Estimates of ISOL beam intensities for fast neutron induced fission fragments

P. Delahaye

Contributions M. Fadil, X. Ledoux

laboratoire commun CEA/DSM CNRS/IN2P3

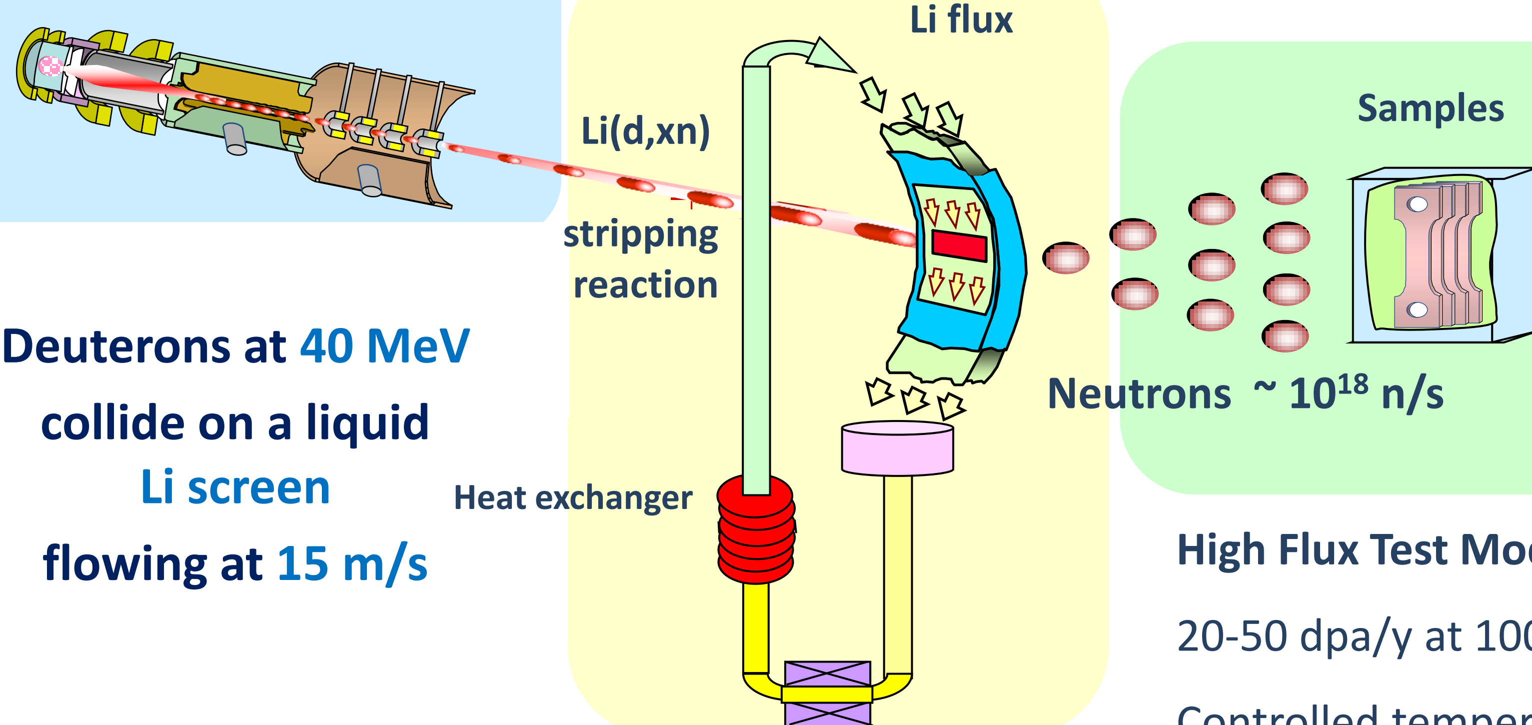
IFMIF/DONES Main Systems

Accelerator

Deuterons: 40 MeV 125 mA (5 MW)

Lithium Loop (Target)

Test (Irradiation) Module



Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

High Flux Test Module:

20-50 dpa/y at 100 cm^3

Controlled temperature: 250 < T < 1000 °C

Heat removal by high velocity Li flux (~15 m/s)

Courtesy: A. Ibarra, P. Barabaschi, A. Moeslang, J. Knaster, R. Heidinger for the IFMIF Team

A flux of neutrons of ~ 10^{18} $m^{-2}s^{-1}$ is generated with a broad peak at around 14 MeV

ISOL method
"Isotope Separation On Line"

- A primary beam impinges on a thick target / n converter
- Reaction products diffuse out of the target to an ion source
- After ionization and post-acceleration, the reaction products are separated

The NBI cyclotron around the time of the experiment. The person is the head of the cyclotron group, Professor J.C. Jacobsen.

P. G. Hansen, Nuclear Physics News 11, n°4

The NBI isotope separator in 1951. The elements are the high-voltage terminal and ion source (top), the analyzing magnet (behind), and the dispersion chamber with the collector slit used in the experiment (in front).

Niels Bohr Institute
O. Kofoed – Hansen
K. Ove Nielsen

11 MeV deutons on Be target
10 kg UO2 (!)

IFMIF/DONES Main Systems

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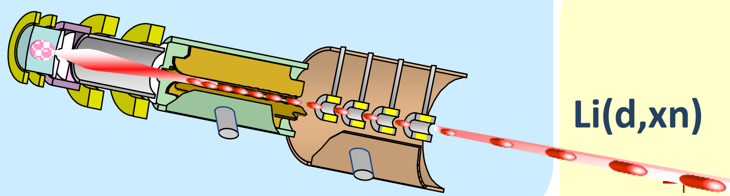


Deuterons at 40 MeV

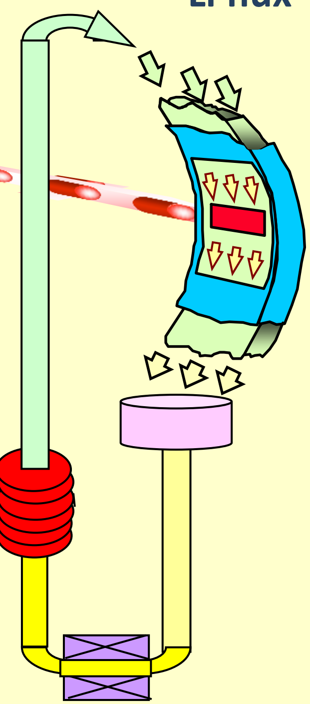
collide on a liquid

Li screen

flowing at 15 m/s

Courtesy: A. Ibarra, P. Barabaschi, A. Moeslang, J. Knaster, R. Heidinger for the IFMIF Team

Lithium Loop (Target)



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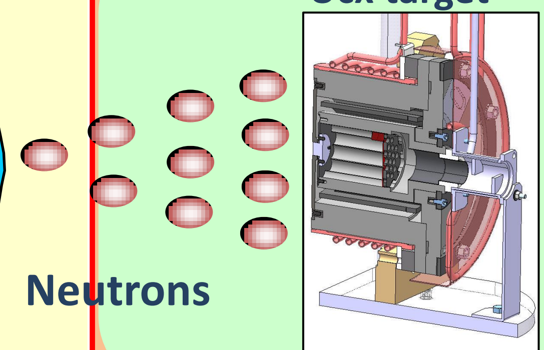


SPIRAL 2 phase 2 - like target

ISOL Target:

10^{12} - 10^{14} fission / s

Controlled temperature: 1800 < T < 2000 °C

A flux of neutrons of ~ 10^{18} $m^{-2}s^{-1}$ is generated with a broad peak at around 14 MeV

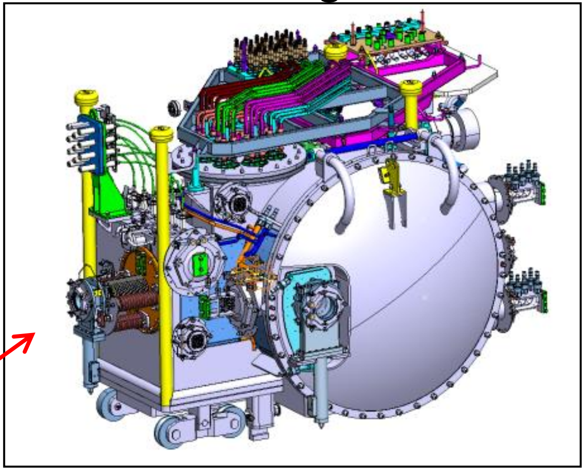
SPIRAL 2 – phase 2 radioactive ion beams

