TARGET DEVELOPMENT FOR S^3

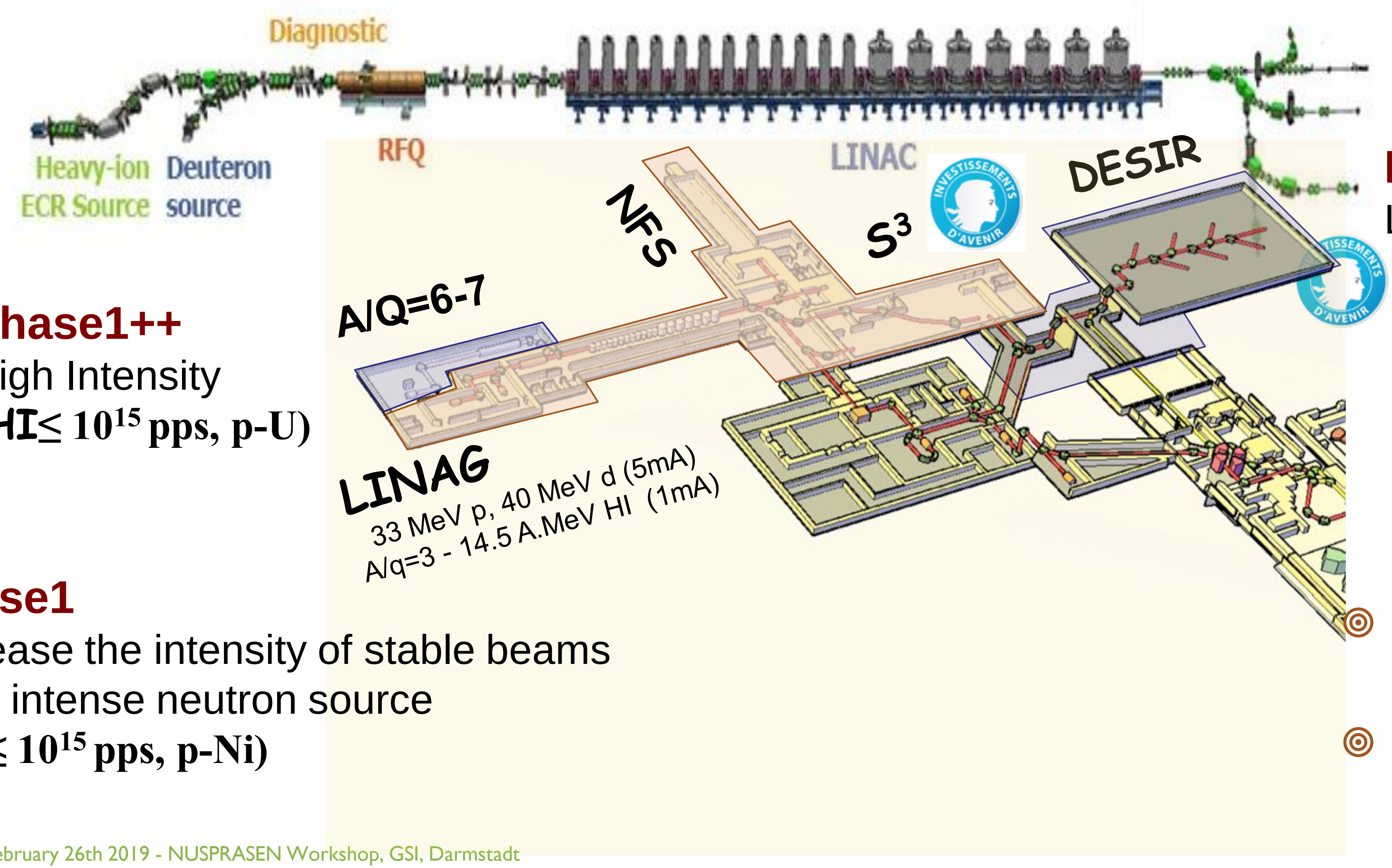
CH. STODEL, GANIL – T. LEFROU, Y. GEORGET, H. SAVAJOLS, J. PIOT, D. ACKERMANN, BE GANIL, ET AL
K. EBERHADRT, JGU MAINZ; B. LOMMEL ET AL, GSI; C. CANNES, IPNO; N. CLAVIER, ICSM

I - S^3
- ✓ Context
- ✓ Stations
- ✓ Monitoring

II - Issues on Targets' Fabrication

III - Conclusions

SPIRAL2 FACILITY



DESIR Phase1+
Low energy facility

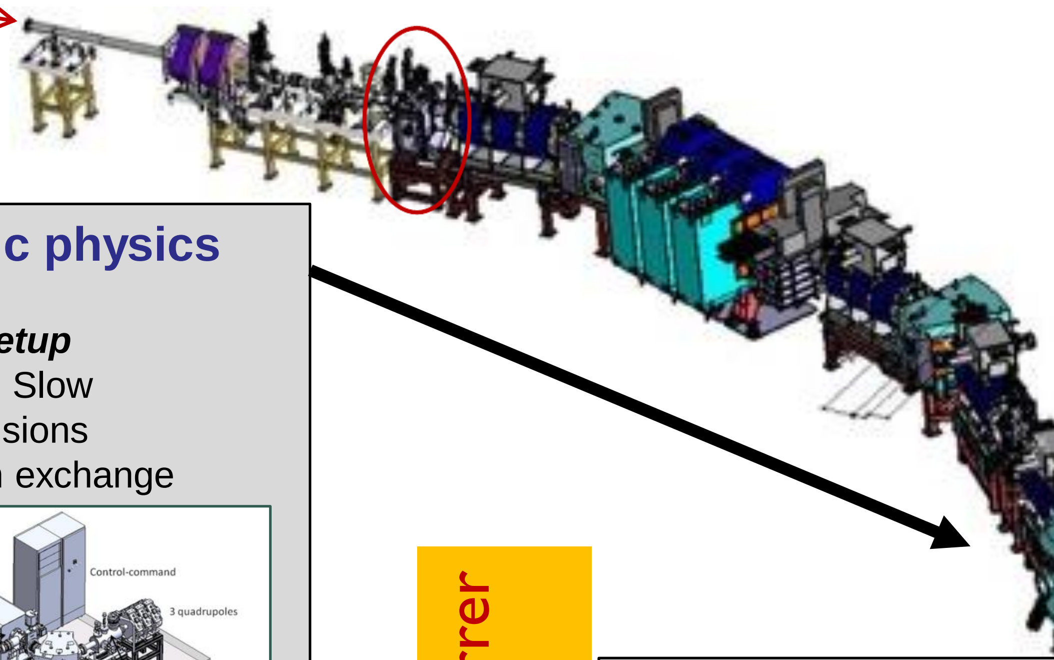
Phase1++
High Intensity
(HI≤ 10^{15} pps, p-U)

Phase1
Increase the intensity of stable beams
High intense neutron source
(HI≤ 10^{15} pps, p-Ni)

- **Reference project ≤ 10^{15} pps, p-Ni, 0.75 MeV/n – 14.5 MeV/n**
- **Phase 1++ ≤ 10^{15} pps, p-U, 0.75 MeV/n – 8.5 MeV/n**

S³ : SUPER SEPARATOR SPECTROMETER
for the study of rare events for atomic and nuclear physics

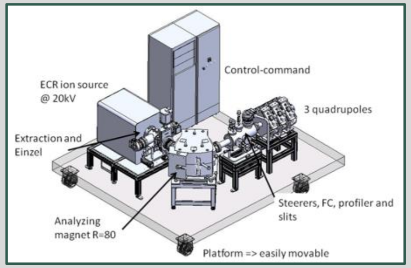
Beam



Phase 2

Atomic physics

FISIC setup
Fast Ion Slow
Ion Collisions
Electron exchange



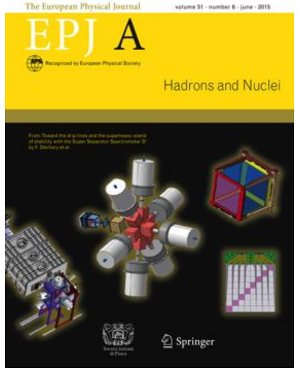
Partially Funded
INSP-CIMAP-JENA/GSI
+ new CPIER

Talk of R. Ferrer & T. Goigoux

Ground state properties
(mass, size, moments, spins)

