The SANDA and APRENDE European nuclear data projects

Daniel Cano Ott on behalf of the SANDA and APRENDE partners

daniel.cano@ciemat.es

Unidad de Innovación Nuclear

Departamento de Fisión Nuclear

CIEMAT

Avda. Complutense 40, 28040 Madrid – España

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

erc European Research Council Established by the European Commission

What are nuclear data?

Almost every nuclear application that requires minimal accuracy must be supported by well-validated experimental data. Nuclear models are not able to predict (by themselves) accurately the microscopic properties of nuclei.

Differential data

- Nuclear reaction data: cross sections (probability of reaction as a function of energy), energy distributions, multiplicity and angular distributions of reaction products ...
- Decay and nuclear structure data: modes of disintegration, half-lives, probabilities of emission of particles (multiplicities, energies, angular correlations), information on the nuclear structure (energy, spin and parity) ...

- Integral data. Macroscopic properties of nuclear systems, some of them measured or determined with high accuracy. They are typically used for the test and validation of microscopic data.

All these quantities are called nuclear data.

Nuclear data are essential for every nuclear application

- Nuclear theory.
- Nuclear technologies: reactor operation and design, nuclear fuel cycle, criticality…
- Fusion reactors: neutronics, diagnostics, activation…
- Nuclear astrophysics.
- Medical applications: therapy, imaging, dosimetry...
- Detector design and calibrations.
- Dosimetry.
- Nuclear forensics.
- Homeland security.
- Climate studies.
- Planetary science.
- Space applications.
- Oil searches.
- Non-destructive analysis techniques.

…

In the beginning… there was Fermi

During the Manhattan project, when reactor engineers were stumped by the lack of nuclear data, they would put their problems to **Fermi**.

Fermi would protest that he could not help them, because the number they wanted had not been measured and could not be predicted. The engineers, ignoring Fermi's protest, began reciting slowly a series of numbers while watching his eyes closely.

The **correct number** would produce an **involuntary twinkle in Fermi's eyes**.

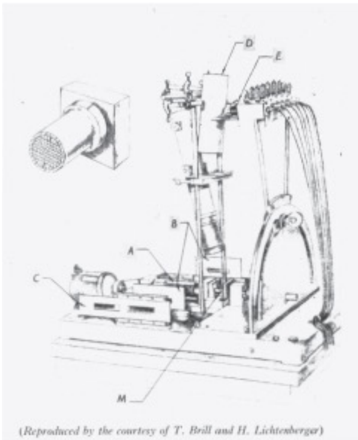
ANL – https://ahf.nuclearmuseum.org/voices/oral-histories/fermi-love-part-3/

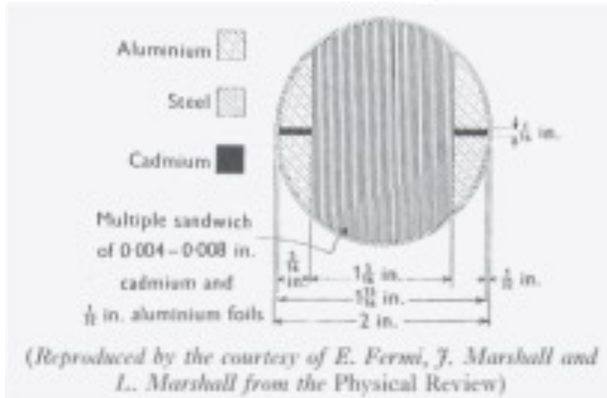
PHYSICAL REVIEW VOLUME 72, NUMBER 3 AUGUST 1, 1947

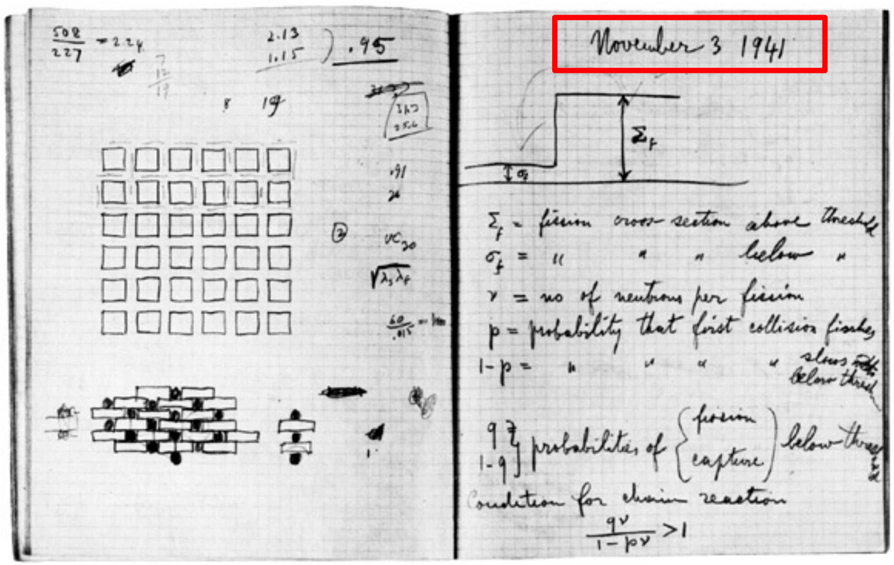
A Thermal Neutron Velocity Selector and Its Application to the Measurement of the Cross Section of Boron

E. Fermi, J. Marshall, and L. Marshall
Argonne National Laboratory, University of Chicago, Chicago,** Illinois*
(Received April 25, 1947)

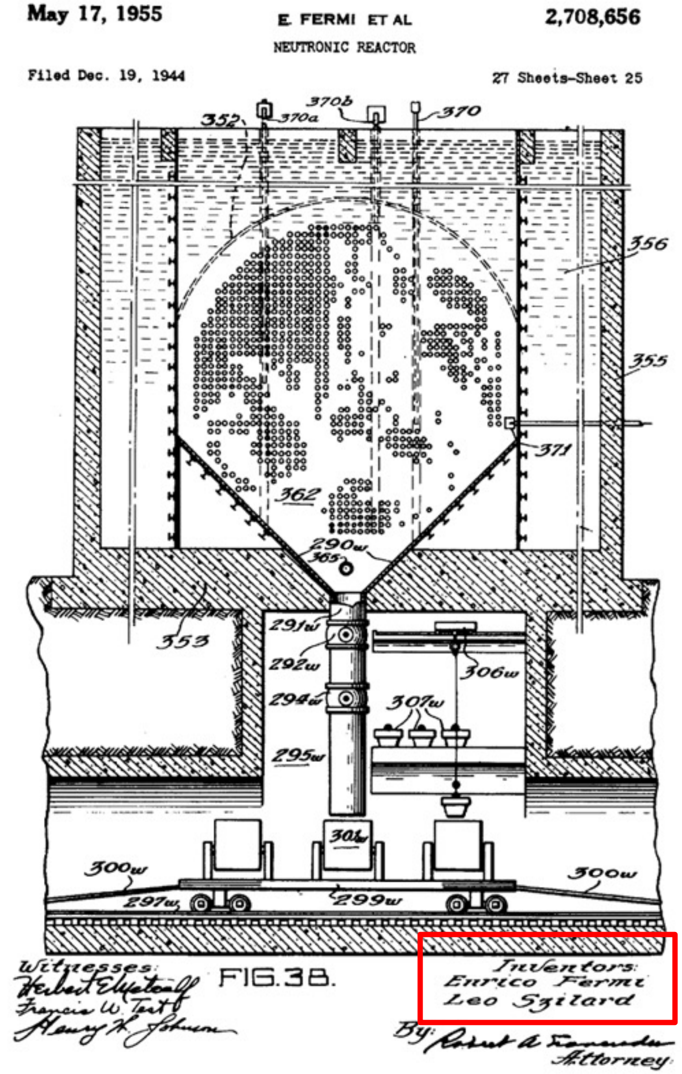
During the Manhattan project







(1941) FERMI's notebook with the design of Chicago PILE-1 (1942)

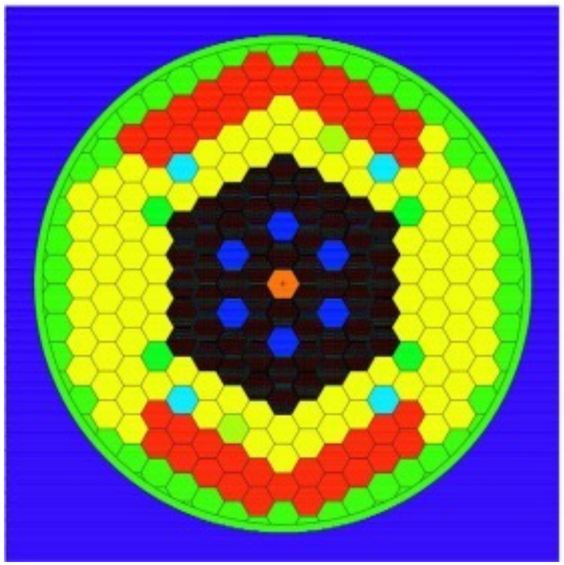


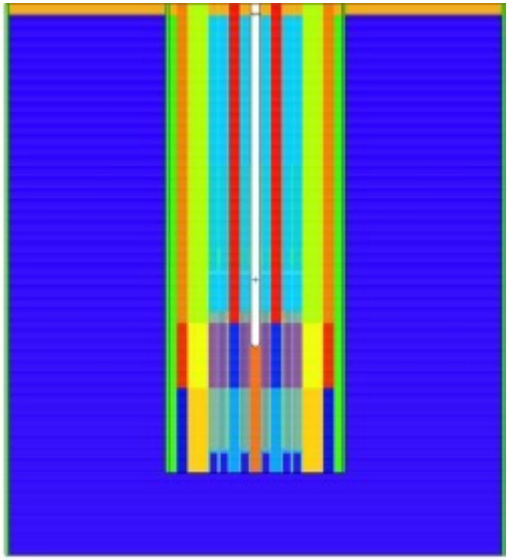
(1945) Patent on Fermi-Szilard reactor design.

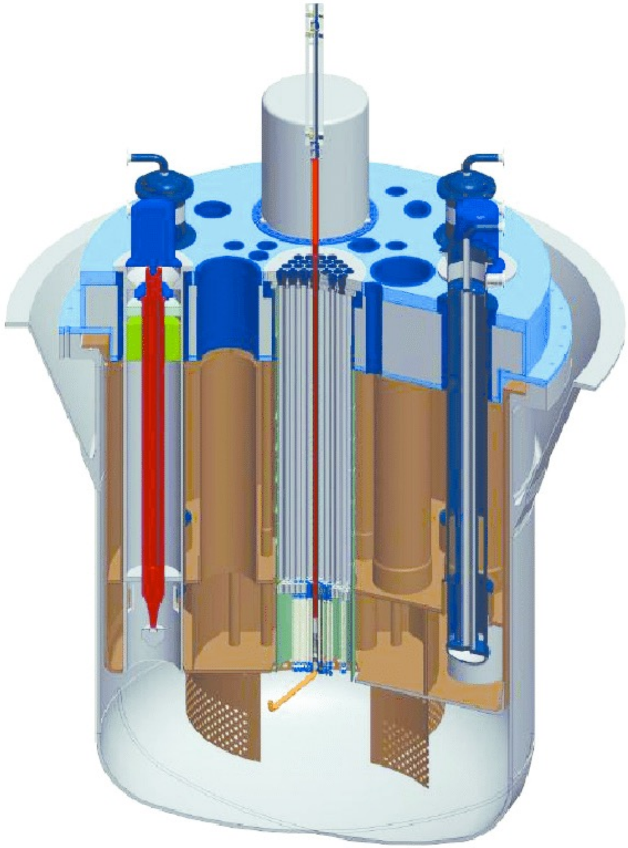
80 years later…

Unfortunately, we don't have Fermi!

1. Better Monte Carlo simulation tools, deterministic codes, and computers.
2. Powerful and well characterised neutron sources, advanced detectors, and data acquisition systems for producing high quality data.
3. Evaluators.
4. Complex validation methodologies.

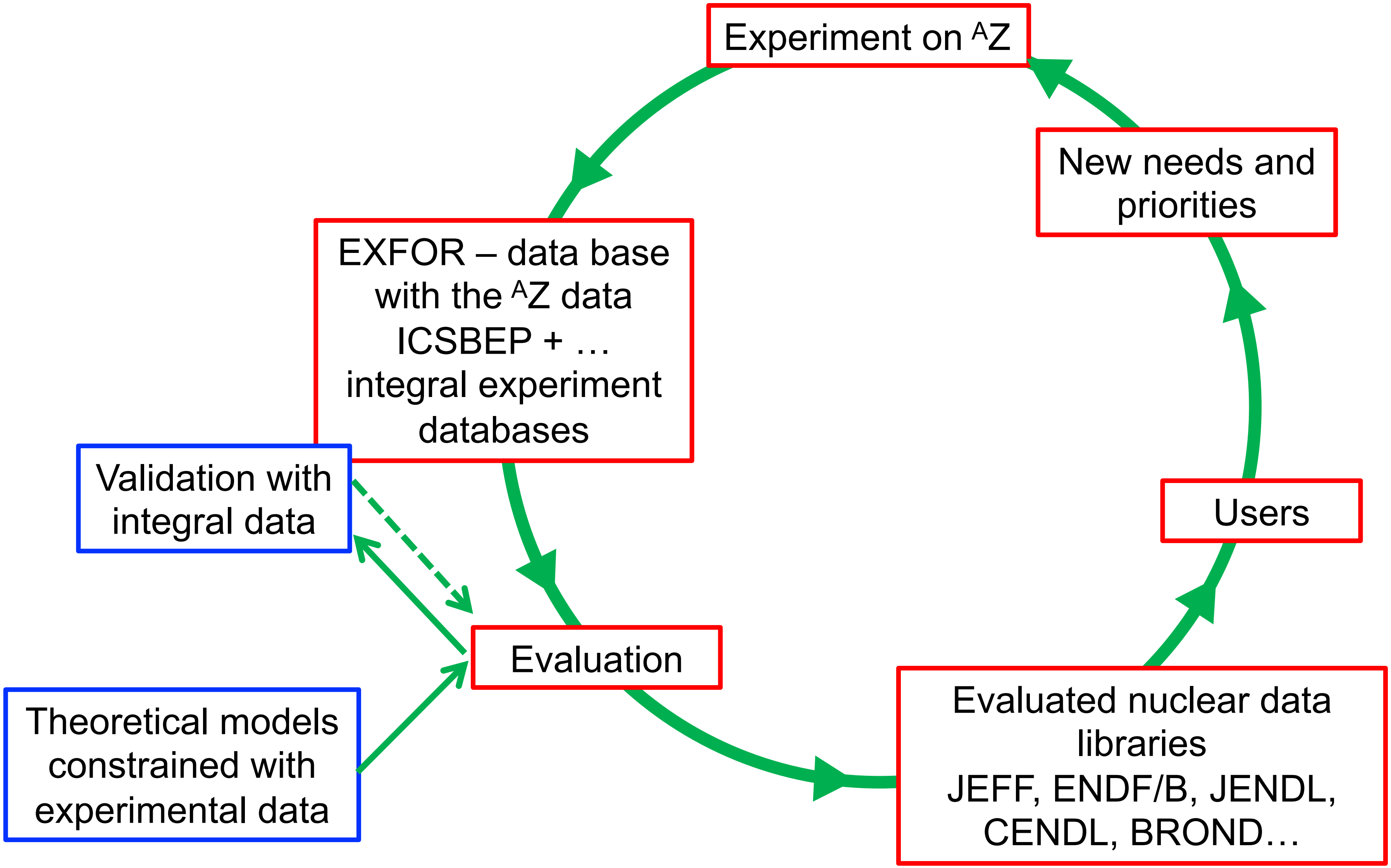






The MYRRHA Accelerator Driven System

The nuclear data cycle



Nuclear data projects in Europe

HINDAS (16)
KU-Leuven 3.3 M€
2000 - 2003
High and
Intermediate energy
Nuclear
Data for
Accelerator-driven
Systems

IP-EUROTRANS (~20)
KIT ~1 M€ NUDATRA
2005 - 2010
EUROpean research programme for the
TRANSmutation
of high-level nuclear waste
in an accelerator driven systems

CHANDA (36)
CIEMAT ~5.4 M€
2013 - 2018
solving
CHAllenges in
Nuclear
DAta

APRENDE (36+4)
CIEMAT ~4 M€
2024 – 2028
Addressing
PRiorities of
Evaulated
Nuclear
Data in
Europe

National funding + Transnational access programs (ERINDA, EUFRAT, ARIEL, OFFERR, EURO-LABS) + Education & training (ARIEL, ENEN2+)

n_TOF-ADS (18)
CERN 2.4 M€
2000 – 2004
Data for
Accelerator
Driven
Systems
nucleard data

CANDIDE (14)
UU ~1 M€
2007 - 2008
Coordination
Action on
Nuclear
Data for
Industrial
Development in
Europe

ANDES (21)
CIEMAT ~3 M€
2010 - 2013
Coordination
Accurate
Nuclear
Data for nuclear
Energy
Sustainability

SANDA (36)
CIEMAT ~5.4 M€
2019 - 2024
Supplying
Accurate
Nuclear
Data for energy and
non-energy
Applications

SANDA and APRENDE

Topics covered:

- Detector development and infrastructure upgrades
- New measurements
- Sample preparation (stable and radioactive)
- Evaluation of nuclear data
- Validation & integral experiments
- Transnational access
- Education & Training

} **APRENDE / dedicated ARIEL project during SANDA**

APRENDE has the ambition to improve nuclear data for the European priorities:

- All aspects of spent nuclear fuel (SNF),
- **Reactor operational characteristics** such as reactivity versus burnup, transients, and margins,
- **Advanced reactor and fuel cycle development** including small modular reactors (SMR) and GenIV systems based on Pb, Na coolants, molten salts, or an accelerator like MYRRHA,
- **Criticality safety** and shielding for safety assessments and safety assessment methodologies,
- **Non-Energy applications**, radiation protection.

SANDA and APRENDE

Topics covered:

- Detector development and infrastructure upgrades
- New measurements
- Sample preparation (stable and radioactive)
- Evaluation of nuclear data
- Validation & integral experiments
- Transnational access
- Education & Training

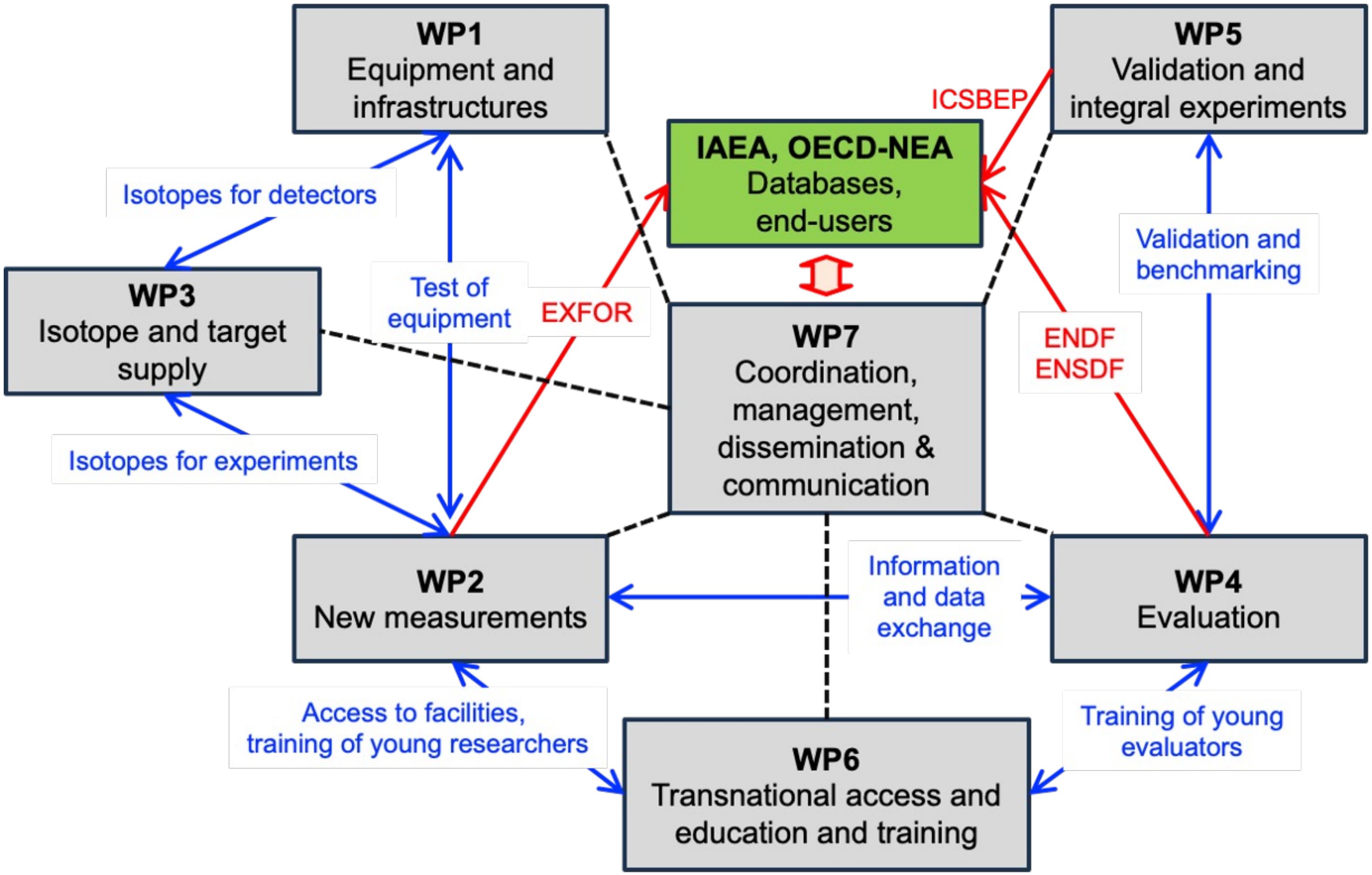
APRENDE / dedicated ARIEL project during SANDA

Emphasis on the training of new evaluators

APREND... ...ion to improve nuclear data for the European priorities:

- All aspects of sp... ...l (SNF),
- Reactor operational chara... ...s reactivity versus burnup, transients, and margins,
- Advanced reactor and fuel cycle developme... ...ll modular reactors (SMR) and GenIV systems based on Pb, Na coolants, molt... ...celerator like MYRRHA,
- Criticality safety and shielding for safety assessments and safety asse... methodologies,
- Non-Energy applications, radiation protection.

A typical EC ND project Pert Chart



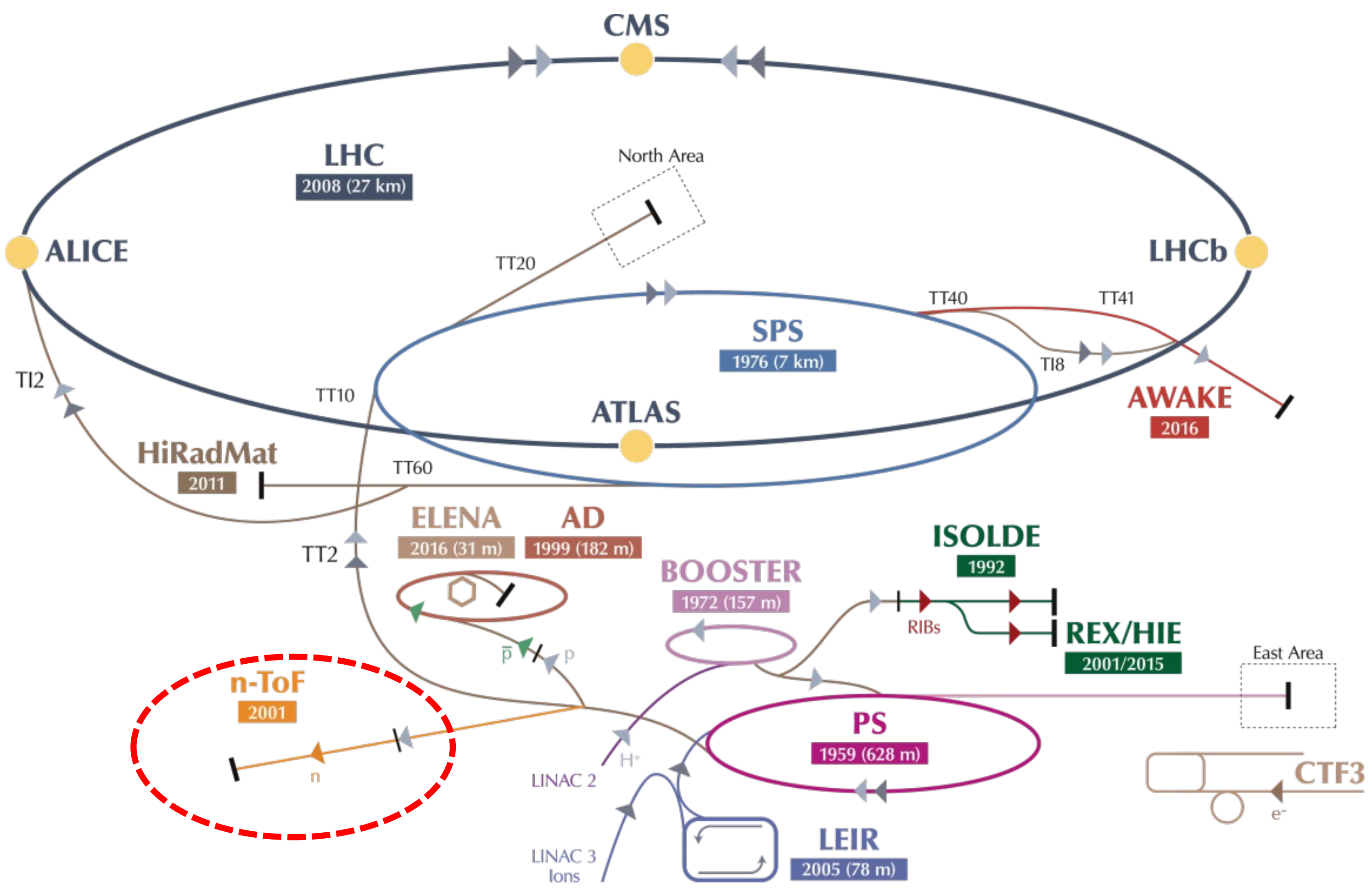
A few selected facilities

Facilities participating in APRENDE

List of the facilities participating in SANDA and APRENDE:

- CERN (CH, international laboratory): n_TOF
- JRC Geel (BE, European Commission): GELINA (neutron TOF) and MONNET (Tandem for monochromatic neutrones)
- GANIL / SPIRAL2 (FR): Neutrons For Science (NFS) & ions
- HZDR (GE): nELBE
- CNRS (FR): AIFIRA (ion beams), ALTO (LICORNE) and GENESIS (14 MeV)
- PTB (GE): reference neutron fields
- JYU (FI): ions
- IFIN-HH (RO): ions & neutrons
- Centro Nacional de Aceleradores (CNA): neutrons & ions
- CVREZ (CZ): LR-0 experimental reactor.

n_TOF @ CERN


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
ISOLDE
1992
TT2
BOOSTER
1972 (157 m)
RIBs
REX/HIE
2001/2015
p̄
p
East Area
n-ToF
2001
PS
1959 (628 m)
n
H⁺
LINAC 2
CTF3
e⁻
LINAC 3
Ions
LEIR
2005 (78 m)

The n_TOF collaboration

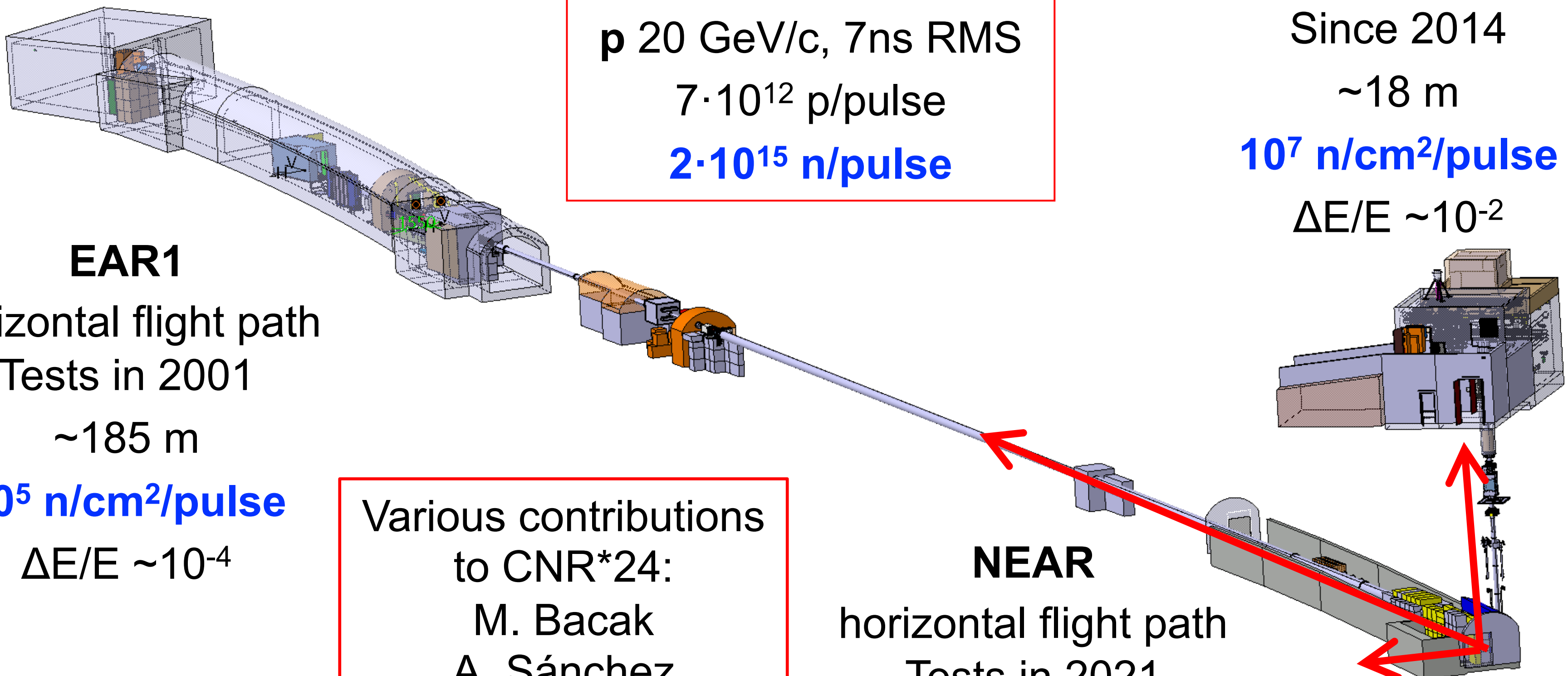
O. Aberle[1]
V. Alcayne[2]
S. Amaducci[3,4]
J. Andrzejewski[5]
L. Audouin[6]
V. Babiano-Suarez[7]
M. Bacak[1,8,9]
M. Barbagallo[1,10]
S. Bennett[11]
E. Berthoumieux[9]
J. Billowes[11]
D. Bosnar[12]
A. Brown[13]
M. Busso[10,14,15]
M. Caamaño[16]
L. Caballero-Ontanaya[7]
F. Calviño[17]
M. Calviani[1]
D. Cano-Ott[2]
A. Casanovas[17]
F. Cerutti[1]
E. Chiaveri[1,11]
N. Colonna[10]
G. Cortés[17]
M. A. Cortés-Giraldo[18]
L. Cosentino[3]
S. Cristallo[14,19]
L. A. Damone[10,20]
P. J. Davies[11]
M. Diakaki[21,1]
C. Domingo-Pardo[7]
R. Dressler[23]
Q. Ducasse[24]
E. Dupont[9]
I. Durán[16]
Z. Eleme[25]
B. Fernández-Domínguez[16]
A. Ferrari[1]
P. Finocchiaro[3]
V. Furman[26]
K. Göbel[27]
R. Garg[22]
A. Gawlik[5]
S. Gilardoni[1]
I. F. Gonçalves[28]
E. González-Romero[2]
C. Guerrero[18]
F. Gunsing[9]
H. Harada[29]
S. Heinitz[23]
J. Heyse[30]
D. G. Jenkins[13]
A. Junghans[31]
F. Käppeler[32]
Y. Kadi[1]
A. Kimura[29]
I. Knapová[33]
M. Kokkoris[21]
Y. Kopatch[26]
M. Krtička[33]
D. Kurtulgil[27]
I. Ladarescu[7]
C. Lederer-Woods[22]
H. Leeb[8]
J. Lerendegui-Marco[18]
S. J. Lonsdale[22]
D. Macina[1]
A. Manna[34,35]
T. Martínez[2]
A. Masi[1]
C. Massimi[34,35]
P. Mastinu[36]
M. Mastromarco[1]
E. A. Maugeri[23]
A. Mazzone[10,37]
E. Mendoza[2]
A. Mengoni[38]
V. Michalopoulou[21,1]
P. M. Milazzo[39]
F. Mingrone[1]
J. Moreno-Soto[9]
A. Musumarra[3,40]
A. Negret[41]
R. Nolte[24]
F. Ogállar[42]
A. Oprea[41]
N. Patronis[25]
A. Pavlik[43]
J. Perkowski[5]
L. Persanti[10,14,19]
C. Petrone[41]
E. Pirovano[24]
A. Ventura[34]
D. Vescovi[10,14]
V. Vlachoudis[1]
R. Vlastou[21]
A. Wallner[47]
P. J. Woods[22]
T. Wright[11]
P. Žugec[12]

