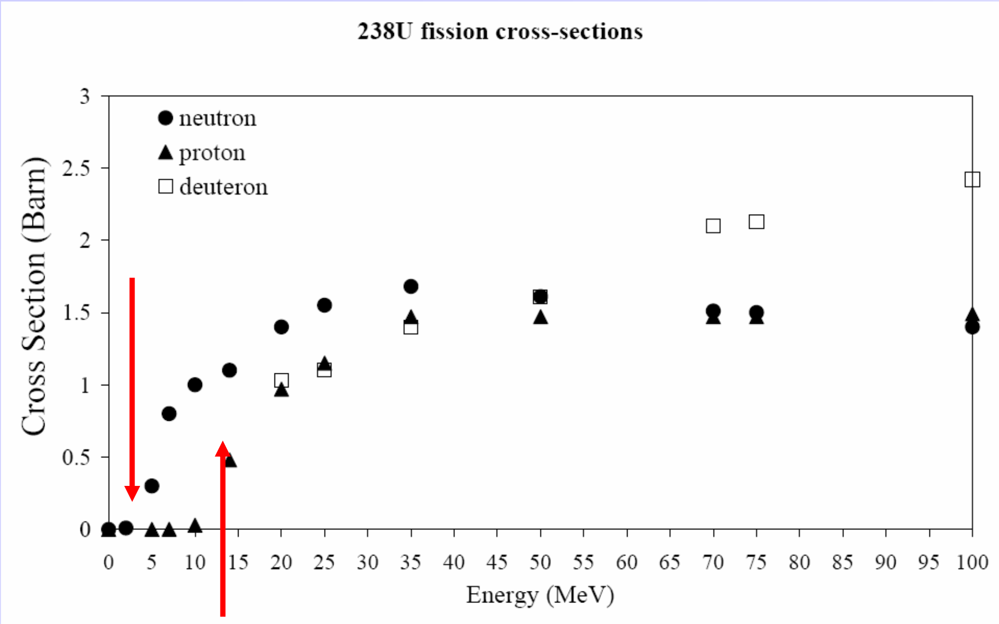
Use of a Converter (2 Step)

High power proton/deuteron beam (5mA)

Crucial Parameters:

1) Neutron Production Efficiency (about 2% for d->C @ 40 MeV)
2) Neutron Angular Distribution
3) Neutron Energy Distribution and cross sections (threshold ~ 2 MeV for ^{238}U)

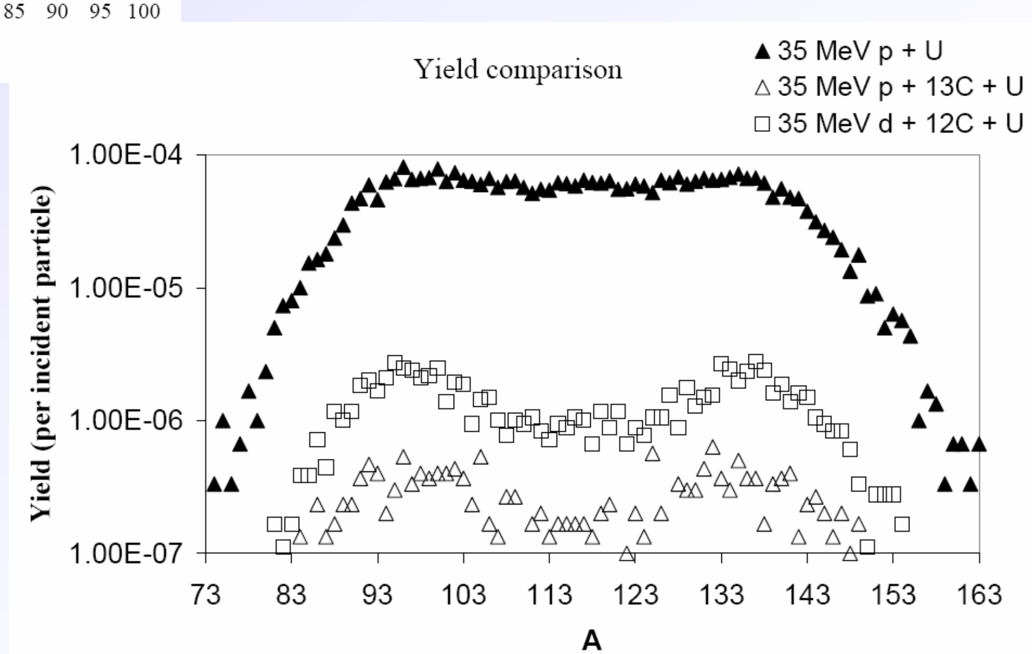
Target Configuration: Comparing two philosophies