REGLIS³ setup
Low Energy
Branch
Funded

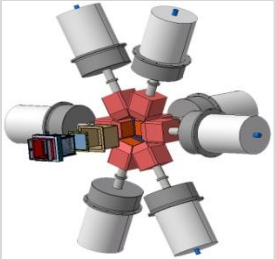
Eur. Phys. J. A (2015) 51: 66



Talk of J. Piot

Delayed spectroscopy

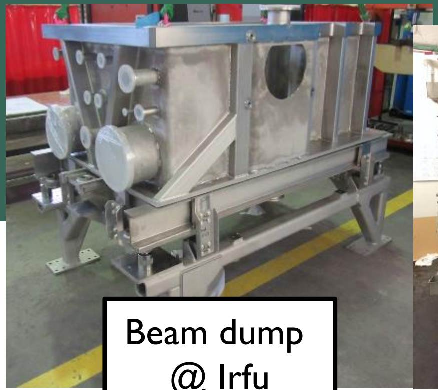
SIRIUS setup
Implantation-decay station at the mass dispersive plan
Funded by new
CPIER



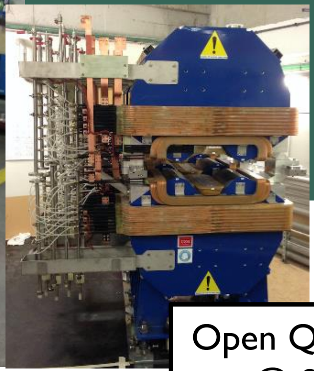
GANIL,IPHC, CSNSM, CEA/Irfu/SPhN

Full assembly & tests planned in 2020

Target System @ GANIL



Beam dump @ Irfu



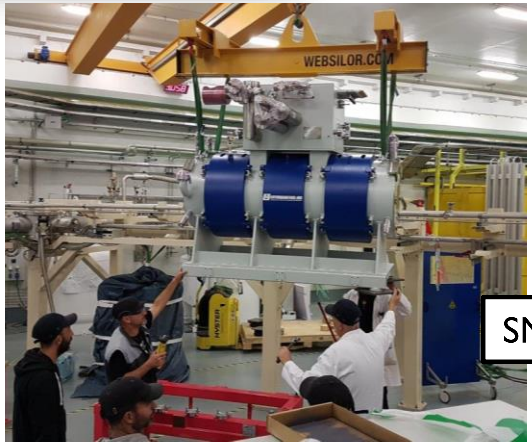
Open Qpoles @ S3

Cold Box @ S3

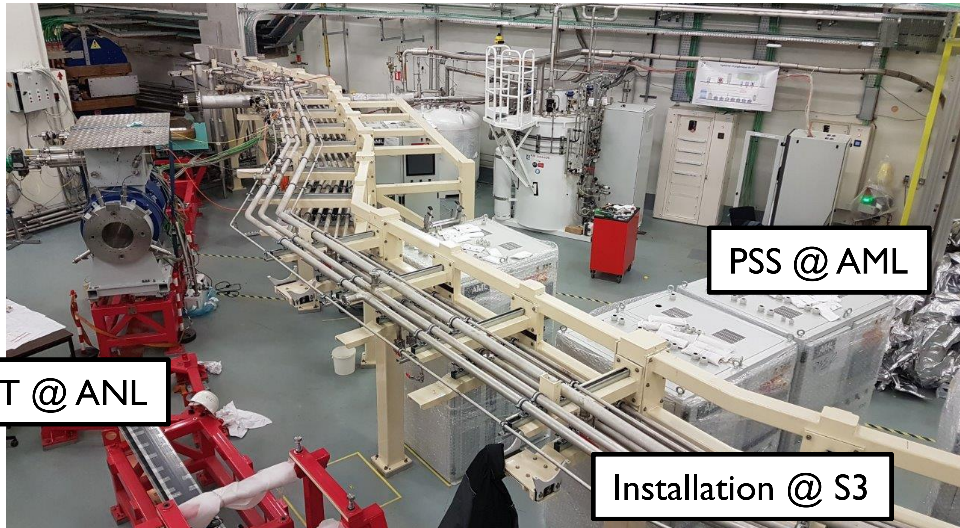
Edipole @ IPNO

S3-LEB @ LPC

Mdipole @ S3



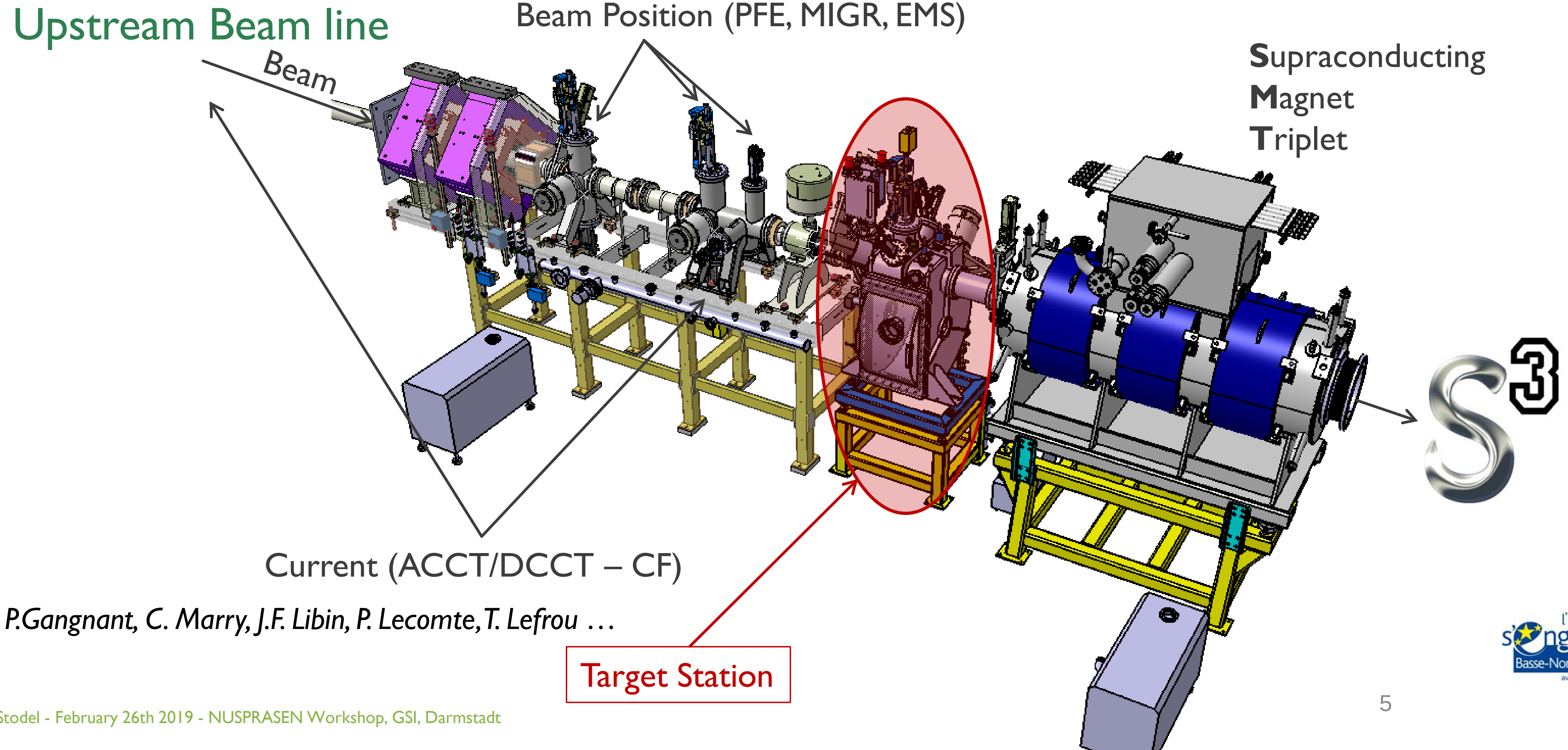
SMT @ ANL



PSS @ AML

Installation @ S3

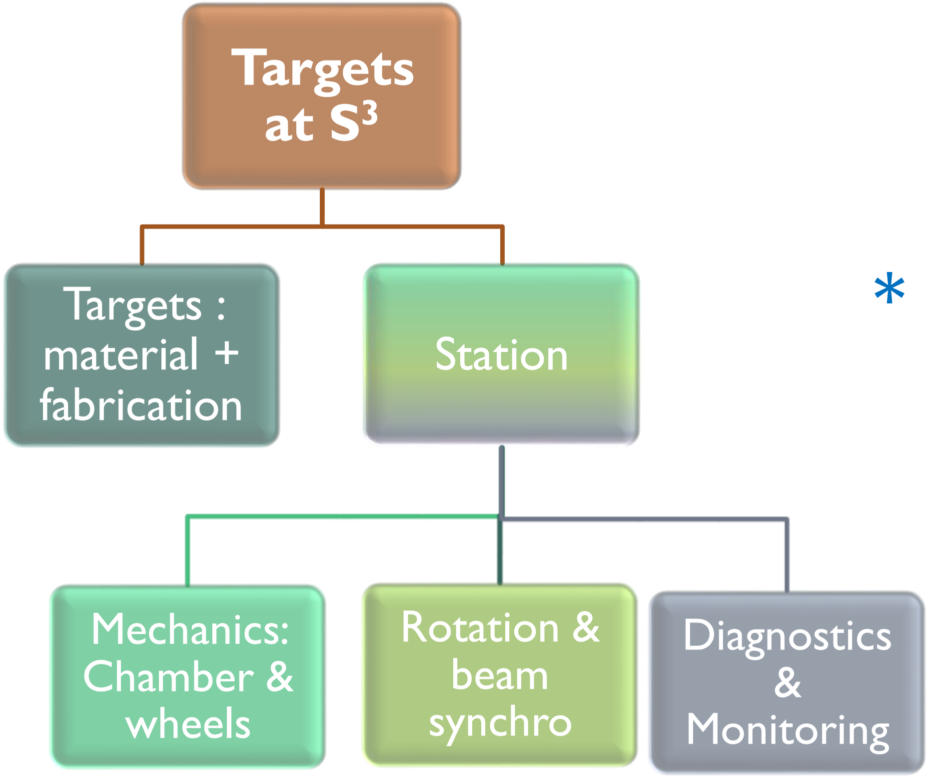
S³ : SUPER SEPARATOR SPECTROMETER – PART I == TARGETS



F. Lutton, P.Gangnant, C. Marry, J.F. Libin, P. Lecomte, T. Lefrou …

WORKPACKAGE « TARGETS @ S3 »

- **Aim:** Development & exploitation of targets for S^3, including the station, while ensuring their integrity



$* 2$

- Targets @ S3 for 1st day …. Experiments
  - Low Energy Branch

    ^{50}Cr (1 mg/cm² = 110 W), ^{58}Ni, ^{nat}Zn, ^{96}Mo, ^{175}Lu, ^{178,180}Hf,

    $^{206-208}$Pb, ^{209}Bi, ^{208}Pb (250µg/cm² = 6 W),

    ^{238}U (250 µg/cm² = 3,4 W)
  - SIRIUS

    ^{58}Ni, ^{164}Yb/^{170}Er, ^{96}Ru, ^{92}Mo, ^{206}Pb, ^{209}Bi, ^{204}Pb (PbS) (300-500 µg/cm²= 30 W), ^{207}Pb (PbS) (400 µg/cm² = 54 W), ^{208}Pb (PbS) (375 µg/cm²= 6,4 W), ^{209}Bi (Bi203) (440 µg/cm²= 8 W),

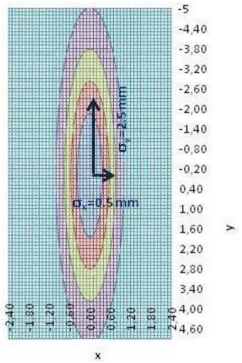
    ^{232}Th (400 µm = 150 W), ^{238}U,

    ^{248}Cm (200-300 µg/cm² (+Ti 1,5 µm) = 45-63 W), ^{243}Am (350 µg/cm² (+Ti 1,5 µm)= 150 W)

STABLE TARGET STATION

- **Aim:** Development & exploitation of targets for S^3, including the station, while ensuring their integrity