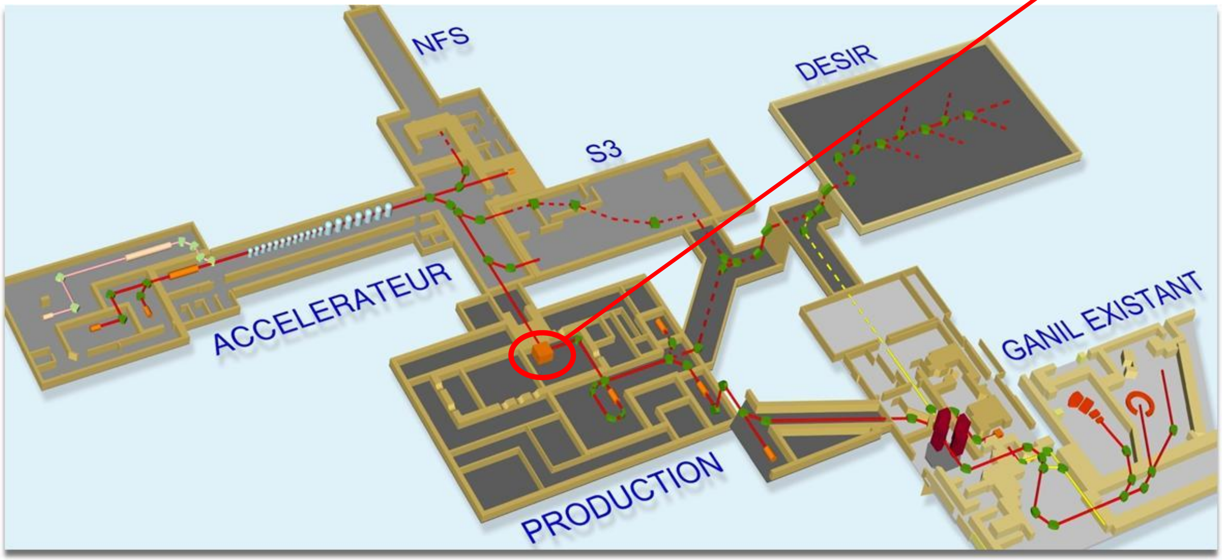
- ❑ **Deuteron beam on neutron converter**
  - •UCx target + ECRIS
  - •UCx target + LIS
  - •UCx target + Febiad
  - •UCx target + SIS

5 mA 40 MeV d
Graphite wheel
200kW on converter

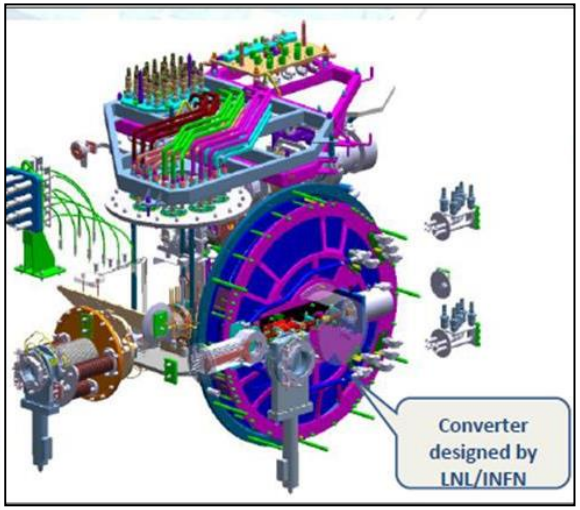
- ❑ **Other beams / other targets**

Converter + target module



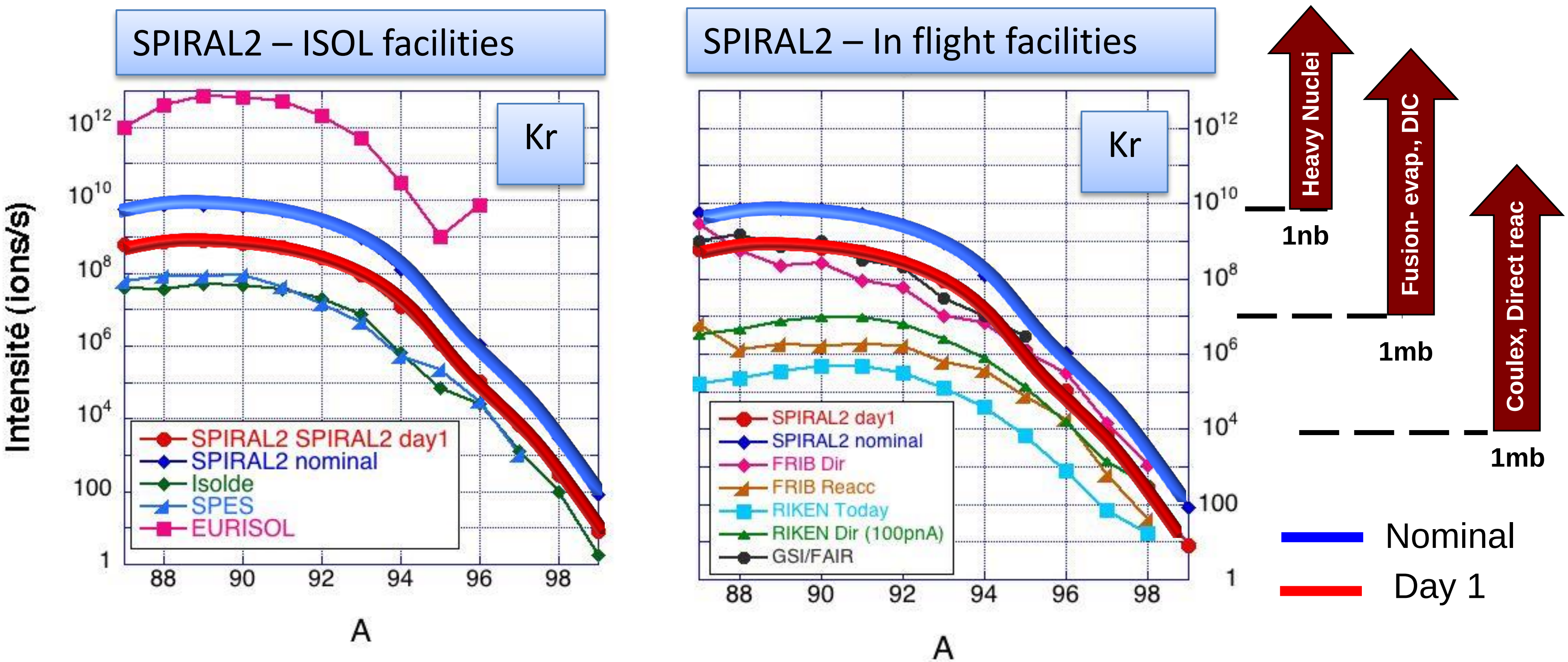


Converter



SPIRAL 2: Advanced RIB facility

Experiments with Radioactive Ion Beams at low cross section
and with very exotic nuclei at a few MeV/nucleon



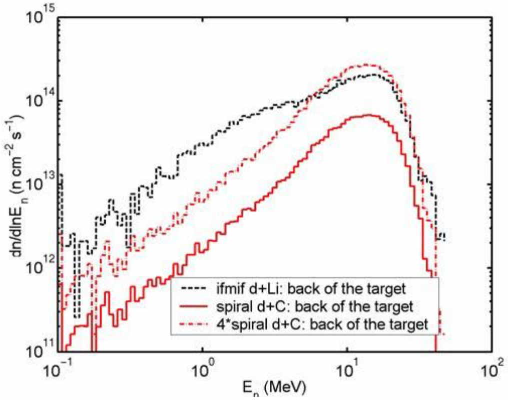
High quality ISOL RIBs
- high intensity, optical quality and purity
SPIRAL 2 also includes light & heavy RIBs, intense stable beams

Multi beam capabilities
Months of beam time
World-class arrays and detectors

Courtesy H. Savajols

Comparison of neutron fluxes

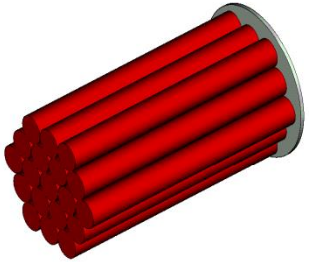
- SPIRAL 2 neutron flux characteristics
  - Neutron spectrum a bit harder than IFMIF / Liquid Li target in DONES