Energy threshold

neutrons E_{th} ~ 2 MeV

deuterons and protons E_{th} ~ 15 MeV

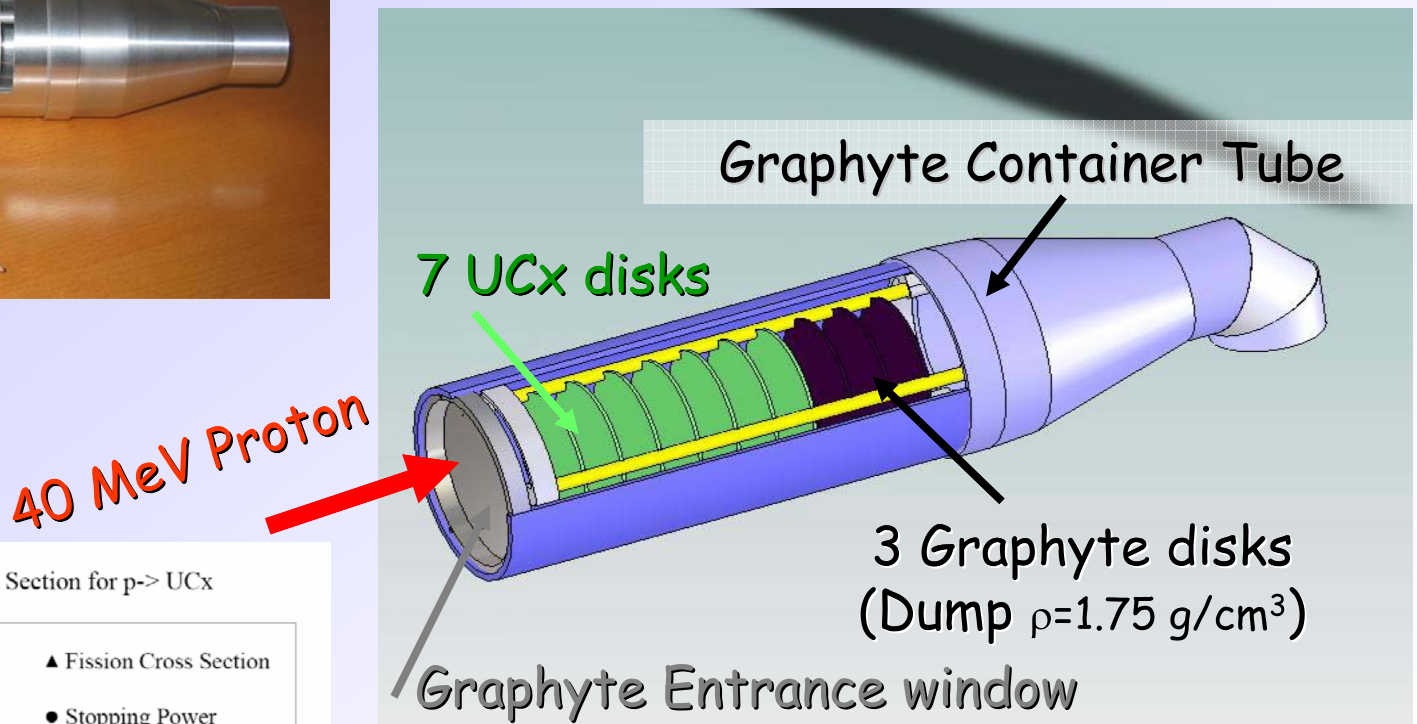


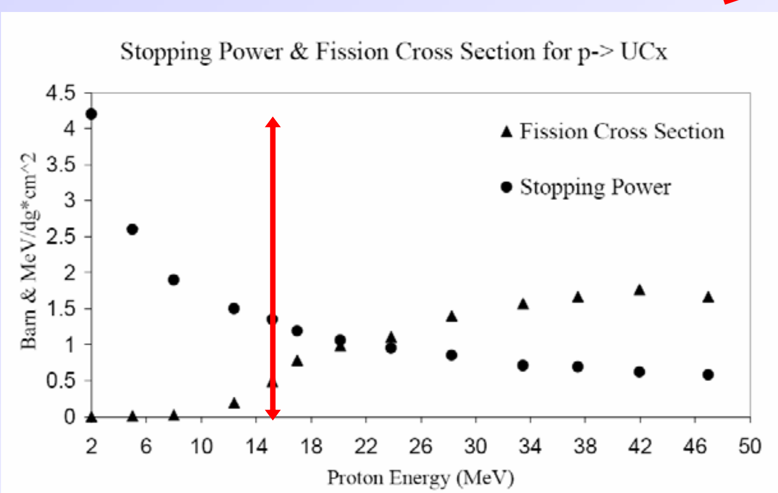
No neutron conversion factor for the direct fission reaction

Direct target Configuration

Each disk is ~1 mm thick, Φ = 6 cm.

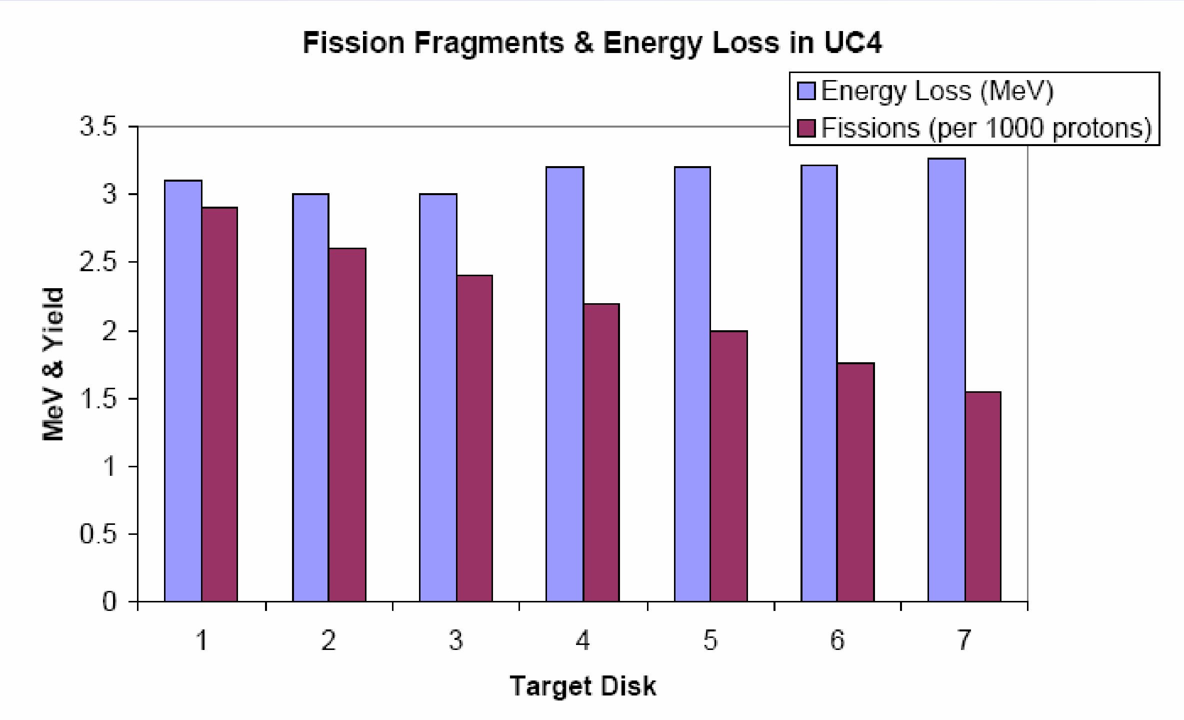
Spacing between the disks = 2cm





[A.Andrighetto, S. Cevolani and C.Petrovich EPJ A 25 (2005) 41-47]

Direct target Configuration



40 MeV p x 200 μA=8 KW

→ 10^{13} fissions/sec

Fission Fragments:
$1.5 \cdot 10^{-2}$ /proton

The disks thickness is calculated in order to have a constant energy loss.

Power distribution:

7 UCx disks 6 cm ϕ ~1 mm thick (ρ=2.5g/cm³, 60g)

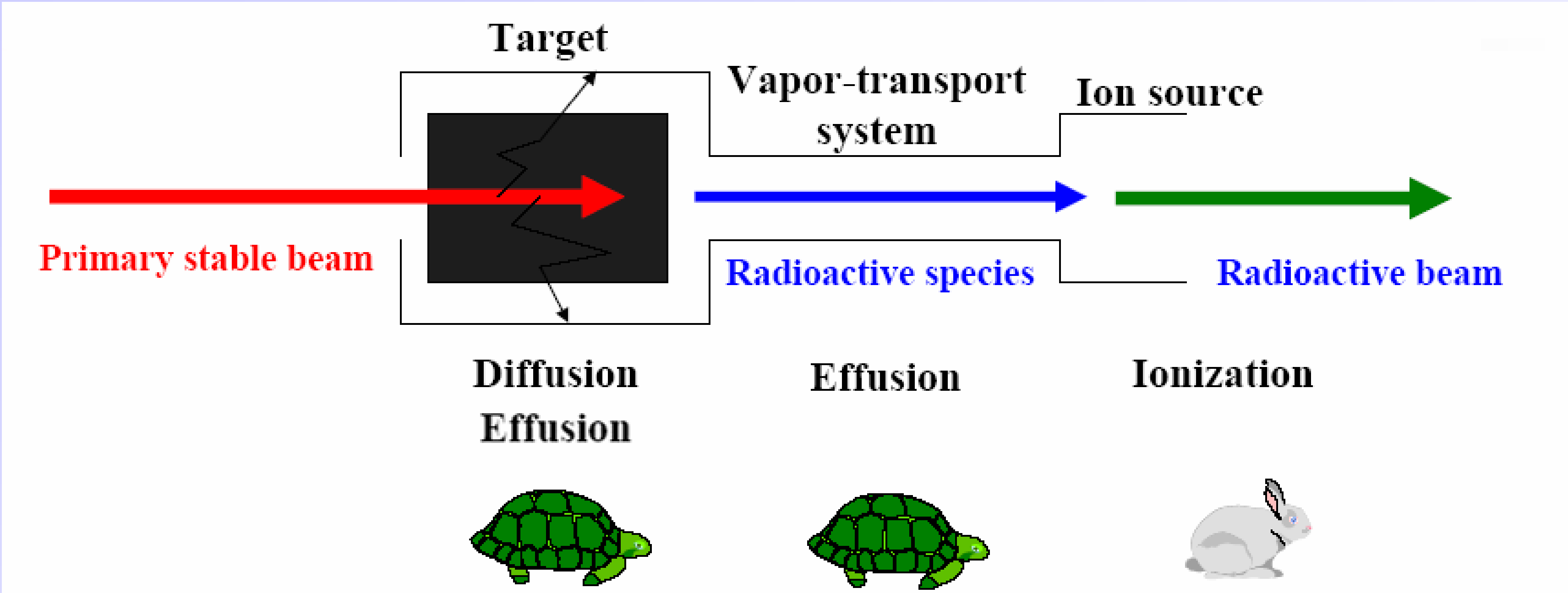
UCx energy loss **23 MeV** → 4.2 KW

600 W each disk, ~70 W/g ⟷ **HRIBF target: 100 W/g**

Window energy loss 1.2 MeV → 200 W

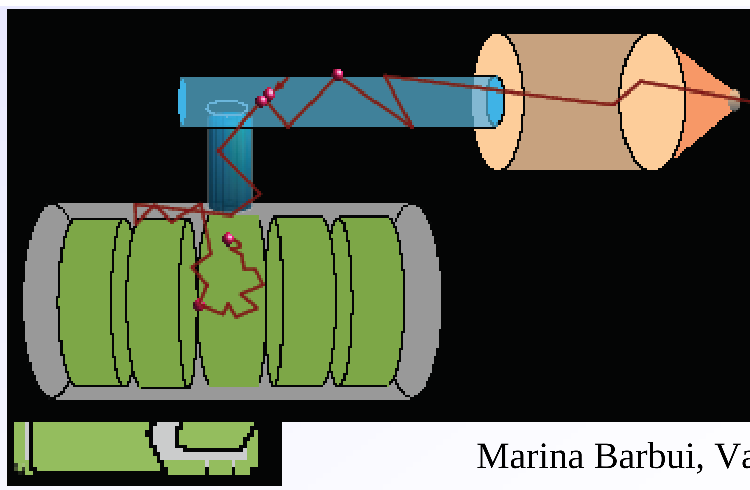
beam-dump energy loss 15 MeV → 3.5 KW

ISOL production process



Release mechanisms:

- ✓ In-grain diffusion
- ✓ Inter-grain effusion
- ✓ Free effusion/adsorption
- ✓ Ionization



RIBs efficiency

The RIB final intensity I_{RIB} depends on:

$$I_{RIB} = (\sigma_{production}\, N_{target}\, I_{primary\ beam})\ \varepsilon_{release}\ \varepsilon_{ionization}\ \varepsilon_{post\text{-}acceleration}$$

In-Target Yields

Target efficiency

Source efficiency

Separator efficiency

$$\varepsilon_{release} = e^{-\frac{t_{release}\ln(2)}{T_{1/2}}}$$

it strongly depends on the release time and on the isotope half-life $T_{1/2}$

$$t_{release} = t_{diffusion} + t_{effusion} + N_{collisons} \cdot t_{sticking}$$

The release time depends on the properties of the target material (porosity, granularity, temperature) and on the target geometry.

Effusion calculations

Two codes (cross check)

GEANT4

(NIM A 506(2003),250-303)

Free effusion calculation considering adsorption desorption on the walls

- The disks are slabs
- The isotopes of different mass (A) are simulated by alpha particles with the proper thermal energy.
  $E_{th}=3/2(8.615*10^{-5})T\ 4/A$
- The temperature is
  T = 2273 K.

RIBO

(M. Santana Leitner Ph.D Thesis)

- In-grain diffusion,
- inter-grain effusion,
- free effusion considering adsorption desorption on the walls,
- ionization.

- The discks may be slabs, powder of fibers
- The temperature is
  T = 2273 K.

Geometry

Container : Cylindrical tube (1 mm thick): radius 4 cm; length 24 cm

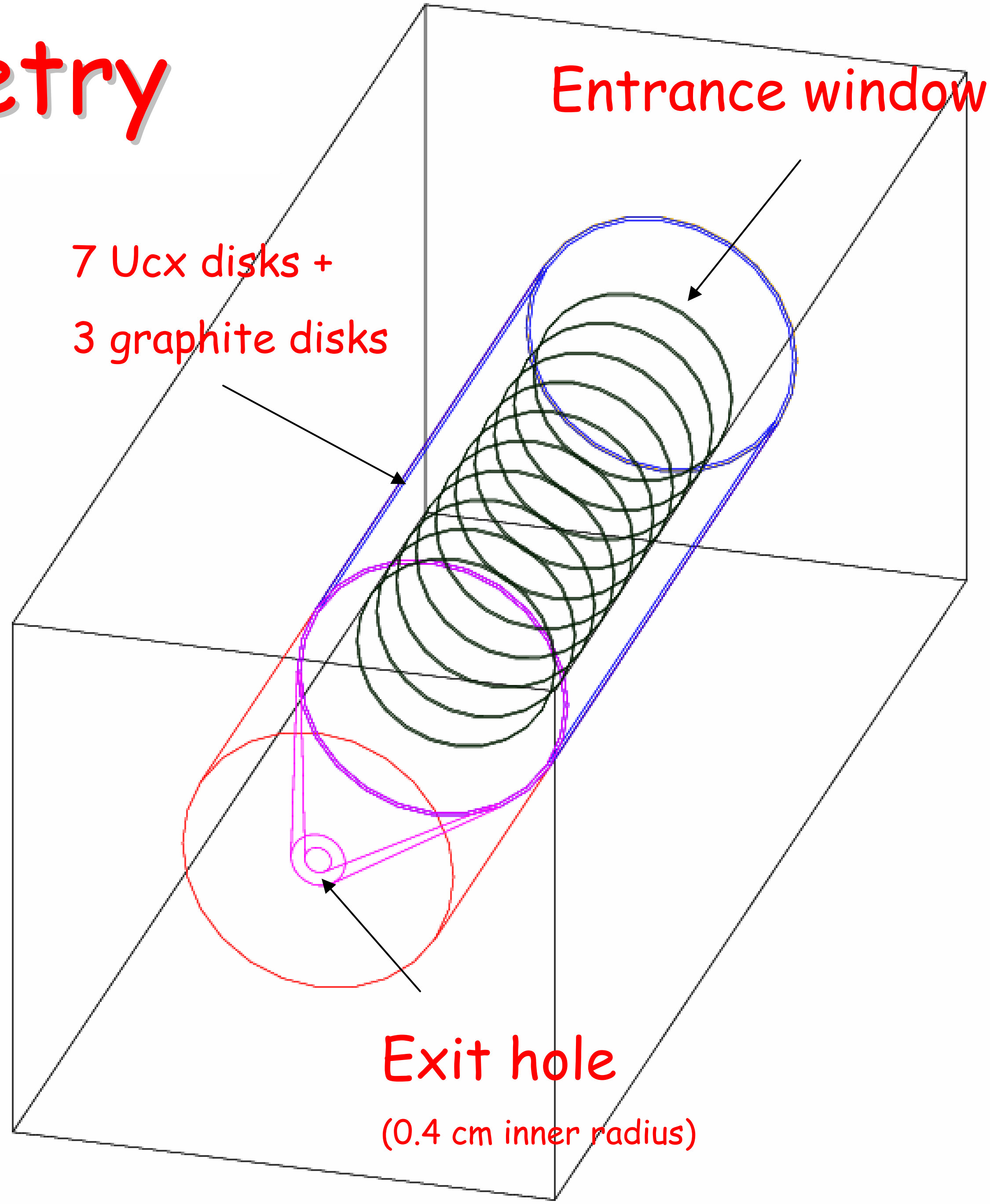
7 UCx Disks: radius 3 cm, 1 mm thick. Mass ~9 g; (ρ = 2.5 g/cm3)

3 Graphite Disks: radius 3 cm, 0.2 mm thick. (ρ = 1.75 g/cm3)

Graphite window: radius 4 cm, 0.4 mm thick.