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc
European Research Council
Established by the European Commission

The n_TOF facility

Spallation source
CERN PS @ 0.8 Hz
p 20 GeV/c, 7ns RMS
$7 \cdot 10^{12}$ p/pulse
$2 \cdot 10^{15}$ n/pulse

EAR2
Vertical flight path
Since 2014
~18 m
10^{7} n/cm^{2}/pulse
$\Delta E/E \sim 10^{-2}$



EAR1
horizontal flight path
Tests in 2001
~185 m
10^{5} n/cm^{2}/pulse
$\Delta E/E \sim 10^{-4}$

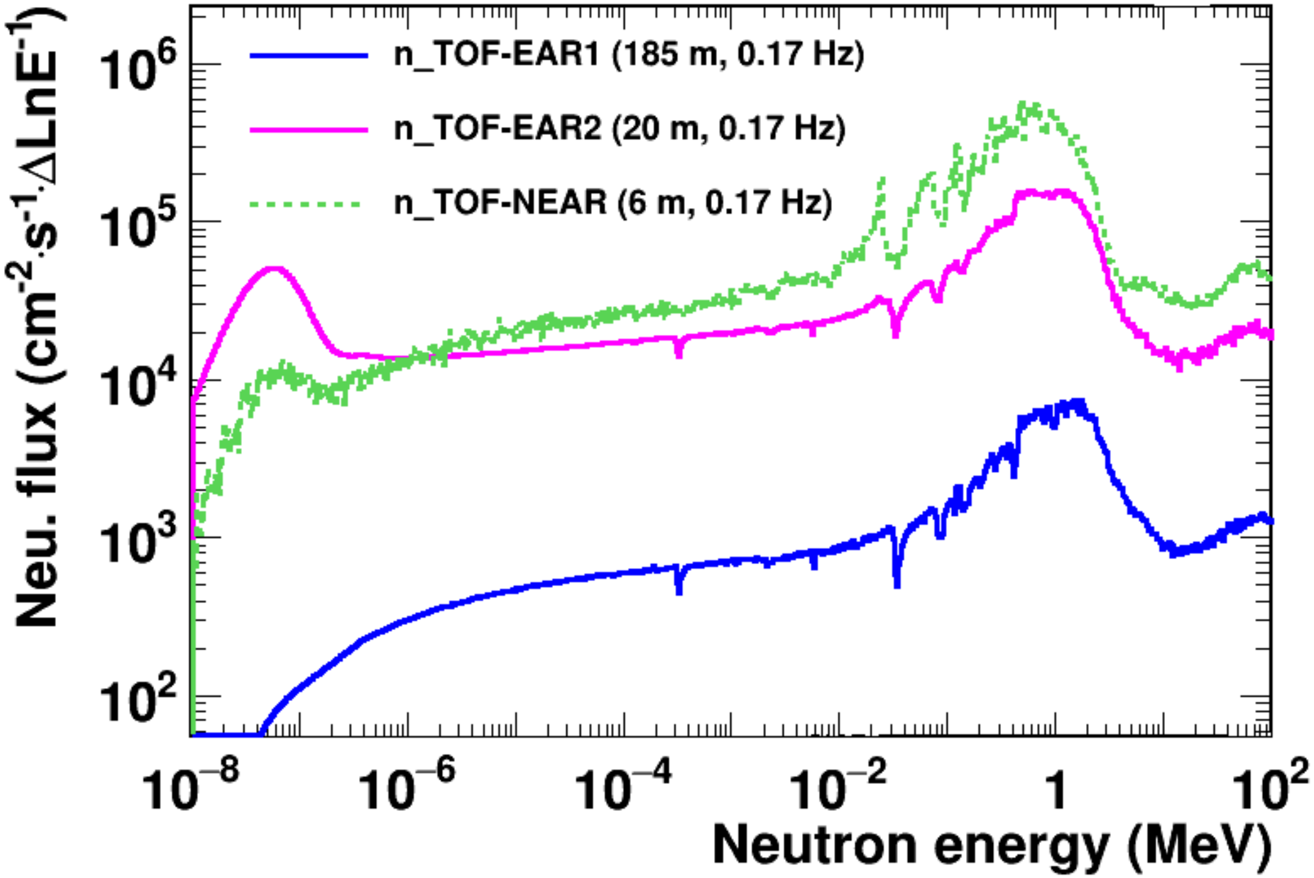
Various contributions to CNR*24:
M. Bacak
A. Sánchez
A. Manna
V. Alcayne

NEAR
horizontal flight path
Tests in 2021
~3 m
10^{8} n/cm^{2}/pulse

nTOF

*N. Patronis et al. EPJ Techniques and Instrumentation **10**, 13 (2023)*

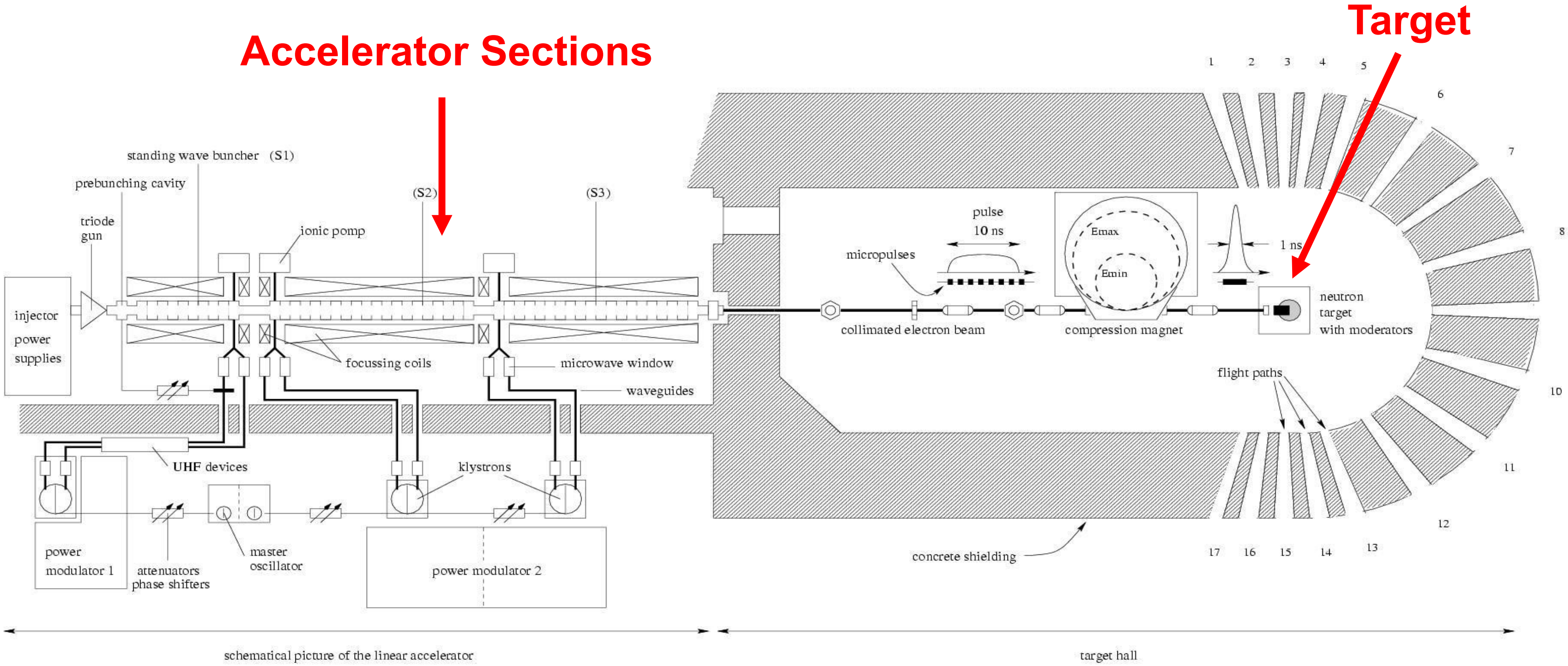
n_TOF fluence



Very high fluence/pulse, low repetition rate.

JRC – Geel: GELINA and MONNET

The GELINA TOF facility



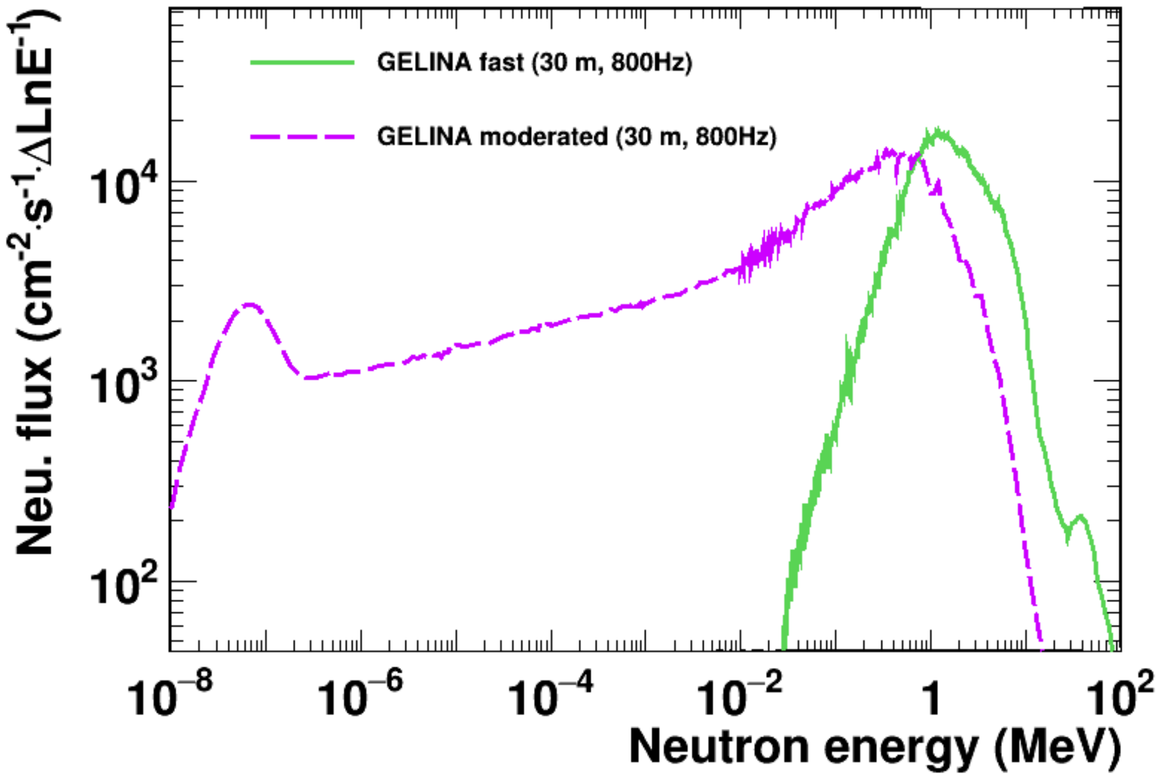
Normal operating parameters

Average current	: 70 pA	Frequency	: up to 800 Hz
Maximum electron energy	: 130 MeV	Pulse width	: 1-2 ns
Mean Power	: 7 kW	Neutron fluence	: **$2 \cdot 10^{13}$**

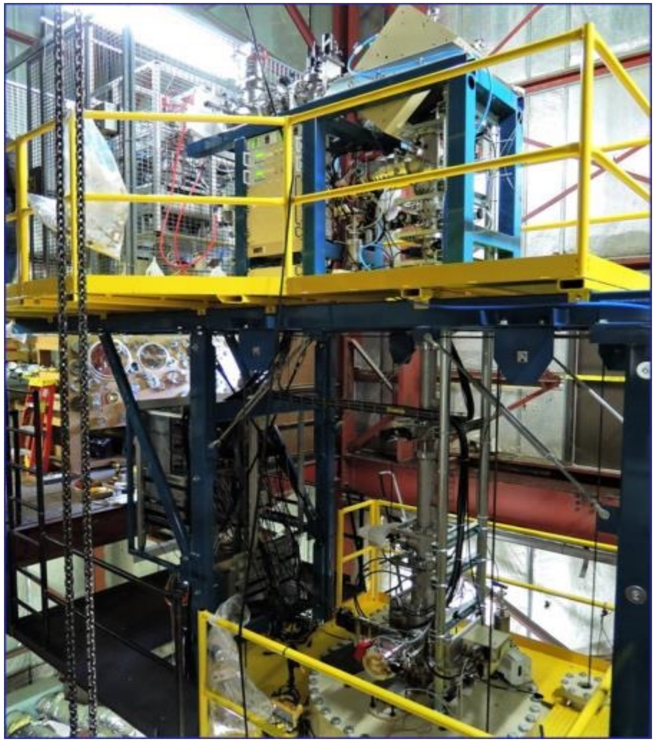
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council

GELINA neutron fluence

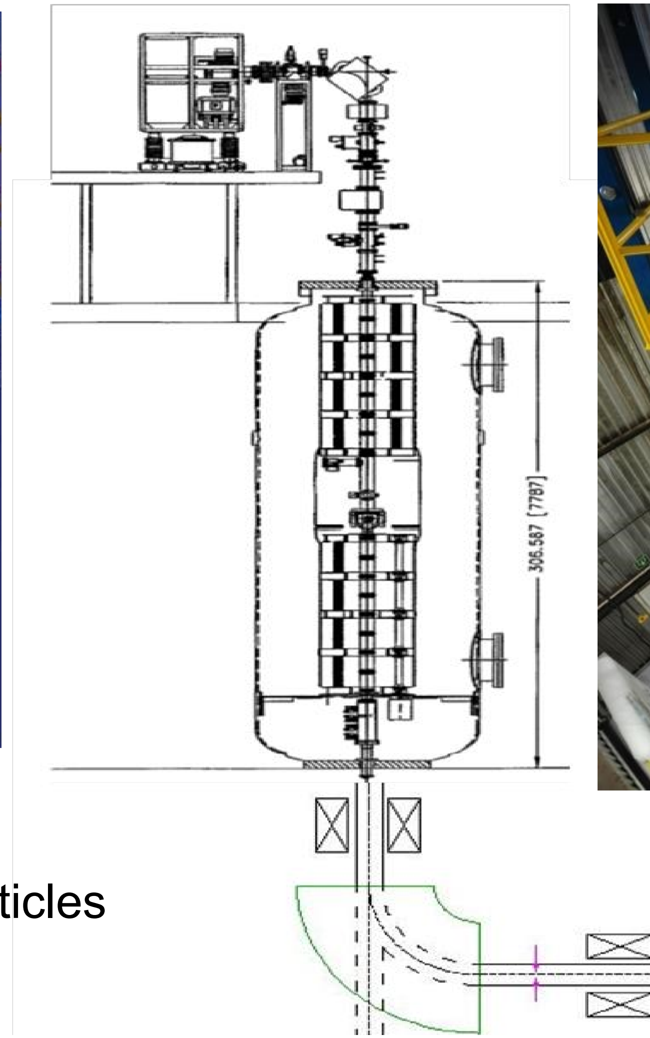
Measurement	Flight paths
Transmission	10 m, 30m, 50 m
Capture	10 m, 30 m, 60 m
Elastic sattering	30 m
Inelastic scattering	30 m, 100 m
Fission, (n,p), (n,α)	10 m

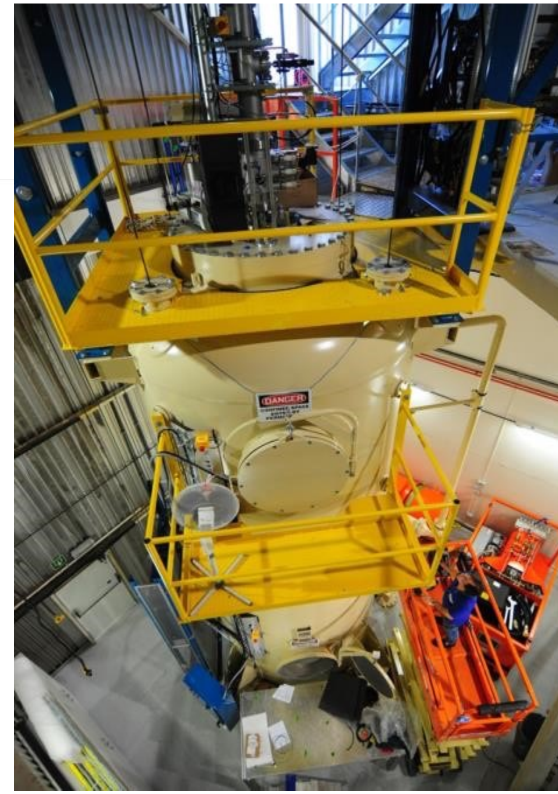


MONo eNErgetic neutrons by Tandem (MONNET)



3.5 MV NEC Tandem

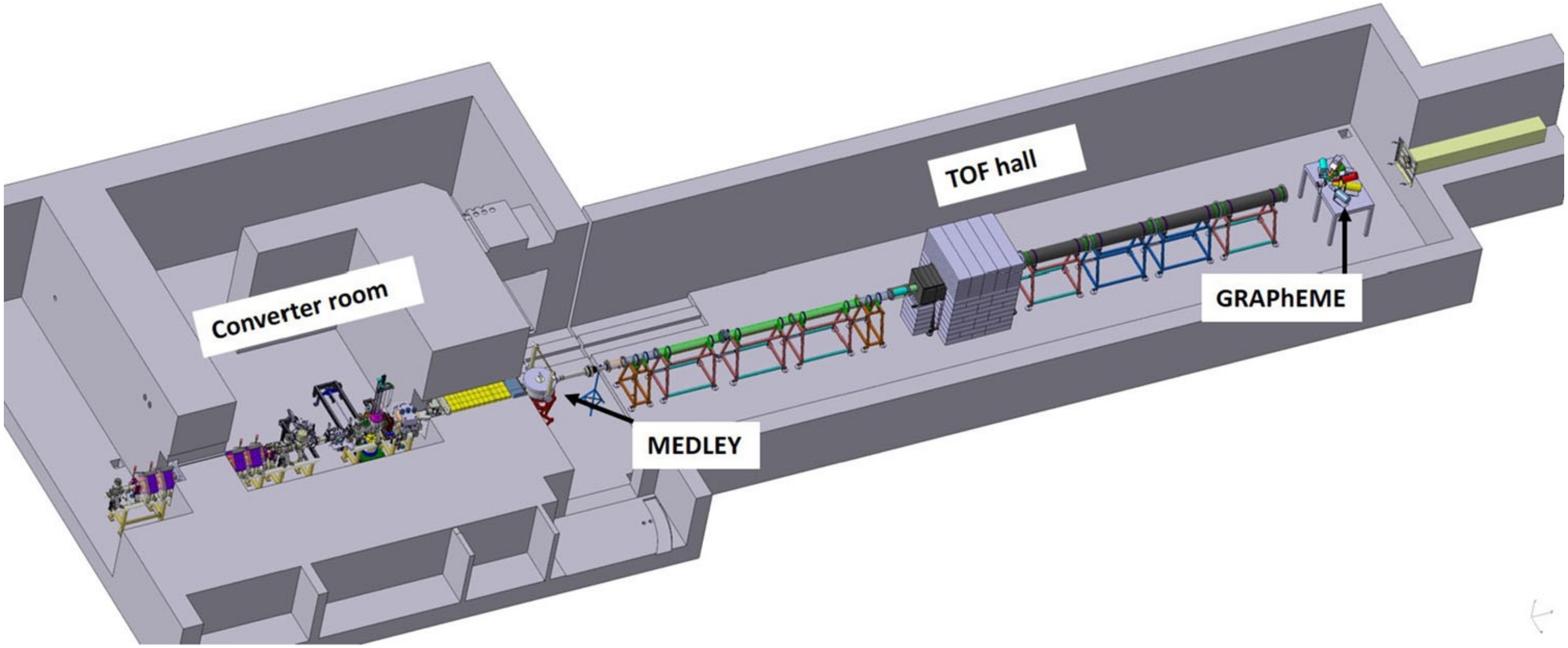




Protons, deuterons and α-particles
DC (p,d < 50 pA)
Pulse beam (1 – 2 ns)
E_n: 200 keV – 7 MeV

Neutrons for Science – NFS @ SPIRAL-2

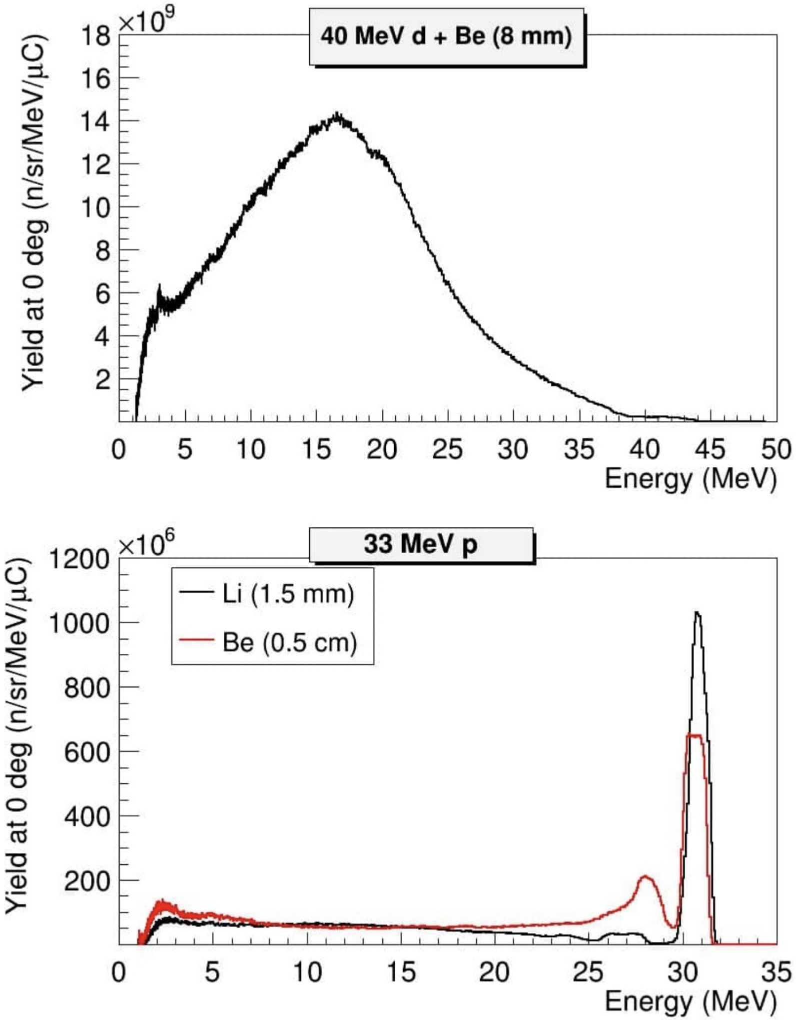
Driven by the high intensity SPIRAL-2 deuteron accelerator.

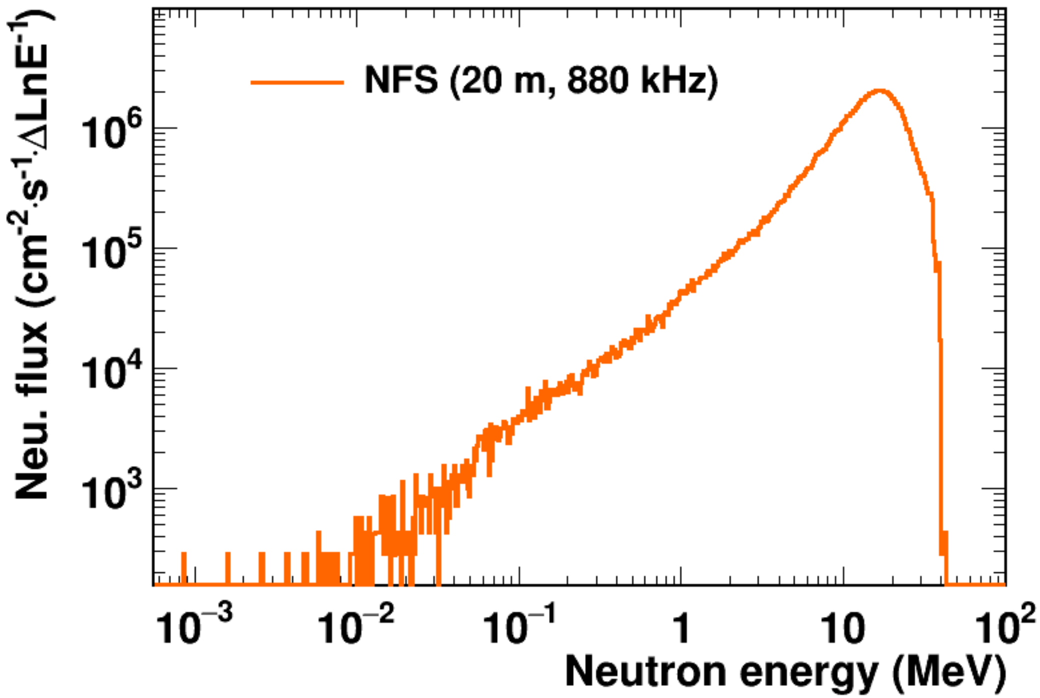


Production mechanism: $^{9}Be(d,xn)$, $^{7}Li(p,xn)$ and $^{nat}C(d,xn)$

I_d 50 μA

Neutrons for Science – NFS @ SPIRAL-2





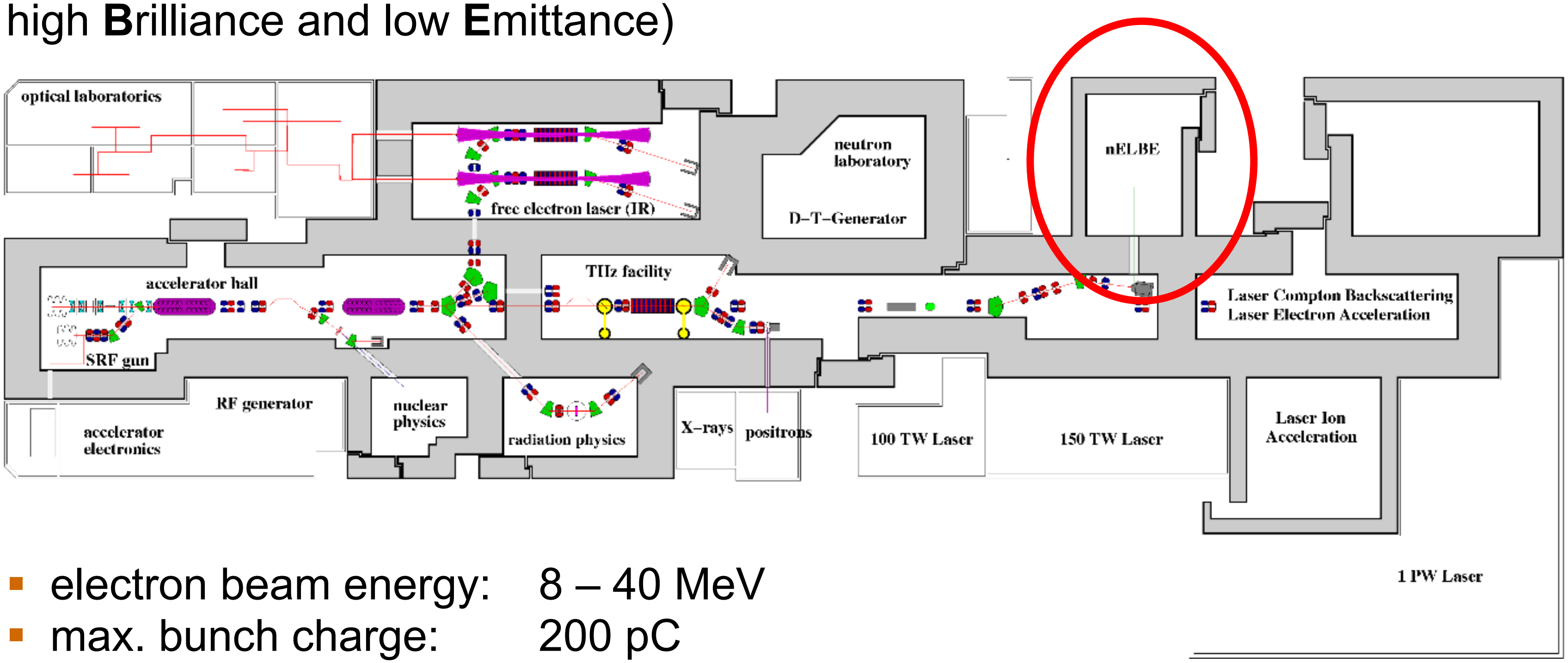
High energy neutron fluence with a high repetition rate.

Fig 2: Continuous and quasi-mono-energetic beams of neutrons produced at NFS. Neutron yields at 0° produced by a) 40 MeV deuteron beam on a Be (8 mm) convertor (upper panel). b) 33 MeV proton beam on thin lithium and beryllium convertors.