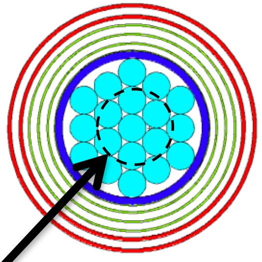


D. Ridikas et al, internal report, 2003, CEA Saclay

Potentially 10* more neutron/cm²/s in 10* larger volume for IFMIF

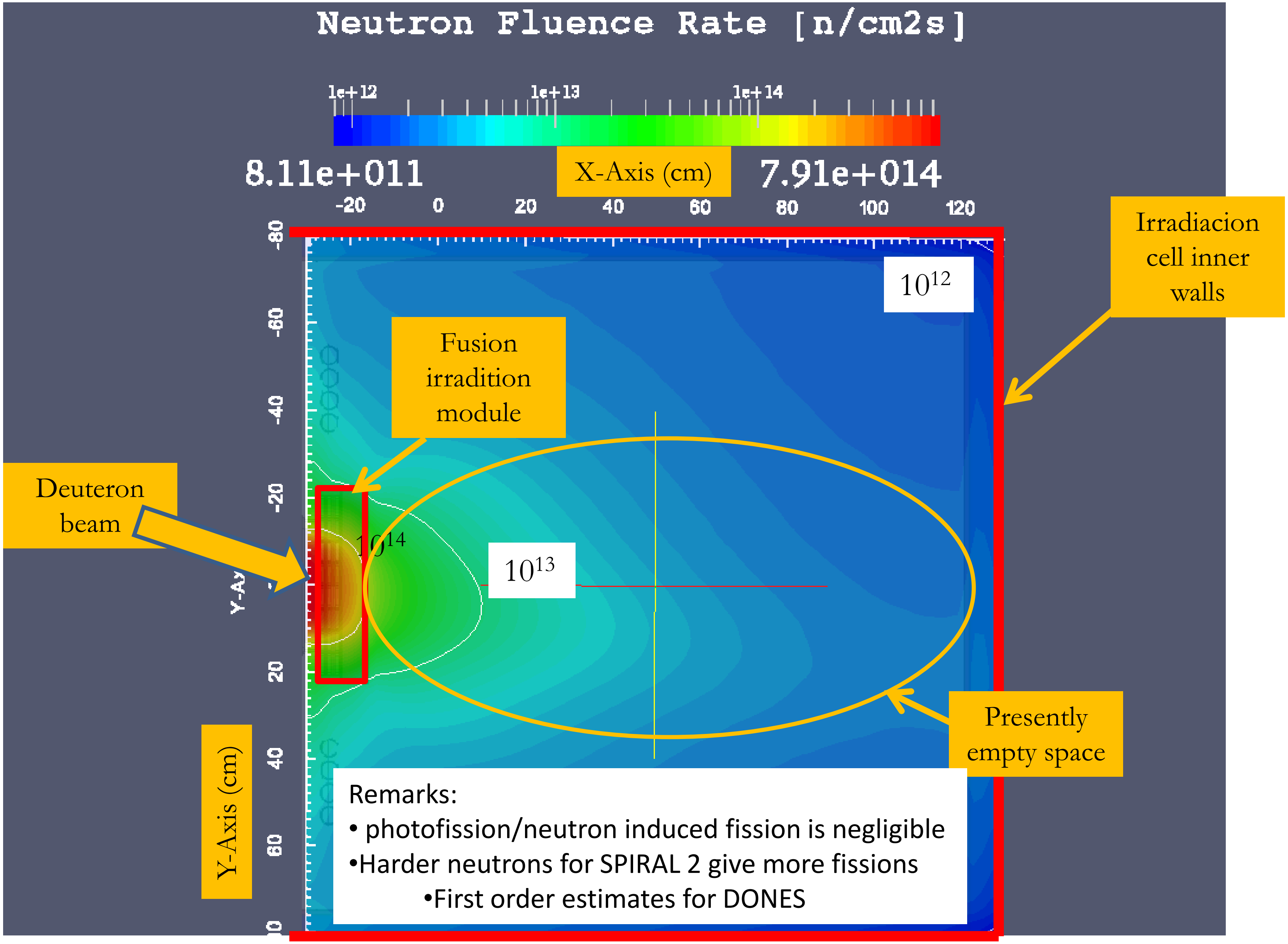
  - SPIRAL 2: Average flux on target:
    - **200 kW with large high density UCx targets** (10g/cm^3)
      - **10^{13} n/s/cm²**
      - **2.8×10^{13} fissions / s**
    - **50 kW with small normal density UCx targets** (3.5g/cm^3)
      - **2.5×10^{12} n/s/cm²**
      - **2×10^{12} fissions / s**





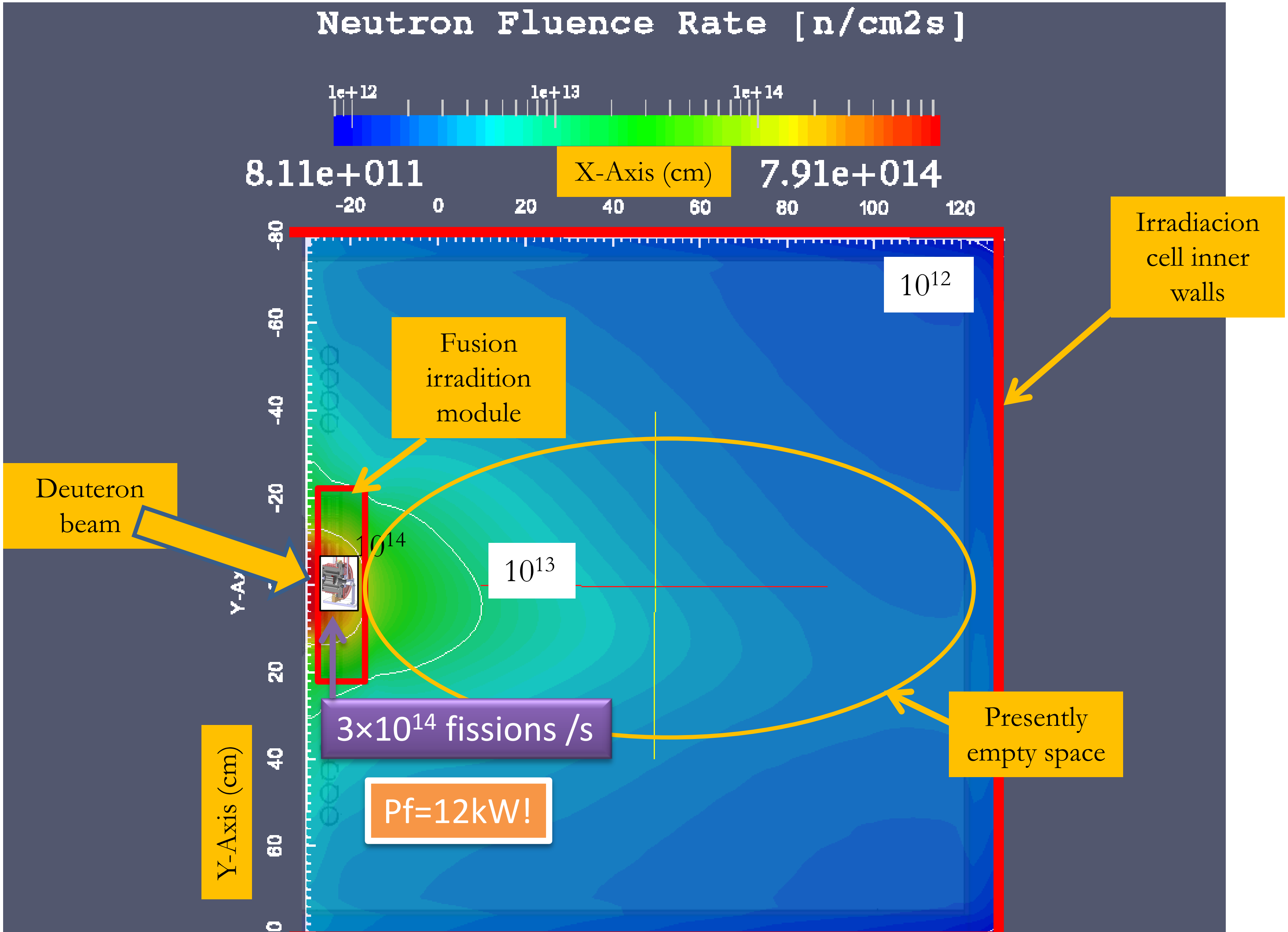
M. Fadil, B. Rannou et al, NIM B 266 (2008) 4318–4321

DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)