Spacing Between disks: 2 cm

Exit cone length: 12 cm

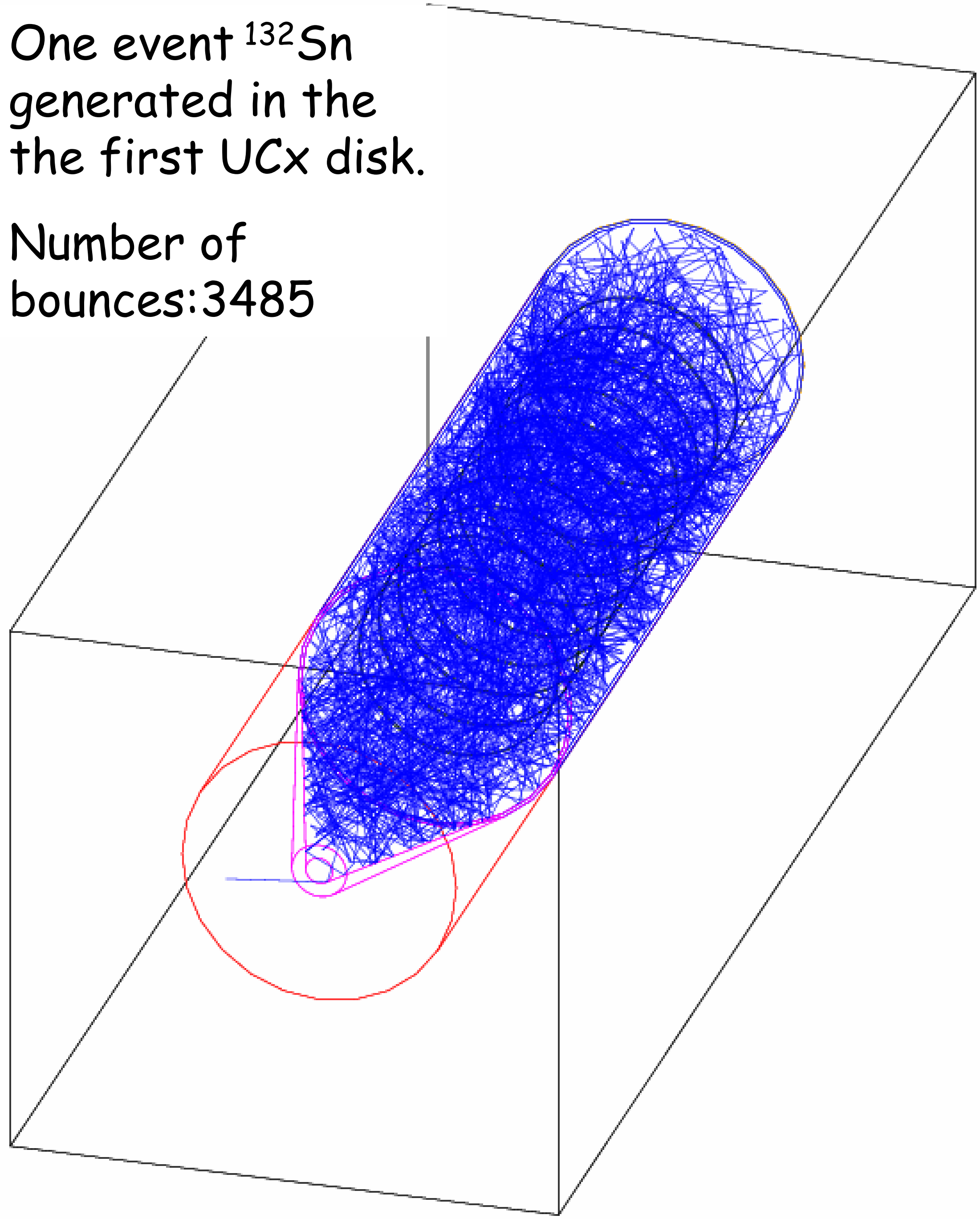


GEANT4 Example

- The events originate with the thermal velocity in the region of the UCx disks with a probability given by mcnpx calculations. The beam shape is supposed to be uniform on the disks surfaces
- Isotopes considered: ^{132}Sn ^{90}Kr, ^{81}Ga.
- When an atom strike the walls of the container or the disks it is emitted following the cosine law after the "sticking time"

One event ^{132}Sn generated in the the first UCx disk.

Number of bounces:3485



GEANT4 preliminary results
Free effusion

- 1000 events
- Average number of bounces: 4161 ± 195
- Average mean path: 166 ± 7 m

$t_{sticking}$ = 0 s

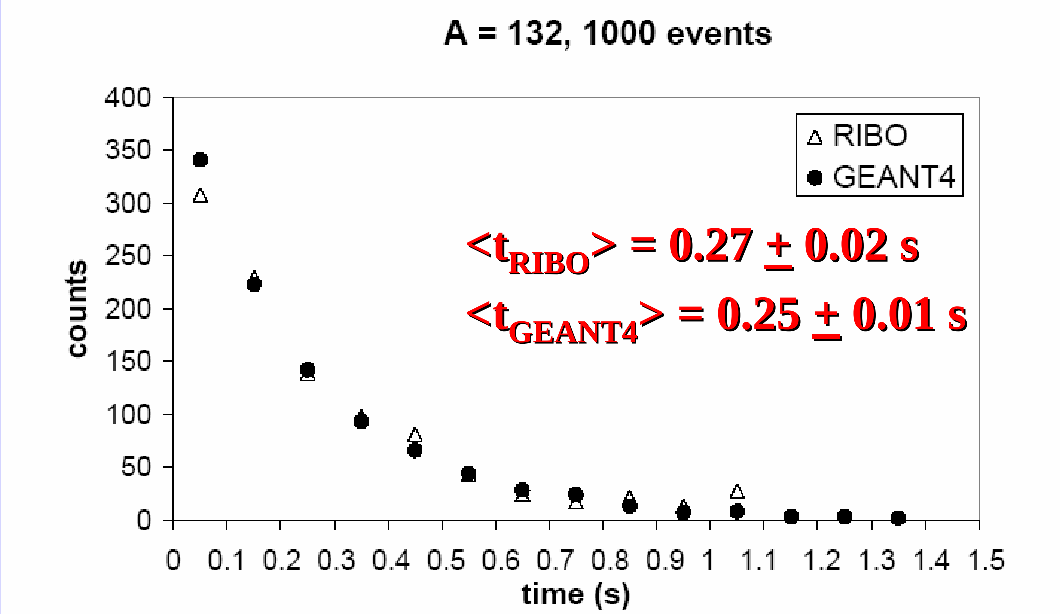
Ion ($T_{1/2}$)	$T_{effusion}$ (s)
^{132}Sn (39.7s)	0.25 ± 0.01
^{90}Kr (32.3 s)	0.20 ± 0.01
^{81}Ga (1.2 s)	0.19 ± 0.01

The effusion time constant is calculated fitting the time distribution with an exponential function

$$y = Ae^{-\frac{t}{T}}$$

No sticking time data are available for the considered ions in Graphite or UC_2

Preliminary results



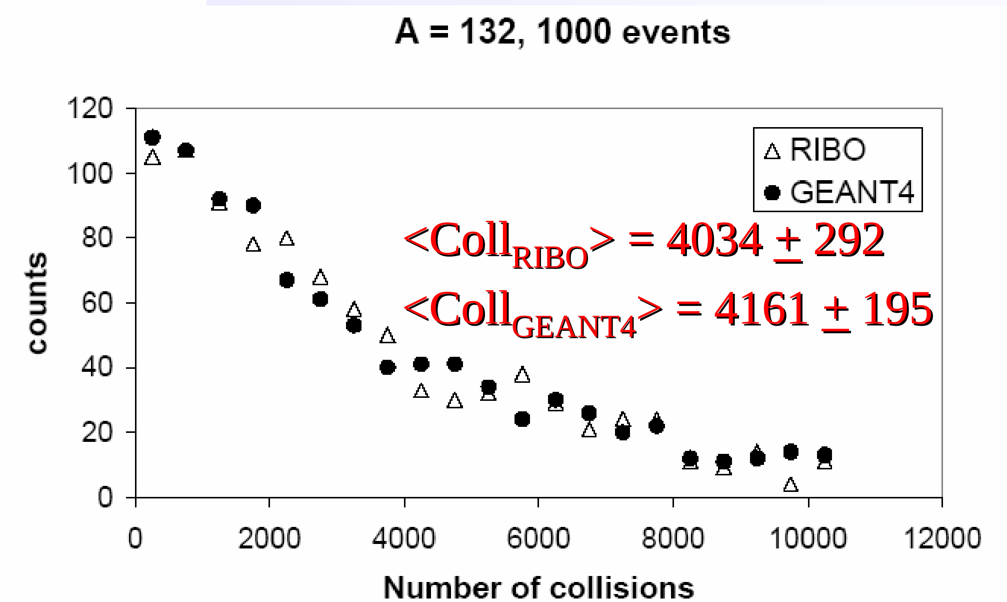
1000 events considered A=132.

RIBO-GEANT4 comparison with disks defined as Slabs.

GOOD agreement!!!!!