σ_t = 0.5 mm
σ_r = 2.5 mm
I=10 pμA



Targets Fabrication

Thickness ±5%

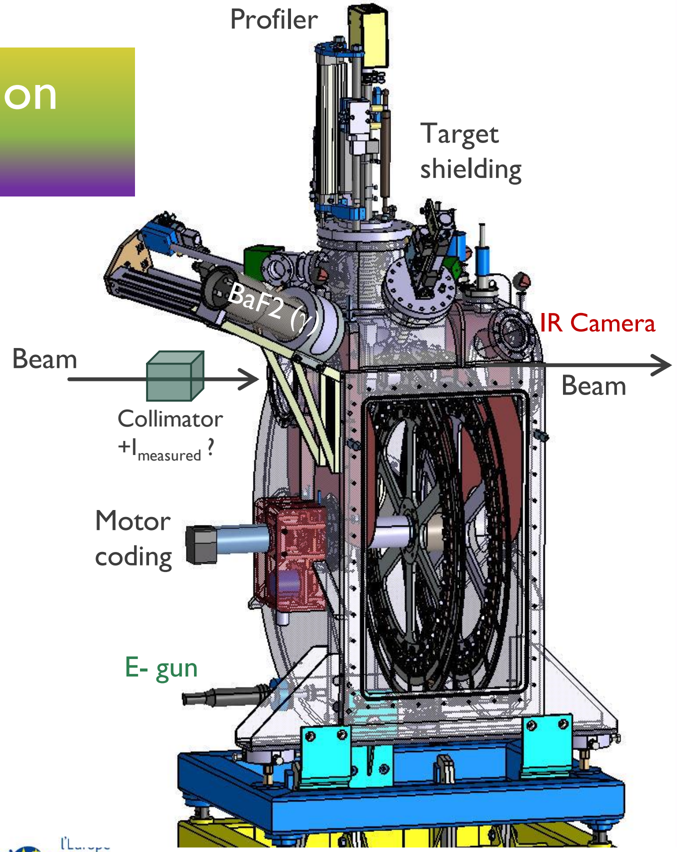
✓ SHE: 300-500 μg/cm²
N=Z : mg/cm²
Stripper: 30-100 μg/cm²
✓ 109*20 mm²

Stable Target Station & diagnostics

Thermal calculation

Φ= 670 mm
ω = 3000 rpm

✓ Vacuum : 10^{-7} / $5*10^{-8}$ mbar
✓ Distance : 900 mm max
✓ Height under beam : 1500 mm± 15
✓ Removable sectors
✓ Movable and adjustable station



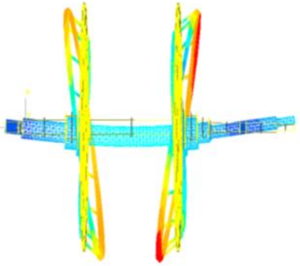
Design Chambre à Cibles Stables / P.Gangnant

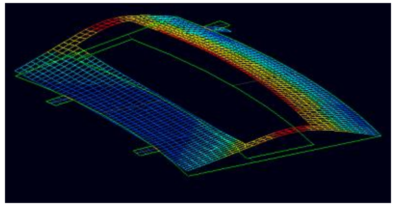
MECHANICS (STABLE): CHAMBER & WHEELS

- Achievements 2014-16:
  - Conception/Fabrication
  - Vacuum definition & material
  - Vibratory Analysis (SAMCEF): frames, axis, wheels*
  - Wheel balancing: class G2.5 == 0,06 mm/s @1500 rpm

    1 resonance @ 2300±100 rpm (no ground bolting)
- On going - To be done:
  - In Lab: Assembling of equipment, vacuum tests, vibratory tests…
  - Implantation & tests @ S^3 (after the 1st SMT)

l'Europe s'engage en Basse-Normandie avec le FEDER





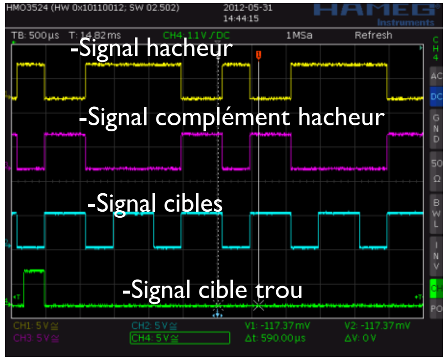
**V. Jean, «Caractérisation de cibles tournantes utilisées dans des expériences de physique nucléaire sous vide poussé,» Caen, 2010 (ENSMA Poitiers).*

ROTATION & BEAM SYNCHRONIZATION (STABLE)

- Achievements :
  - Acquisition of motor's material including controller modules (compact RIO from NI)
  - Programming:
    - C&C: velocity, choice of target's irradiation modes (beam on/off) *
    - Monitoring*
    - Output anlogic signals

- To be done:
  - In lab : Longevity test (endurance) @3000 rpm
  - @S^3: Coupling and tests with ECSF LINAG

*G. Clusier, «Conception sous LABVIEW d'une supervision pour station-cibles,» Caen, 2012.