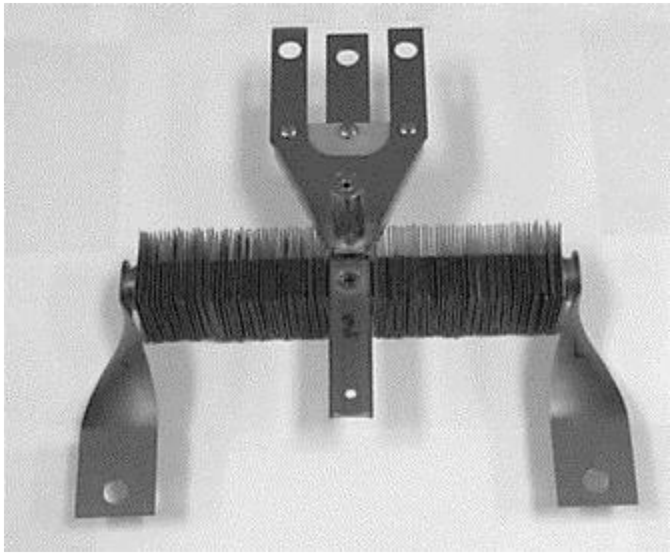
Remarks:
- photofission/neutron induced fission is negligible
- Harder neutrons for SPIRAL 2 give more fissions
  - First order estimates for DONES

DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)



High power targets

- See for example ISAC high power targets



P. Bricault et al, NIM B 204(2003)319

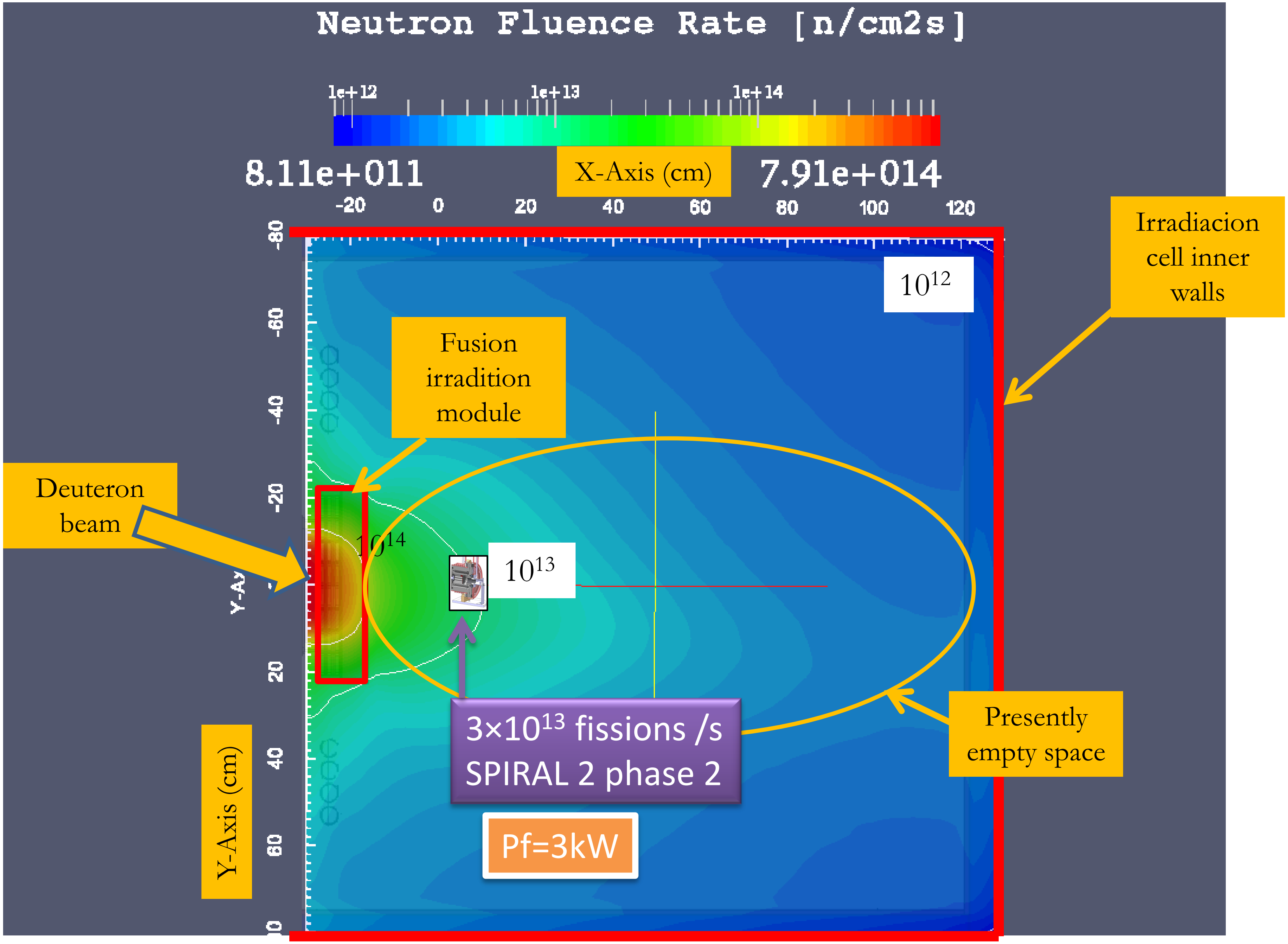
Ta fins to be adapted to a SPIRAL 2 phase 2 –like target?

Or normal density target / nanostructured UCx targets (ACTILab)

* Pf~4kW, 10^{14} fissions/s

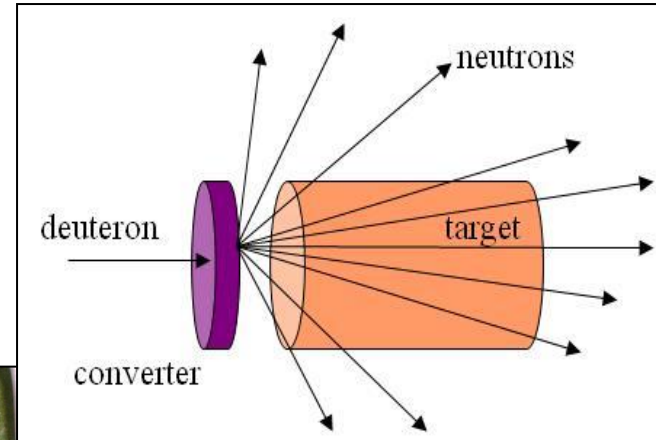
* Higher release efficiency for short lived isotopes

DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)

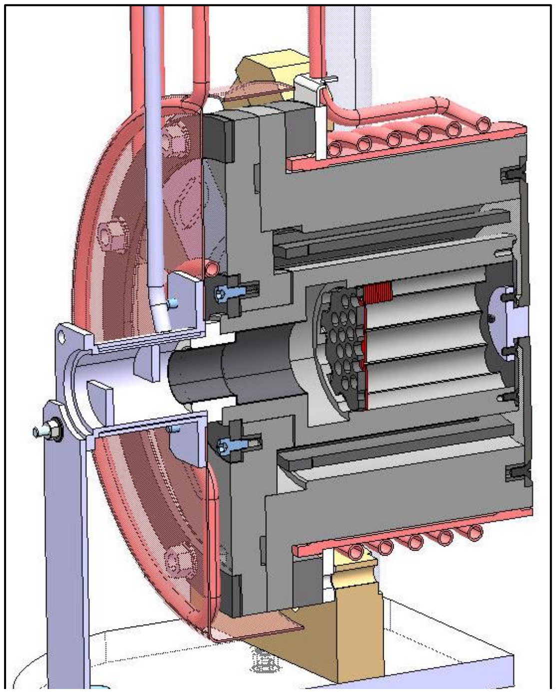


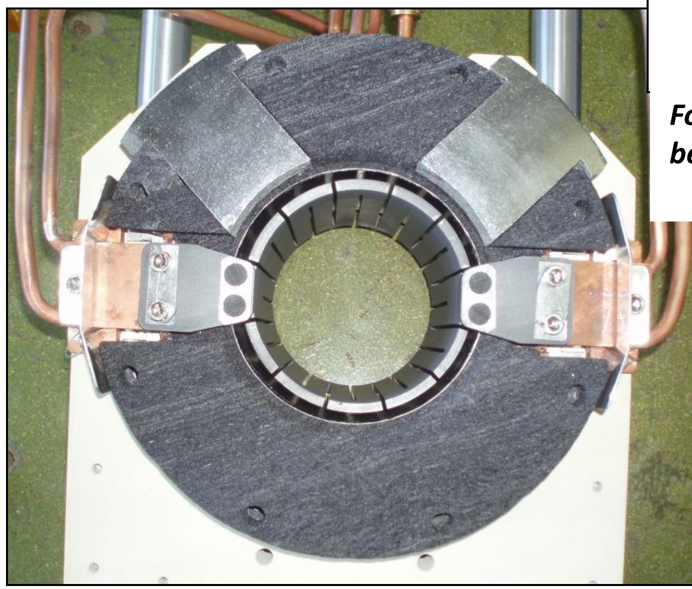
Spiral 2: the oven for the UCx target

- 5.10^{13} fission/s with 5 mA / 40 MeV deuteron.
- Coupled with ECRIS, LIS, FEBIAD or SIS ion source
- Temperature of 2000°C
- Working period : 3 months
- 19 series of 80 Ucx pellets (Ø 15; thickness 1mm)



For optimized production, the converter must be as close as possible to the target.