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council Established by the European Commission

nELBE – The neutron time-of-flight facility at ELBE

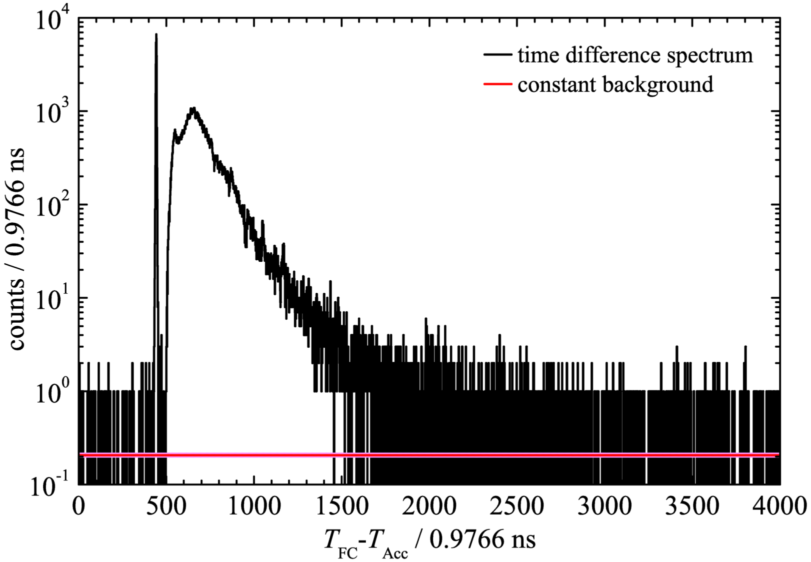
ELBE - Center for high-power radiation sources (**E**lectron **L**inac for beams with high **B**rilliance and low **E**mittance)

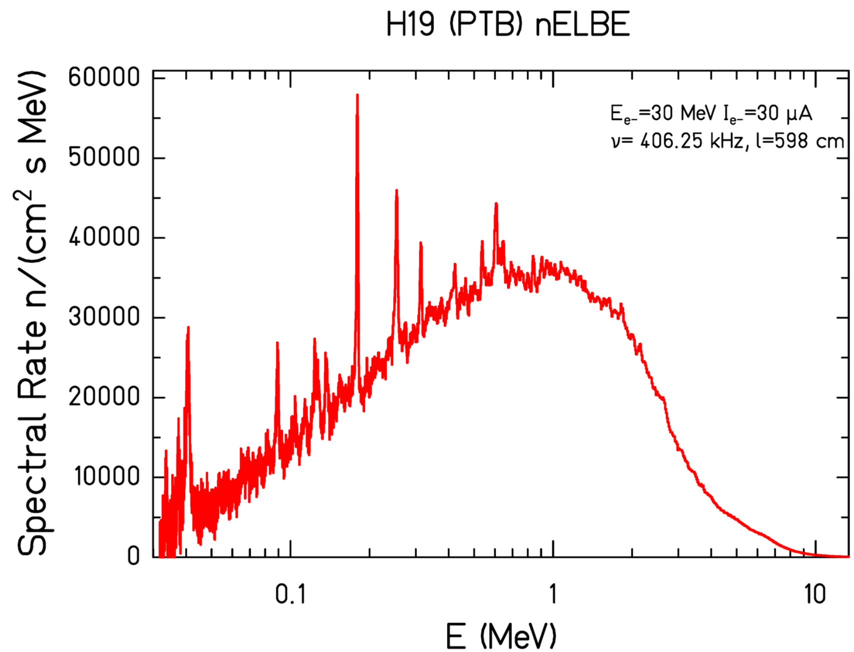


- electron beam energy: 8 – 40 MeV
- max. bunch charge: 200 pC
- repetition rate (cw): $13/2^n$ MHz (n = 0 - 7)
- max. mean beam current: 1 mA
- micro pulse length: ca. 5 ps

http://www.hzdr.de/elbe

nELBE neutron spectrum





Photoneutron spectrum (measured with the PTB ^{235}U fission chamber H19)

TOF spectrum: Photofission from bremsstrahlung and neutron induced fission

Photoneutron spectrum similar to the fission neutron spectrum

Neutron time of flight range 100 ns – 2,5 µs

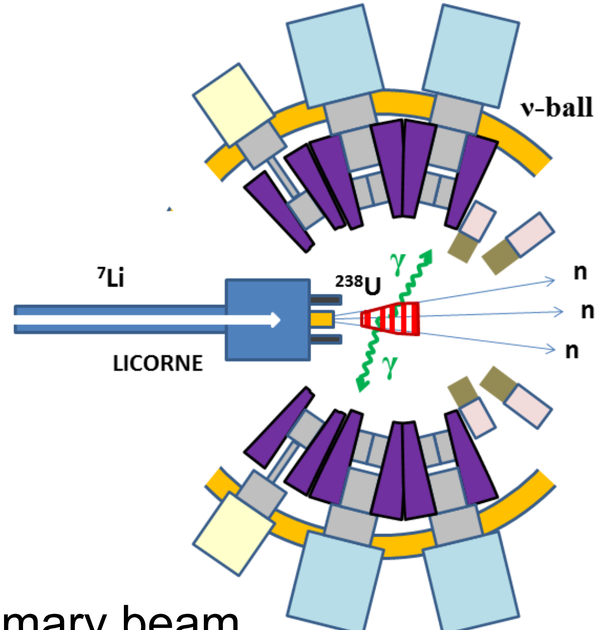
Neutron energy range from 100 keV – 7 MeV

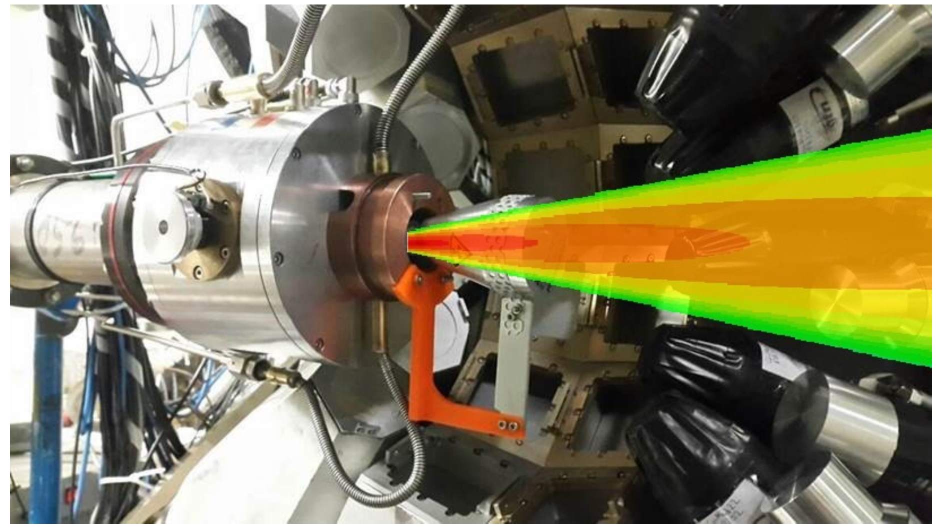
Neutron spectral rate on target ca. **$2*10^4$ n/(cm² s MeV)**

R. Beyer et al., NIM A723 (2013) 151

The LICORNE facility

LICORNE: The unique inverse kinematics neutron source of the ALTO facility





Primary beam
(400ns – pulsed)
2 x 10^{11} /s

^{7}Li (16 MeV)

200 nA

Gas target

H_2

3 x 10^{20} atoms/cm^{2}

Secondary beam
2 x 10^{7} n/s

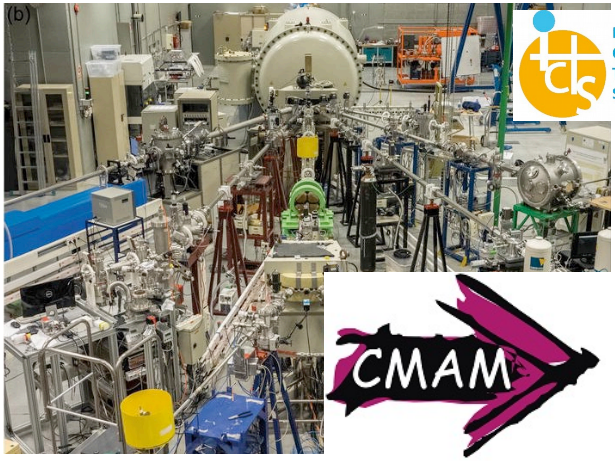
1.5 MeV neutrons

Samples
up to 10^{5} fissions/s

^{238}U
^{232}Th ~100 g

Measurements of (A,N) Yields and spectra (MANY)

Two Spanish facilities with electrostatic accelerators:



UPC

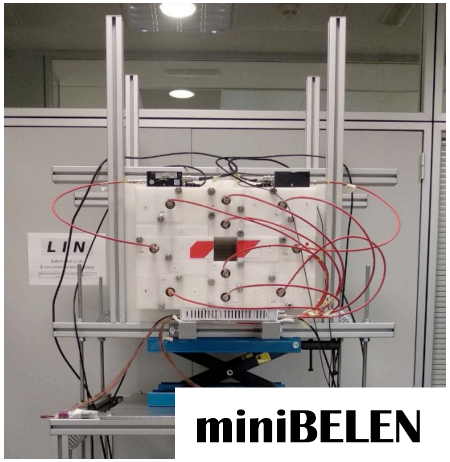
UNIVERSIDAD DE SEVILLA

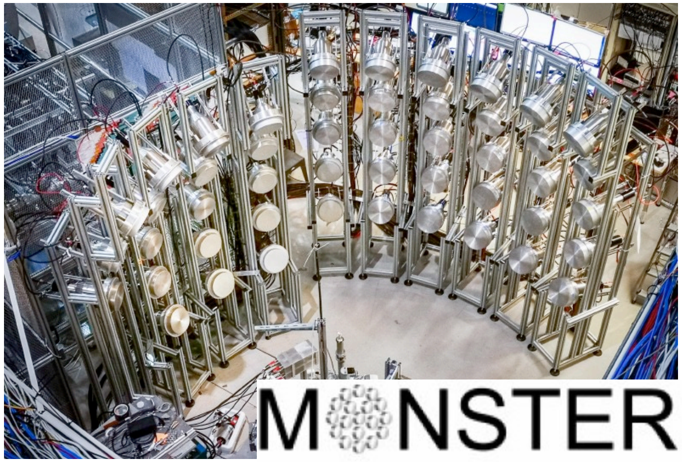
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

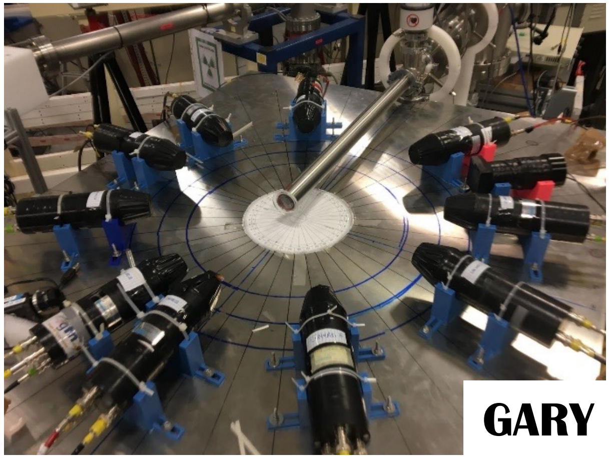
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

UNIVERSIDAD COMPLUTENSE MADRID

IEM
Instituto de Estructura de la Materia



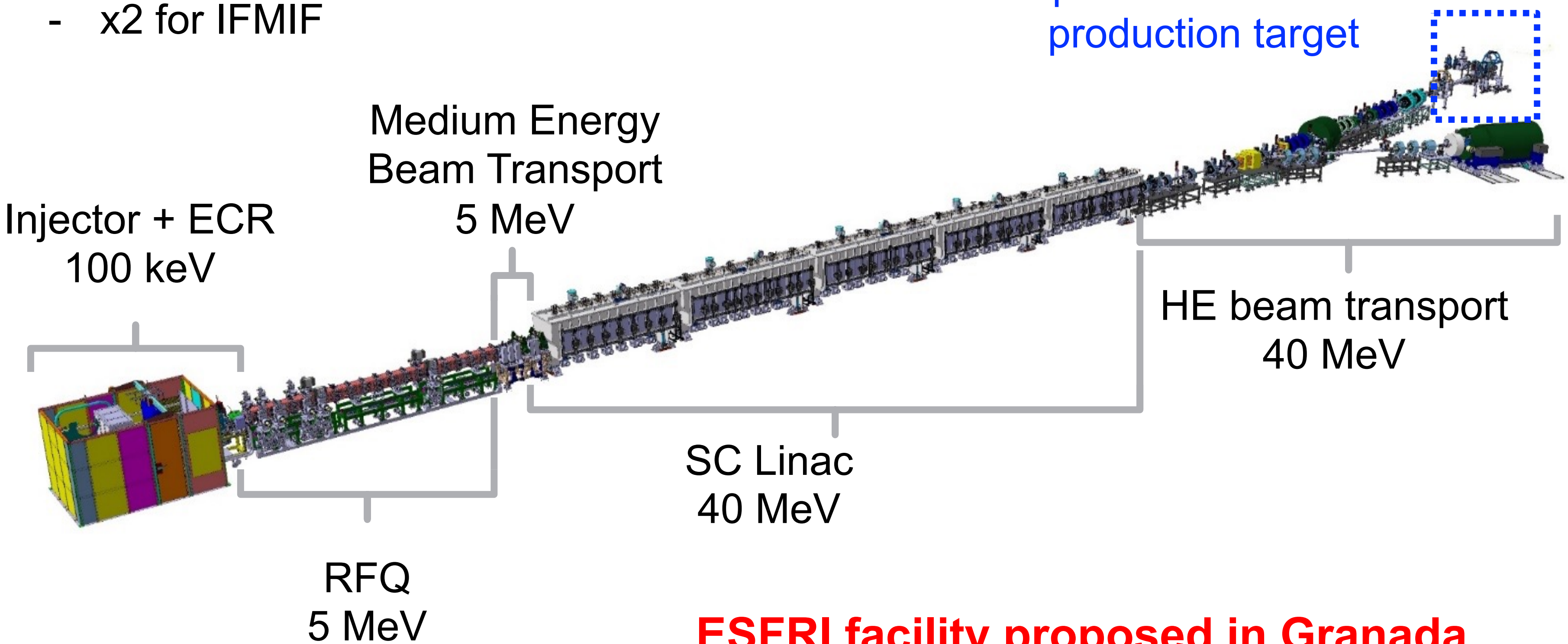




Time for one ad

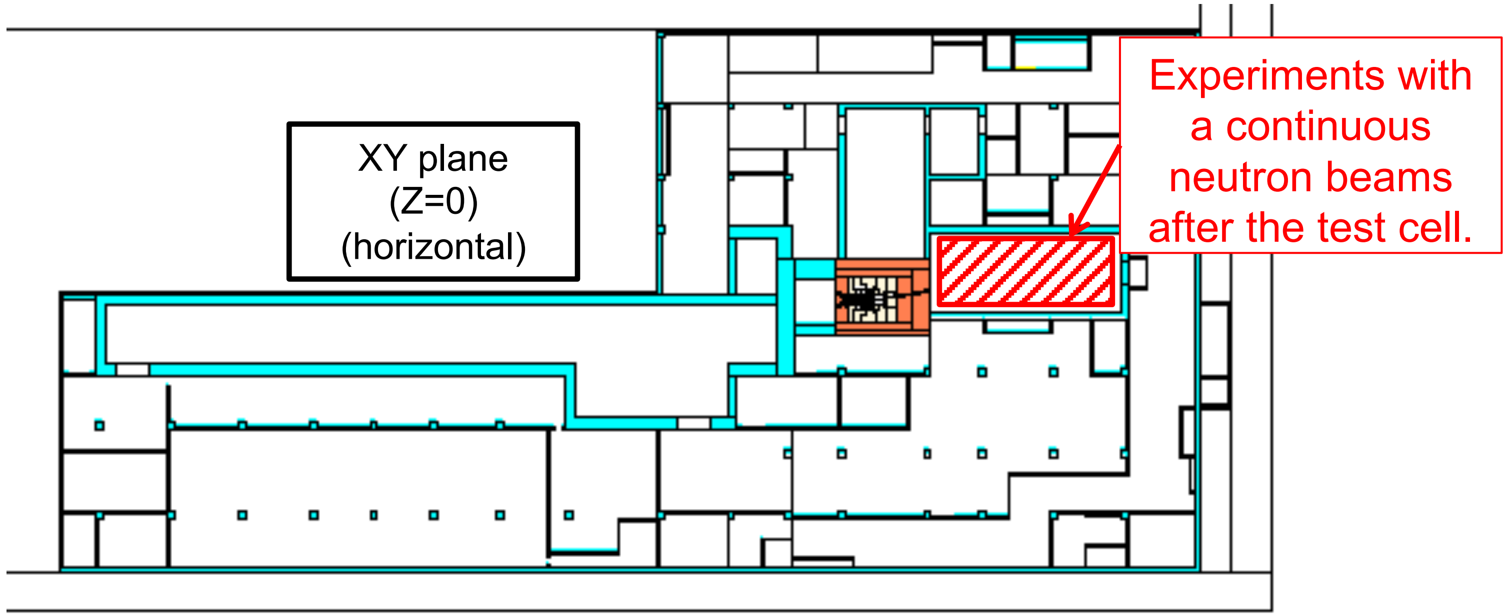
Demo Oriented NEutron Source (DONES)

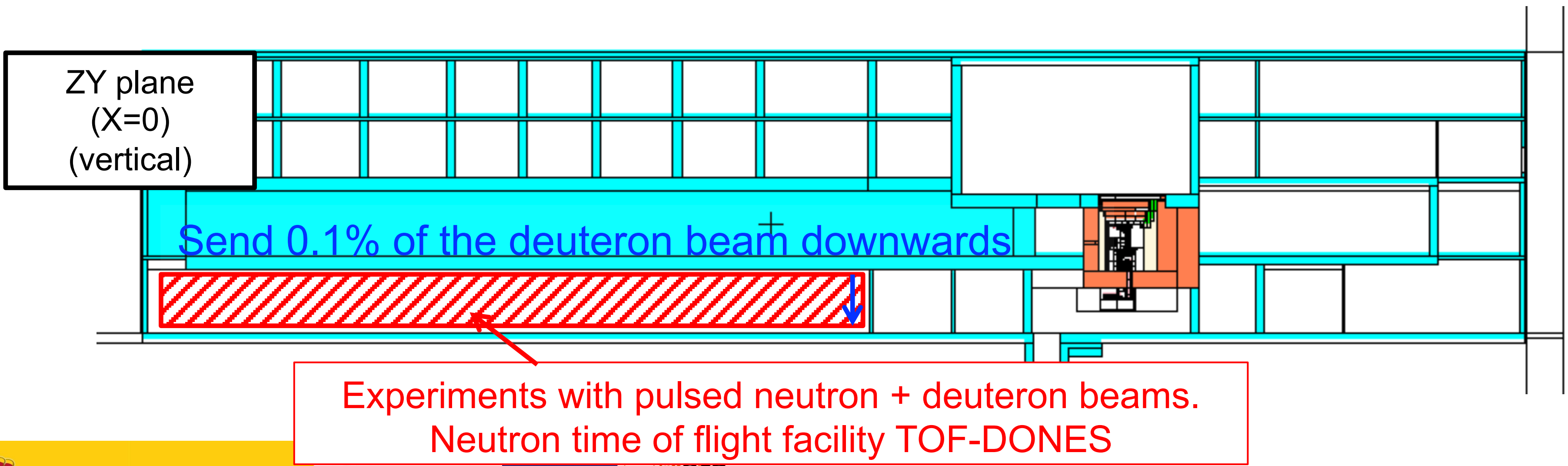
One of the most powerful accelerators in the world:
- 40 MeV deuterons.
- Broad beam profile: 20 cm x 5 cm.
- 125 mA
- x2 for IFMIF



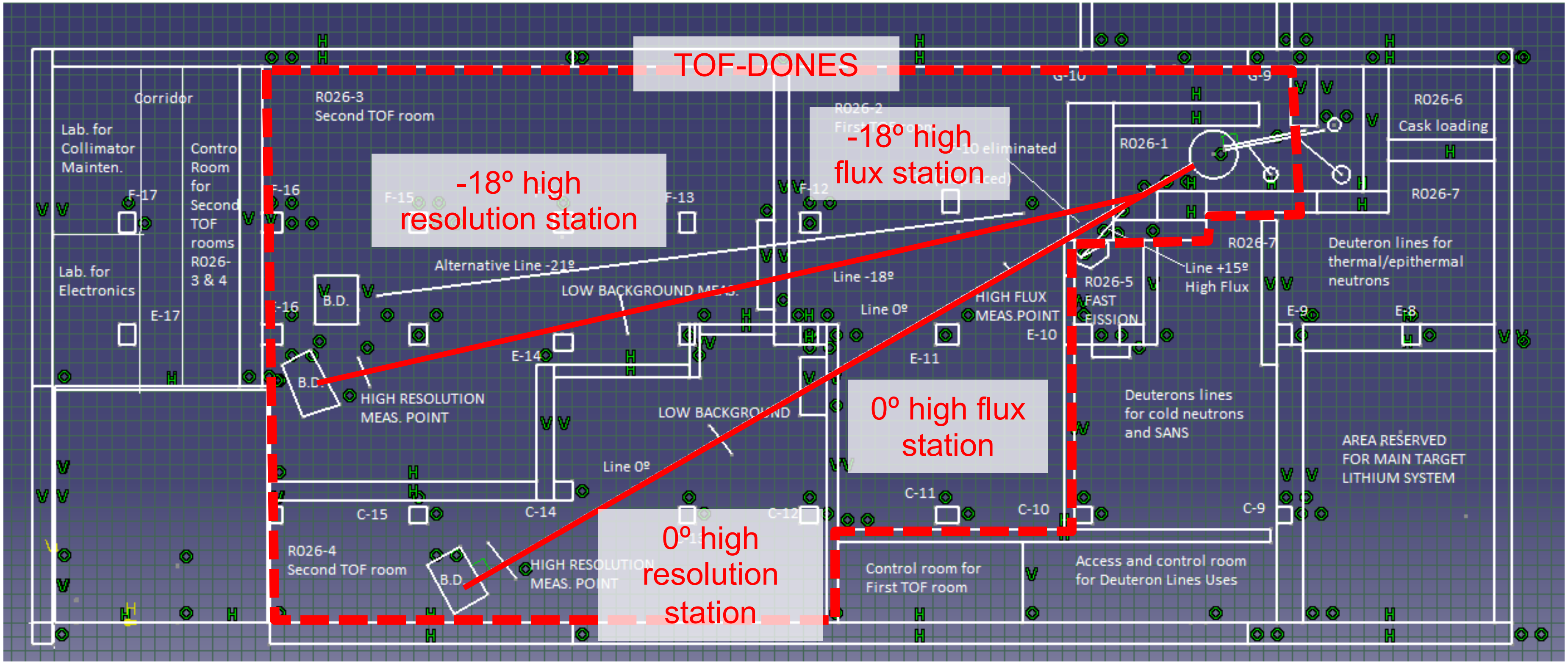
ESFRI facility proposed in Granada

The DONES facility

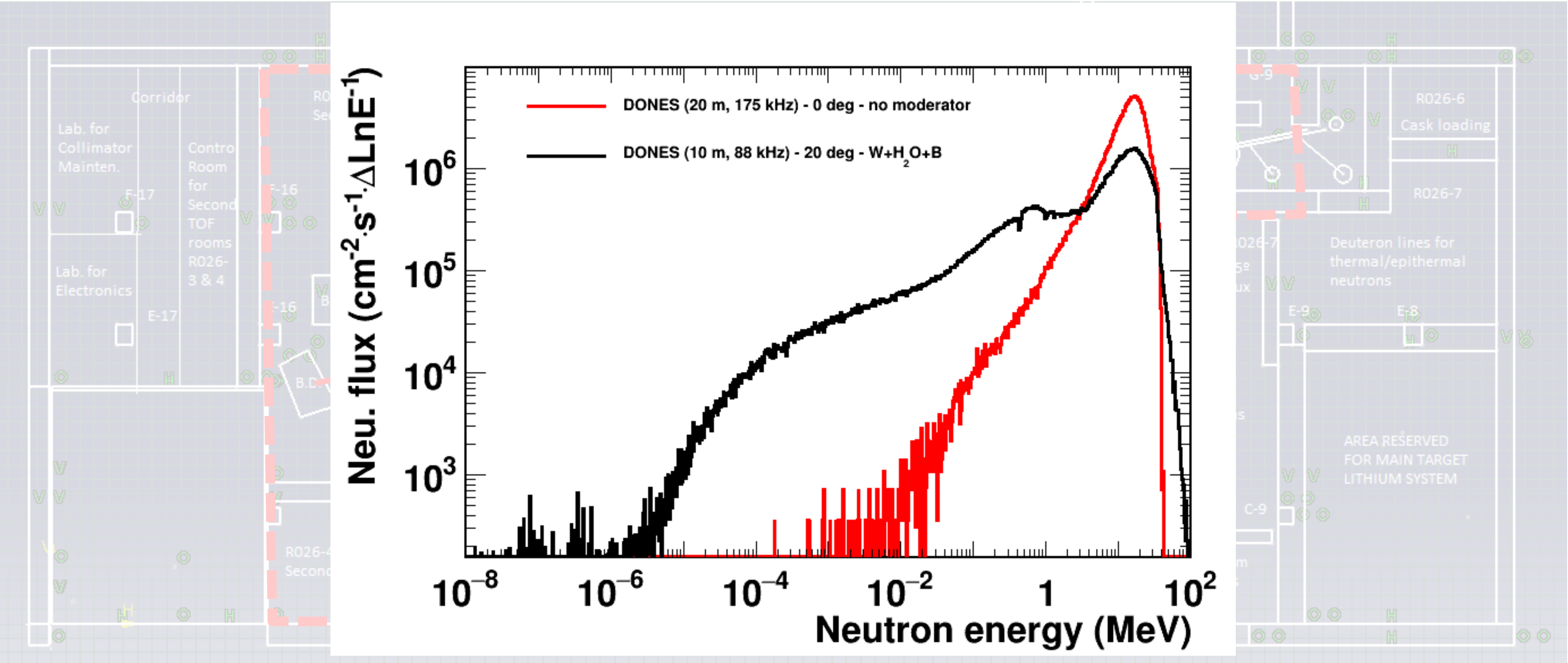




The TOF-DONES layout



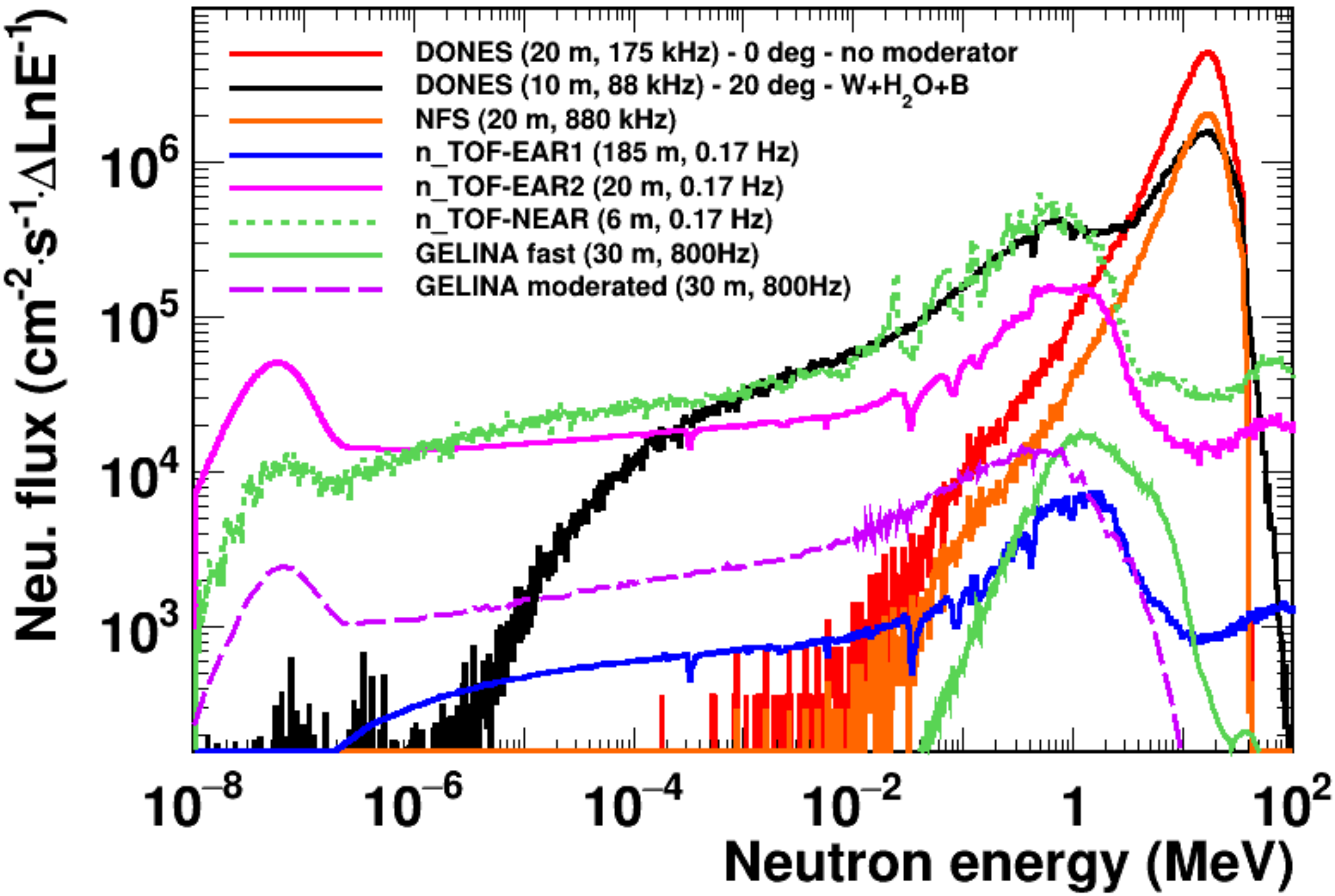
Neutron flux of TOF DONES



Summary table of facilities

	L	E_n	(n,tot)	(n,γ)	(n,f)	(n,xn)	(n,n'γ)	(n,el)	F.Y.	Act.
n_TOF	185 m 20 m 60 m	meV – GeV	in progress	X	X	under study	under study	-	X	X
GELINA	3 m – 400 m	meV – MeV	X	X	X	X	X	X	-	-
NFS	40 m	1 – 40 MeV	X	X	X	X	X	X	X	-
nELBE	5 m	0.1 – 10 MeV	X	-	X	X	X	X	-	-