ACTINIDE TARGET STATION

- Considerations: ^{232}Th, ^{238}U, ^{243}Am, ^{248}Cm, $^{239/242/244}Pu$

0,3 - 0,5 mg/cm² ≈ 25 mg ≈ $10^2 – 10^8$ Bq

Material Supply

ORNL / Dubna

Target fabrication

Thickness ±5%

✓ SHE: 300-500 µg/cm²

✓ Method: + backing : Ti <2 µm

✓35*15 mm²

❑ PRCI TATTOO (next slides)

❑ « Consortium » between experts

Actinide target station + diagnostics

Thermal Calculation

Φ= 150 mm

ω = 5000 rpm

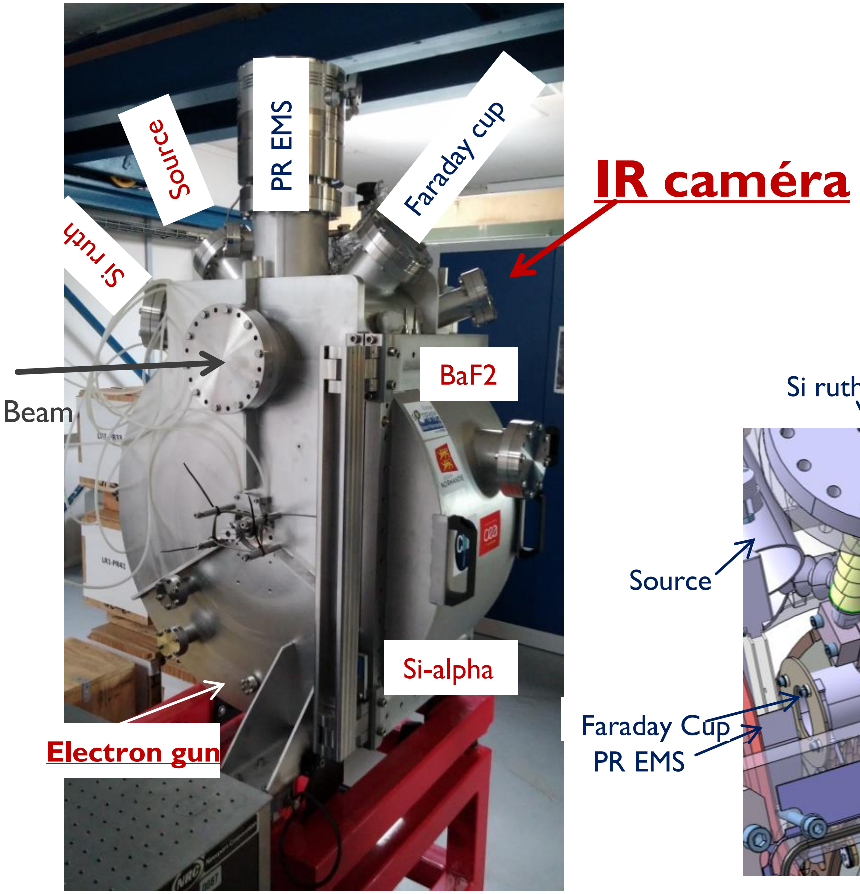
Prototype

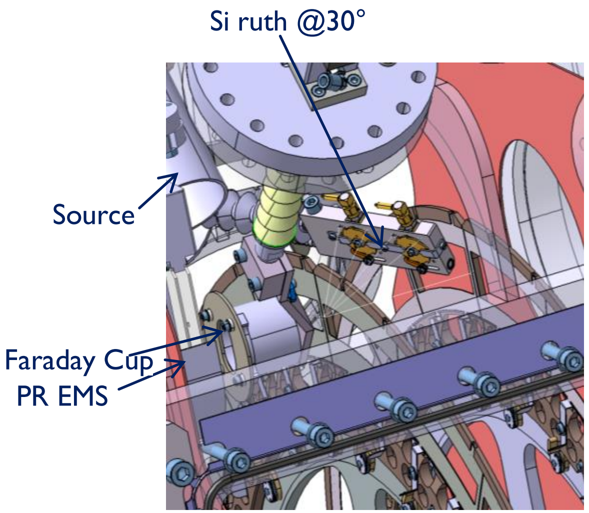
J. Radioanal. Nucl. Chem. 2015, Volume 305, Issue 3, pp 761-767

❑ **Article 26:** authorization for the use of actinide at S^3

❑ 2019 ….: **Actinide Station** : design, issues about glove box, mounting/dismounting…, fabrication,

DIAGNOSTIC & MONITORING





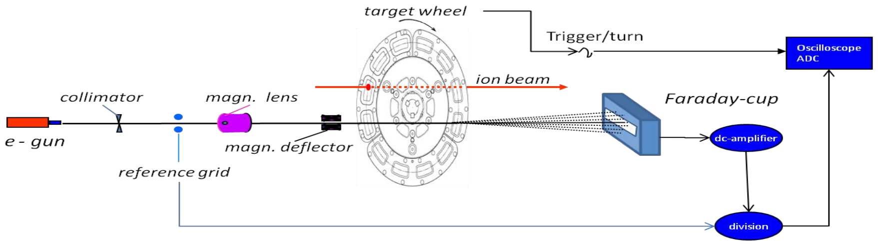
- For 1st experiments :
  - Beam properties with profilers, Faraday Cup, collimator
  - Target thickness/structure: alpha energy loss, Scattered beam, electron transmission
  - Beam synchronization: γ detection
- On going - To be done:
  - Integration of equipment
  - Insertion commands
  - Signal processing & Data Acquisition (NUMEXO2*)
  - Tests
  - IR camera measurements (beam profile, Ttargets)

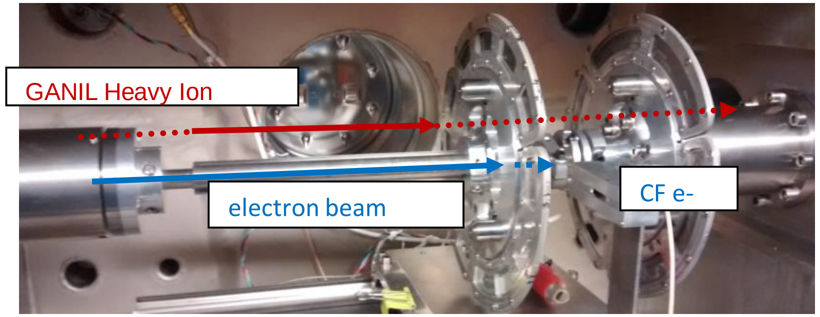
C. Houarner, « Specifications liées au FPGA V6 (Protocoles, IPs...) pour CIBLE-S3 - Ver 13,» http://wiki.ganil.fr/gap/wiki/cible, Caen, 2017.

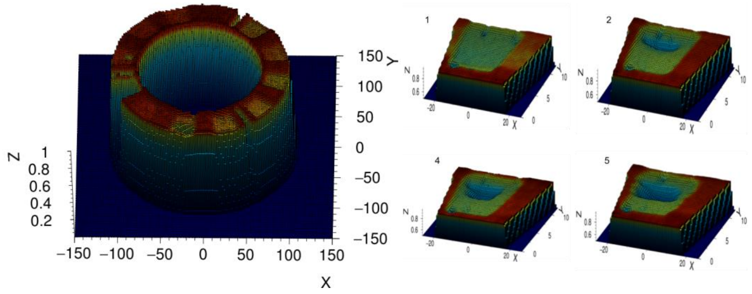
DIAGNOSTIC & MONITORING – *ELECTRON GUN*

Electron Gun - R. Mann (patent DE 10242962 A1-GSI) [9, 10]

Principle : measuring attenuation of electron current using angular scattering and absorption *resolution (≤ 0.4mm , 15µs)*







- Achievements :
  - Tests with intense heavy ion beams *
  - Operation principal demonstrated *
  - Electronic working functions **

**C. Stodel et al, «High Intensity targets stations for S3,» J. of Radioanal. and Nuc. chem., vol. 305, n°3, pp. 761-767, 2015.*

J. Kallunkathariyil et al, «S^3 Target Monitoring with an Electron gun,» AIP Conf. Proc. 1962, 030019-1-9 (2018); doi 10.1063/1.5035536

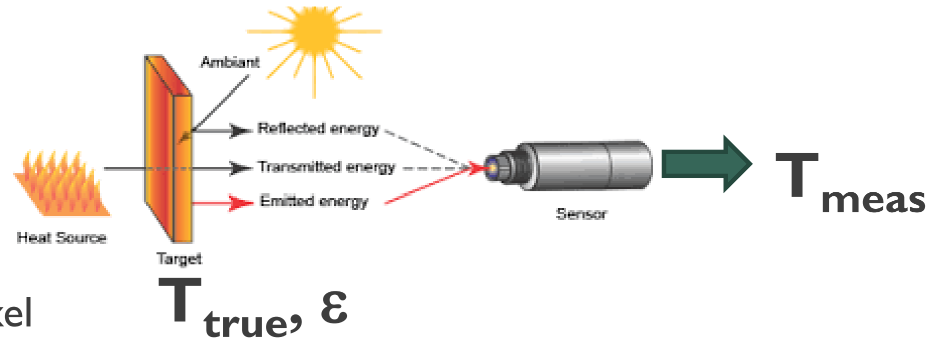
***A. Lebehot, T. Lefrou, Y. Georget et C. Stodel, «Caractérisation d'une chaîne de mesure autour d'un canon à électrons,» Caen, 2016*