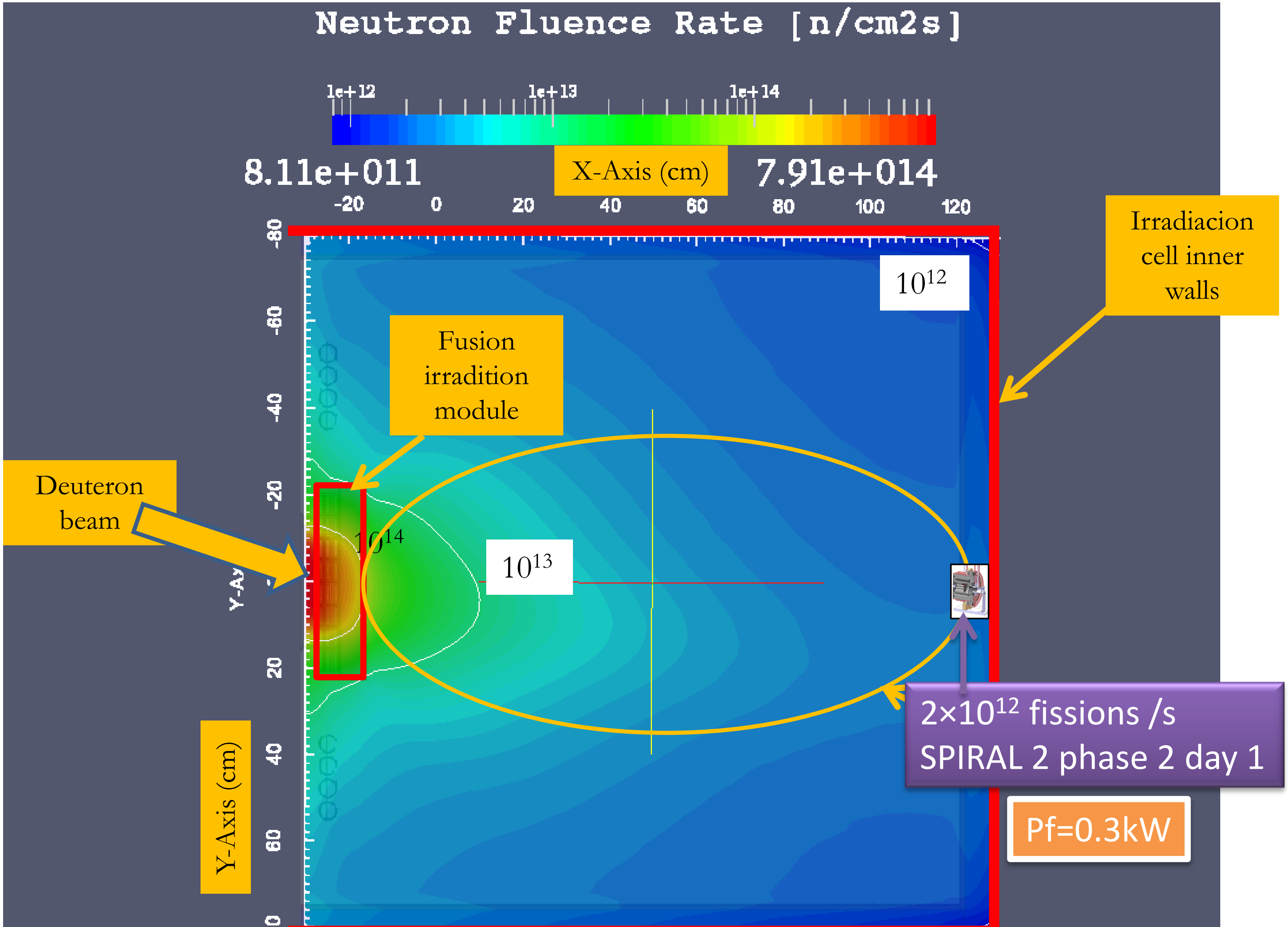


A prototype in carbon

- Easier than Tantalum to reach more than 2000°C
- Lifetime lower due to high evaporation rate of carbon

~10^{13} fissions / s with nanostructured UCx

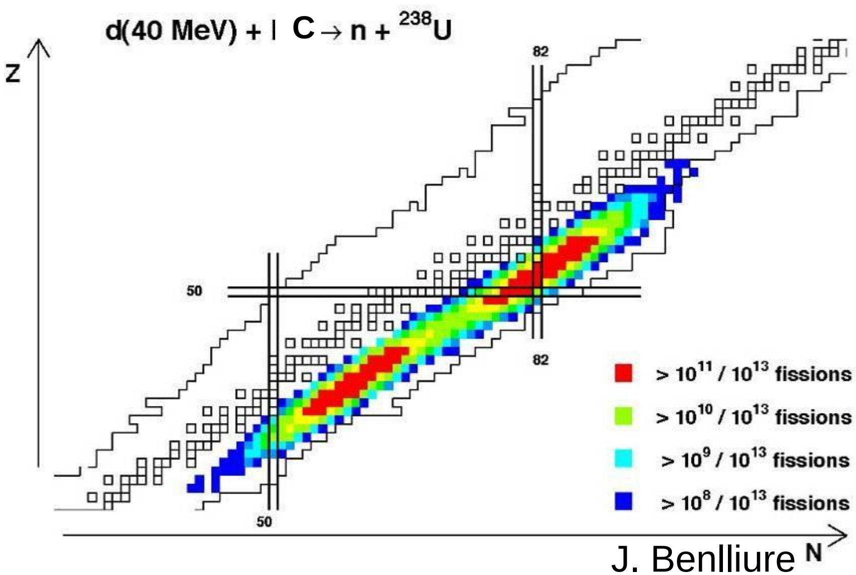
DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)