$\langle Path_{RIBO} \rangle = 159 \pm 10$ m

$\langle Path_{GEANT4} \rangle = 166 \pm 7$ m



RIBO results
inter-grain and free effusion

- A=132, $t_{sticking}$ = 0 s, inter-grain mean free path = 15 μm
- Free effusion

  Average path ~ 150 m

  Average number of collisions = 2700 $\pm$ 150

  $T_{free\ eff}$ = 0.27 $\pm$ 0.01 s

- Inter-grain effusion

  Average path ~ 1.5 m

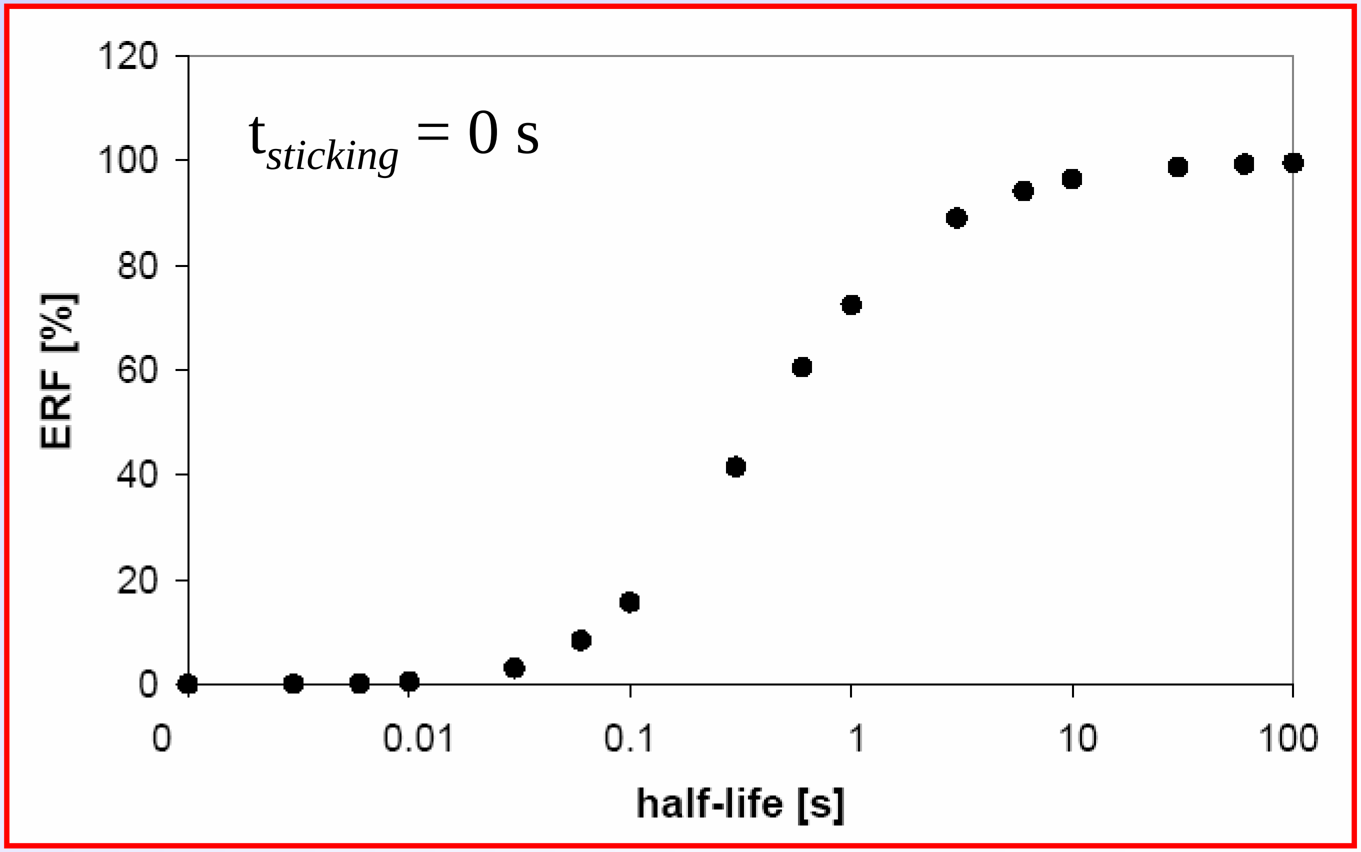
  Average number of collisions = 98610 $\pm$ 6347

  $T_{inter\text{-}grain\ eff.}$ = 0.0026 $\pm$ 0.0001 s

- T_{eff_tot} = 0.27 $\pm$ 0.01 s

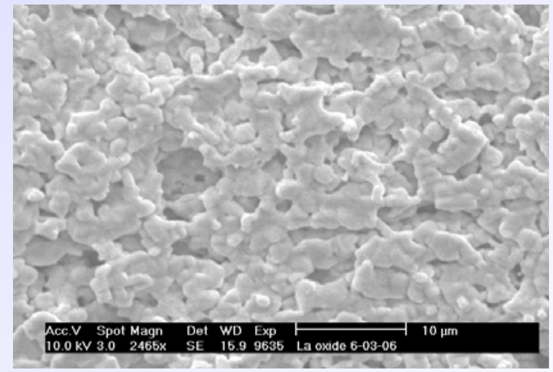
RIBO results
inter-grain and free effusion

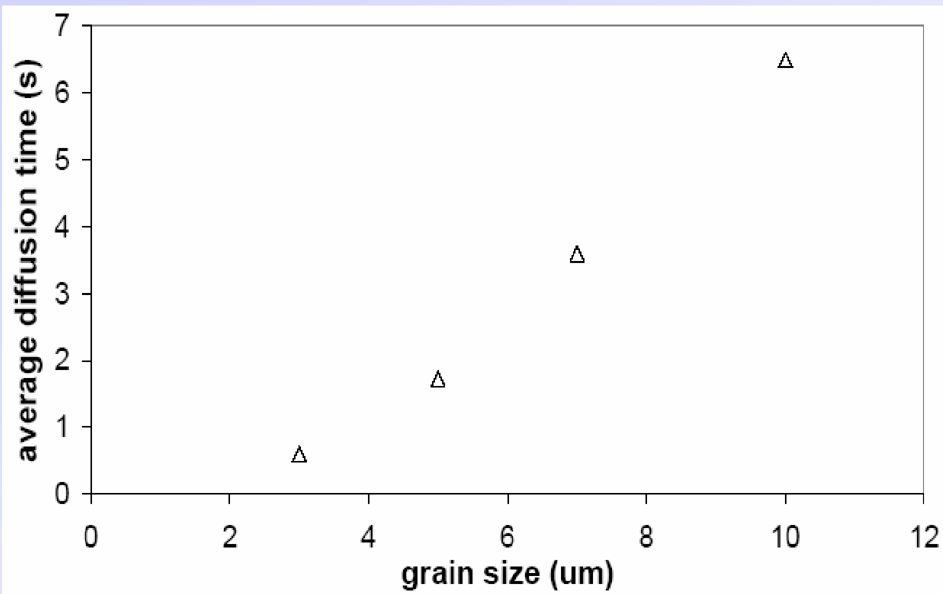
Effusion release fraction for different values of the half-life

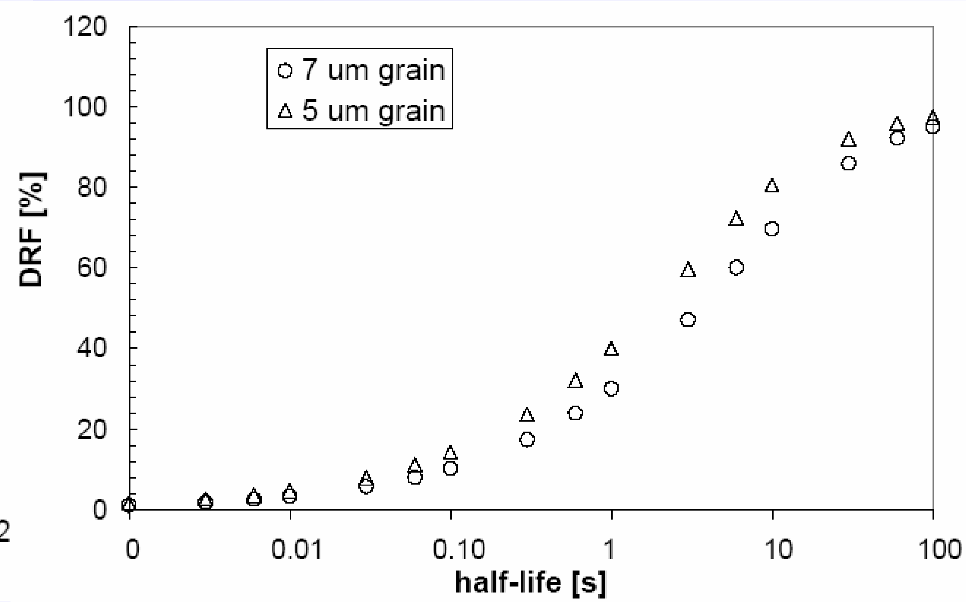


Diffusion calculations using RIBO

- A = 132, T = 2000 °C
- Inter-grain mean free path: 15 μm
- Diffuser Grain Sizes: d = 10 μm, 7 μm, 5 μm, 3 μm
- Diffusion coefficient = 9E-9 cm^2/s