- On going - To be done:
  - Upgrade of the existing e-gun for targets' R&D
  - Reception of a « commercial » e-gun for reliable operation

DIAGNOSTIC & MONITORING – *IR CAMERA*

- Achievements:
  - <u>FLIR SC7000</u>:
    - 1.5 à 5 µm;
    - 5-1500°C;
    - 320*256: 380 Hz or 80*64: 3500Hz = Resolution of 0.3mm per pixel
  - Preliminary measurements of emissivity, window transmission & reflectivity with external heating, temperature with various set-up *
- To be done:
  - Can we control target temperature under irradiation ?: Temperature = fct (emissivity)
  - Can we measure beam spot dimensions?
  - How to deport it ? Resolution (spatial and temperature) after deport ?
  - Analysis of images for decision

R&D thermal camera



**C. Leveille, C. Stodel et T. Lefrou, «Mise en œuvre d'une caméra thermique pour cibles tournantes S3,» Caen, 2016.*
+ E. Duguet,, O. Bajeat, Ch. Stodel « Thermal measurements of heated materials with pyrometers and IR camera », April-June 2018

ISSUES ON TARGETS: MATERIAL, FABRICATION, LIFETIME….

I = 1-1.5 pμA → 5 - 10 – 20 pμA ???

- GSI UNILAC: 5ms on /15ms off → I_{mean}= 1 pμA → « I_{max}= 4pμA »
- Cooling → larger wheels + gas cooling
- Targets == Ti(2 μm) + Act (450 μg/cm²)

  dE(Ti) = 12 MeV = 4*dE(Act) → thinner backings ?

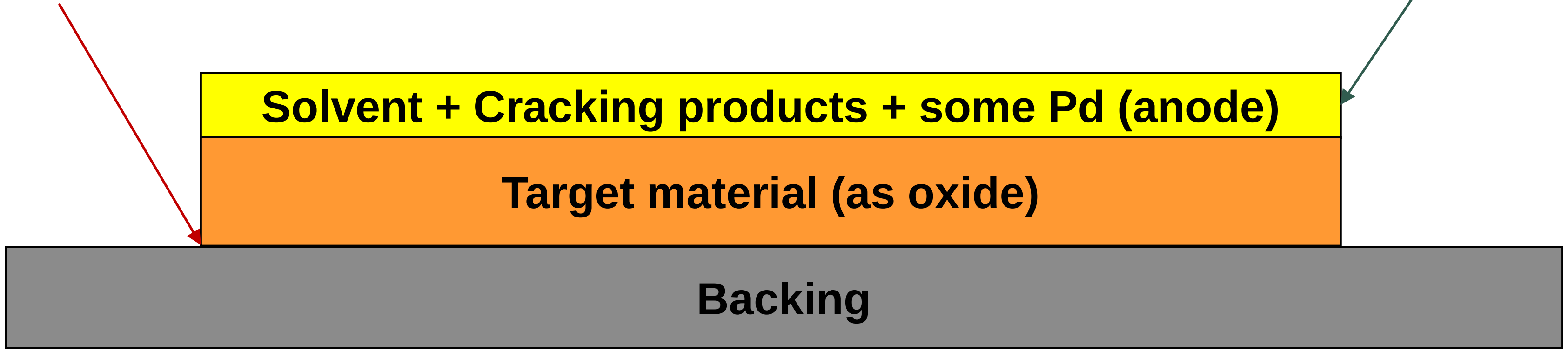
  Or « reasonnable » dE(backing), new backing materials?

ISSUES ON TARGETS: MATERIAL, FABRICATION, LIFETIME….

Targets == Backing + deposit

Removed with previous Ar+ sputtering or during experiment (conditionning)

Interlayer interaction ?



Characterization:
- Impurities
- Thickness
- Surface roughness

Change of material structure with irradiation ?
Nanometric damage ?
Migration of oxide → metallic to oxide backing ?

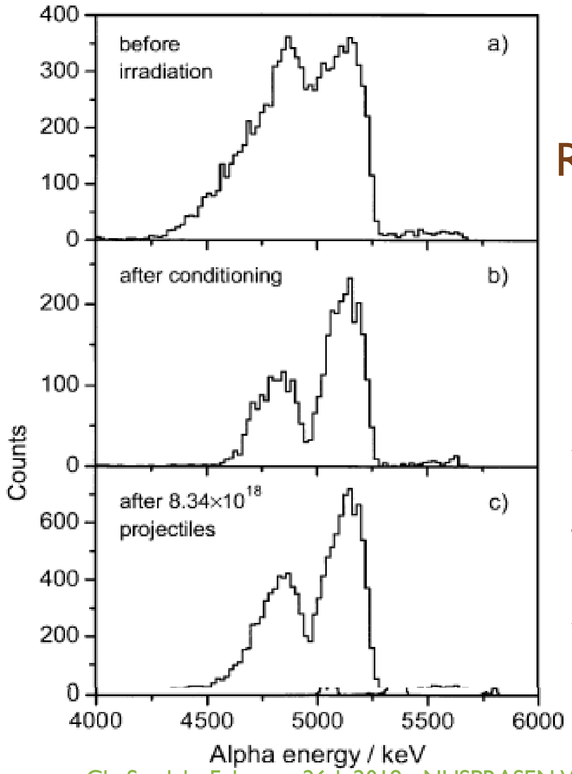
D. Liebe et al, Nucl. Instr. Meth. A590 (2008) 145-150
A. Vascon et al, Nucl. Instr. Meth. A 714 (2013) 163-175

CHANGE OF MATERIAL STRUCTURE

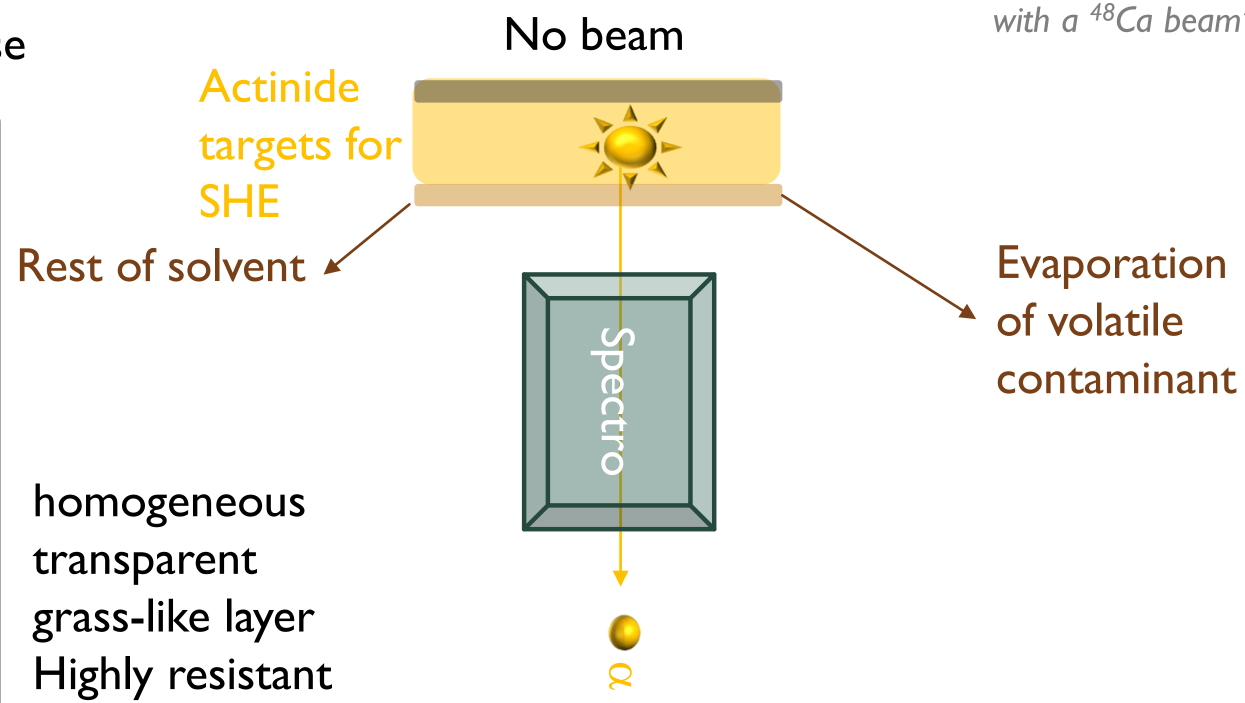
S. Hofmann et al, Eur. Phys. J. A (2012) 48:12 "The reaction $^{48}Ca + ^{248}Cm \rightarrow ^{296}116^*$ studied at the GSI-SHIP"