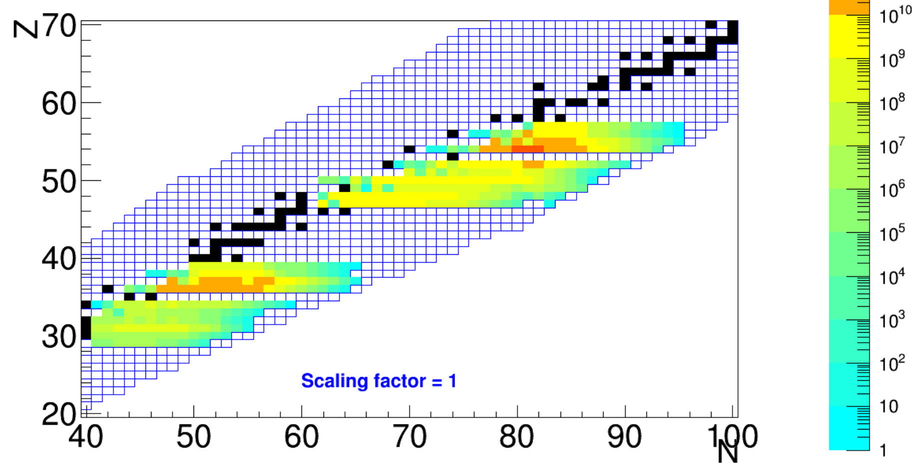
Radioactive ion beam intensities

In target yields

Y_{target}



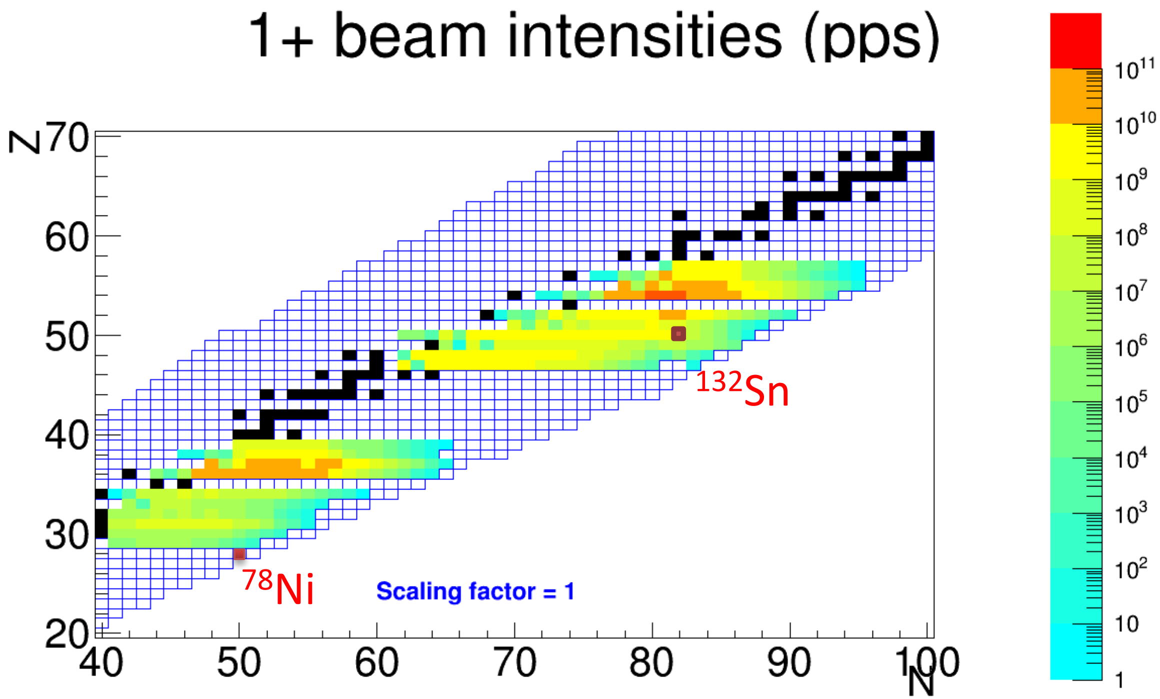
1+ beam intensities (pps)



$$Y_{1+} = Y_{target} * \varepsilon_{release} * \varepsilon_{ionisation} * \varepsilon_{transport\ 1}$$

Y_{target}	$\varepsilon_{release}$	$\varepsilon_{ionisation} * \varepsilon_{transport\ 1}$
MCNPx FISPACT	On-line data ISOLDE, Parnne data Litterature (Kirchner)	On-line data ISOLDE data

Radioactive ion beam intensities



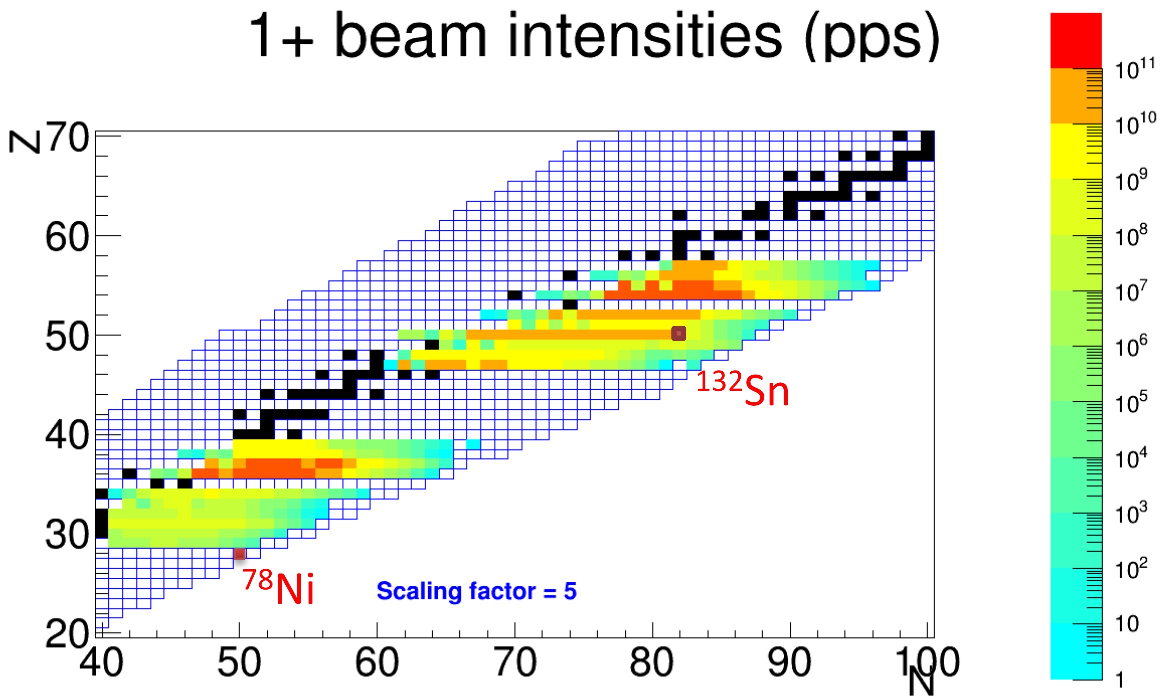
On the side of the irradiation cell

~SPIRAL 2 day 1

$$Y_{1+} = Y_{target} * \varepsilon_{release} * \varepsilon_{ionisation} * \varepsilon_{transport\ 1}$$

- Y_{target}: MCNPx, FISPACT
- $\varepsilon_{release}$: On-line data, ISOLDE, Parnne data, Litterature (Kirchner)
- $\varepsilon_{ionisation} * \varepsilon_{transport\ 1}$: On-line data, ISOLDE data

Radioactive ion beam intensities



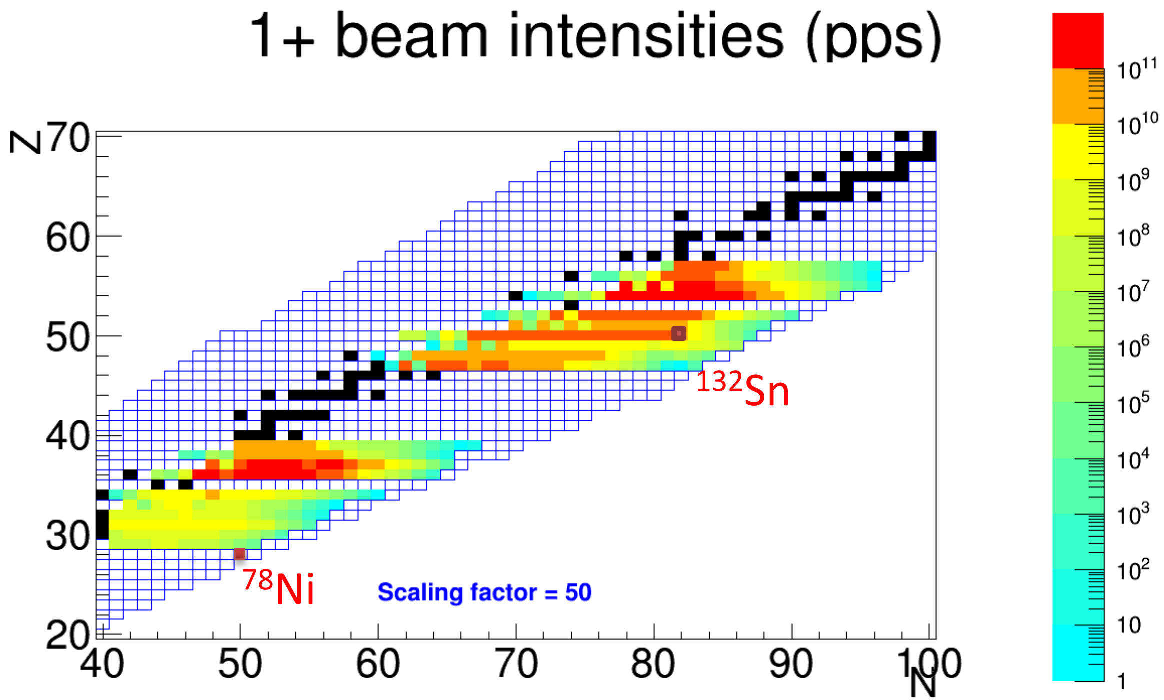
Close to the fusion irradiation module

~SPIRAL 2 nominal

$$Y_{1+} = Y_{target} * \varepsilon_{release} * \varepsilon_{ionisation} * \varepsilon_{transport\ 1}$$

- Y_{target}: MCNPx, FISPACT
- $\varepsilon_{release}$: On-line data, ISOLDE, Parnne data, Litterature (Kirchner)
- $\varepsilon_{ionisation} * \varepsilon_{transport\ 1}$: On-line data, ISOLDE data

Radioactive ion beam intensities



In the fusion irradiation module

~10 * SPIRAL 2 nominal

Intermediate step towards EURISOL

$$Y_{1+} = Y_{target} * \varepsilon_{release} * \varepsilon_{ionisation} * \varepsilon_{transport\ 1}$$