Comparison of the facilities: fluences

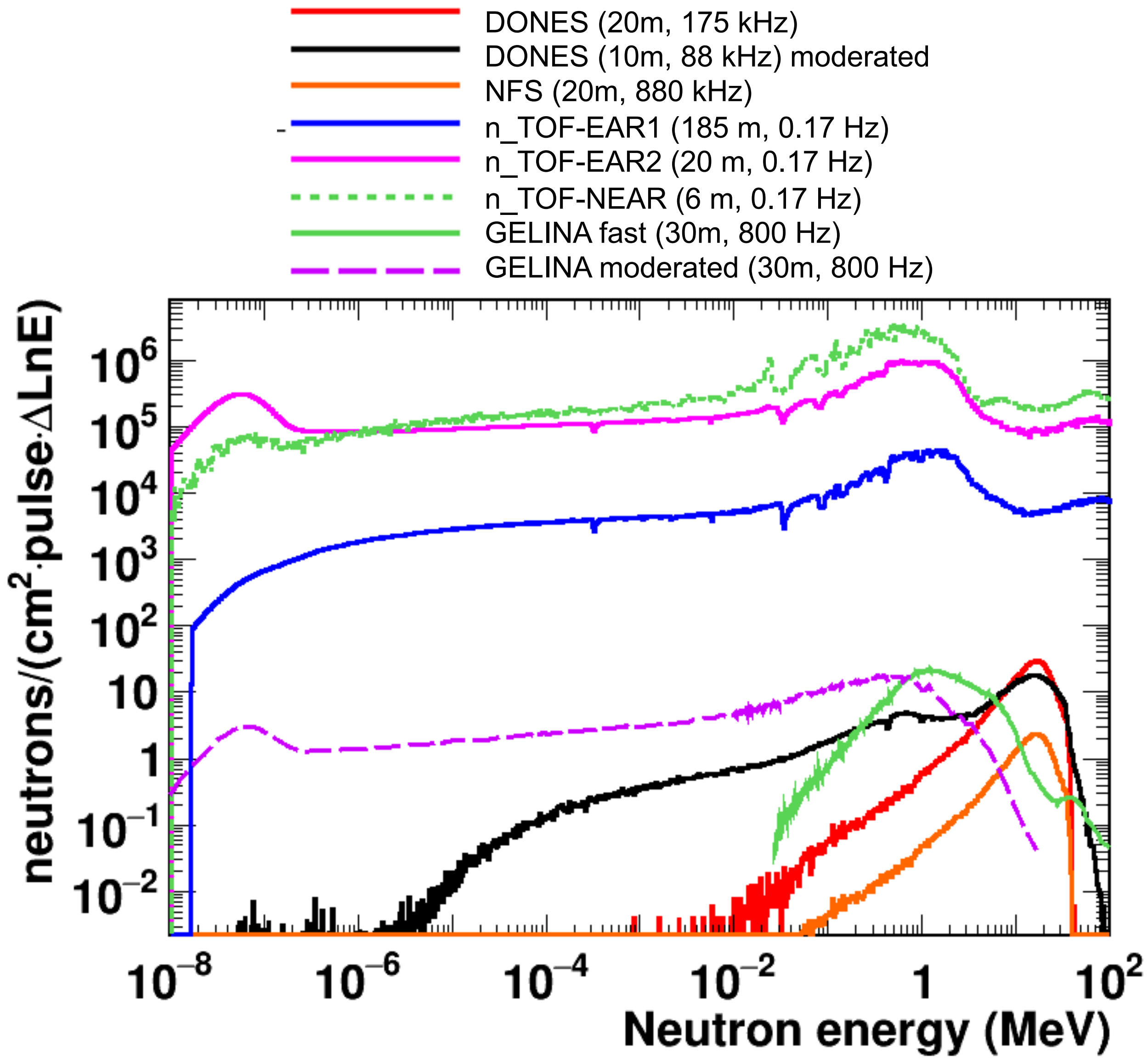


GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

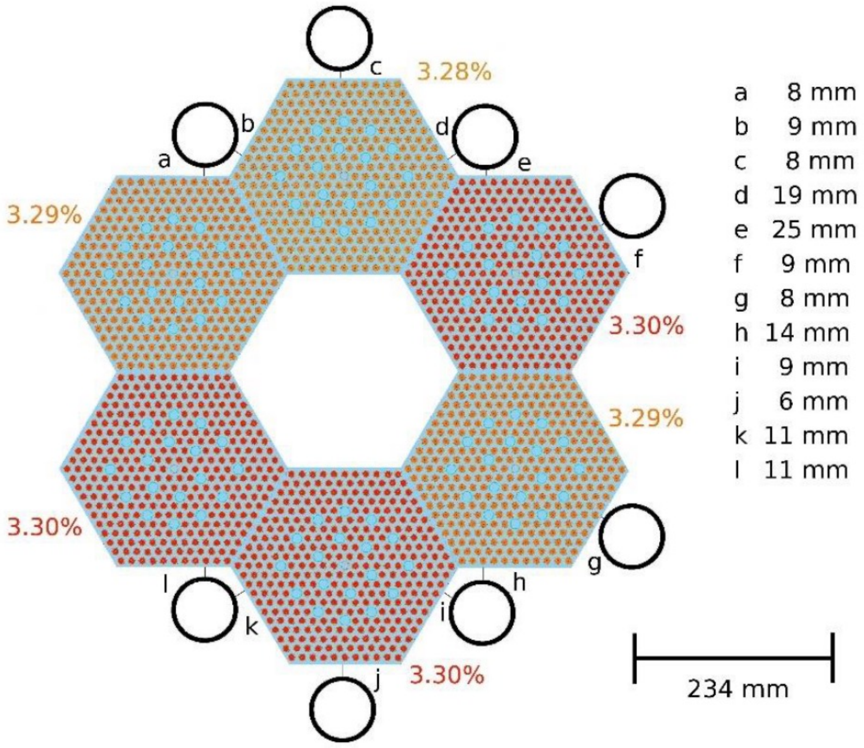
erc European Research Council Established by the European Commission

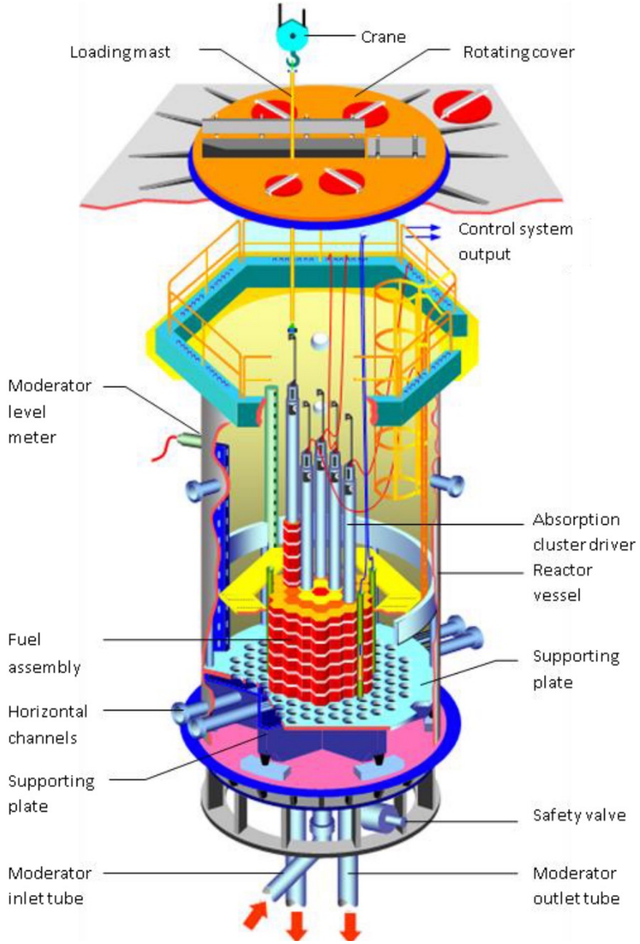
Comparison of the facilities: neutrones / pulse



LR-0 reactor at CVREZ

The **LR-0** is a zero-power light water pool type reactor operated by the Research Centre Řež (Czech Republic). Continuous nominal power is 1 kW with a thermal neutron flux of about **10^9 $cm^{-2}·s^{-1}$** and a fast neutron flux (above 1 MeV) of **$2×10^8$ $cm^{-2}·s^{-1}$**.





GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

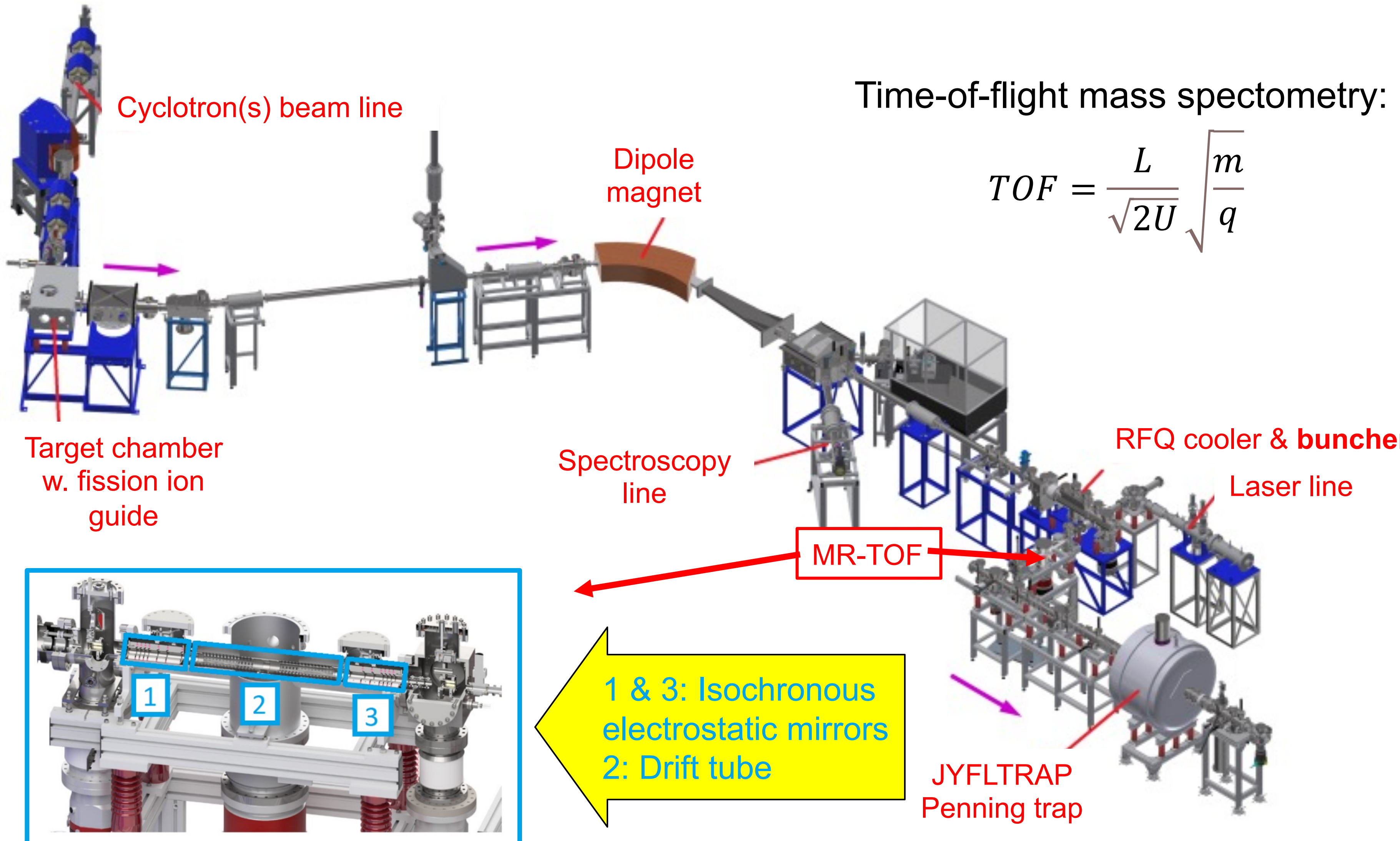
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

erc European Research Council Established by the European Commission

IGISOL with PI-ICR technique and MR-TOF device

Time-of-flight mass spectometry:

$$TOF = \frac{L}{\sqrt{2U}}\sqrt{\frac{m}{q}}$$

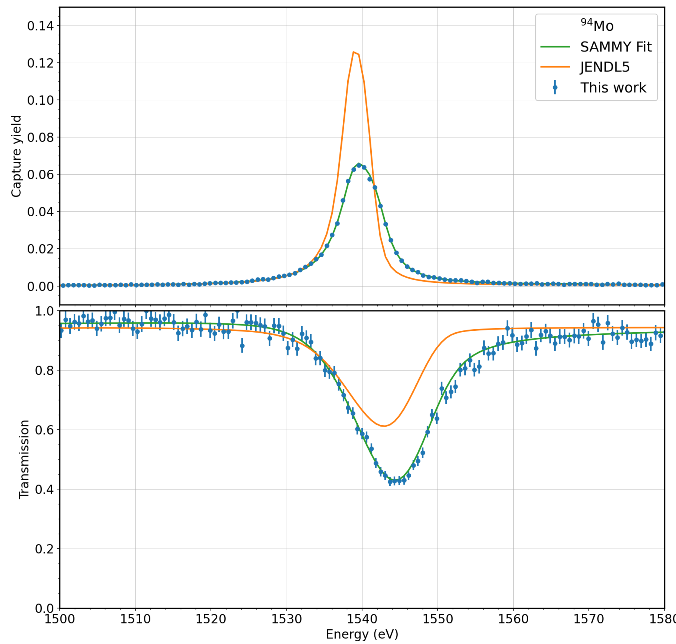


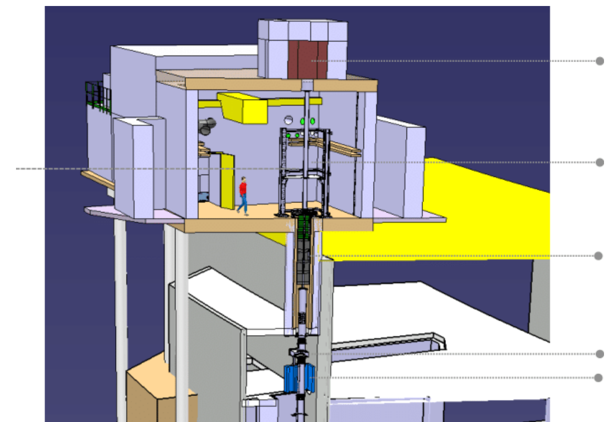
Measurements

^{94,95,96}Mo(n,γ) and (n,tot) cross section measurements

Multi-facility experiment at GELINA and two n_TOF experimental areas.

- Transmission measurement with enriched pellets at 10 m station of GELINA
- Transmission measurements with natural samples at 50 m station of GELINA
- Capture measurements at n_TOF EAR1 (185 m) and EAR2 (20 m)





Isotope	Mass (mg)
^{94}Mo (98.97%)	1,952.6
^{95}Mo (95.40%)	1,974.5
^{96}Mo (95.90%)	1,917.5
^{nat}Mo-5 μm	2,014.0
^{nat}Mo-350 μm	1,989.0

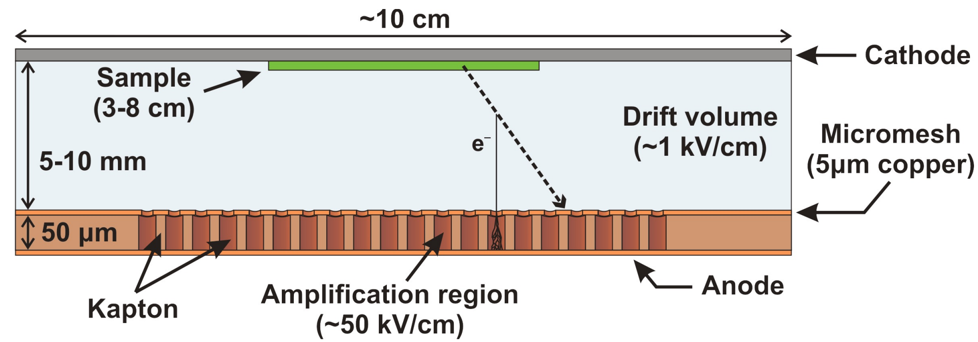
^{241}Am(n,f) at n_TOF EAR2

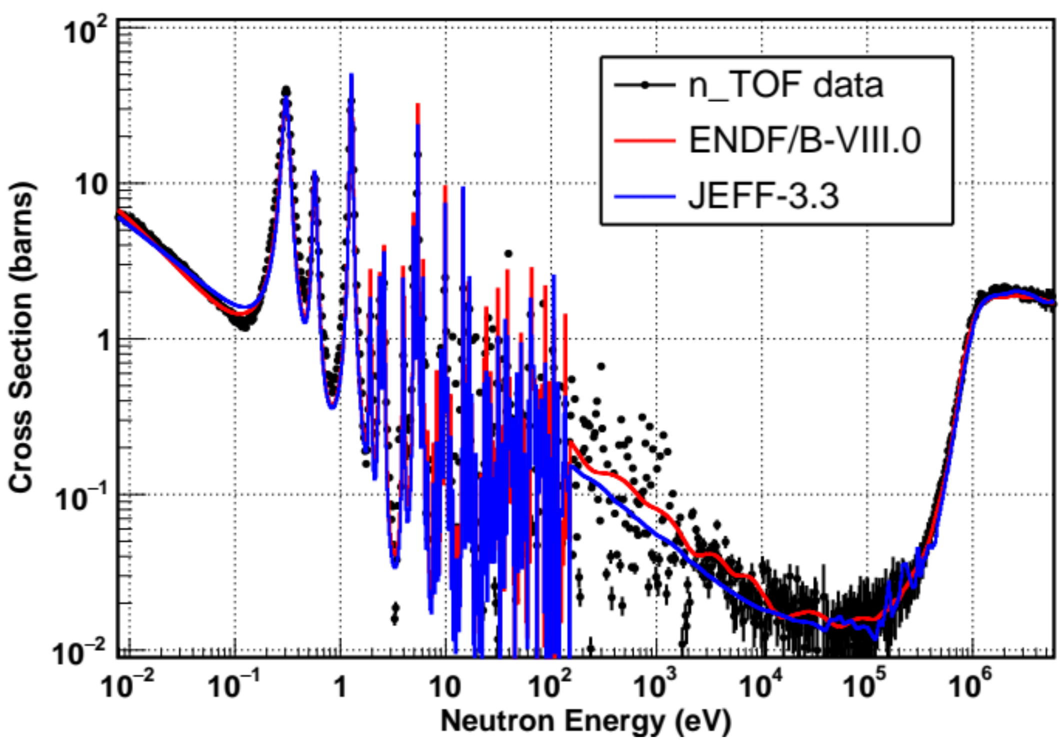
Measurement done at EAR2

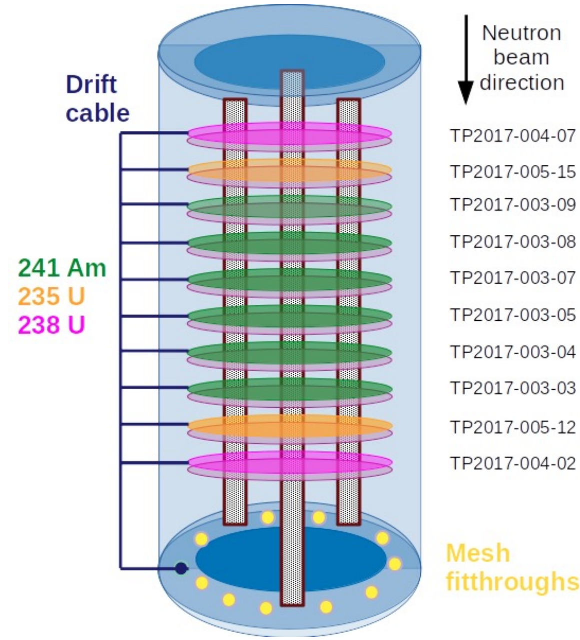
Specific activity of ^{241}Am: 127 MBq/mg

Micromegas detectors (MICRO- Mesh Gaseous Structure) detectors

^{241}Am (0.77 mg) + ^{235}U + ^{238}U







PhD thesis of Zinovia Eleme (UIO)

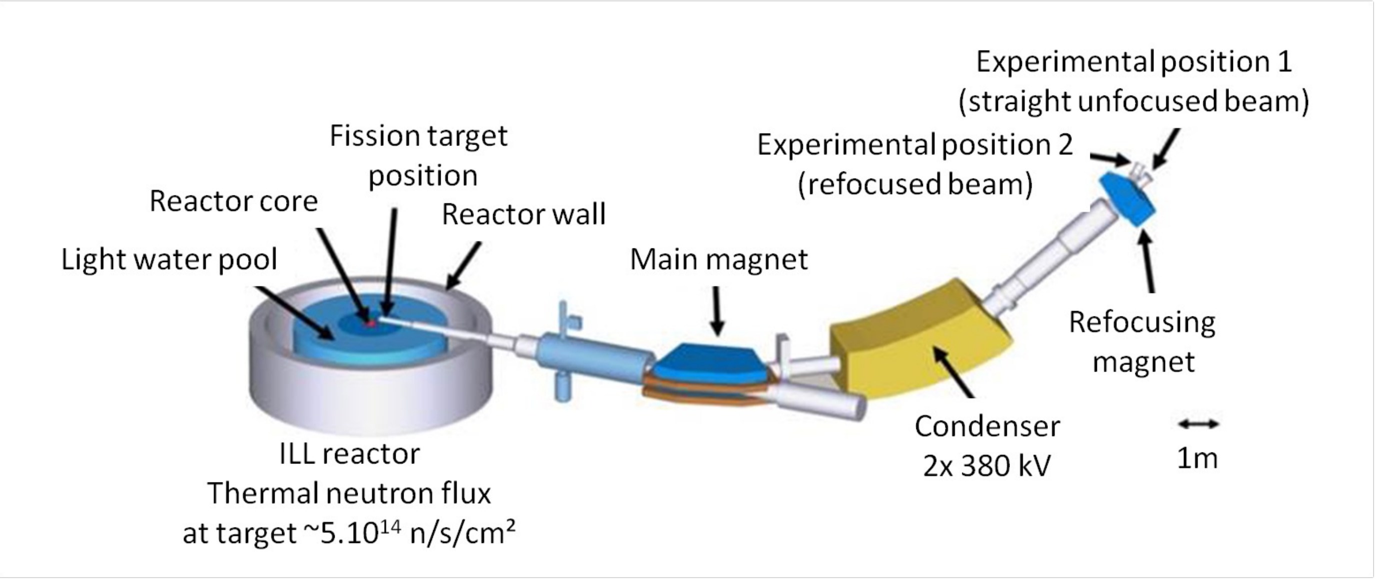
$^{239}Pu(n,\gamma)$ and (n,f) / $^{233}U(n,n'\gamma)$, $^{13}N(n,n'\gamma)$

^{239}Pu(n,γ) and (n,f) / ^{233}U(n,n'γ), ^{13}N(n,n'γ)

No spoiler:

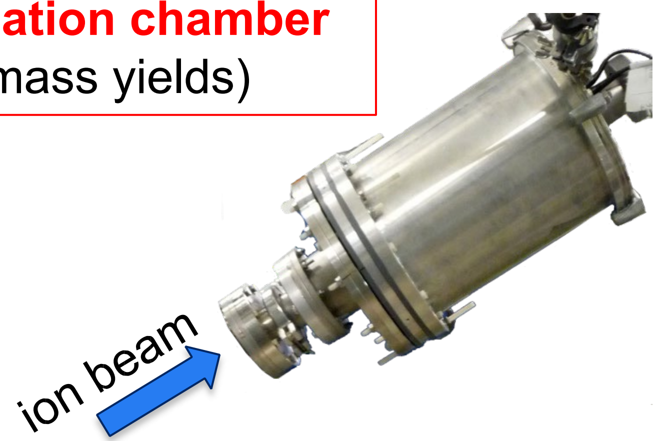
See the talks by A. Sánchez (^{239}Pu) and Maëlle Kerveno (inelastic xs measurements)

Fission yield measurements at ILL - Grenoble

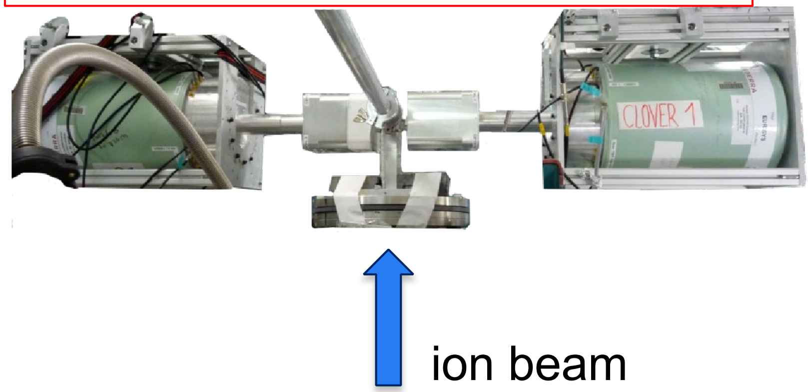


Lohengrin:
Selection in A/q & E/q
A : mass
q : ionic charge
E : kinetic energy
Flight path : 23 m
Flight time ~ μs

Measurements with an **ionisation chamber** (mass yields)



Or with **HPGe detectors** (isotopic yields, isomeric ratios)

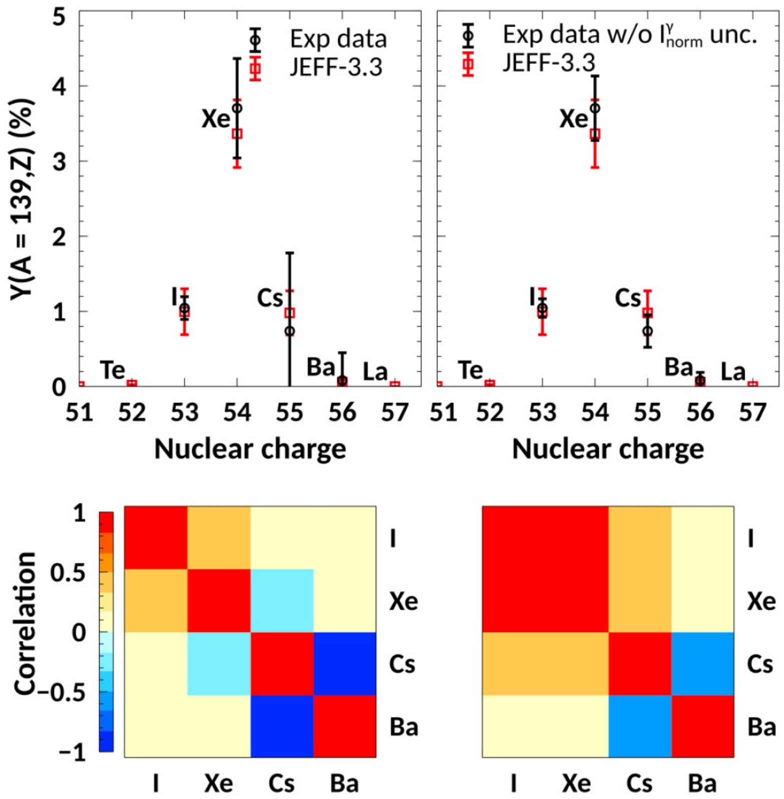


Fission yield measurements at ILL - Grenoble

Absolute isotopic yields for $^{241}Pu(n_{th},f)$

New measurement and analysis protocol

Evaluation of the systematicsof the setup(correlations E-q, target burnup…) and computation of the experimental variance-covariance matrices



Mass A = 139:
All the uncertainties propagated (left)
Case where the uncertainty of the normalization the normalization intensity is equal to zero

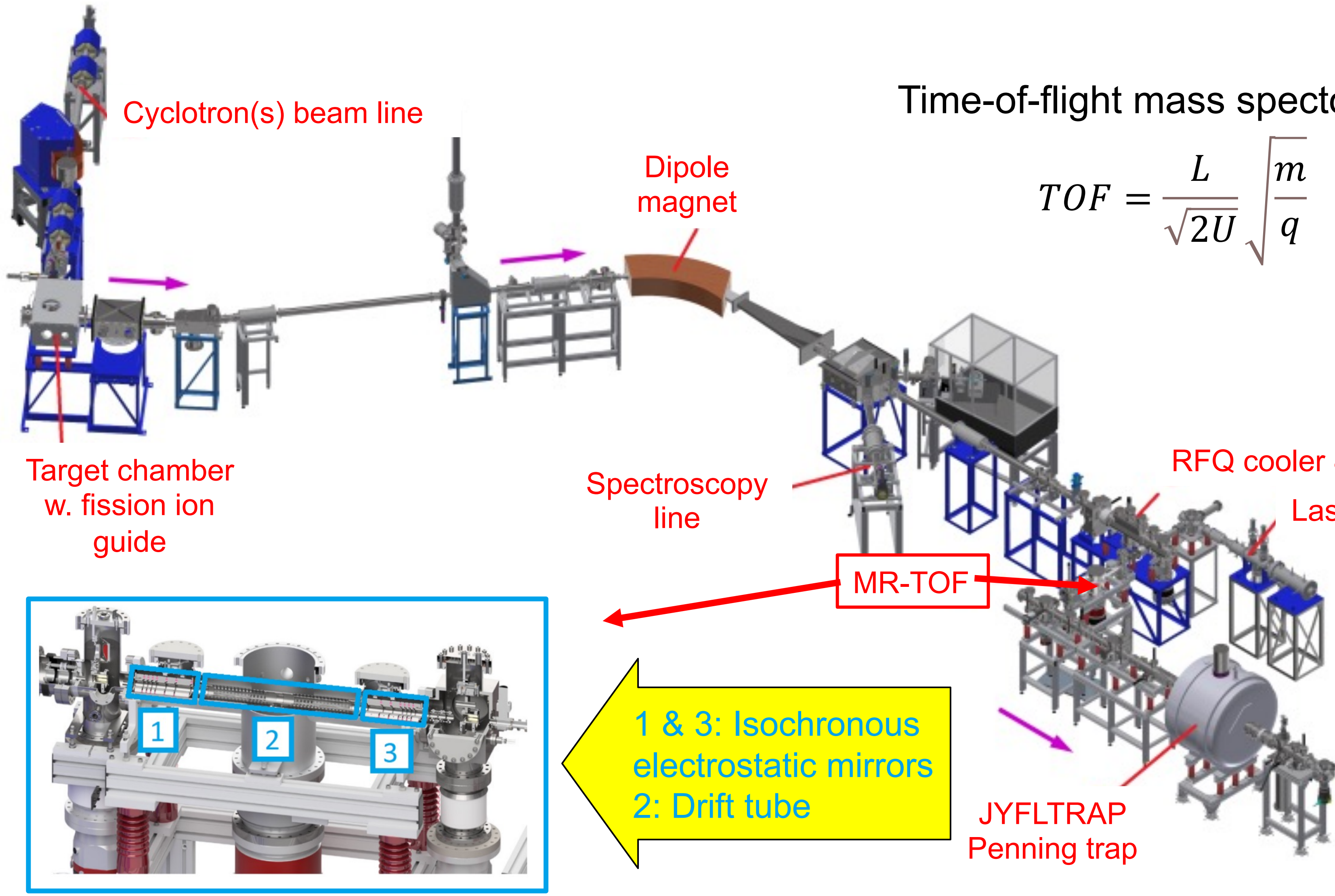
→ uncertaintiesmainly coming from nuclear decay data