N. Brewer et al, Phys. Rev. C 98, 024317 (2018) "Search for the heaviest atomic nuclei among products from reactions of mixed-Cf with a ^{48}Ca beam"

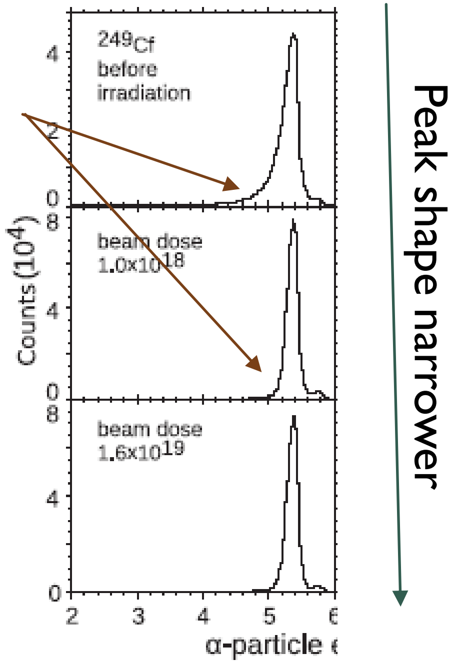
Conditionning phase



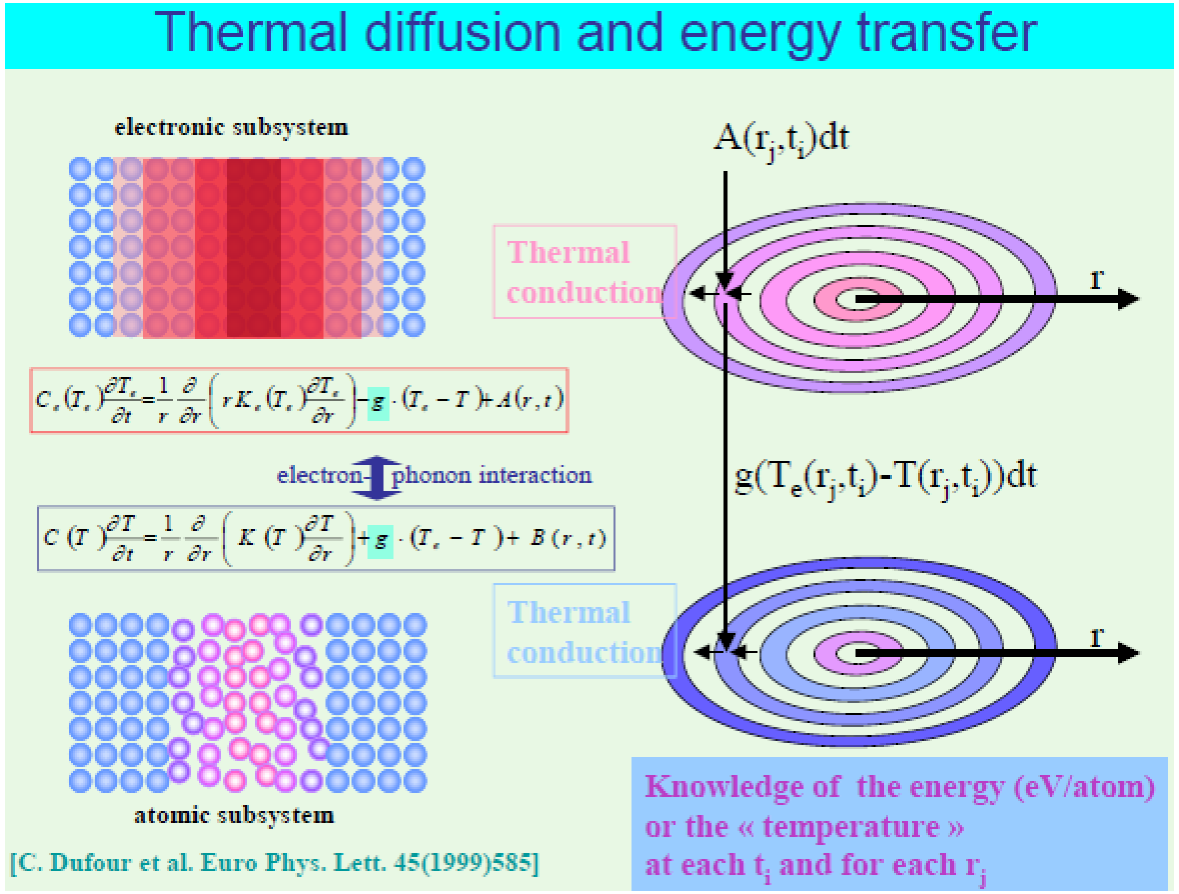
homogeneous transparent grass-like layer
Highly resistant to beam dose



2005
^{249}Cf
340 µg/cm²

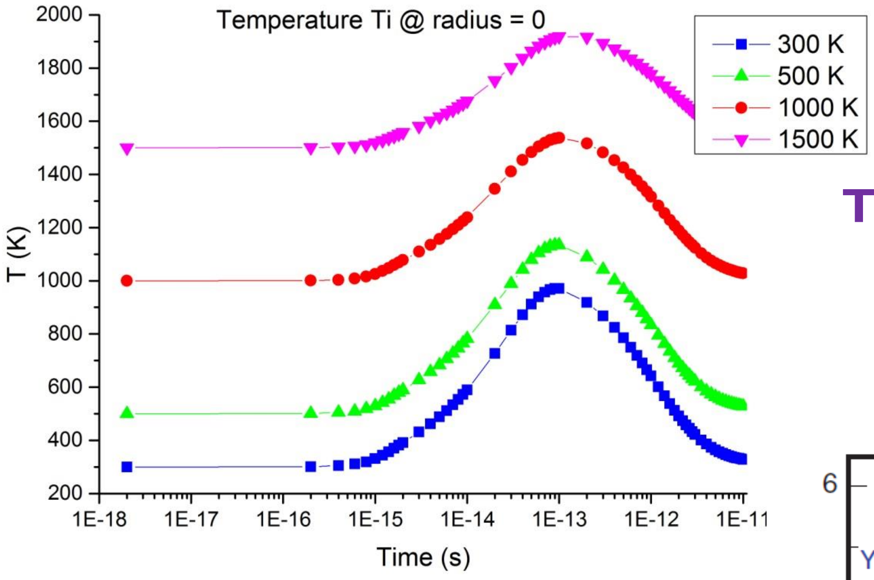


NANOMETRIC TRACKS; STRUCTURAL CHANGE ?
THERMAL SPIKE MODEL: ^{48}Ca (5MeV/u) + Ti (2µm) + ActOx



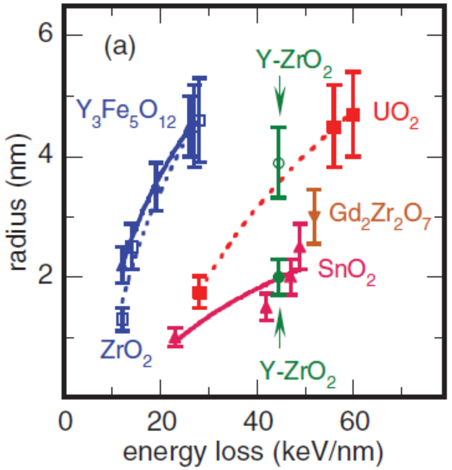
+ Sputtering yield

T_{fus} = 1973 K – T_{crit} = 2610 °K



$T_{TS} \approx T_{eq}$ + 400 °K *

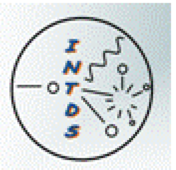
What about actinide in oxyde form ?
Calculations to be done



*Ch. Stodel « Thermal Spike model applied to thin targets irradiated with heavy ions at low energy » INTDS 2018c

ISSUES ON TARGETS: MATERIAL, FABRICATION, LIFETIME…

- ✓ Next « Chanda » with WP targets nuclear data + …..
- ✓ INTDS Community
- ✓ ORNL / Dubna