MCNPx
FISPACT

On-line data
ISOLDE, Parnne data
Litterature (Kirchner)

On-line data
ISOLDE data

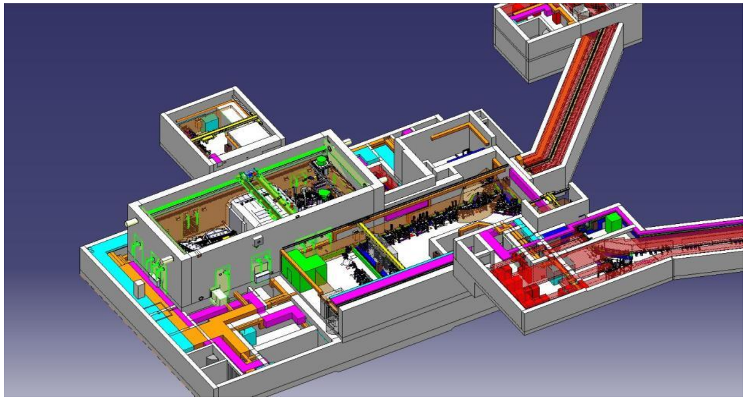
Comments on the ISOL target ion source

- Experience from ISOLDE, TRIUMF, SPIRAL, HRIBF, ALTO, ACTILab collaboration
  - Small integrated systems have to be prefered over large volumes
    - Higher release efficiencies due to shorter effusion times
    - Large volumes are only beneficial for long lived isotopes (ex ^{132}Sn)
    - A target size like the one of SPIRAL 2 nominal is already large
  - NanoUCx materials developped in the frame of ACTILab
    - nanoUCx is a low density material presents generally (much) better yields than the standard (high) density Ucx
  - Improving intensities by orders of magnitude can be done by dedicated R&D
    - Grain size of targets: towards nanostructured materials
    - Molecular beams for refractory elements
    - Efficient ionization
      - Lasers, FEBIAD (+Lasers), ECR sources, Surface ionisation sources

Large volume targets limited to some applications for long-lived isotopes
The resulting intensities are quite often marginally a question of fissions / s!

Comments on the ISOL target ion source

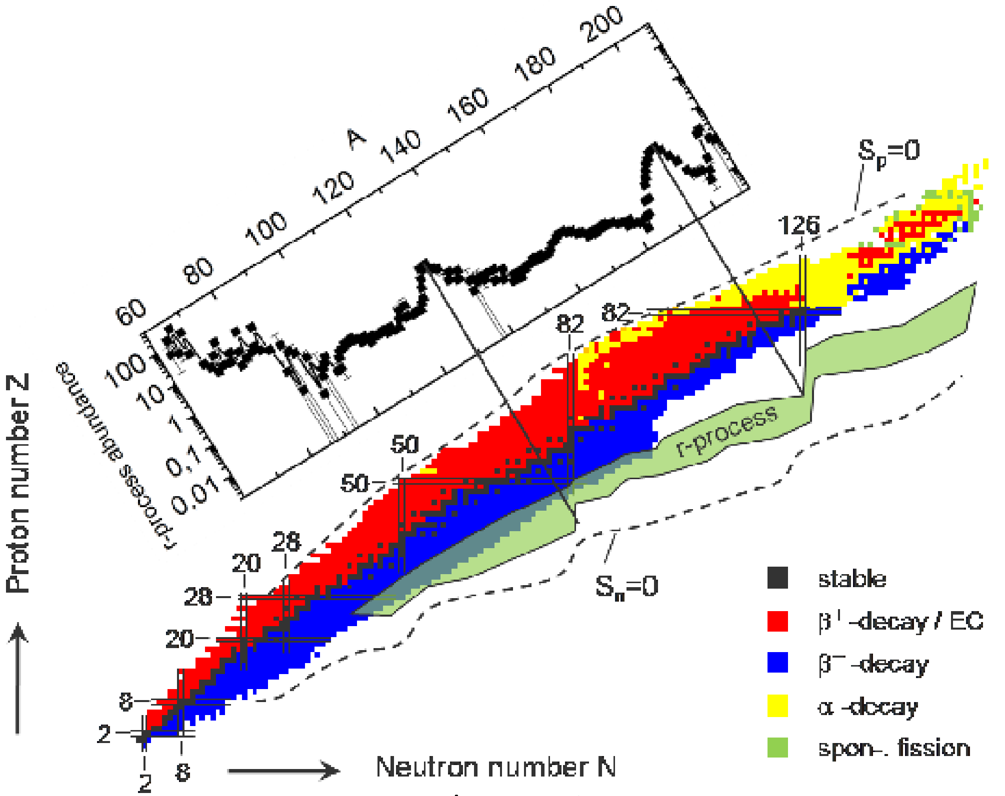
- Required infrastructure
  - Hot cell
  - Target storage
  - Remote handling
  - Target front end
  - Beam lines, separators
    - 1 or 2 targets? Or more…?
  - Experimental areas
    - DESIR like?
    - Post-acceleration?
  - Radiation Shielding (target bunker, experimental areas)
  - Nuclear ventilation
  - Gas storage
  - Services
    - Power supplies
    - Cooling
    - Etc
  - Staff and offices
  - Etc



SPIRAL 2 phase 2 production building

The target and ion source is the tip of the iceberg!

Physics cases and instrumentation



R. Krücken, arXiv:1006.2520v1

A vast unknown territory to study

Towards EURISOL

See for example : Updated Physics and Instrumentation case for ISOL facilities and for EURISOL
ENSAR Final deliverable report

r- process and nuclear structure far from stability

DESIR – like facility

Masses,
T1/2,
Beta decay spectroscopy
Gamow strength
Bn
Spins, moments
Charge radii
...

Traps

Tape stations, γ arrays, TAS, n detector

laser spectroscopy

Postaccelerated beam facility

Coulomb excitation, transfer reactions
DIC , FE Superdeformation and highly deformed states ...

Assuming E<=10-15AMeV/n

γ arrays, wide variety of detectors, active targets, spectrometers etc

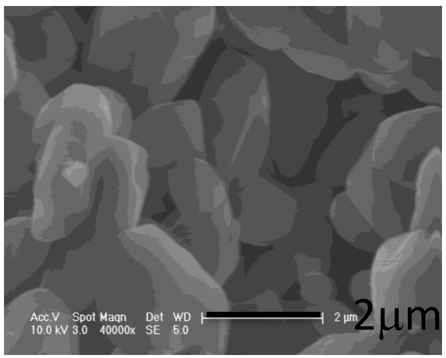
Conclusions

- Preliminary considerations
  - High neutron flux at IFMIF/DONES gives interesting perspectives for RIB production using a SPIRAL 2 like target
    - Up to 10 times higher flux than from SPIRAL 2
  - More detailed studies needed for
    - The actual fission rate in the target
    - According to the possible target location
  - Using one or several targets at DONES require a developing a complex/advanced infrastructure
  - The physics cases should motivate the project
    - Defining instrumentation
    - Depending on the interest, post-acceleration may be envisaged at at short or longer term
- Not considered but should be considered
  - Other targets (examples)
    - $^{9}Be(n,a)\,^{6}He$ (BeO target)
    - $^{11}B(n,a)\,^{8}Li$ (BN or B_4C target)

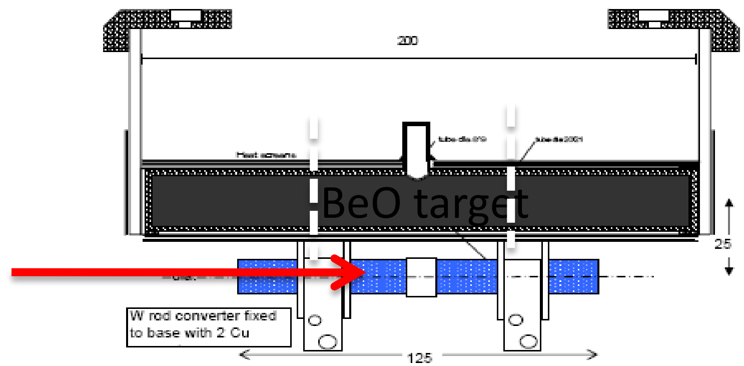
Thanks a lot for your attention!