*S. Julien-Laferrière et al., Phy. Rev. C **102**, 034602 (2020)*

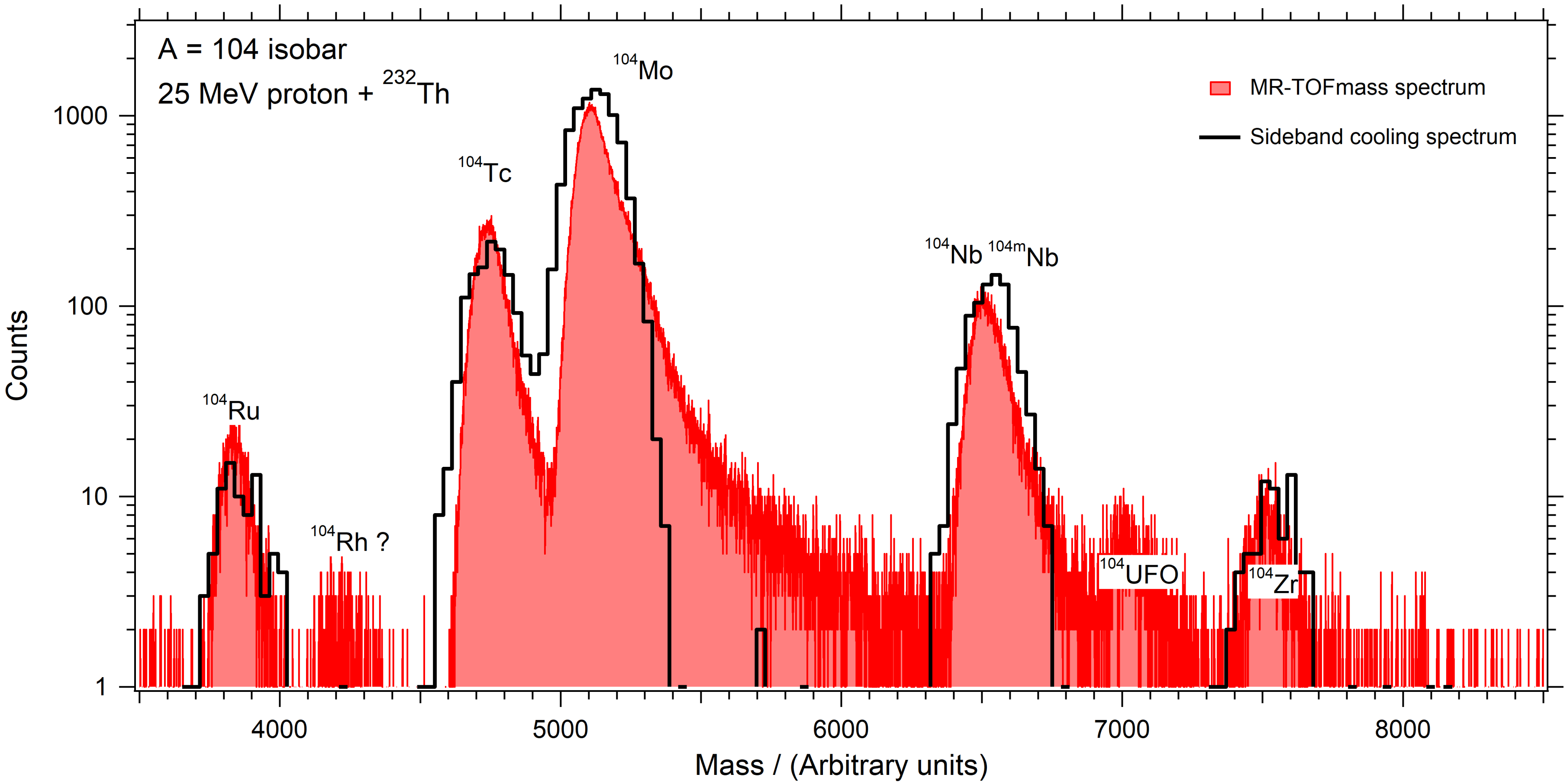
IGISOL with PI-ICR technique and MR-TOF device

Time-of-flight mass spectometry:

$$TOF = \frac{L}{\sqrt{2U}}\sqrt{\frac{m}{q}}$$



Fission with PI-ICR technique and MR-TOF device



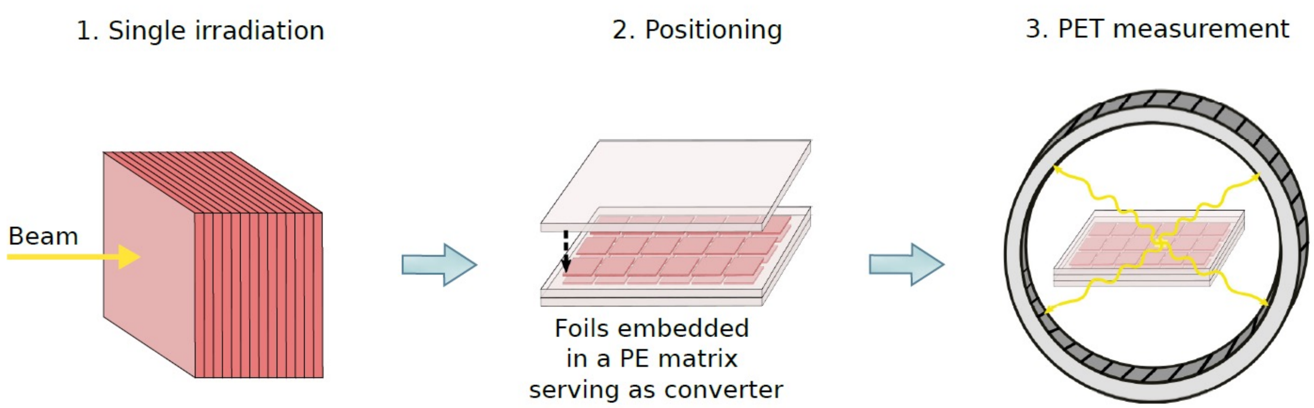
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council

Activation cross sections for proton therapy

Isotope	Half-life	Q_{β^+} (MeV)	Reaction channel	Threshold (MeV)
^{11}C	20.36 min	0.960	^{12}C(p,x)^{11}C ^{14}N(p,x)^{11}C ^{16}O(p,x)^{11}C	17.9 3.13 23.6
^{13}N	9.97 min	1.198	^{12}C(p,x)^{13}N ^{14}N(p,x)^{13}N ^{16}O(p,x)^{13}N	- 8.93 5.55
^{15}O	122 s	1.735	^{14}N(p,x)^{15}O ^{16}O(p,x)^{15}O	- 14.3
^{12}N	11 ms	16.316	^{12}C(p,x)^{12}N	19.6
^{38m}K	0.925	5.022	^{40}Ca(p,x)^{38m}K	14.0
^{29}P	4.14 s	3.921	^{31}P(p,x)^{29}P	15.6

PhD Thesis of Teresa Rodríguez-González.
Courtesy of C. Guerrero

T. Rodriguez et al., Rad. Phys. Chem. 190 (2022)
T. Rodriguez et al., Nucl. Data Sheets 187 (2023)



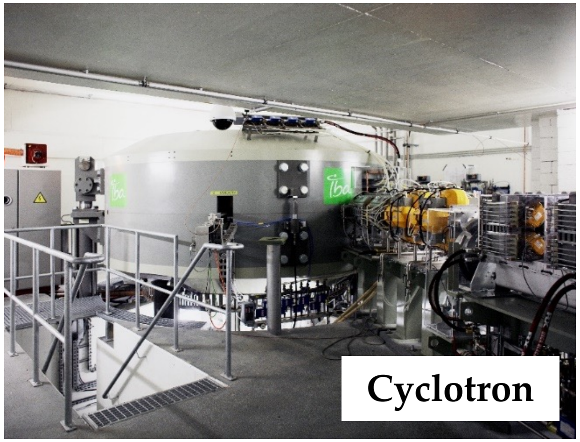
Irradiaton facilities

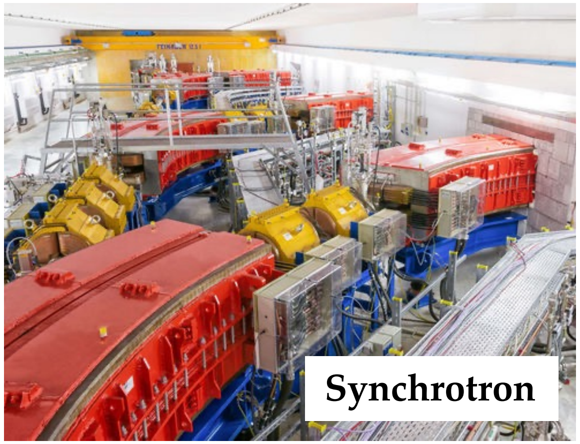
CNA Centro Nacional de Aceleradores — ICTS Infraestructuras Científicas y Técnicas Singulares

wpe Westdeutsches Protonentherapiezentrum Essen

HIT Heidelberger Ionenstrahl-Therapiezentrum — HITRIplus Heavy Ion Therapy Research Integration

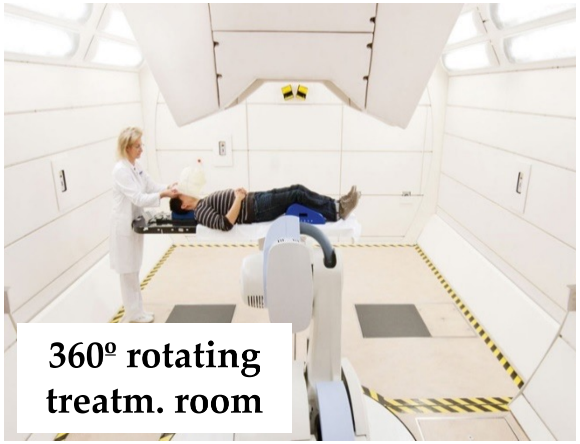

Cyclotron


Cyclotron

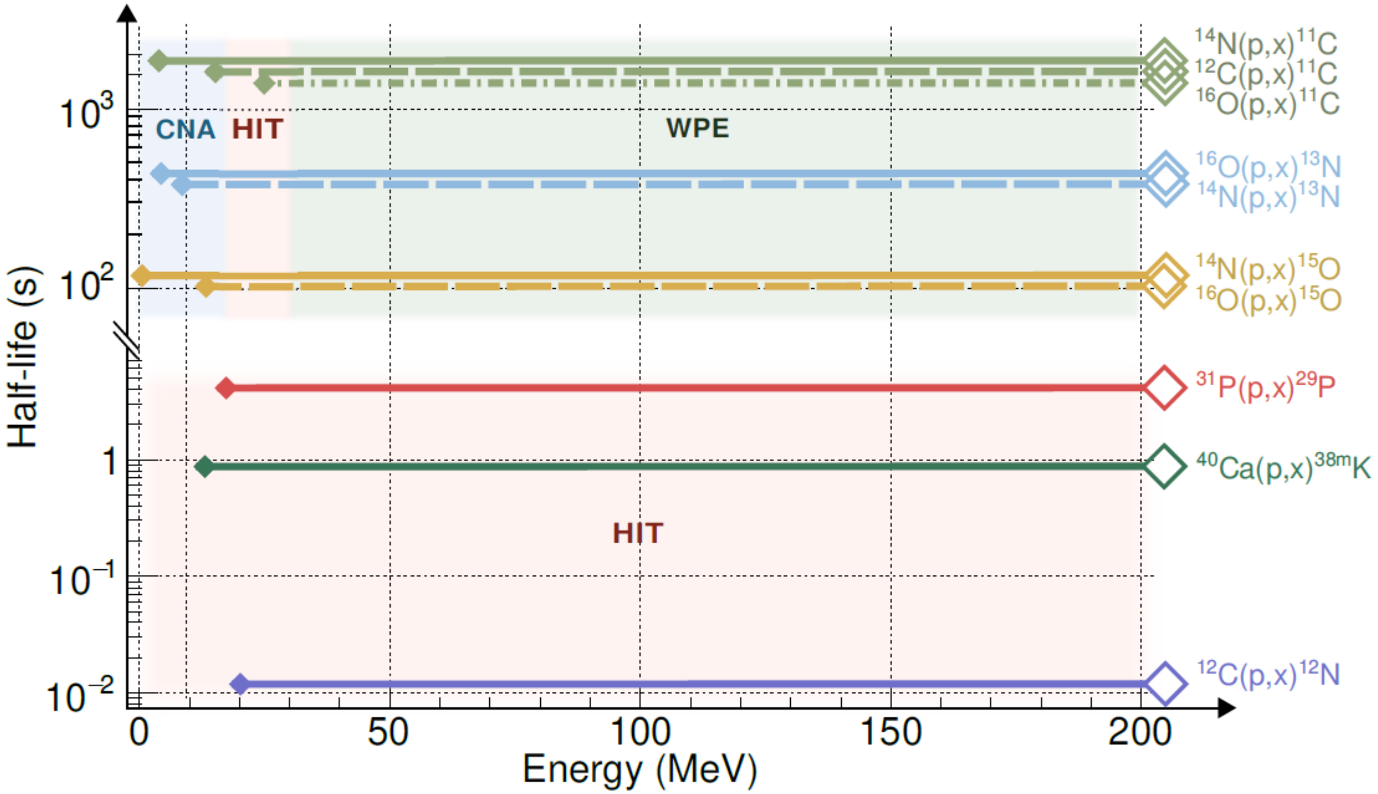

Synchrotron


Exp. beam line


360º rotating treatm. room


360º rotating treatm. room

Multi facility experimental campaign

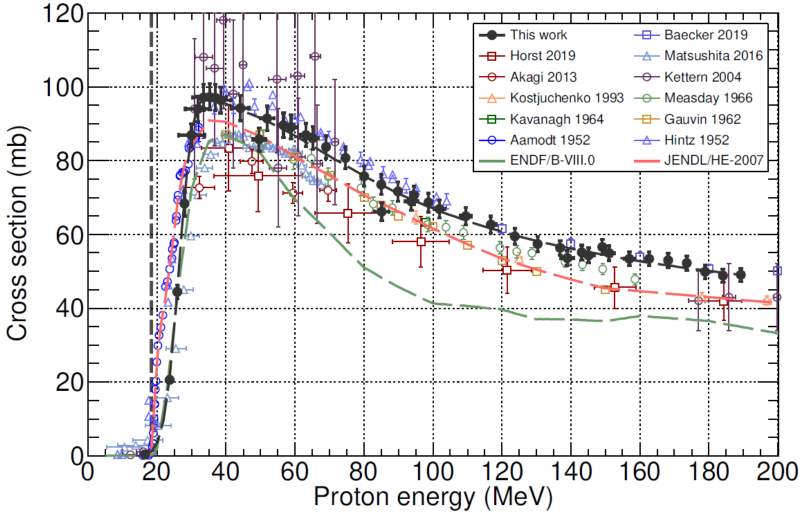


Multi-foil activation and PET scanner

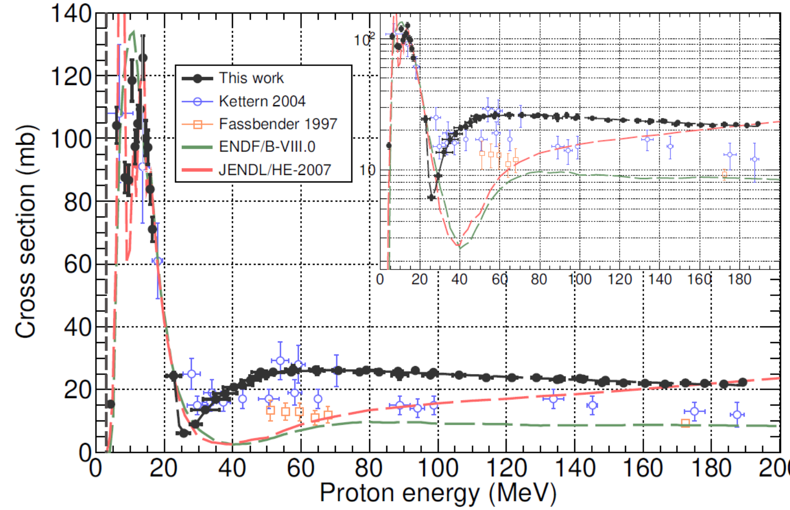
Single-foil activation and conventional detectors

A few results

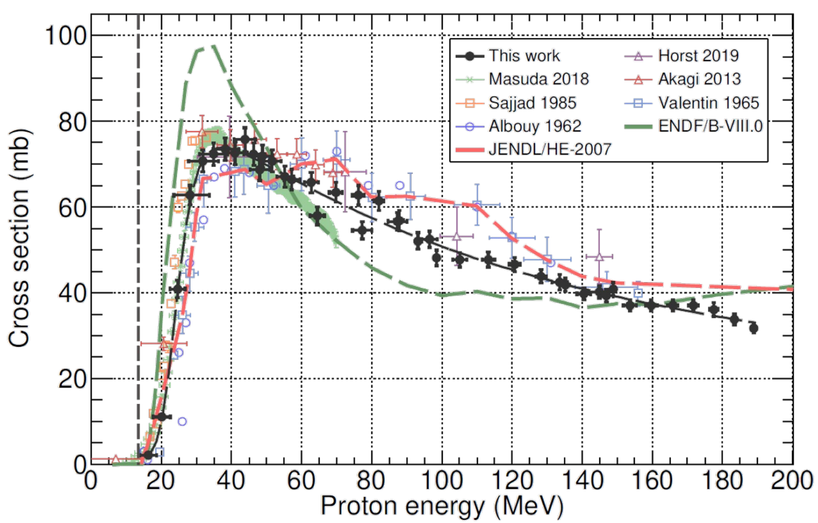
$^{12}C(p,x)^{11}C$



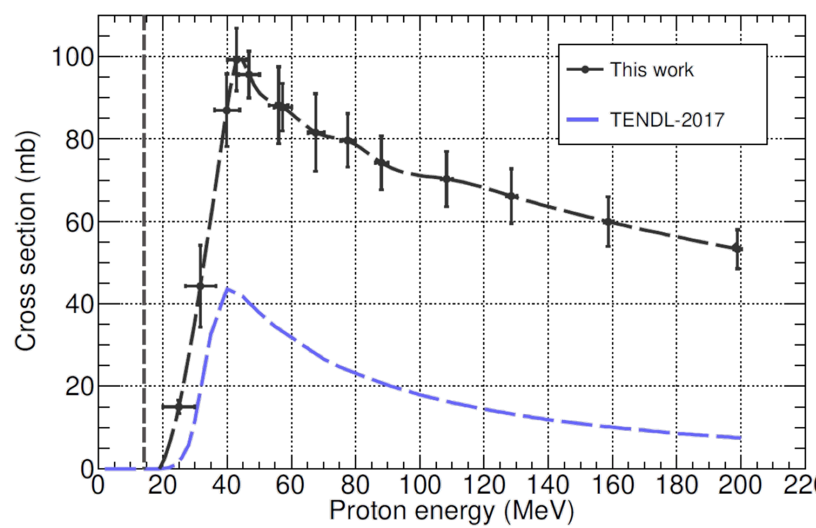
$^{14}N(p,x)^{11}C$



$^{16}O(p,x)^{15}O$



$^{40}Ca(p,x)^{38m}K$



Measurements carried out in SANDA

(p,x)	(n,ch.p.)	(n,f)	(n,inel)	(n,γ)	decay b-n	decay T1/2	Fission yields	SACS
^{12}C(p,γ)^{13}N	^{nat}C(n,lchp)	^{235}U(n,f)	^{197}Au(n,2n)	^{92}Mo(n,γ)	Ni-75	^{106}Ru	^{235}U	^{117}Sn
^{12}C(p,x)11C	^{14}N(n,p)^{14}C	^{230}Th(n,f)	^{197}Au(n,3n)	^{94}Mo(n,γ)	Ni-76	^{153}Sm	^{237}Pa	^{60}Ni
^{14}N(p,x)^{11}C	^{16}O(n,α)	^{239}Pu(n,f)	^{209}Bi(n,3n)	^{95}Mo(n,γ)	Cu-76	^{166}Ho		
^{14}N(p,x)^{13}N	^{nat}C(n,ch.p.)	^{239}Pu(n,f)	^{209}Bi(n,4n)	^{239}Pu(n,γ)	Cu-77	^{186}Re		
^{14}N(p α)^{11}C		^{241}Am(n,f)	^{58}Ni(n,2n)/^{27}Al(n,α)		Cu-78	^{212}Pb		
^{14}N(p,γ)^{15}O			^{19}F(n,2n)/^{27}Al(n,α)		Cu-79	^{225}Ac		
^{16}O(p,α)^{13}N			^{239}Pu(n,n'γ)		Zn-79	^{223}Ra		
^{16}O(p,3p3n)^{11}C			^{233}U(n,n'γ)		Zn-80			
^{16}O(p,x)^{11}C			^{14}N(n,n'γ)		Zn-81			
^{16}O(p,x)^{13}N			^{35}Cl(n,n'γ)		Ga-82			
^{16}O(p,x)^{15}O			^{37}Cl(n,n'γ)		Ga-83			

12	5	6	12	5	12	8	3	3
66								

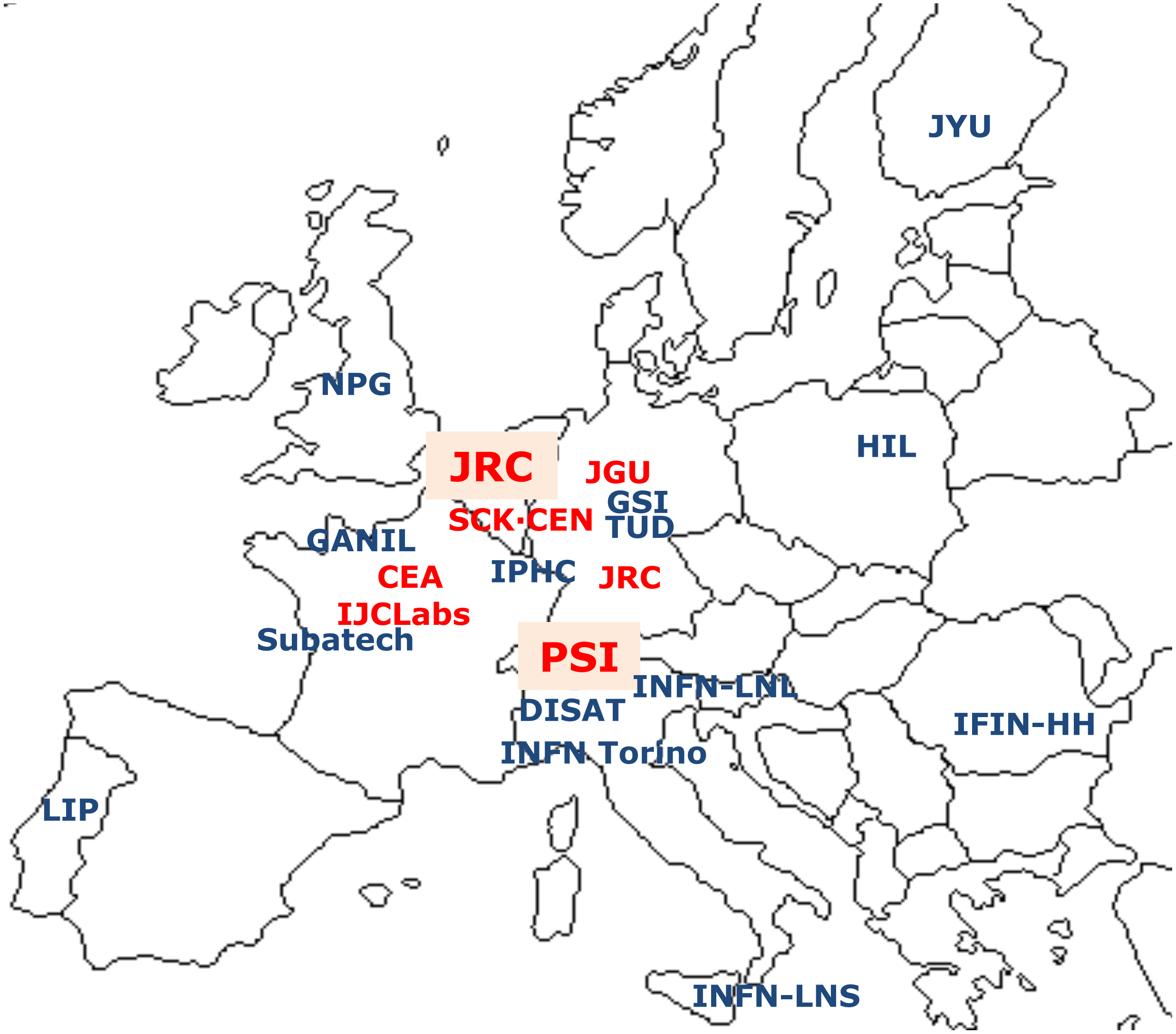
Measurements proposed in APRENDE

(α,n)	(ch.p.,xn)	(n,ch.p.)	(n,el)	(n,f)	(n,inel)	(n,γ)	decay	PFNS	Fission yields
^{9}Be(α,n)	^{7}Li(d,2n)^{7}Be	^{35}Cl(n,p)	^{54}Fe(n,n)	^{242}Pu(n,f)	^{56}Fe(n,n')	^{59}Co(n,γ)	^{91}Br	^{239}Pu	^{235}U
^{10}B(α,n)^{13}N	^{6}Li(d,n)^{7}Be	^{35}Cl(n,α)	^{65}Cu(n,n)	^{241}Pu(n,f)	^{56}Fe(n,n)	^{65}Cu(n,γ)	^{91}Kr	^{252}Cf	^{233}U
^{27}Al(α,n)		^{54}Fe(n,α)	^{63}Cu(n,n)	^{240}pu(n,f)	^{54}Fe(n,2n)	^{63}Cu(n,γ)	^{92}Rb		^{239}Pu
			^{208}Pb(n,n)	^{239}Pu(n,f)	^{54}Fe(n,n')	^{109}Ag(n,γ)	^{96}Y		^{243}Cm
			^{206}Pb(n,n)	^{243}Am(n,f)	^{65}Cu(n,n')	^{167}Er(n,γ)	^{99}Nb		^{252}Cf
					^{63}Cu(n,n')	^{166}Er(n,γ)			
					^{92}Zr(n,n'γ)	^{186}W(n,γ)			
					^{90}Zr(n,n'γ)	^{209}Bi(n,γ)			
					^{208}Pb(n,n')	^{232}Th(n,γ)			
					^{206}Pb(n,n')	^{238}U(n,γ)			
					^{238}U(n,2nγ)	^{241}Pu(n,γ)			
					^{238}U(n,3nγ)				

3	**2**	**3**	**5**	**5**	**12**	**11**	**5**	**2**	**5**
53									

Production of samples

European target laboratories



Stable
Radioactive

Boundary conditions:

- For own experiments
- With a collaboration agreement

Targets prepared for SANDA

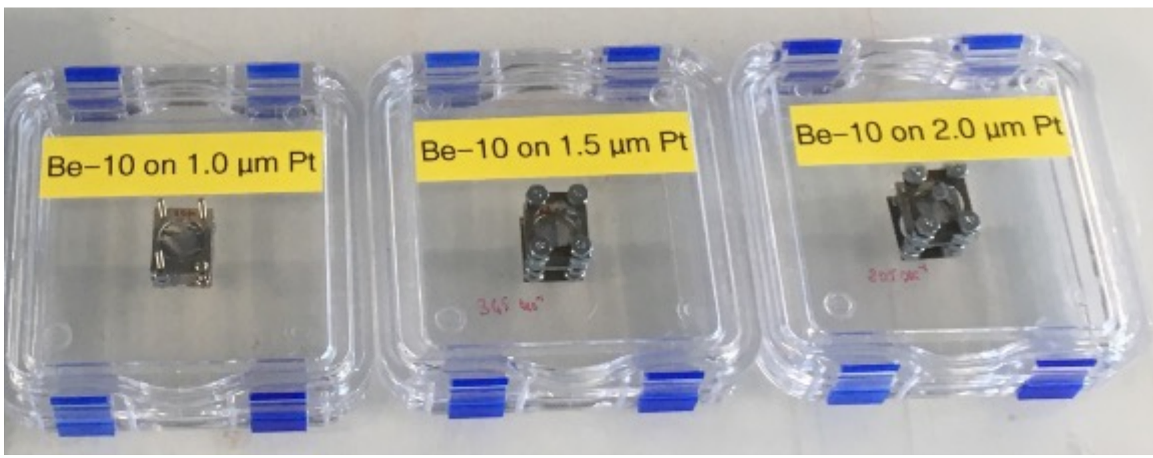
Isotope	Experiment @	Target lab
^{179}Ta	TRIGA Mainz	PSI
^{79}Se	n_TOF	PSI
^{94}Nb	n_TOF	PSI
^{94}Nb	n_TOF	PSI
^{10}Be	NL Argonne	PSI
^{50,53}Cr	n_TOF	PSI
^{50,53}Cr	n_TOF	PSI
^{239}Pu	n_TOF	JRC–Geel
^{239}Pu (various)	GELINA	JRC–Geel
^{235}U (various)	NFS	JRC–Geel
^{238}U (various)	NFS	JRC–Geel

Targets produced in SANDA

molecular plating of $^{10}Be(OH)_2$ solution on thin Pt foils at PSI

Backing
1 µm, 1.5 µm and 2 µm thick Pt foil, ø 7 mm

Deposit
160 µg/cm2 ^{10}Be (500 µg/cm2 Be)



^{10}Be target on a 1µm platinum foil that was used in the experiment

Collaboration with University of York, UK and Argonne National Laboratory, Illinois, USA.

Targets produced in SANDA

A 304 mg of high purity ^{93}**Nb wires** were shaped in a spiral pattern **at PSI** and afterwards activated at the high-flux nuclear ILL-Grenoble reactor for 51 days.

The target was then analyzed at PSI by a customized HPGe gamma-ray spectroscopy set-up.

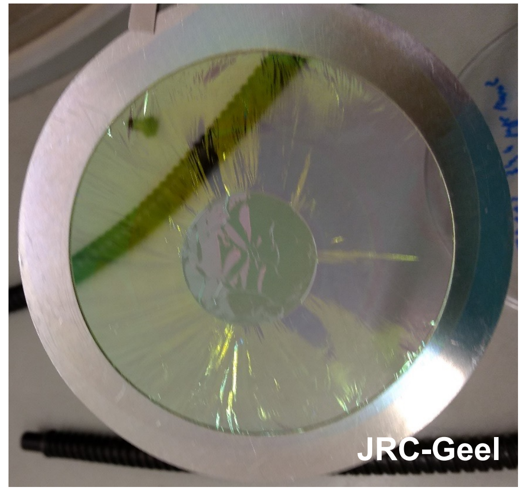
^{94}Nb activity: 10.1 MBq

Targets produced in SANDA

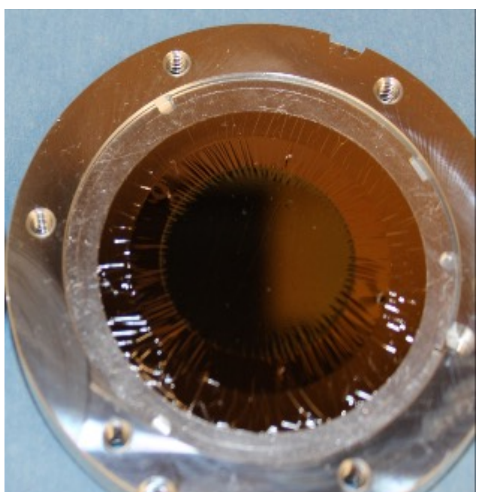
$^{238}UF_4$ deposits by physical vapour deposition at JRC Geel

Backing
34 μg/cm^2 polyimide foil
on 1 mm thick Al ring $Ø_{out}$ 90 mm
$Ø_{in}$ 70 mm

Deposit
^{238}U diameter: 20 mm
^{238}U areal density: 377 μg/cm^2
^{238}U mass:1.84 mg



Al layer 87nm. Physical vapour deposition CEA

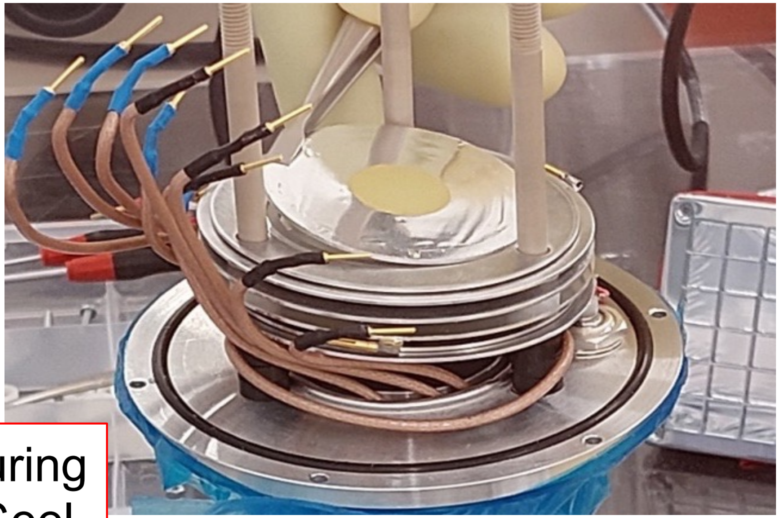


Material: 99.998 at% ^{238}U
Deposited layer: UF_4
Mass ^{238}U: 4.43 mg
Areal density ^{238}U: 628 μg/cm^2
Deposit diameter: 29.96 mm
Physical vapour deposition JRC-Geel

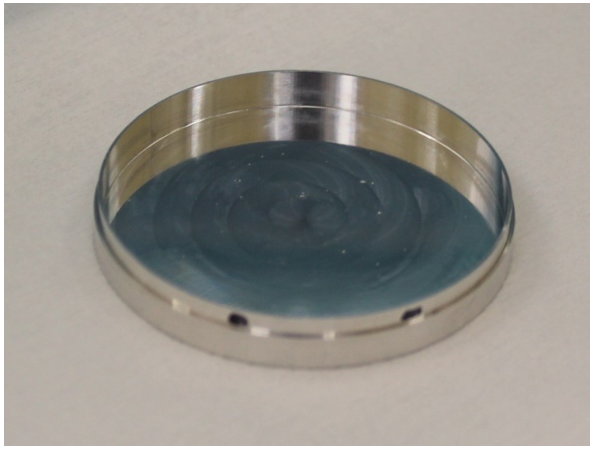
Targets produced in SANDA

Deposit
^{239}Pu diameter: 20 mm
^{239}Pu areal density: 320-330 μg/cm^2

Backing
20 μm Al foil



^{239}Pu (99.902% pure) targets during the mounting process at JRC – Geel.