ACTINIDE TARGETS: MATERIAL & FABRICATION → TATTOO

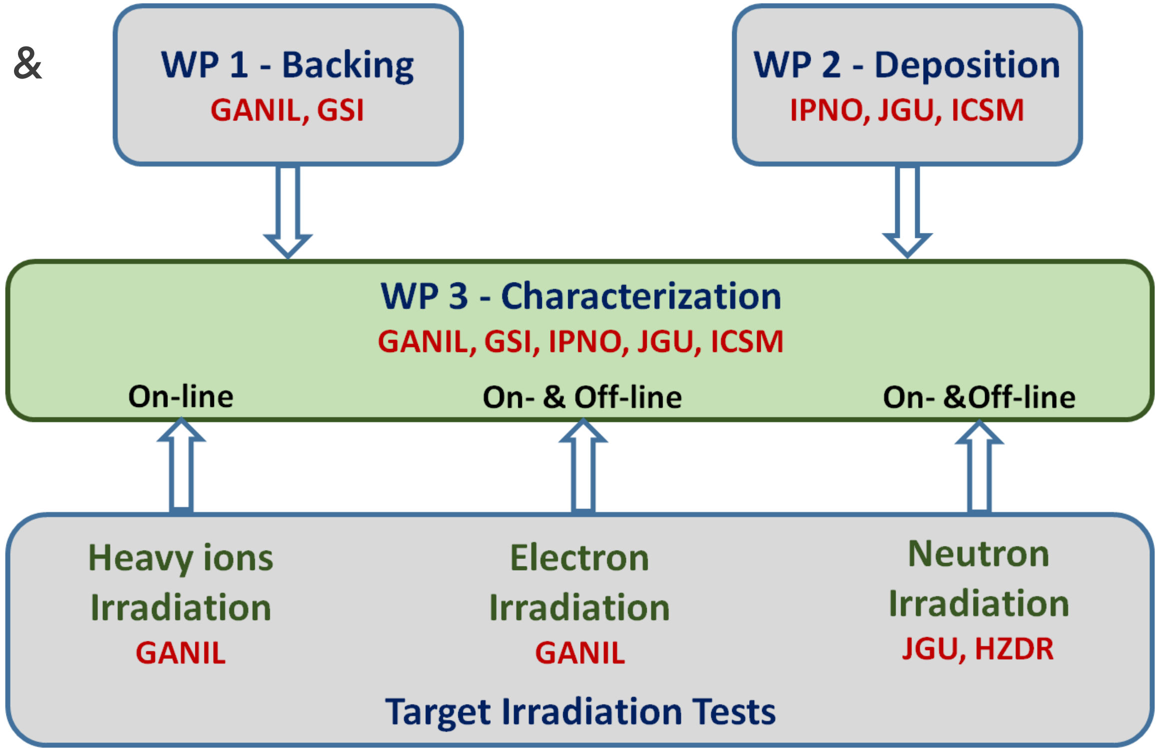
THIN ACTINIDE TARGET COOPERATION
HERSTELLUNG VON DÜNNEN AKTINIDENTARGETS
COOPÉRATION SUR LES CIBLES MINCES D'ACTINIDE

- DFG / ANR
- Klaus Eberhardt, Radiochemist, JGU Mainz
- Christelle Stodel, Physicienne, GANIL
- Bettina Lommel, Head of the department Target lab., GSI, Darmstadt
- Céline Cannes, Radiochimiste, IPN Orsay
- Nicolas Clavier, Radiochimiste, ICSM, Marcoule

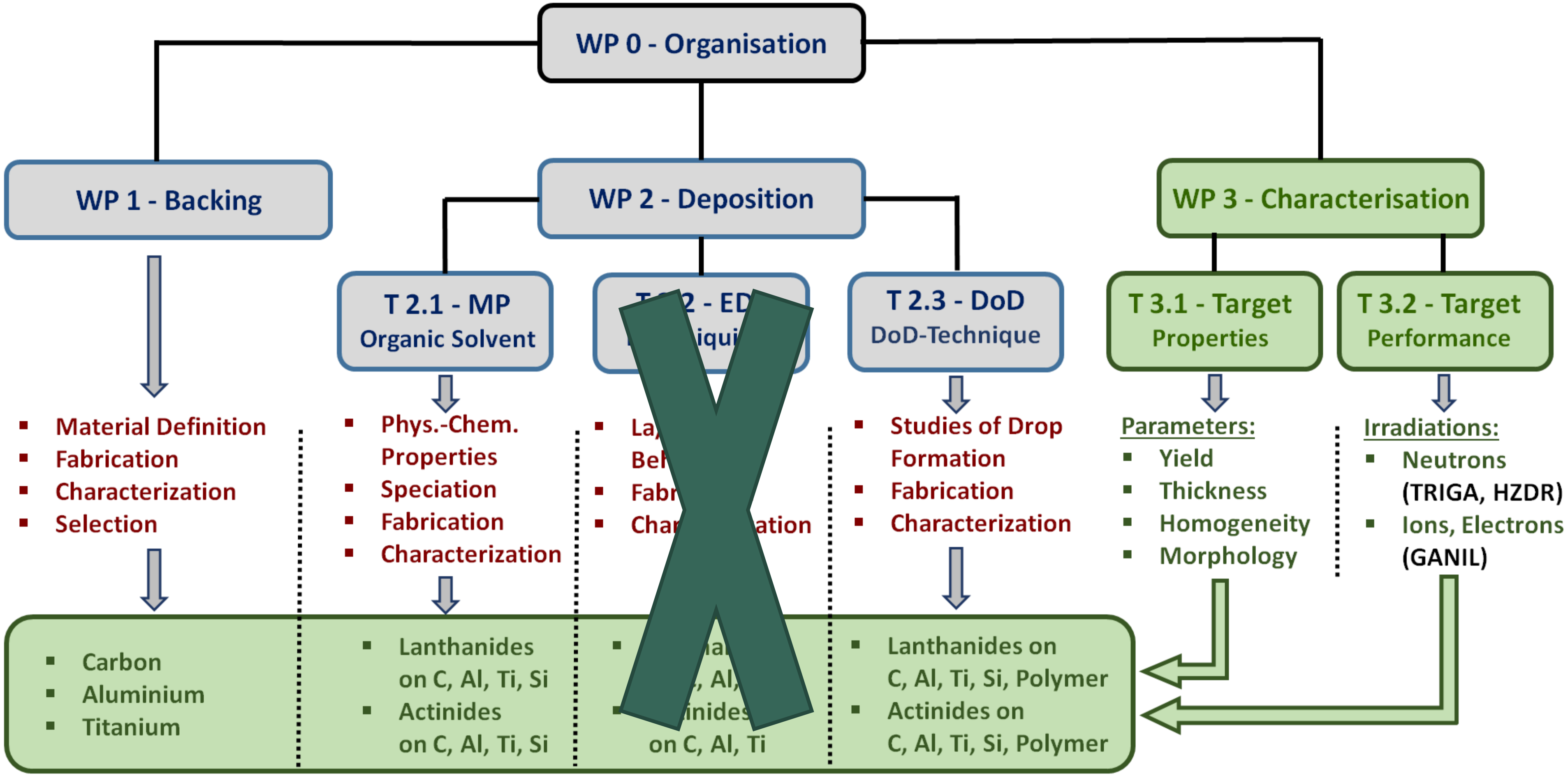
TATTOO OBJECTIVES

✓ Supply thin actinide targets which have specific characteristics depending on the application (thickness, choice of backing, roughness, homogeneity ….) for French and German physicists (heavy-ion- and neutron-induced reactions, σ & structure of HN & SHN at S3, fission studies = σ & process at NFS…)

- ○ Development of novel fabrication methods for actinide targets on various substrates
- ○ Characterization and performances under irradiation of backings and deposits



WORK PROGRAM



Talk of D. Renisch

TATTOO:WP1 BACKINGS (GSI & GANIL)

Carbon : 5 – 2000 µg/cm²
Titanium: ≈ 1.5 / 2 µm
Aluminium: oxide layer

TATTOO

Study of structure /surface according to interlayer material, processes, conditions etc..(high-resolution 3D microscope)
Ti < 1.5 µm pin-hole free
Large surface homogeneous

12 Ton manual Press
5mm Pellet

Rolling Mill

TATTOO: WP2 DEPOSITION

T2.1 Organic Solvent – IPNO/ICSM/JGU

systematic studies → better understanding of deposition mechanism and deposition kinetics.