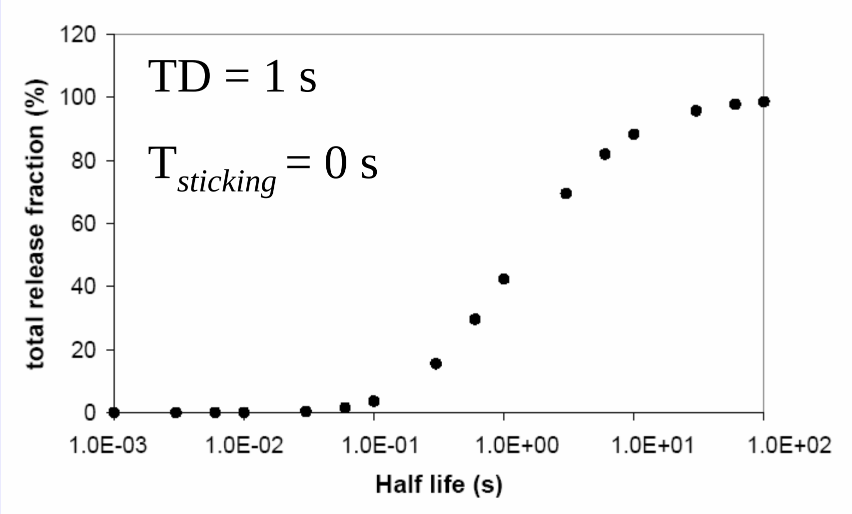


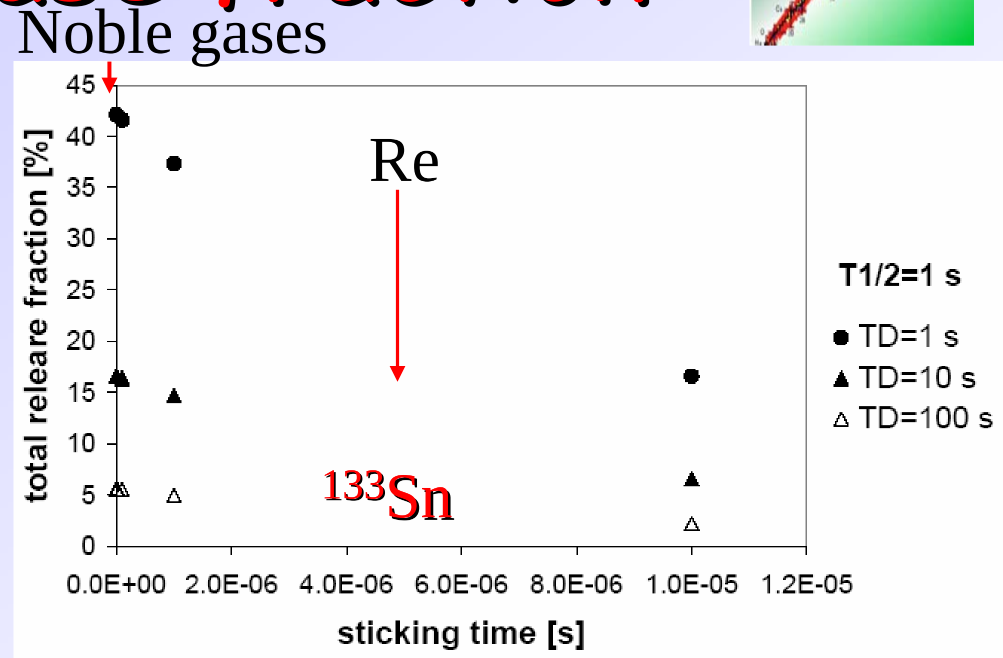


Diffusion strongly depends on diffuser Grain Size!

Marina Barbui, Vancouver, April 2006

Total release fraction

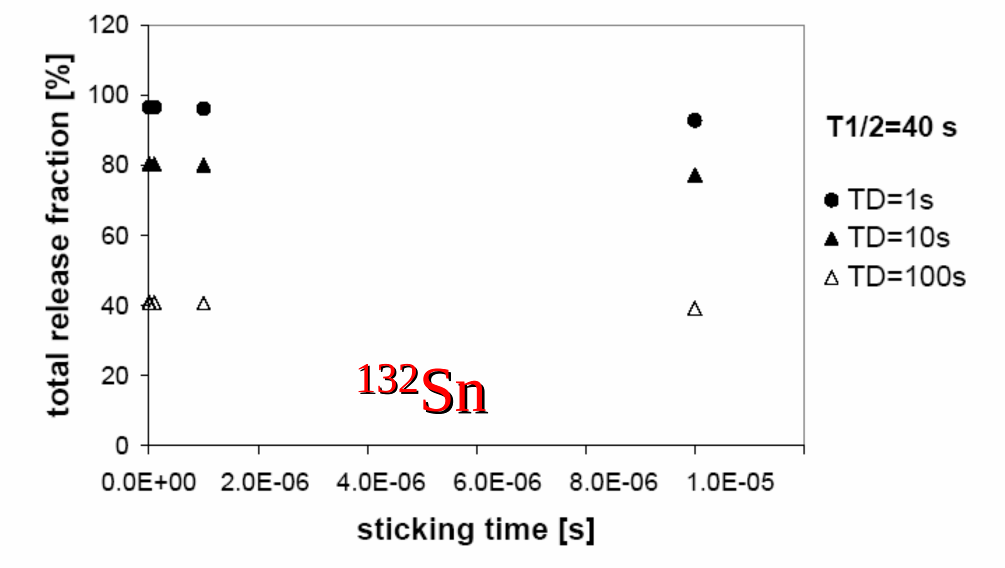




Total release fraction as a function of the sticking time for different values of the diffusion time constant τ_D.