Material provided by SCK·CEN

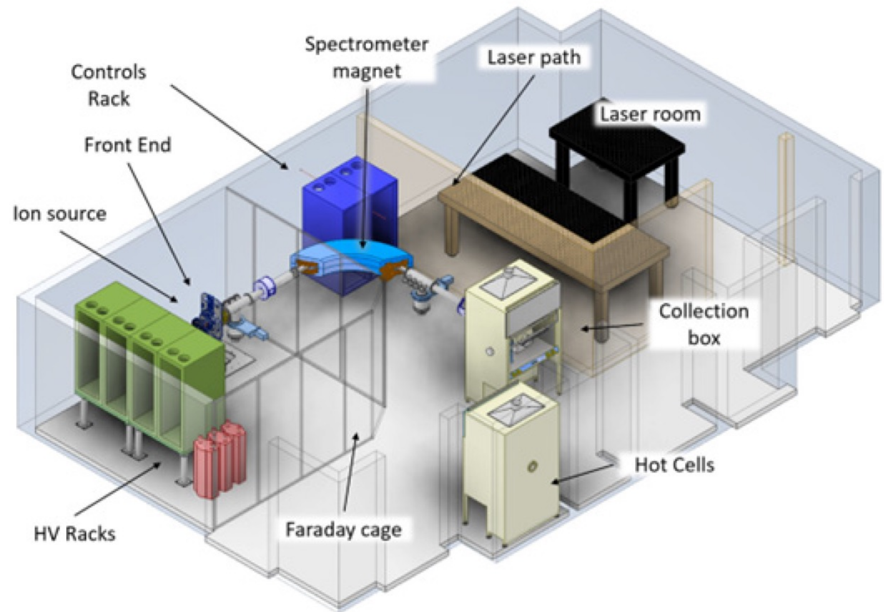
2 g of ^{239}Pu powder canned in a container, Ø 50mm, thickness 0.5 mm at JRC-Geel.

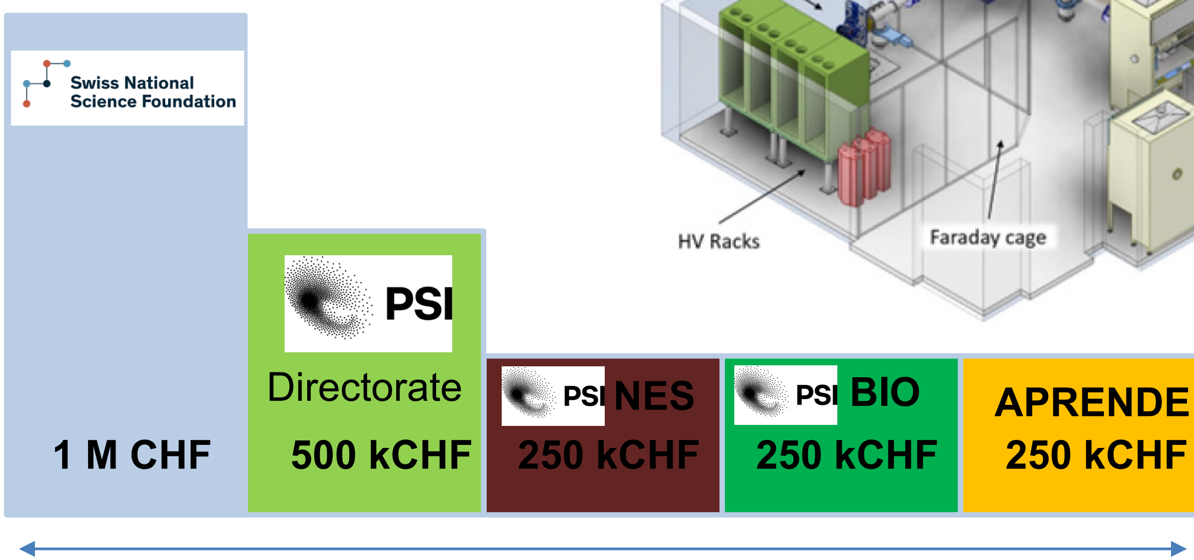
The PROMAS Project (SANDA and APRENDE)

PReparative Offline MAss Separation

Project was submitted in May 2024.

Project starts: 01.12.2024
Project ends: 30.11.2025
Project Budget: 2.250 kCHF





Total budget: 2.250 kCHF

PAUL SCHERRER INSTITUT PSI

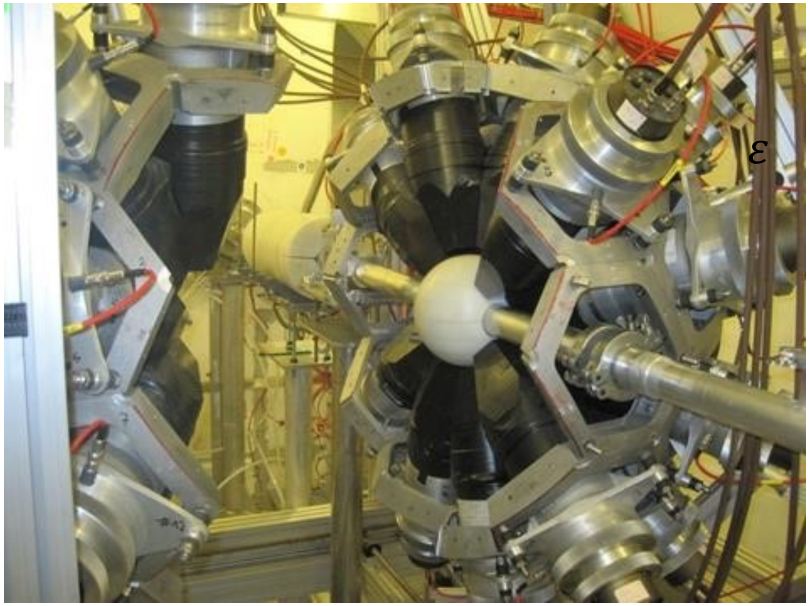
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council Established by the European Commission

Development of detectors

Improved γ-ray detectors for capture measurements

(n,γ) cross section measurements are performed using γ-ray detectors. At n_TOF EAR1 (185 m flight path):

- 40 crystal BaF_2 Total Absorption Calorimeter
- Various types of C_6D_6 liquid scintillators (Al and carbon fibre housing)



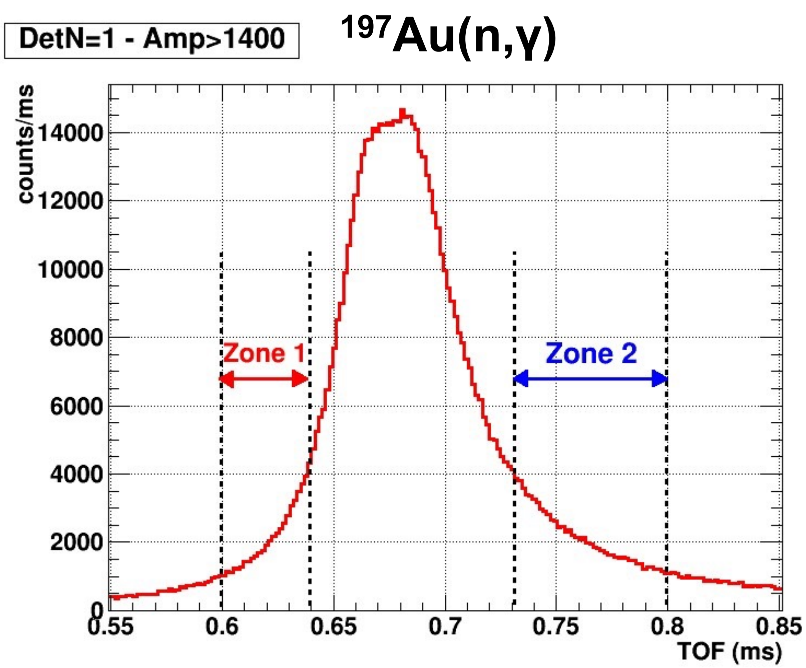
$$\epsilon = 100\%$$

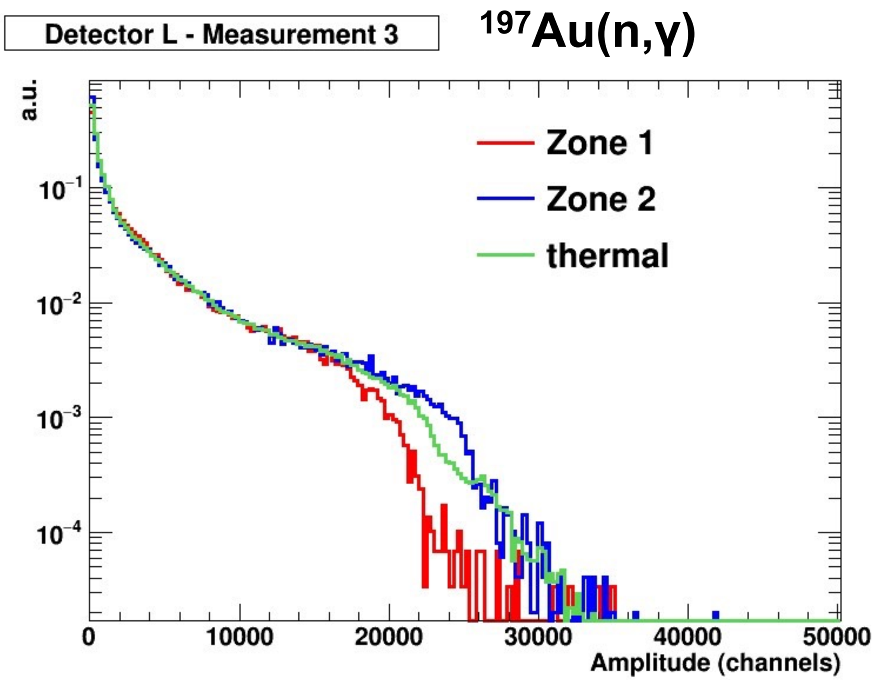
$$\epsilon \simeq k \cdot \sum E_\gamma$$

Extreme counting rate coinditions

2014 -> construction of the EAR2 20 m flight path.

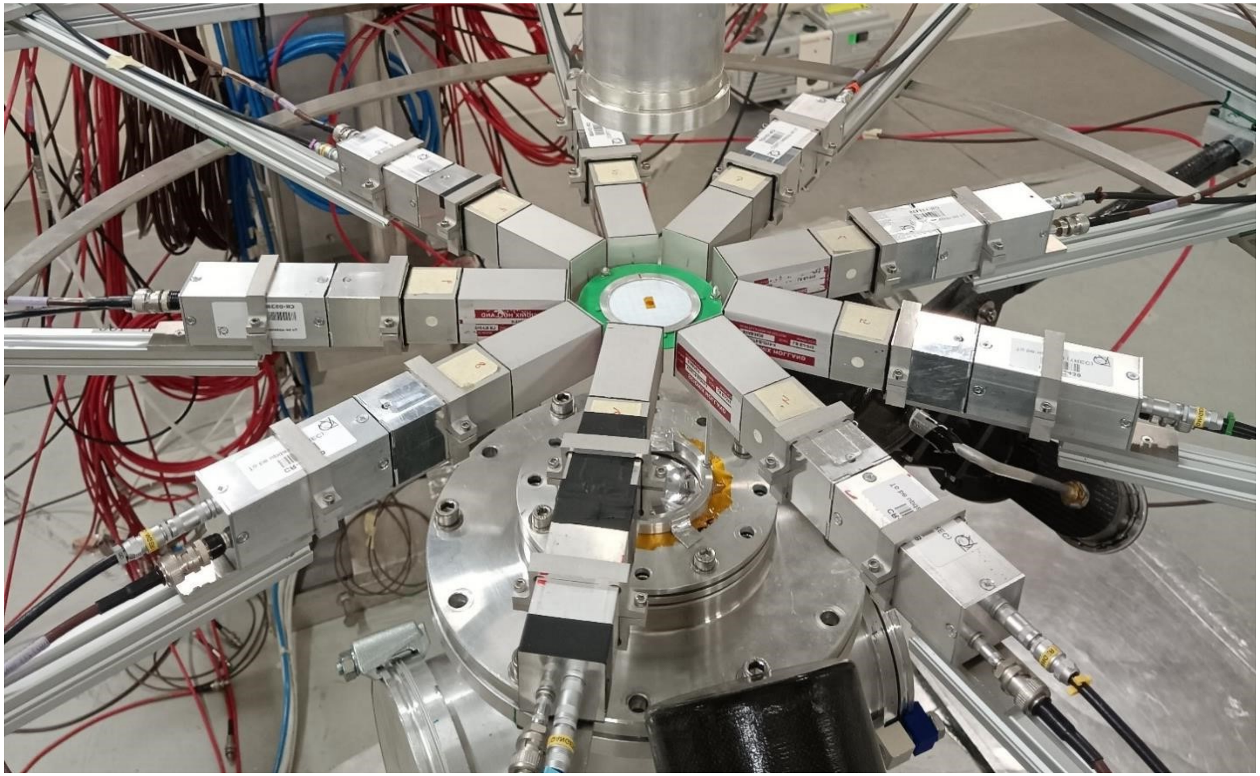
The counting rates in EAR2 are ~300 times larger than counting rates in EAR1 (10^7 cps). The γ-ray detectors designed for EAR1 did not work properly in EAR2.





The segmented TED detector (sTED)

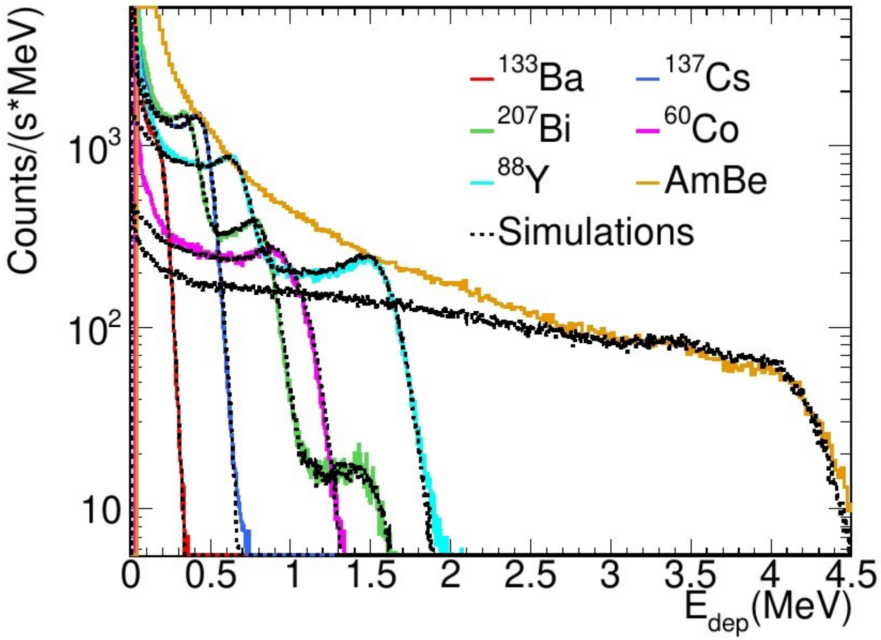
Simple idea: use smaller detectors & improved photomultipliers and VD

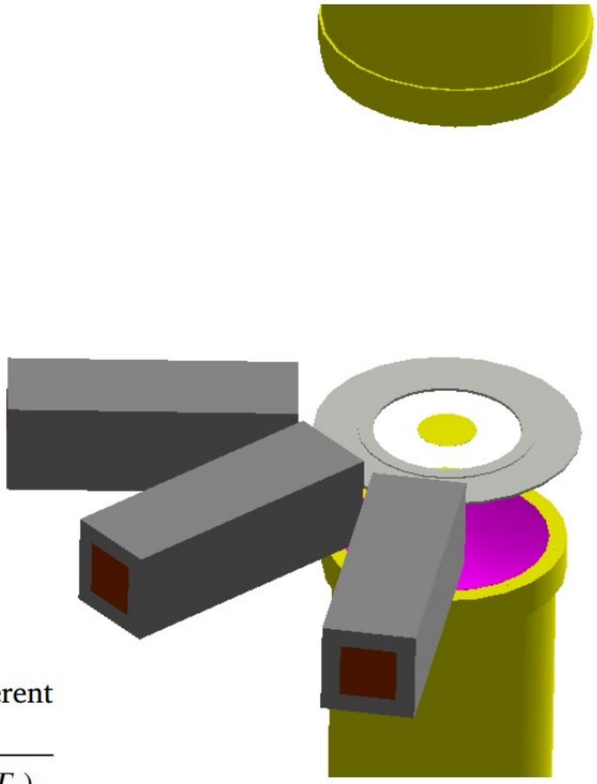


V. Alcayne et al., A Segmented Total Energy Detector (sTED) optimized for (n, γ) cross-section measurements at n_TOF EAR2, Radiat. Phys. Chem. 217, 111525 (2024).

E. Mendoza et al., Neutron capture measurements with high efficiency detectors and the Pulse Height Weighting Technique, Nucl. Instr. Meth. 1047, 167894 (2023).

Characterisation of the sTED detectors

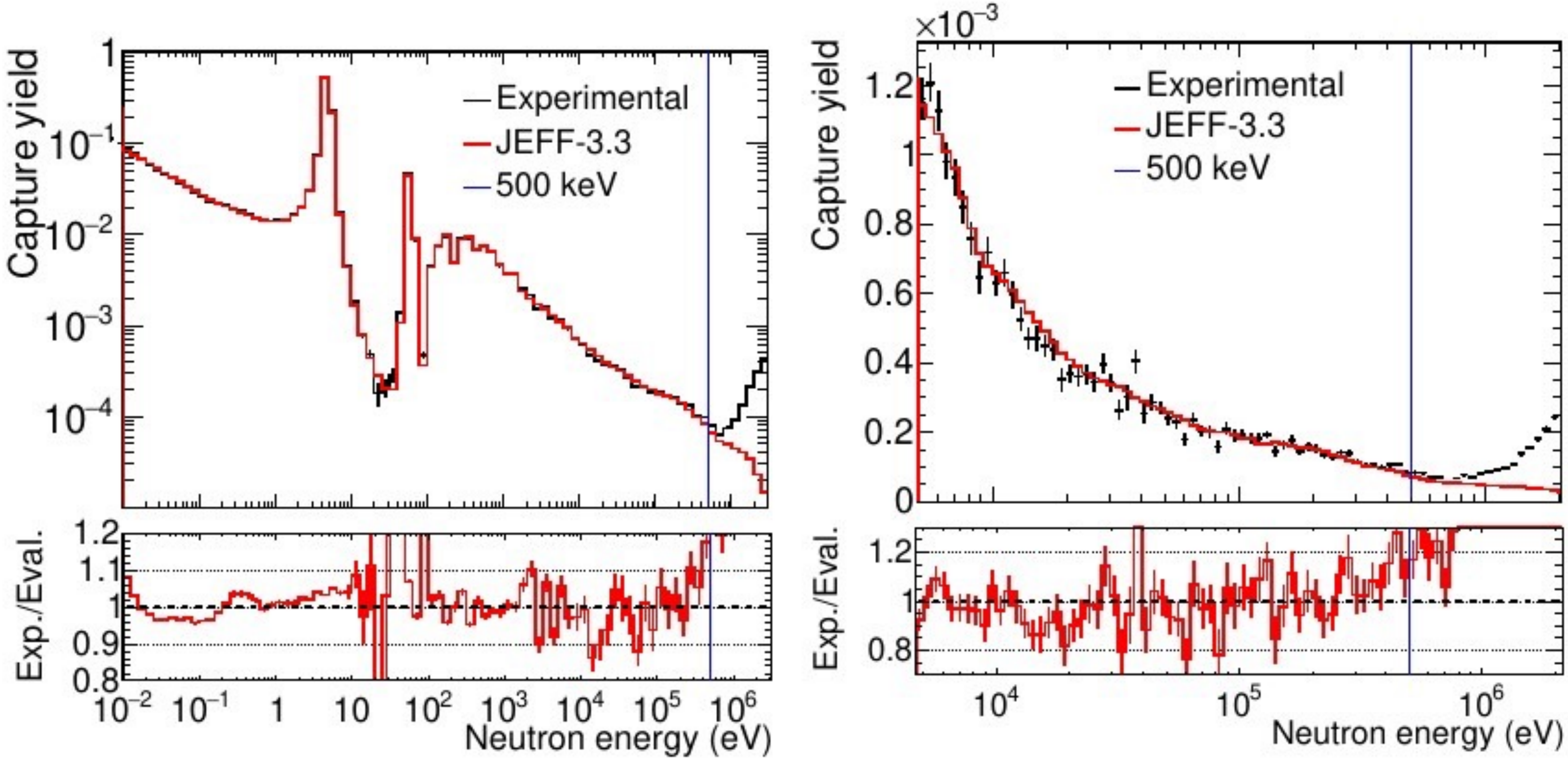




Estimation of the neutron sensitivities $((\varepsilon_n/\varepsilon_\gamma)\cdot(\Gamma_n/\Gamma_\gamma))$ of one sTED module for different nuclei and resonances. For details see the text.

Isotope	E_n (eV)	$\frac{\Gamma_n}{\Gamma_\gamma}$	$\frac{\varepsilon_n}{\varepsilon_\gamma}$	$(\varepsilon_n/\varepsilon_\gamma)\cdot(\Gamma_n/\Gamma_\gamma)$
^{197}Au	4.91	$1.2\cdot10^{-1}$	$1.6\cdot10^{-3}$	$2.0\cdot10^{-4}$
^{240}Pu	5.01	$8.4\cdot10^{-2}$	$1.6\cdot10^{-3}$	$1.4\cdot10^{-4}$
^{244}Cm	7.66	4.9	$1.6\cdot10^{-3}$	$8.0\cdot10^{-3}$
^{244}Cm	86.1	$6.6\cdot10^{-1}$	$5.5\cdot10^{-4}$	$3.6\cdot10^{-4}$
^{207}Bi	12 100	$2.2\cdot10^{3}$	$1.1\cdot10^{-4}$	$2.4\cdot10^{-1}$
^{207}Pb	41 100	$3.7\cdot10^{2}$	$2.3\cdot10^{-4}$	$8.4\cdot10^{-2}$

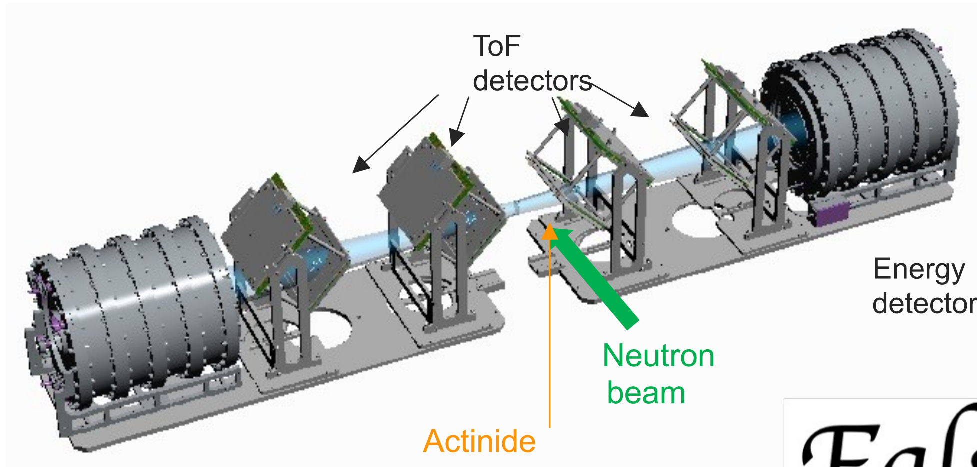
Validation with the reference ^{197}**Au(n,γ) cross section**



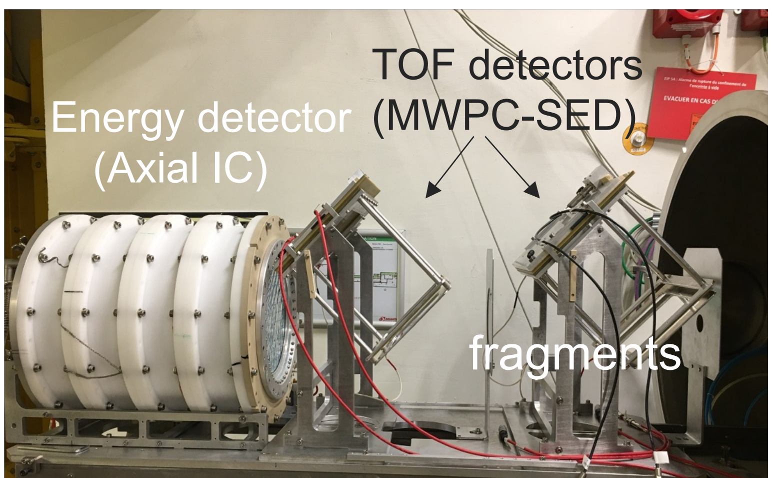
The sTED are now the standard capture setup for n_TOF EAR2. They (9 sTEDs) have been used to measure: ^{94,95,96}Mo(n,γ), ^{79}Se(n,γ), ^{28,29,30}Si(n,γ), ^{64}Ni(n,γ), ^{160}Gd(n,γ), ^{209}Bi(n,γ), ^{146}Nd(n,γ), ^{97,98}Mo(n,γ). **18 more on the way!**

Fission yield detector (FALSTAFF)

cea irfu

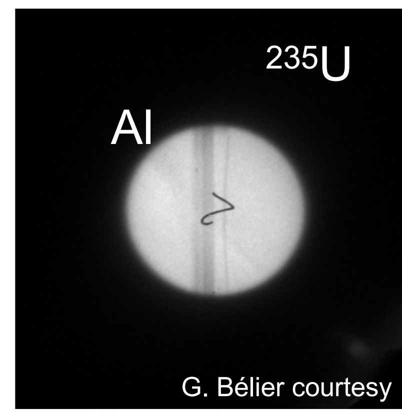


Falstaff



^{235}U target:

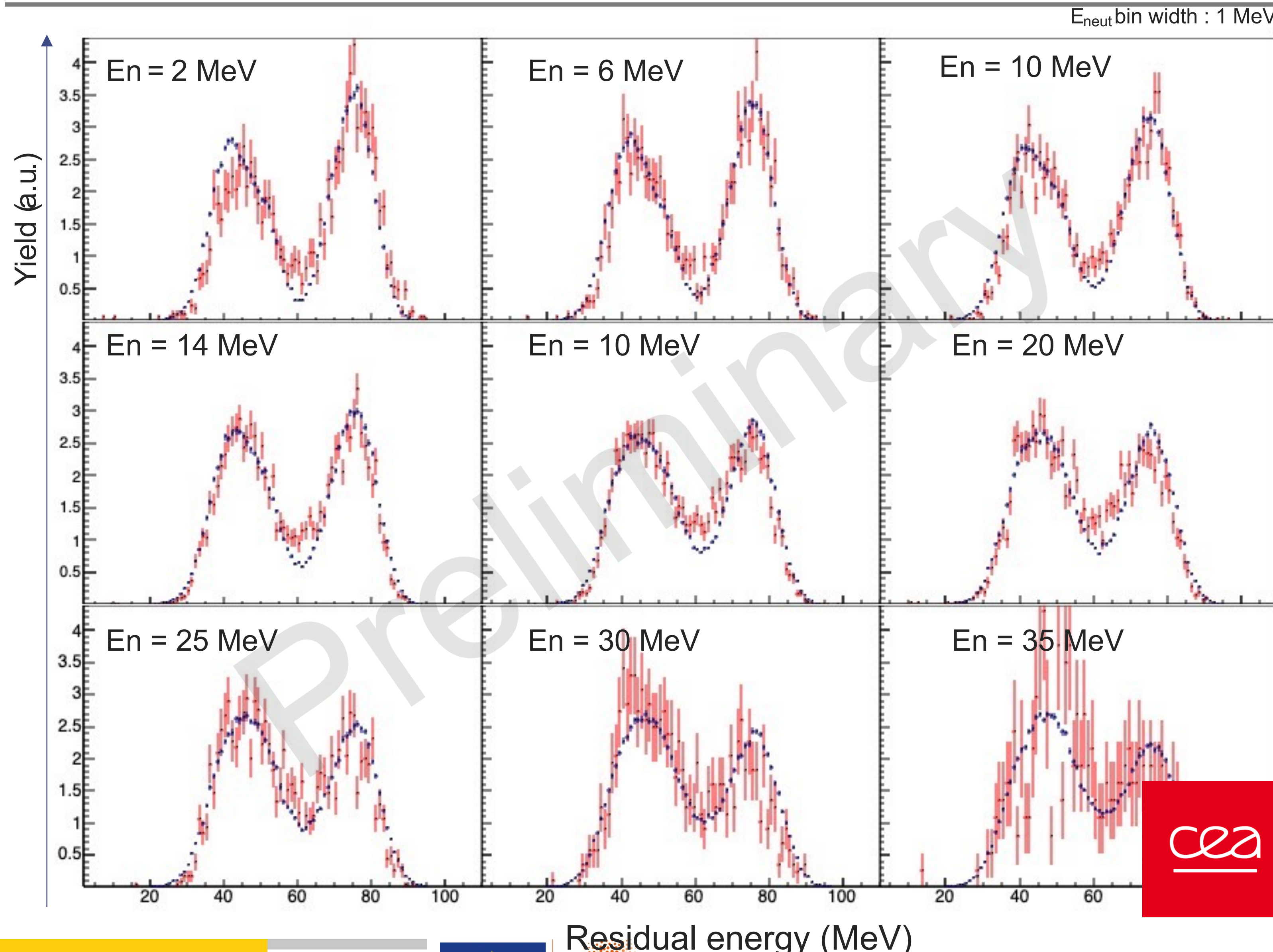
- JRC-Geel (99.94% ^{235}U)
- 195 µg/cm^2
- F 28 mm
- 1.2 mg
- Ta backing
- Al support



Courtesy by D. Doré (CEA)

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council Established by the European Commission

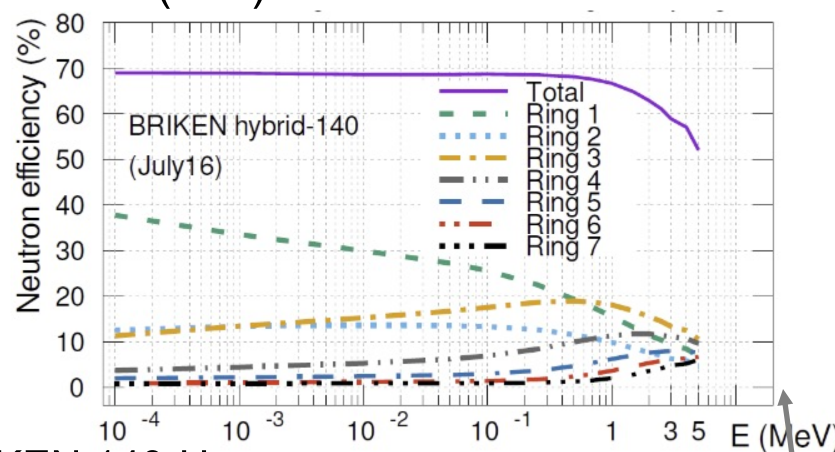
^{235}U fission yields measured at NFS



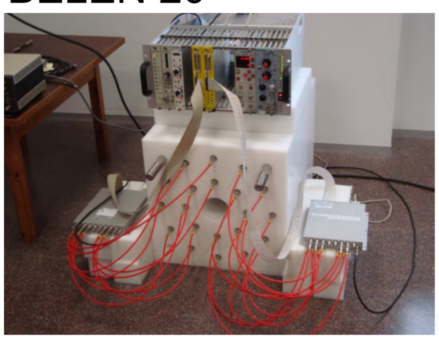
BEta-deLayEd Neutron detector (BELEN)

Measurements of β-delayed neutron emission probabilities (Pxn values) are typically measured with high efficiency detectors (^{3}He) embedded in a moderator (polyethylene) matrix.