^6He from BeO target

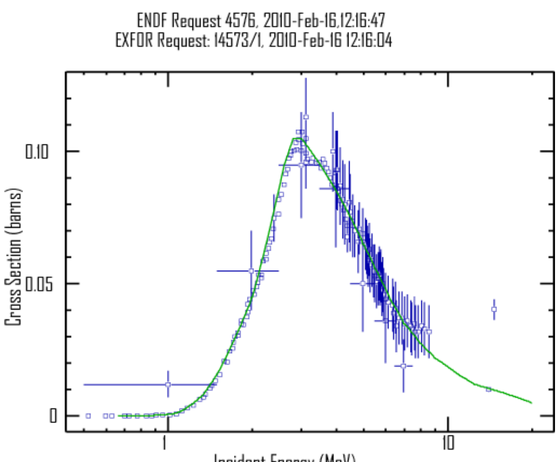
Collaboration ISOLDE – GANIL
SOREQ – Weissman Institute



Small microstructure = quick diffusion

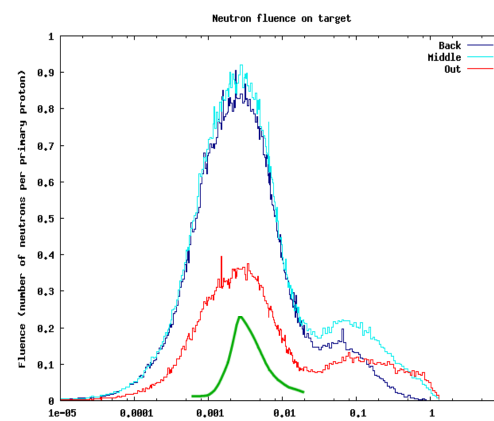


Proton beam on W converter

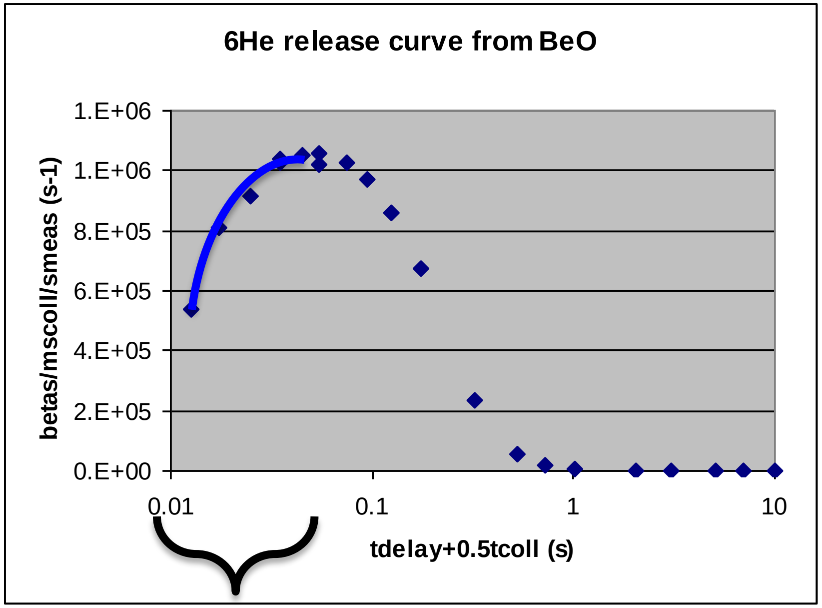


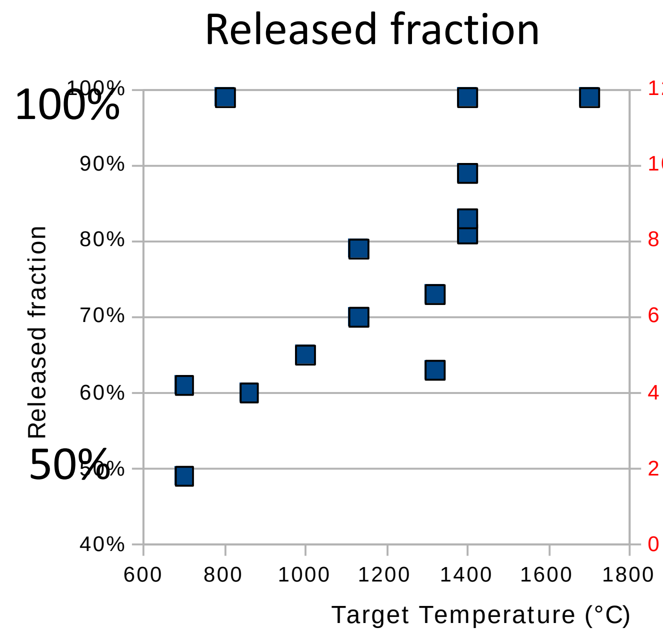
Neutron flux measurement with the activation foil method

FLUKA simulation results gives reasonable agreement



^{6}He from BeO target - results





[redacted]

t_{rise} is a characteristic of the effusion

(Ionisation in VADIS!)

Rapid diffusion and effusion!

Record intensities for ISOLDE: 3^{E}8 /uC

Up to **4^{E}11 pps** for SPIRAL 2 (5mA d on converter)

(20% ionization in ECRIS)

New opportunities for $\beta-\nu$ angular correlation measurements!

Using LPCtrap or the double MOT at DESIR

Nano structured UCx targets

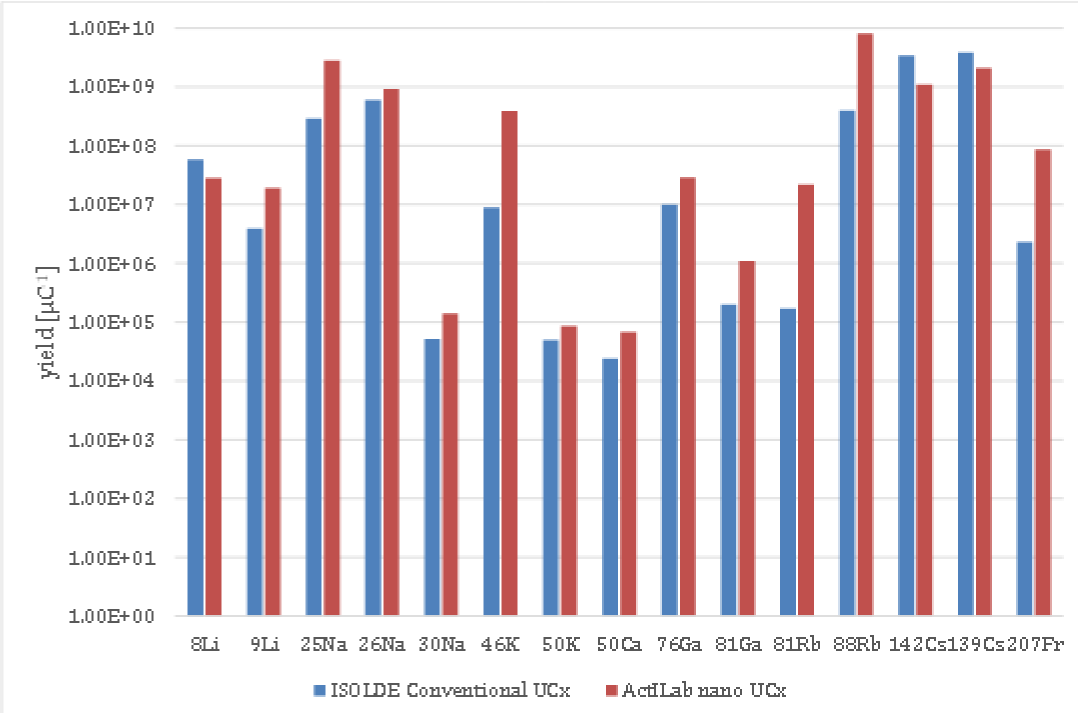


Figure 14. Preliminary results of the ActILab nano-structured UCx (#525UC-Re) in comparison to conventional ISOLDE UCx targets. The references are mostly taken from the ISOLDE yield database, or in the case of 26Na from a measurement on target #410 UC-W, and for 88Rb from #301UC-Ta

Generally higher yields than standard density targets

From ACTILab final report

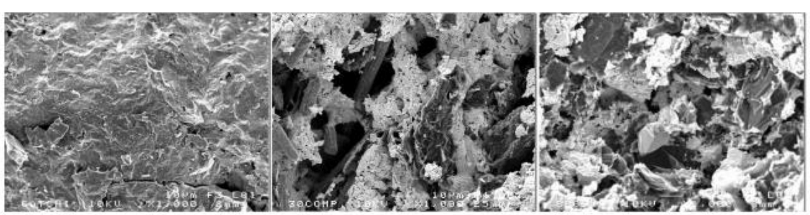


Figure 6. SEM images. From left to right: compact structure of high-density UC, open structure containing UC_2 grains and carbon fibers, open structure containing UC_2 grains and graphite residual clusters (black blocks).

Different structures according to density