Half-lives

$T_{1/2} \approx 1$ s & $T_{1/2} \approx 40$ s



1:5 scaled prototype

RIBO calculations

Container : Cylindrical tube (1 mm thick): radius 0.8 cm; length 5 cm

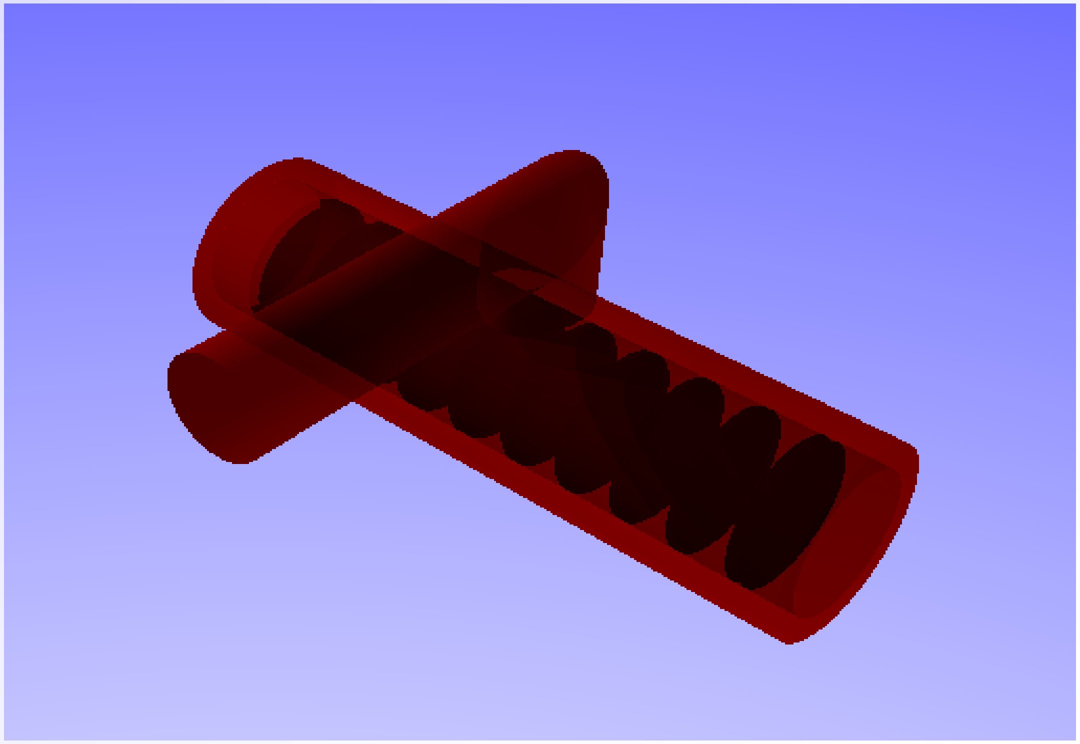
7 active Disks: radius 0.6 cm; ≈1 mm thick.

3 Graphite Disks: radius 0.6 cm. (ρ = 1.75 g/cm3)

Graphite window: radius 0.8 cm, 0.4 mm thick.

Spacing Between disks: 0.4 cm

Target dimensions allow testing the prototype at existing RIB facilities (LNS, ORNL, TRIUMF, ISOLDE)



1:5 prototype Results with RIBO

- A=132, $t_{sticking}$ = 0 s, inter-grain mean free path = 15 μm
- Free effusion

  Average path ~ 8 m

  Average number of collisions = 863 ± 36

  $T_{free\ eff}$ = 0.015 ± 0.001 s
- Inter-grain effusion

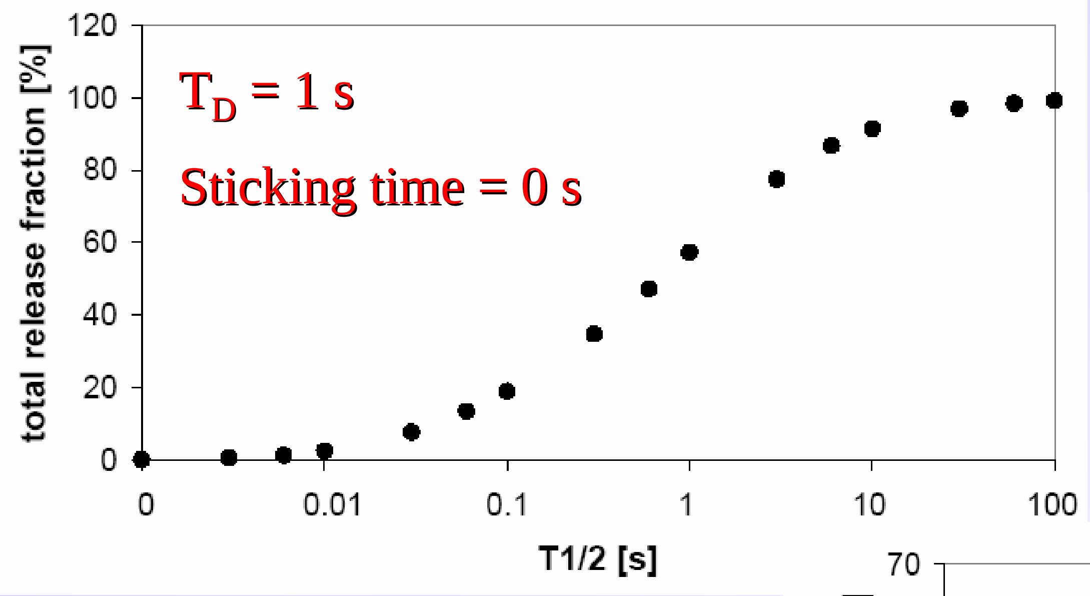
  Average path ~ 0.4 m

  Average number of collisions = 28062 ± 2544

  $T_{inter\text{-}grain\ eff.}$ = 0.0008 ± 0.0001 s
- Diffusion (7 um grain)

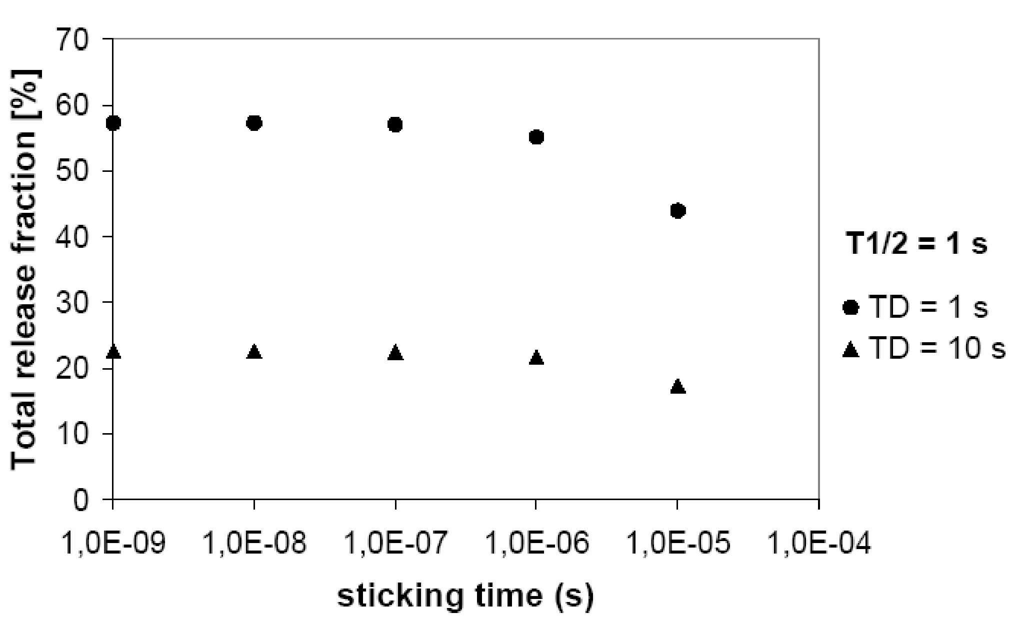
  $T_{diff.}$ = 2.9 ± 0.3 s

1:5 prototype Results total release fraction



Total release fraction as a function of the ion half-life

Total release fraction as a function of the sticking time for two different values of the diffusion time constant τ_D.



Conclusions (1)

- The release time was calculated for the direct SPES target (full-scale prototype and 1:5 scaled prototype) taking into account diffusion, inter-grain effusion and free-effusion processes.
- The total release time is dominated by the diffusion time, therefore it is very important to optimize the structure of the target material.
- An extensive study of the target materials is in progress at LNL. SiC and LaC_2 pellets have been produced and characterized, ThO_2 and UC_x pellets have been produced but still not characterized.