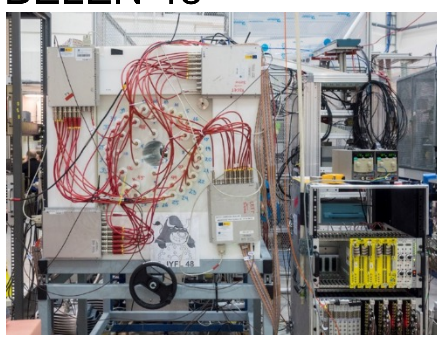
- Maximise the efficiency
- Flat response (ε vs E_n)



BELEN 20



BELEN 48



BRIKEN 140-H

$\rightarrow P_{1n}, P_{2n}, \ldots$

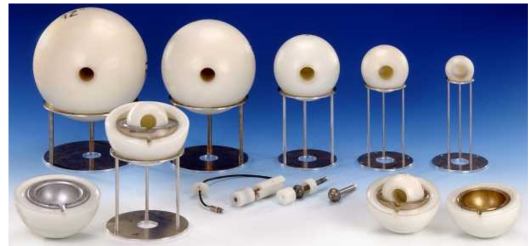
BRIKEN was the world largest moderated neutron counter for beta-delayed neutrons!

A. Tarifeño-Saldivia et. al. J. Instrum. (2017)

BELEN with spectrometric capabilities

Bonner spheres (BS) spectrometers is a widespread technique for neutron spectrometry.

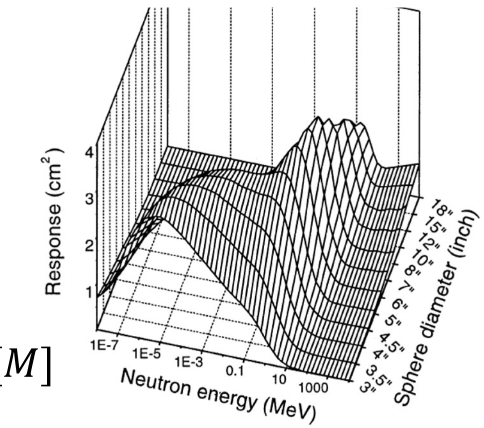
- Moderated proportional neutron counters. Useful from thermal to GeV region.
- Ill-posed linear inverse problem!
- Extensive MC simulations and unfolding algorithms are required



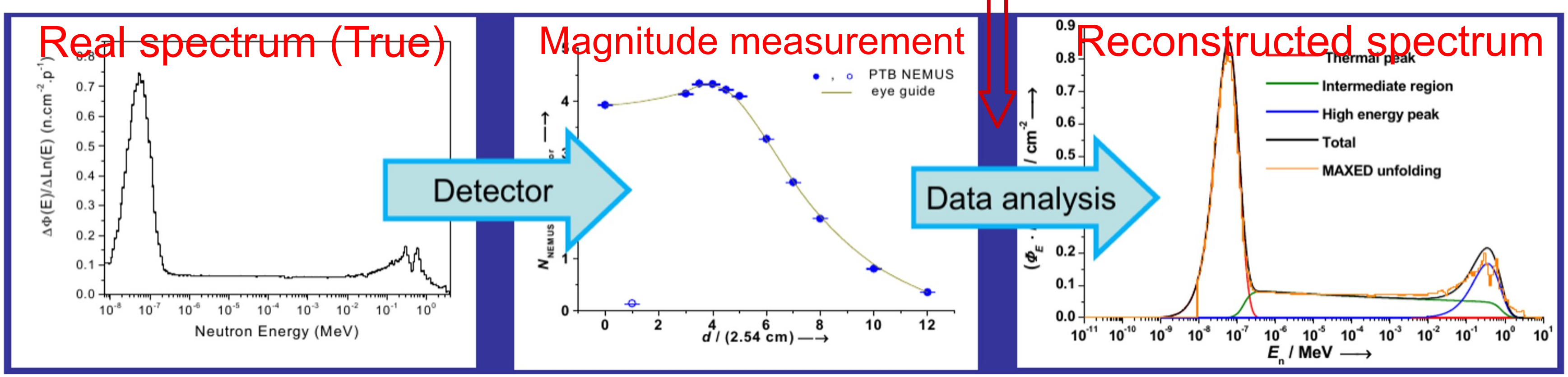
$$M_i = \int R_i(E)\phi(E)dE$$

$$M_i = \sum_j R_{ij}\phi_j \Rightarrow [\phi] = [R]^{-1}[M]$$

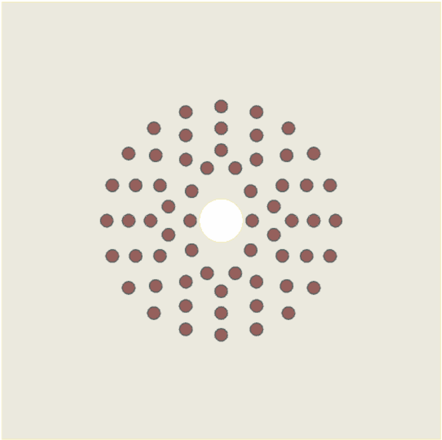
MC computed response matrix R_{ij}

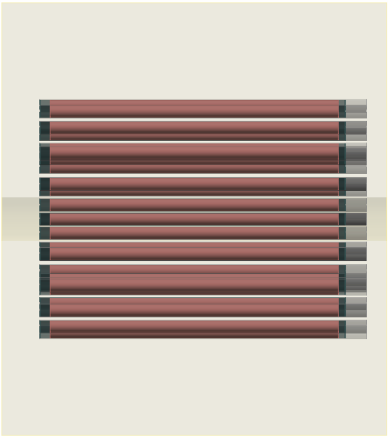


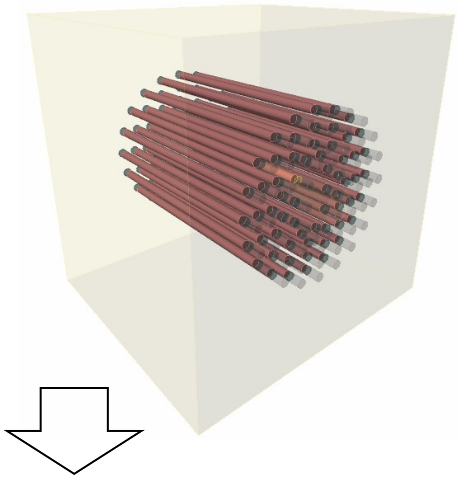
Unfolding algorithm ← Educated guess of n-spectrum



Beta-dELayEd Neutron detector (BELEN)

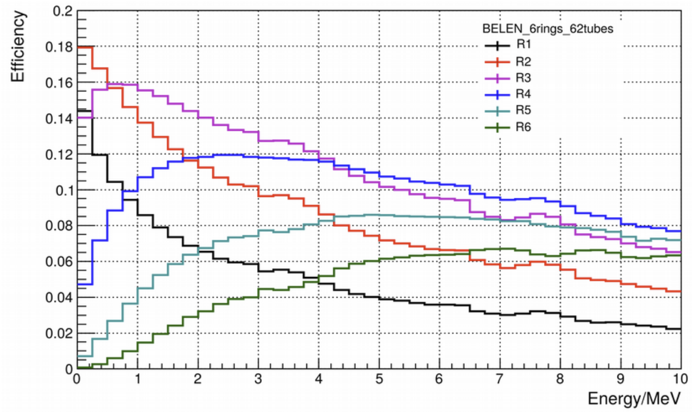


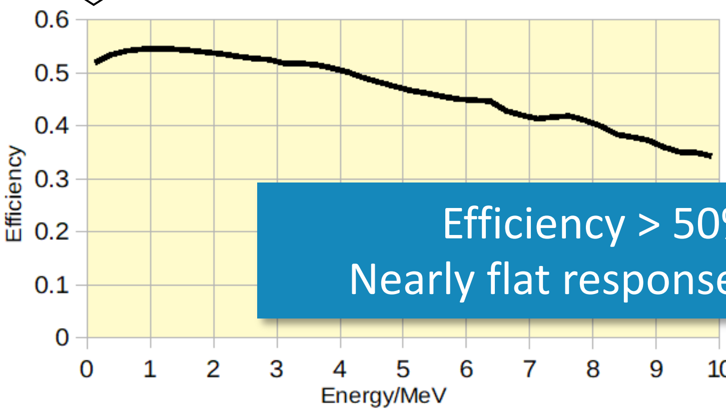




Best candidate!

Ring	Tubes	R, cm
1	2	6.38
2	4	8.58
3	8	11.20
4	12	14.50
5	16	19.00
6	20	23.50





Efficiency > 50% un to 4 MeV
Nearly flat response up to 4 MeV!

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

VNIVERSITAT DE VALÈNCIA

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

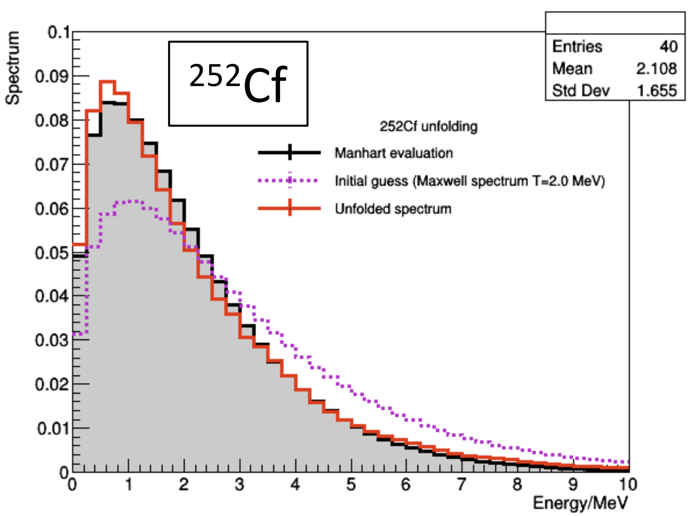
erc European Research Council Established by the European Commission

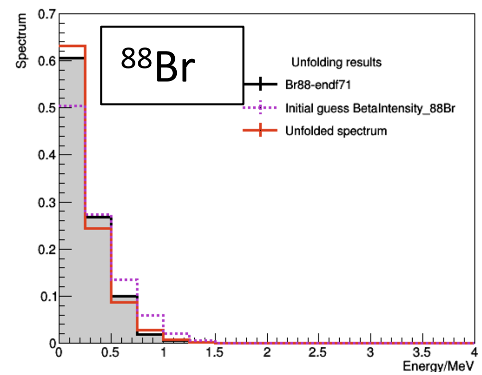
Beta-dELayEd Neutron detector (BELEN)

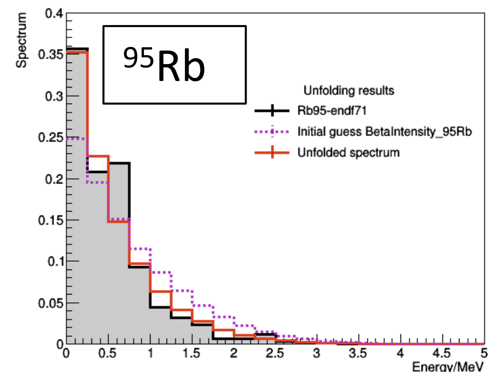
Nucleus	Q_{bn}, MeV	<E>, MeV
Cf-252	---	2.13
Br-88	1.922	0.2515
Rb-94	3.452	0.4424
Rb-95	4.883	0.5295
I-137	2.001	0.6298

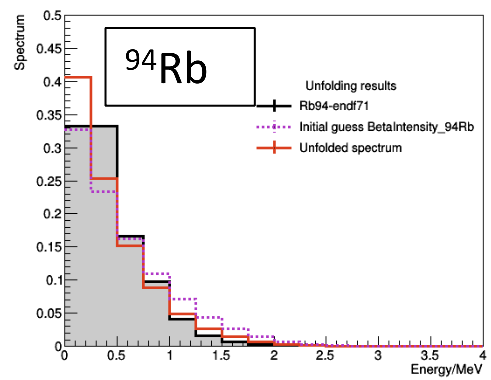
Simulation of virtual decays and analysis of the data GEANT4 A SIMULATION TOOLKIT

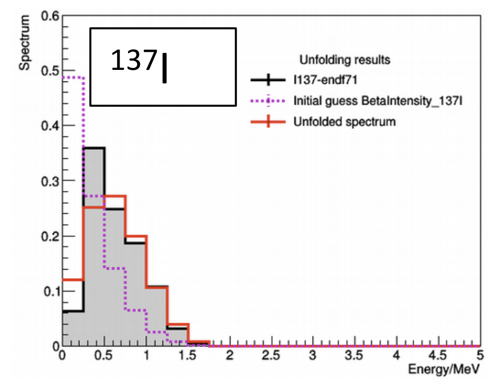
Nucleus	Ratio <E>
Cf-252	1.019
Br-88	1.033
Rb-94	1.032
Rb-95	1.091
I-137	1.023











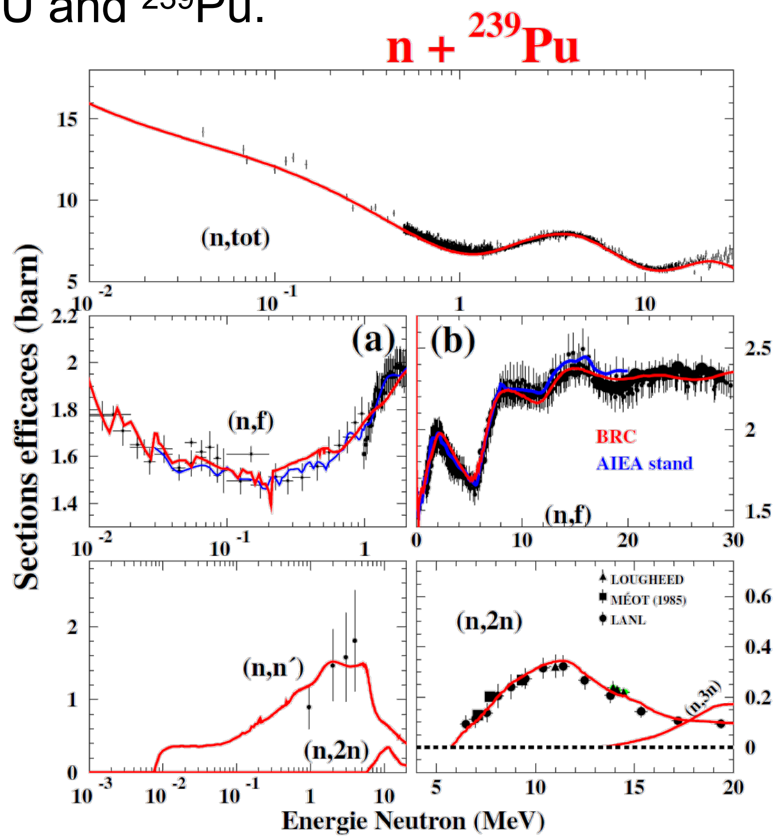
Evaluation

Evaluation and modelling

Improvements of TALYS & EMPIRE

- New OMP developed by P. Romain.
- New photon strength functions based on QRPA (S. Goriely, S. Hilaire, S. Peru)
- Evaluation of the high energy part of $^{235,238}U$ and ^{239}Pu.

Courtesy of S. Hilaire and G. Noguere

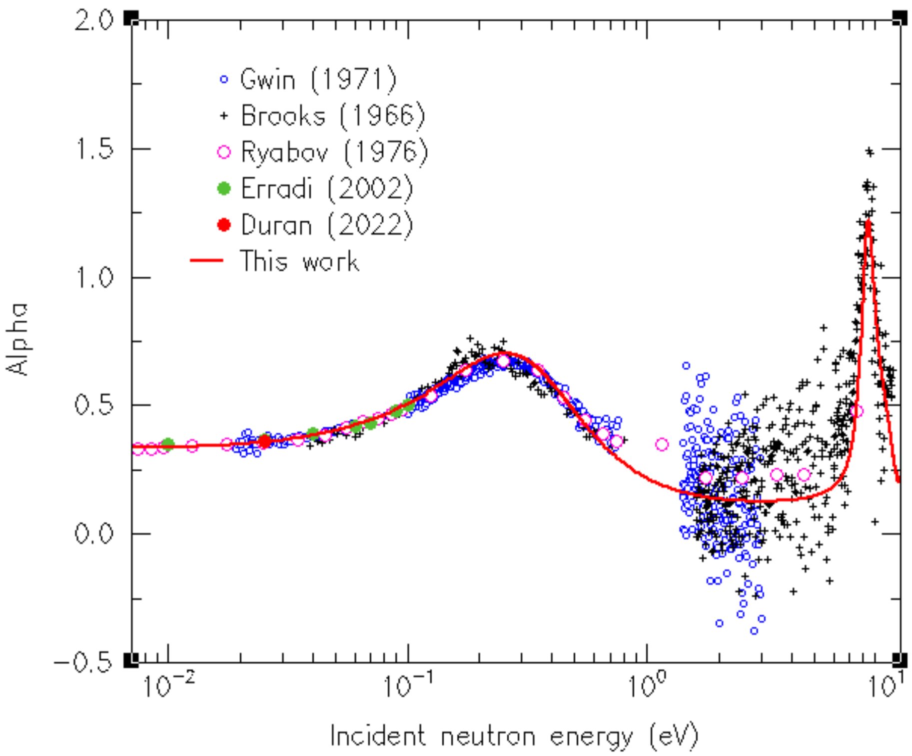


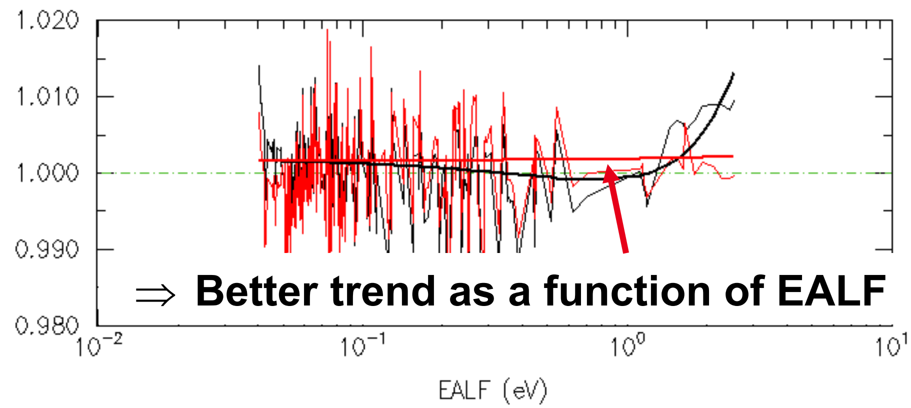
- Actinides like $^{235,238}U$, ^{239}Pu, ^{239}Np and ^{241}Am (CEA/DEN, CEA/DAM/DIF, CNRS)
- Fission fragments Sm, Nd, Cs, Mo, Ru, Eu, Gd, Rh: CEA/DEN, PSI)
- New Cr evaluations (U Uppsala)
- Light elements ^{16}O, ^{9}Be (TU Wien)

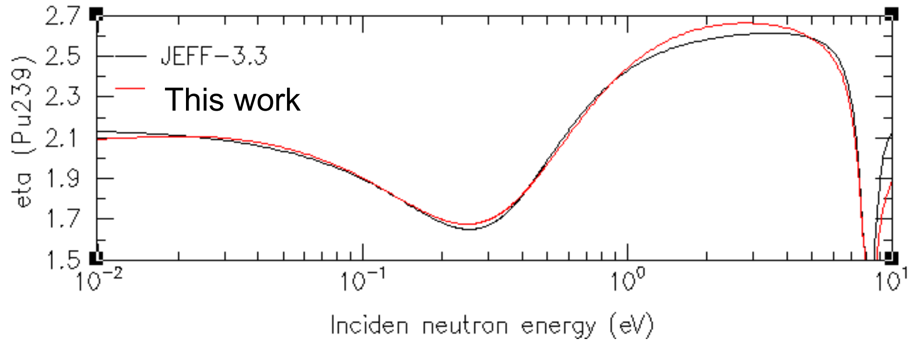
Evaluations will be part of **JEFF-4**

Evaluation and modelling: ^{239}Pu

Courtesy of G. Noguere



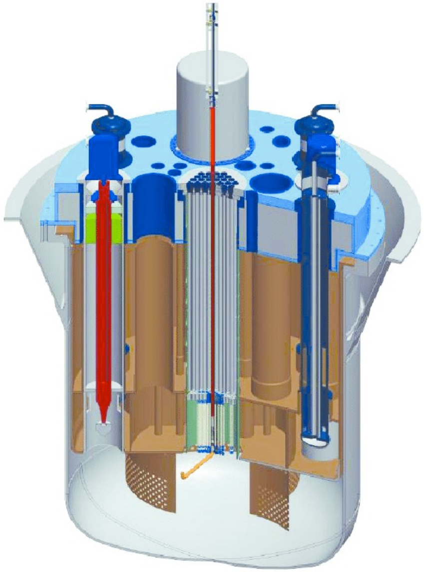




Validation & sensitivity analyses

Nuclear data needs for advanced reactor designs

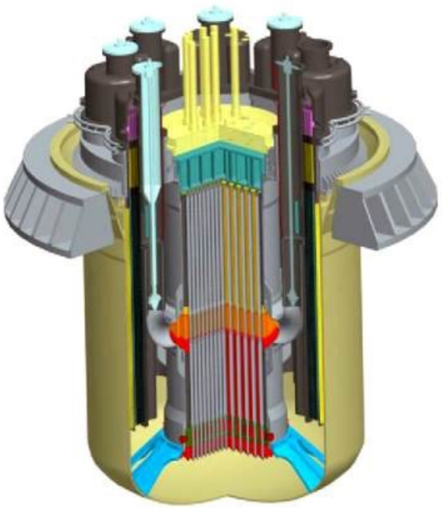
4 different advanced reactor technologies are being explored in Europe:



MYRRHA

Pb/Bi-cooled Accelerator Driven System that can also be operated in critical mode.

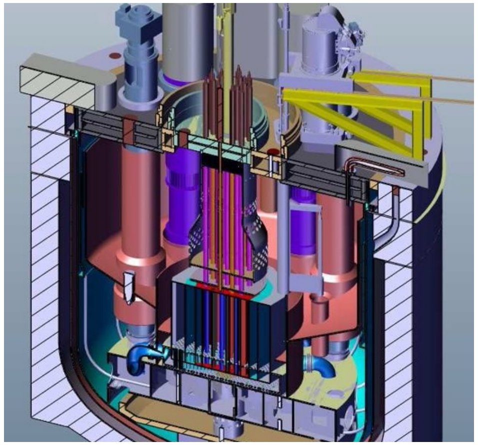
< 100 MW_{th}



ALFRED

Pb-cooled critical reactor.

~ 300 MW_{th}



ASTRID

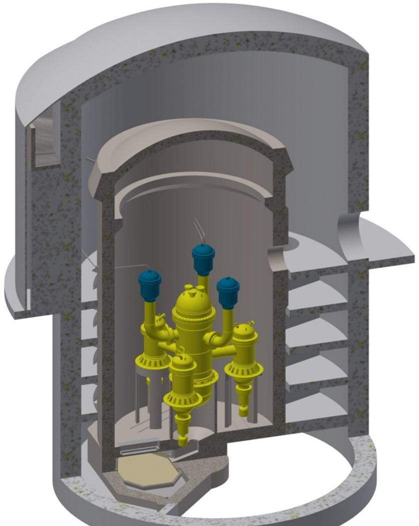
Na-cooled critical reactor.

~ 1500 MW_{th}

ESFR

Na-cooled critical reactor.

~ 3600 MW_{th}



ALEGRO

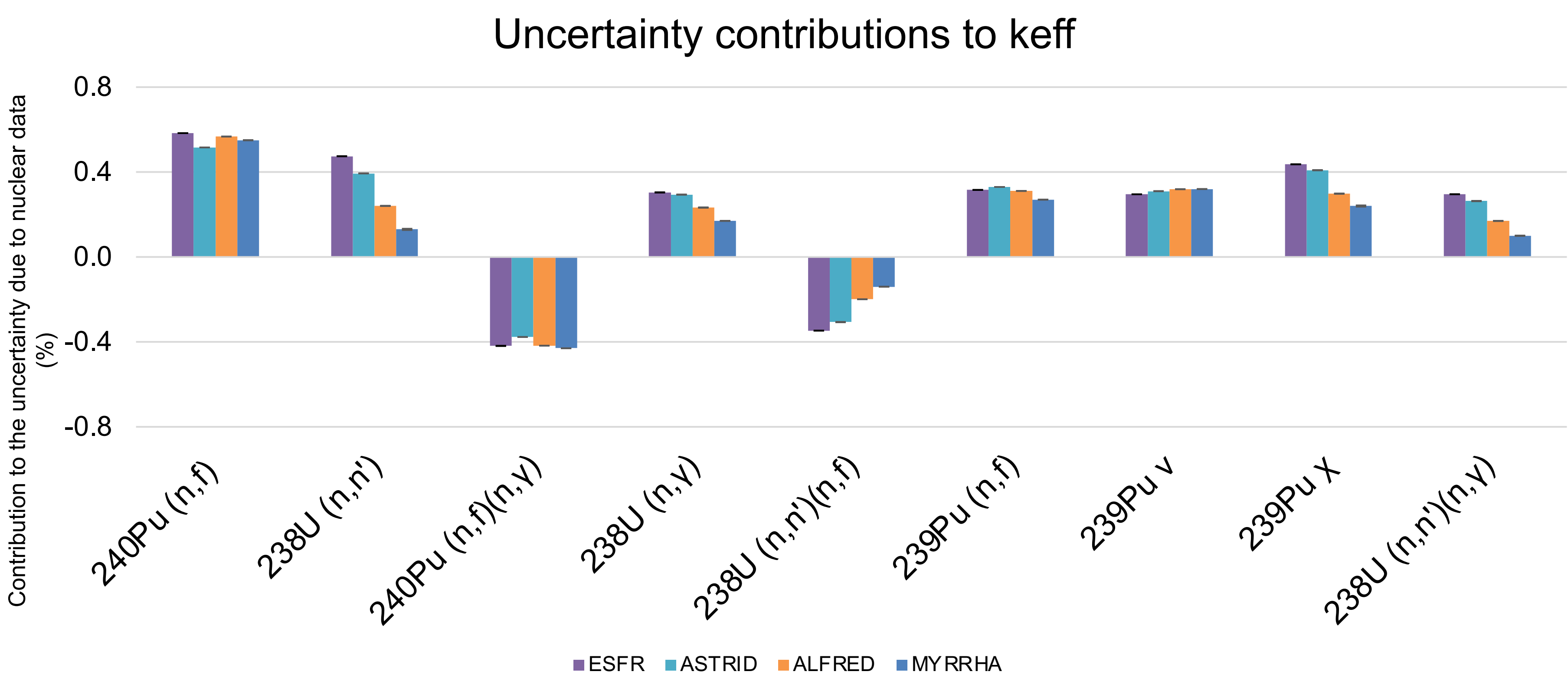
Gas-cooled fast critical reactor.

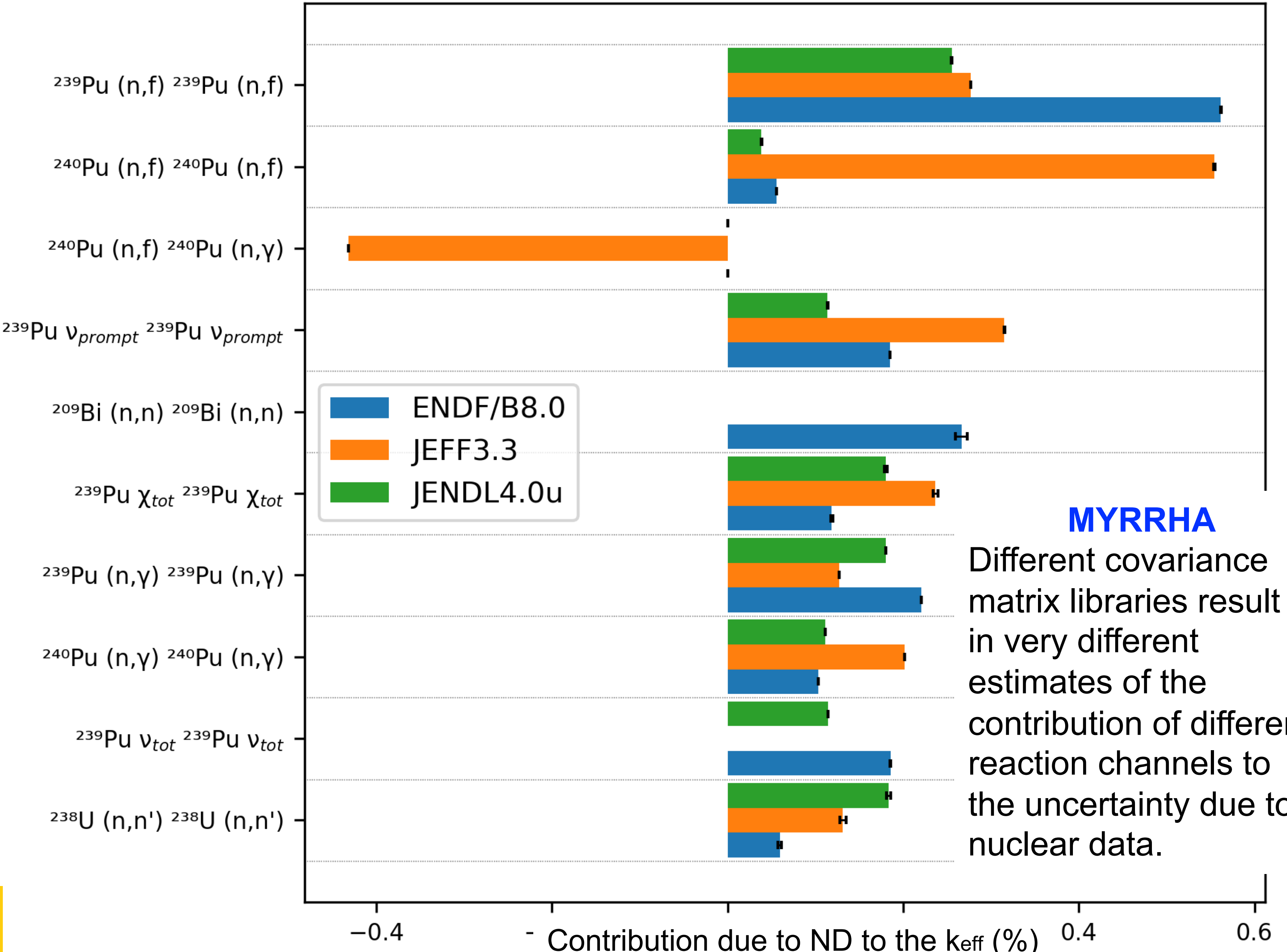
~ 75 MW_{th}

Uncertainties due to nuclear data

These four examples of different systems do not meet the target accuracy for the k_{eff} because of the uncertainty due to nuclear data.