42 cm^2 ^{242}Pu targets on Ti-coated Si wafers

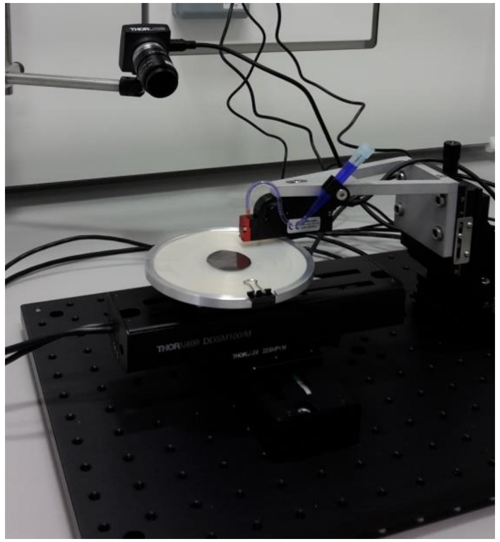
$^{233,234,235,238}U$, ^{237}Np and ^{232}Th deposited on 2 μm thin Al foils [34, 12-13, 41-43]

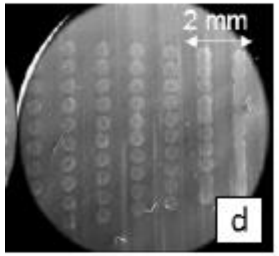
TATTOO

Reference
Determination of physico-chemical properties
Speciation of Eu, Ce, U
Thermal treatments

TATTOO: WP2 DEPOSITION: T2.2 DOD TECHNIQUE @ JGU

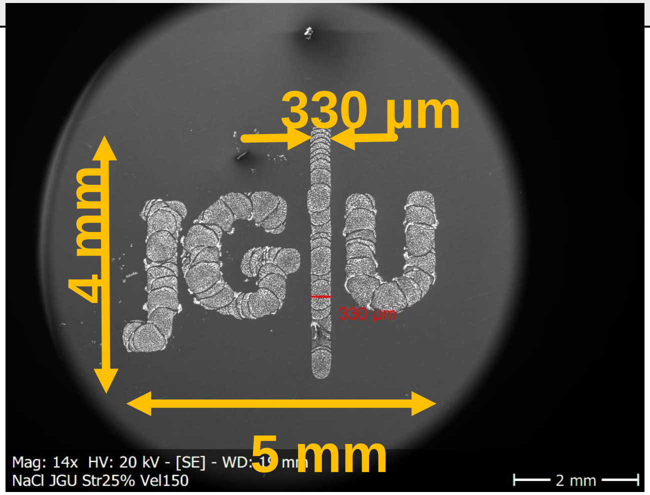
R. Haas et al, *Nuclear Instruments and Methods A*, vol. 874, pp. 43-49, 2017





^{140}La, ^{198g}Au tracers as natural nitrate solution
on graphene 12 µm or Ti 50µm
diam 25 mm

Printing of JGU-Logo with NaCl-solution on Ti-surface



TATTOO

Organic solvents
Other substrate, thickness
Diam = 100 mm

Study of drop formation

Stroke: 16.25 µm

Stroke velocity: 150 µm/ms

Droplet size: 15 ± 5 nL

Courtesy of K. Eberhardt

Talk of D. Renisch

TATTOO WP3: CHARACTERIZATION
T3.1 PROPERTIES

thickness

α Energy loss
Precise analytical balance
UV-Vi Spectrophotometry
*Low geometry α-particle (LGA)
*Radiographic Imaging (RI)

surface morphology

Scanning Electron Microscpe (SEM)
AFM
X-ray diffractometer (XRD)
Optical microscope
High Temperature Raman Spectro
HT- Environmental SEM

TARGET

thickness uniformity

Rutherford Back Scatterir
PhotoElectron Spectrosc
Energy Dispersive X-Ray
Particle Induced X-ray Em
Particle Induced γ-ray Em

surface roughness

Isotopic abundances

identification of impurities

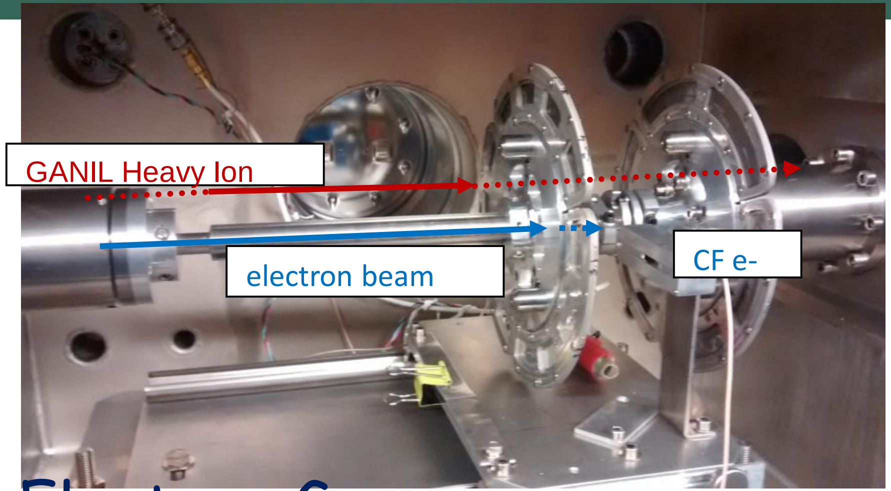
Thermal Ionization Mass Spe
Neutron Activation Analysis

TATTOO

Knowledge & experience gained shared among all partners of TATTOO (+CIMAP)

JGU: 3D Optical Profiler in radioactive controlled area
GSI: High-Resolution 3D Microscope

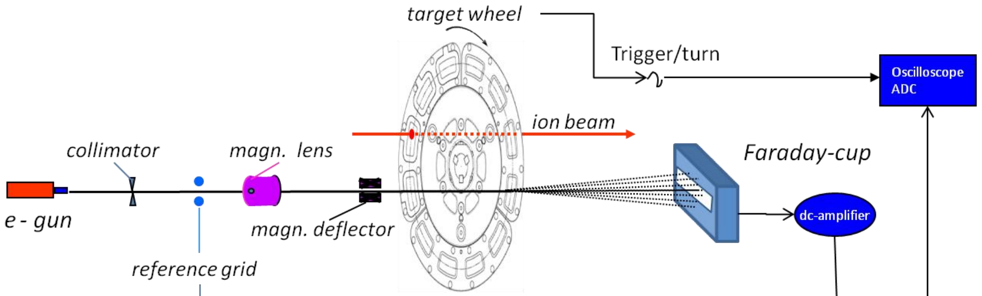
TATTOO WP3: CHARACTERIZATION – T3.2 PERFORMANCES WITH HEAVY IONS

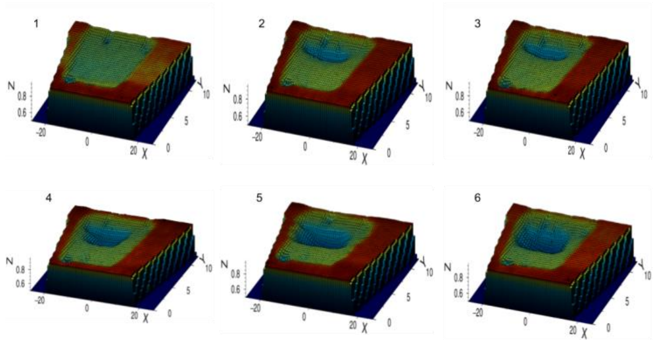


FLIR SC7000: 1.5 à 5 µm / 5-1500°C
320*256:380 Hz // 80*64: 3500Hz
(3000 rpm = 50 Hz; 3500Hz= 70 images)
Resolution of 0.3mm per pixel

Electron Gun - R. Mann (patent DE 10242962 A1-GSI)

Principle : measuring attenuation of electron current using angular scattering and absorption





TATTOO WP3: CHARACTERIZATION – T3.2 PERFORMANCES WITH NEUTRONS

- ✓ Neutrons of variable energy @nELBE

- ✓ Thermal Neutrons : Measurements of the layer thickness are possible using radioactive tracers or by Neutron Activation Analysis (NAA)

TRIGA MARK II

Continuous Thermal Power… 100 kW

Neutron Flux…$7 \cdot 10^{11}$- $4 \cdot 10^{12}$ n cm^{-2} s^{-1}

Several irradiation facilities

CONCLUSION & PERSPECTIVES

- S^3
  - One Target station ready for first experiments at S^3 (stable and U or Th)
  - Monitoring on targets to be optimized with the use of the electron technique, IR camera
  - Use of an « Actinide Prototype Target Station » with GANIL beams
  - S^3 Actinide Target Station to be designed
- **R&D on targets technology**
  - Backings
  - Deposition techniques
  - Characterization: prior-, during-, post-irradiation
  - Impact on other research topics (^{229}Th nuclear clock, neutron induced reaction, …)