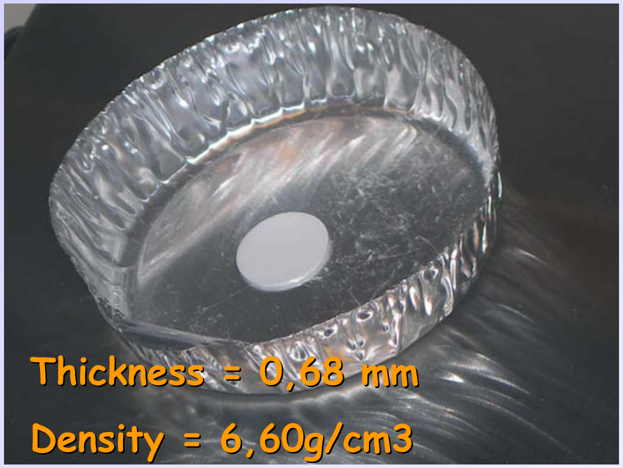
Conclusions (2)

SiC pellets

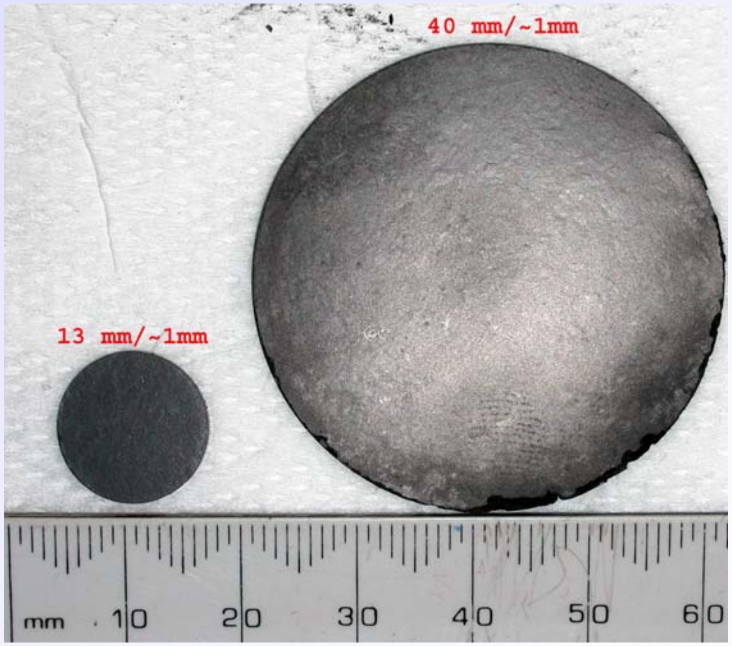
Hexoloy® SG Silicon Carbide

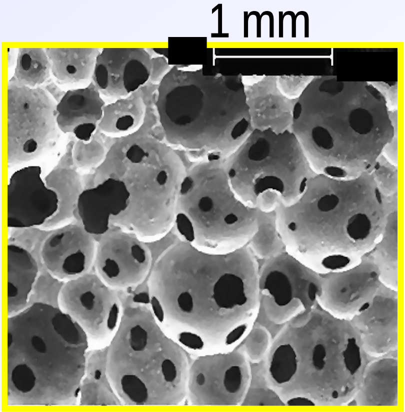
Saint-Gobain Advanced Ceramics
Structural Ceramics

ThO_2 pellets



LaC_2 pellets





New materials!
Macro-cellular
Ceramic Foams

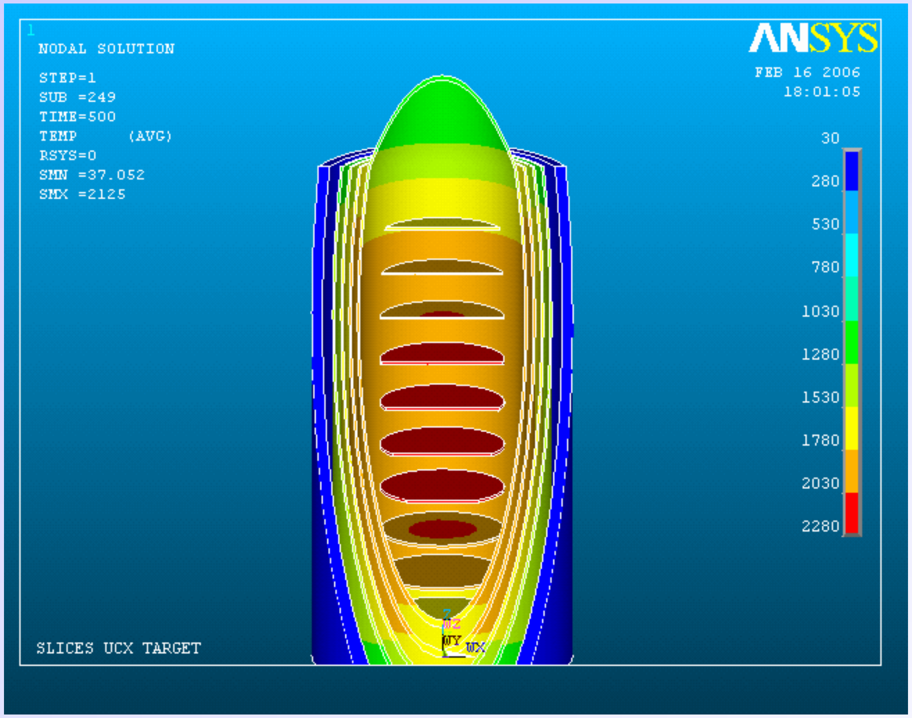
Marina Barbui, Vancouver, April 2006

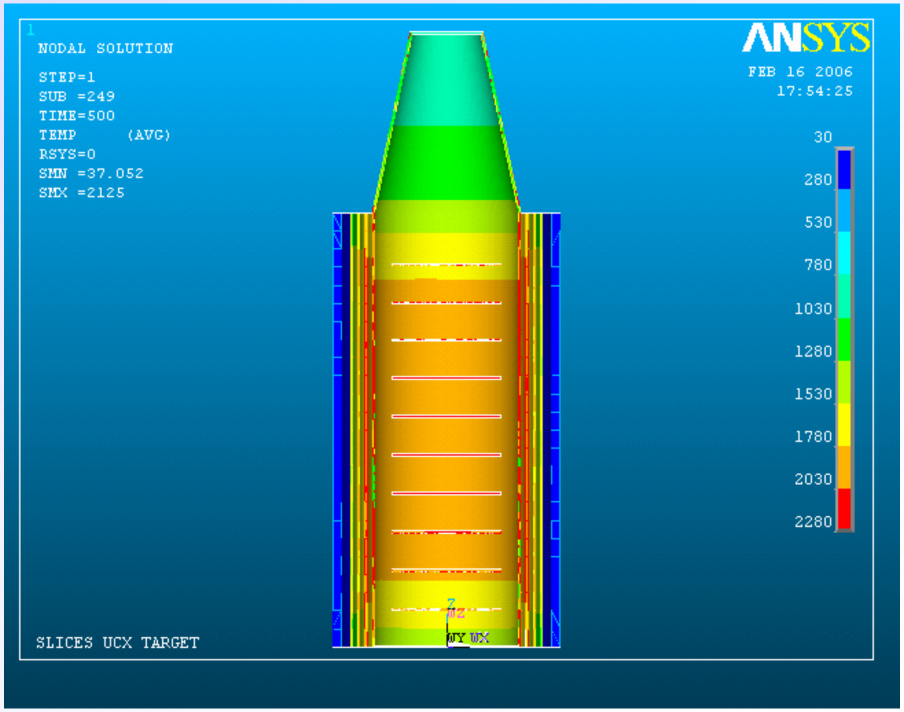
Conclusions (3)

- The total release fraction for long lived isotopes ($T_{1/2}$ > 10 s) resulted to be larger than 80% (T_D < 10 s).
- The total release fraction for short lived isotopes ($T_{1/2}$ ~ 1 s) ranges from 60% to 15% depending on the T_D and the sticking time.
- Experimental data are needed!

Thank you for your attention!

Thermal Calculation :
(Target inside chamber)





Alberto Andrighetto 2006

40 MeV Multiple Target :

Temperture distribution in the discs

disk	thickness [mm]	power [W]	Tmax [°C]	T-max in radial dir. [°C]	T-max in thickness dir. [°C]
window	0.4	189	2069	22	0
target 1	1.4	583	2167	31	36
target 2	1.4	595	2175	50	38
target 3	1.4	606	2180	68	41
target 4	1.3	570	2176	78	39
target 5	1.3	580	2186	88	40
target 6	1.3	589	2195	98	44
target 7	1.2	560	2194	101	41
dump 1	0.8	539	2136	68	3
dump 2	0.7	583	2142	68	3
dump 3	1.0	595	2145	70	4

Melting point 2350 °C

Alberto Andrighetto 2006