SYSTEM	k_{eff}	Unc ND (%)	TA
ESFR	1.00499(9)	1.04%	0.2 %
ASTRID	1.00779(8)	0.97%	0.2 %
ALFRED	0.99904(10)	0.877%	0.435%
MYRRHA	1.01542(3)	0.76%	0.3%

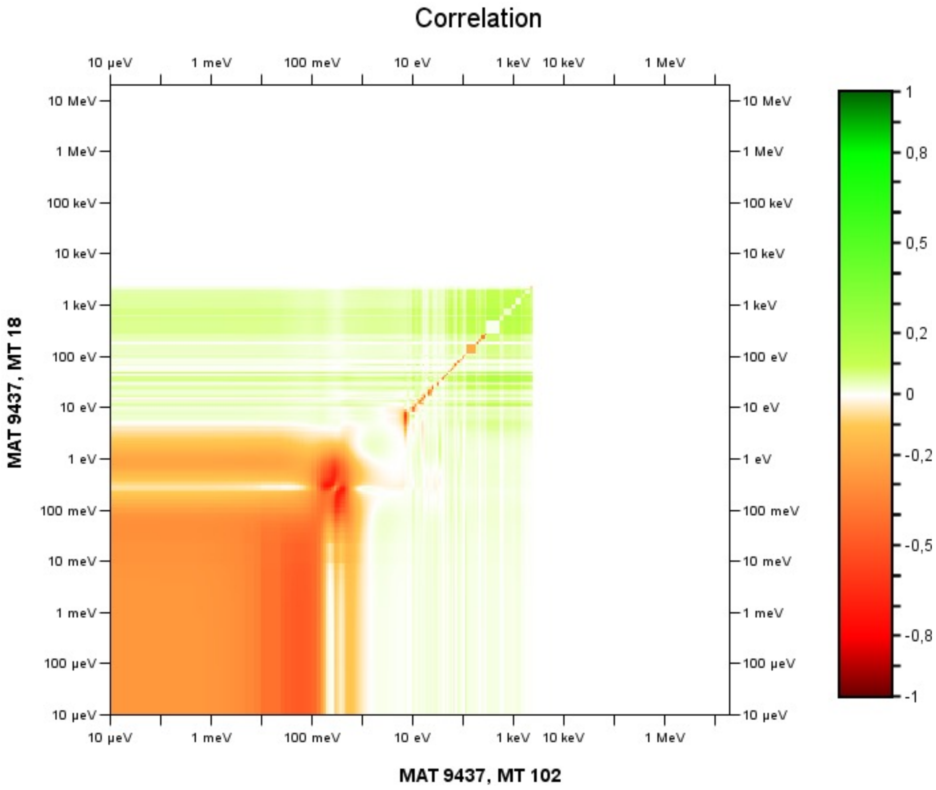




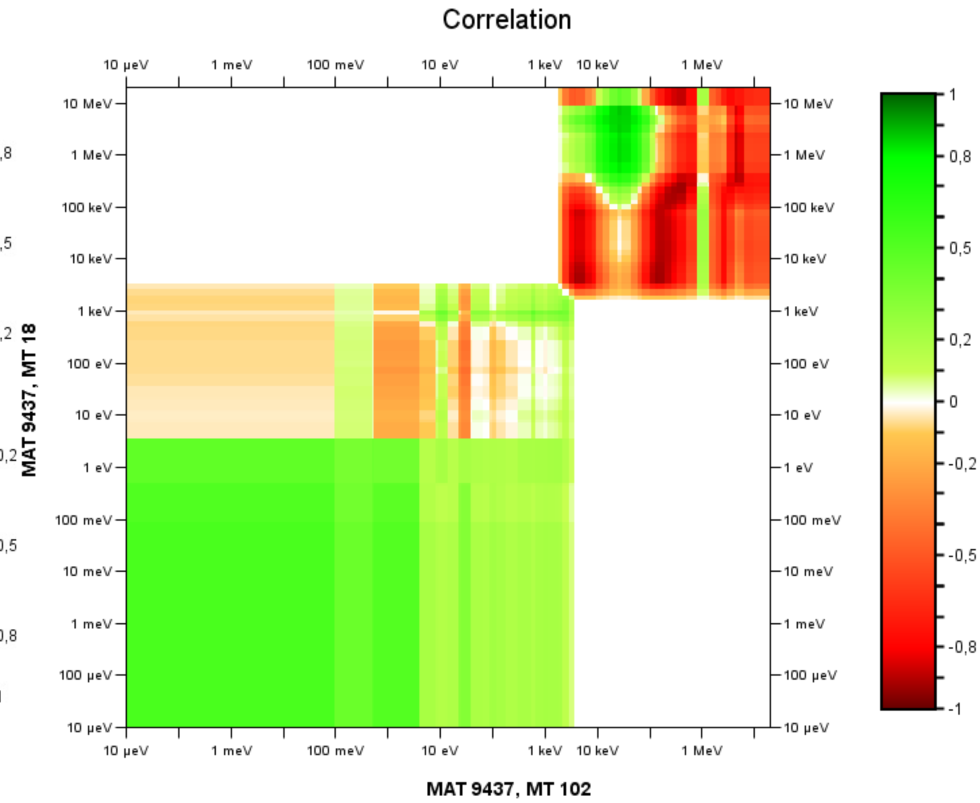
MYRRHA

Different covariance matrix libraries result in very different estimates of the contribution of different reaction channels to the uncertainty due to nuclear data.

Significant differences in the covariance matrices



JENDL-4.0u: ^{239}Pu (n,f) (n,γ)



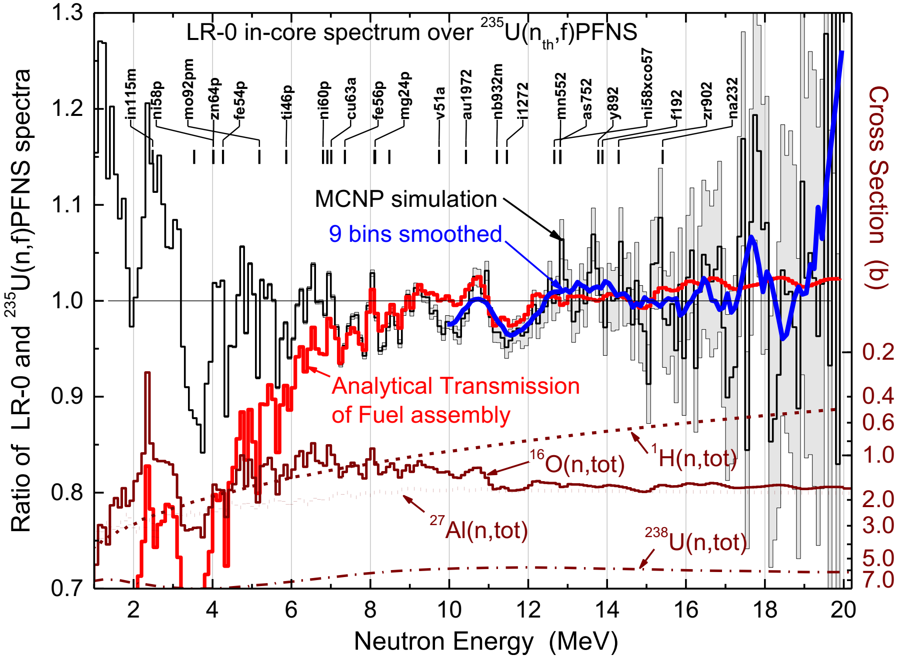
JEFF-3.3: ^{239}Pu (n,f) (n,γ)

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
erc European Research Council Established by the European Commission

Integral experiments

Integral experiments at LR-0

SACS measured in LR-0 corrected to ^{235}U PFNS.



	$E_{50\%}$	SACS [mb]	Rel. unc.	Eval./E-1
^{115}In(n,n')	2.589	**209.3**	**2.70%**	**-10.30%**
^{47}Ti(n,p)	3.647	17.97	2.00%	-0.70%
^{64}Zn(n,p)	4.036	38.21	5.30%	1.80%
^{58}Ni(n,p)	4.051	106.1	2.20%	2.00%
^{54}Fe(n,p)	4.294	78.33	2.40%	-0.30%
^{92}Mo(n,p)	5.19	6.938	2.20%	-3.60%
^{46}Ti(n,p)	5.862	**10.72**	**2.20%**	**7.40%**
^{60}Ni(n,p)	6.811	2.086	8.50%	4.50%
^{63}Cu(n,α)	7.019	0.5009	2.90%	3.30%
^{54}Fe(n,α)	7.205	0.8707	10.50%	-0.70%
^{56}Fe(n,p)	7.362	1.05	2.60%	2.80%
^{48}Ti(n,p)	8.103	0.2909	2.60%	3.60%
^{24}Mg(n,p)	8.125	1.412	4.60%	2.60%
^{27}Al(n,α)	8.471	0.6764	2.30%	3.60%
^{51}V(n,α)	9.737	0.0234	3.50%	4.00%
^{197}Au(n,2n)	10.414	3.372	4.00%	0.40%
^{93}Nb(n,2n)^{92*}	11.21	0.4307	3.10%	0.90%
^{127}I(n,2n)	11.459	1.177	4.00%	1.80%
^{55}Mn(n,2n)	12.796	0.2324	4.50%	0.00%
^{75}As(n,2n)	12.797	0.3228	4.30%	-1.10%
^{89}Y(n.2n)	13.797	0.1698	3.20%	0.80%
^{19}F(n,2n)	13.911	**0.00769**	**4.00%**	**5.90%**
^{90}Zr(n,2n)	14.32	0.1053	4.00%	-0.70%
^{23}Na(n,2n)	15.483	0.00394	4.80%	-1.90%

CVŘ Research Centre Řež

UJV Group PEOPLE | INNOVATION | TECHNOLOGY

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

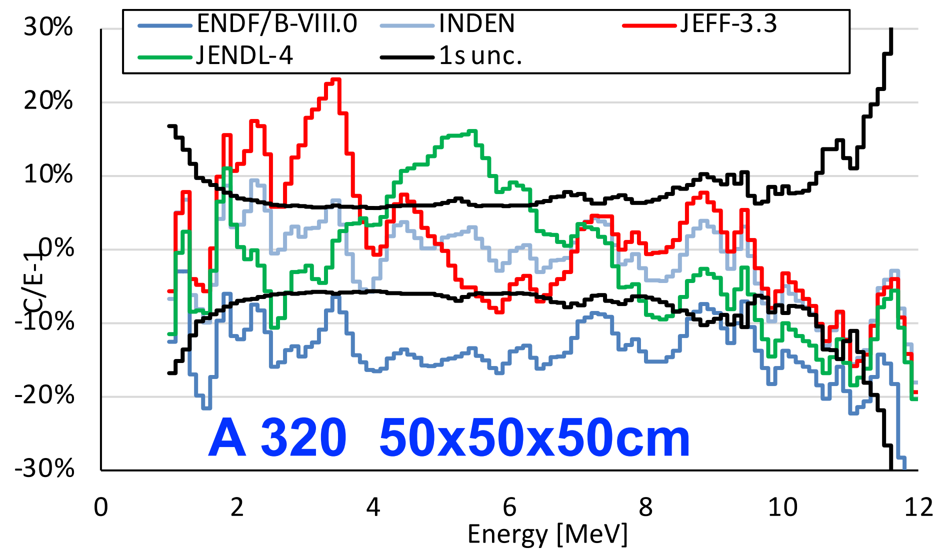
erc European Research Council Established by the European Commission

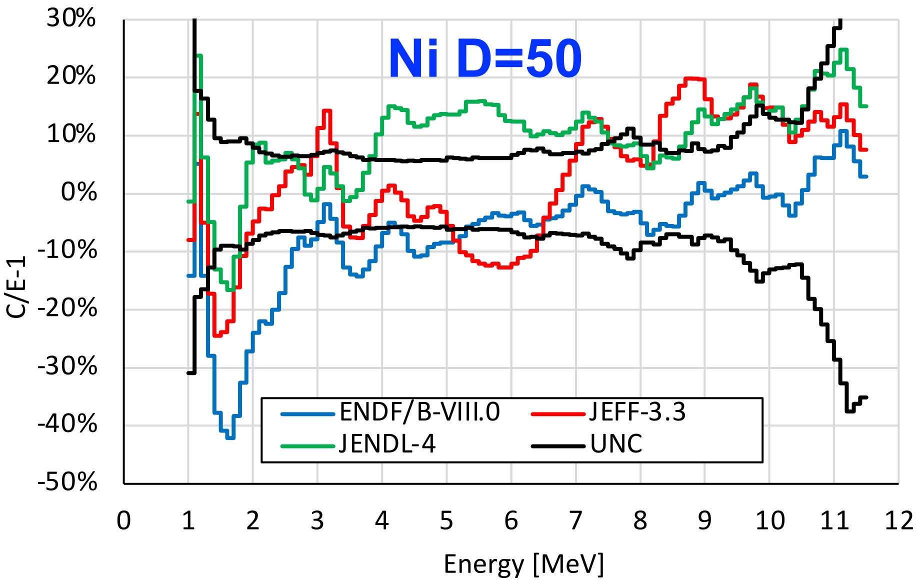
Benchmarking

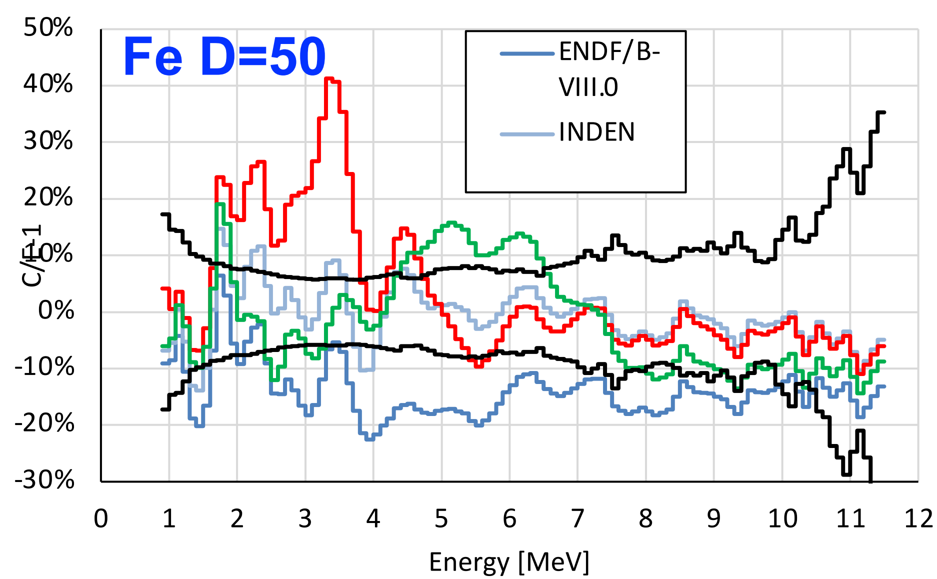
ALARM-CF-NI-SHIELD-001 "Neutron Activation Foils and Fast Neutron Leakage Spectra from **Nickel Sphere** with ^{252}Cf Source in the Center"

ALARM-CF-FE-SHIELD-002 "Neutron Activation Foils and Fast Neutron Leakage Spectra from **Iron Sphere** with ^{252}Cf Source in the Center"

ALARM-CF-SST-SHIELD-001 "Neutron Activation Foils and Fast Neutron Leakage Spectra from a **Stainless Steel 321 Block** with a ^{252}Cf Source in the Center."







GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

erc European Research Council Established by the European Commission

Summary & conclusions

- High-quality nuclear data are essential for ensuring the safety and optimal operation of existing nuclear reactors, managing nuclear waste, designing news systems, and for many non-energy nuclear applications.
- Europe has a rather large inter-disciplinary Nuclear Data community, which has benefited from several EURATOM projects since FP6, among which EUROTRANS/ NUDATRA, ANDES, EUFRAT, ERINDA, CHANDA, and now SANDA, ARIEL and now APRENDE (2024 – 2028).
- The community is well organized and has strong links with the International Agencies (IAEA, NEA/OECD) and JEFF.
- The amount of work carried out in the EC ND projects is huge.

However, **the situation is precarious**, since it depends mainly on the variable (and underfinanced) EURATOM calls for its funding.

Nuclear data projects in Europe

HINDAS (16)
KU-Leuven 3.3 M€
2000 - 2003
High and
Intermediate energy
Nuclear
Data for
Accelerator-driven
Systems

IP-EUROTRANS (~20)
KIT ~1 M€ NUDATRA
2005 - 2010
EUROpean research programme
for the
TRANSmutation
of high-level nuclear waste
in an accelerator driven systems

CHANDA (36)
CIEMAT ~5.4 M€
2013 - 2018
solving
CHAllenges in
Nuclear
DAta

APRENDE (36+4)
CIEMAT ~4 M€
2024 – 2028
Addressing
PRiorities of
Evaluated
Nuclear
Data in
Europe

National funding + Transnational access programs (ERINDA, EUFRAT, ARIEL, OFFERR, EURO-LABS) + Education & training (ARIEL, ENEN2+)

n_TOF-ADS (18)
CERN 2.4 M€
2000 – 2004
Data for
Accelerator
Driven
Systems
nucleard data

CANDIDE (14)
UU ~1 M€
2007 - 2008
Coordination
Action on
Nuclear
Data for
Industrial
Development in
Europe

ANDES (21)
CIEMAT ~3 M€
2010 - 2013
Coordination
Accurate
Nuclear
Data for nuclear
Energy
Sustainability

SANDA (36)
CIEMAT ~5.4 M€
2019 - 2024
Supplying
Accurate
Nuclear
Data for energy and
non-energy
Applications

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas | erc European Research Council Established by the European Commission

Towards a European ND program

Towards a sustainable European ND program

- Mobilization of Member States representatives for the inclusion of a new nuclear data project in HORIZON-EURATOM-2023-NRT-01-06 -> **APRENDE project**.

- Joint effort between IAEA and NuPECC (preparing the long-range plan 2024). Organisation of **Consultants' Meeting on Comprehensive European plan to acquire and curate nuclear data** with invited participants representing nuclear physics research and EU ND community.

- Side event at the IAEA 2023 conference on **Providing the Best Nuclear Data for Tomorrow's Nuclear Solutions: Challenges and Opportunities.**

- **NuPECC long-range plan** will emphasise the importance of mastering the complete ND cycle and maintain the competences.

Towards a sustainable European ND program (ii)

A European ND program (similar to the one existing in the USA) is needed:

- Bring together ND providers, database managers and stakeholders from all the domains needing ND to discuss current needs.

- Ensure the coordination of the work done by the ND community in Europe, identifying challenges and opportunities, and guarantying that ND end up in nuclear databases.

- Support key infrastructures for the production of ND.

- Ensure that a sufficient workforce is available, in particular for evaluation.

- Invest in education and training to bring new people into the nuclear data community.

- Ensure the liaison with international partners and agencies (NEA, IAEA).

The SANDA participants

CENTRO DE INVESTIGACIONES ENERGETICAS (Coordinator),
MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT
Magyar Tudomanyos Akademia Atommagkutato Intezete
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS
AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS
CENTRUM VYZKUMU REZ S.R.O.
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE
HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF EV
INSTITUTUL NATIONAL DE CERCETARE -DEZVOLTARE PENTRU FIZICA SI INGINERIE NUCLEARA "HORIA HULUBEI" (IFIN-HH)
INSTITUT DE RADIOPROTECTION ET DE SURETE NUCLEAIRE
ASSOCIACAO DO INSTITUTO SUPERIOR TECNICO PARA A INVESTIGACAO E DESENVOLVIMENTO
JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION
INSTITUT JOZEF STEFAN
JYVASKYLAN YLIOPISTO

KARLSRUHER INSTITUT FUER TECHNOLOGIE
USTAV JADERNE FYZIKY AV CR
NPL MANAGEMENT LIMITED
NUCLEAR RESEARCH AND CONSULTANCY GROUP
NATIONAL TECHNICAL UNIVERSITY OF ATHENS - NTUA
PAUL SCHERRER INSTITUT
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
STUDIECENTRUM VOOR KERENERGIE/ CENTRE D ETUDE DE L ENERGIE NUCLEAIRE
SOFIISKI UNIVERSITET SVETI KLIMENT OHRIDSKI
TECHNISCHE UNIVERSITAET WIEN
UNIVERSITATEA DIN BUCURESTI
UNIWERSYTET LODZKI
JOHANNES GUTENBERG-UNIVERSITAT MAINZ
THE UNIVERSITY OF MANCHESTER
PANEPISTIMIO IOANNINON
UNIVERSITAT POLITECNICA DE CATALUNYA
UNIVERSIDAD POLITECNICA DE MADRID
UNIVERSIDAD DE SANTIAGO DE COMPOSTELA
UNIVERSIDAD DE SEVILLA
UPPSALA UNIVERSITET

The APRENDE participants

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Coordinator)
Atommagkutato Intezet
Commissariat a l'Energie Atomique et aux Energies Alternatives
Organisation Europeenne pour la Recherche Nucleaire
Centrum Vyzkumu Rez sro
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile
European Spallation Source Eric
Grand Accelerateur National d'ions Lourds
Helmholtz-Zentrum Dresden-Rossendorf EV
Agencia Estatal Consejo Superior de Investigaciones Cientificas
Institutul National de Cercetare-dezvoltare pentru fizica si inginerie nucleara-horia Hulubei
Istituto nazionale di fisica nucleare
Institut de radioprotection et de surete nucleaire
Institut Jozef Stefan
Karlsruher Institut fuer Technologie
LGI sustainable innovation
Nuclear research and consultancy group
Ethnicon metsovion polytechnion
Institut Mines Telecom
Institut Polytechnique de Grenoble
JRC -Joint Research Centre- European Commission

Physikalisch-technische Bundesanstalt
Studiecentrum voor Kernenergie/Centre d'etude de l'Energie Nucleaire
Slovenska Technicka Univerzita v Bratislave
Technische Universitaet Wien
Universitatea din Bucuresti
Rijksuniversiteit Groningen
Panepistimio Ioanninon
Jyvaskylan Yliopisto
Uniwersytet lodzki
Faculty of natural sciences and mathematics, university of Maribor
Universitat Politecnica de Catalunya
Universidad Politecnica de Madrid
Universidad de Sevilla
Sofia University St Kliment Ohridski
Uppsala Universitet
Ecole Polytechnique Federale de Lausanne
Paul Scherrer Institut
United Kingdom atomic energy authority
NPL management limited
The University of Edinburgh
European Nuclear Education Network
Centre National de la Recherche Scientifique
Nantes Université
Paul Scherrer Institut
Ecole Politechnique de Lausanne
National Physical Laboratory
University of Edinbourgh

Announcement: ND2025 in Madrid

An excellent conference for presenting your work!

https://www.nd2025madrid.com/

Abstract submission is open!

Spare slides

More about it in…

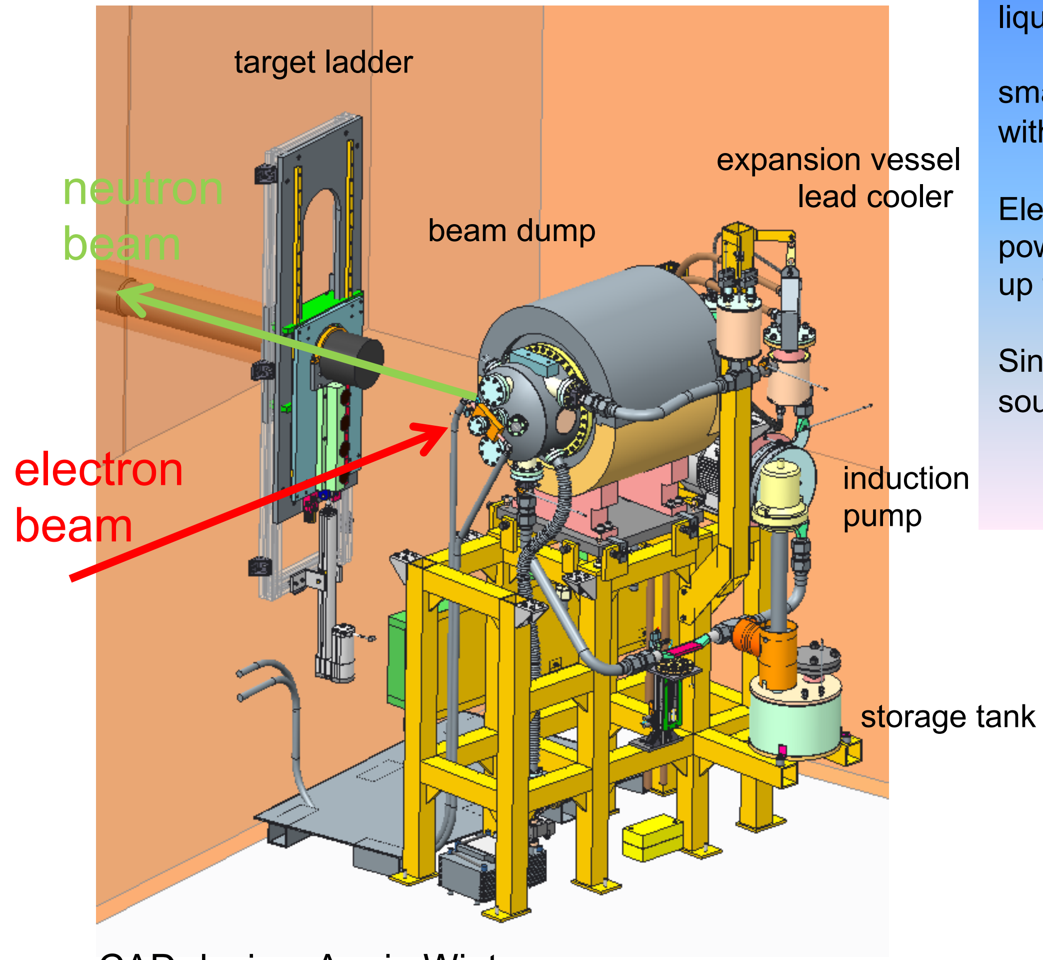
Nuclear Science for the Manhattan Project and Comparison to Today's ENDF Data

by M. B Chadwick

Nuclear Technology 207 (2021)

https://doi.org/10.1080/00295450.2021.1901002

Liquid Pb-loop



CAD design: Armin Winter

E. Altstadt et al., Ann. Nucl. Energy **34** (2007) 36

liquid lead circuit for heat transport

small Mo tube (11 mm diam.)
with liquid lead as neutron radiator

Electron beam power up to 40 kW
power density in the neutron radiator
up to 25 kW/cm^3

Single pulse to 400 kHz micropulse rate
source strength $6 \cdot 10^{11}$ n/s

SRF injector for photo neutron production
variable repetition rate
bunch charge up to 300 pC
kicker for parallel operation of neutron tof
with high repetition rate experiments at ELBE

The PROMAS program

PROMAS

- I — **Mass-separated radionuclides for fundamental nuclear sciences** → **APRENDE**
- II — **Mass separated medically relevant radionuclides**
- III — **RILIS Development**
- VI — **Auger-electron emitters: thin targets and spectroscopy**
- V — **Low-energy ion beams for superheavy element research**
- VI — **Sources for Mössbauer spectroscopy**

PROMAS project timeline

Phase I

- Develop and improve versatile ion source schemes
- A high-resolution mass separator (mass resolution > 1000)
- Suitable ion collector
- Ion optical elements
- Dedicated vacuum system (10^{-6}-10^{-7} mbar)

Phase II

- Installation in the radioactive zone (interim)

Site preparation in the hotlab (Pu-zone) is in progress (Swiss Decommissioning Fund), and it is expected to be ready in 2028.

- Test experiments

Proposed first-generation experiments:

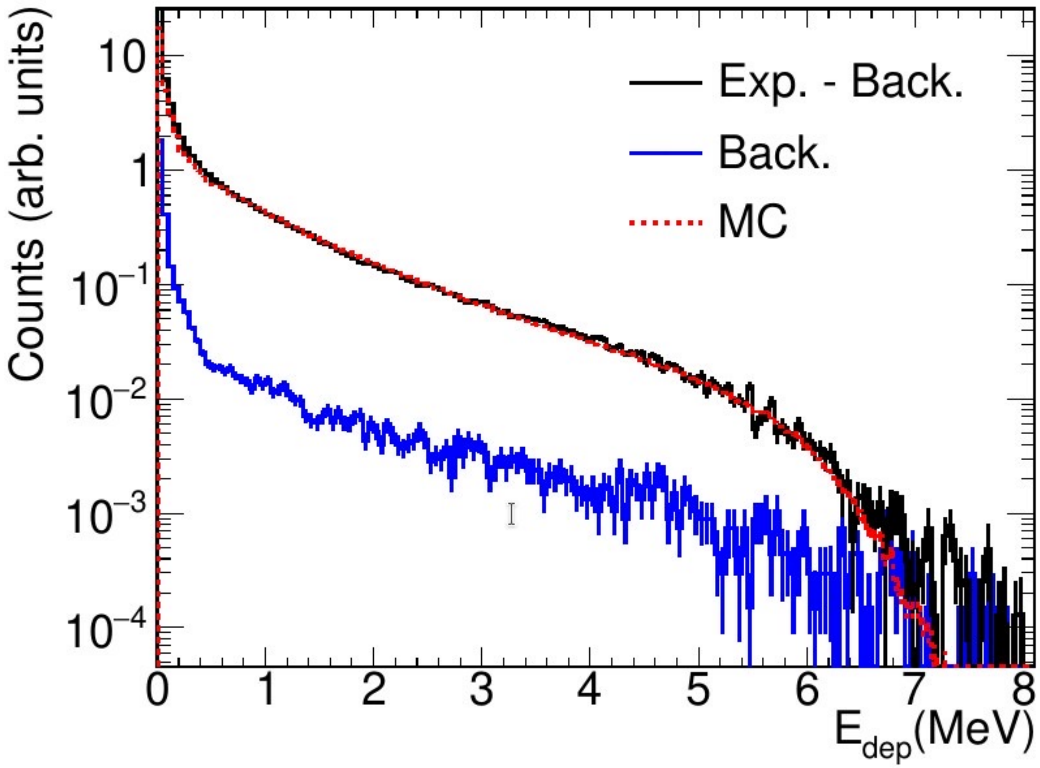
^{39}Ar, ^{135}Cs, ^{40}K, ^{150}Gd, ^{205}Pb

The infrastructure will be accessible to national and international academic research scientist.

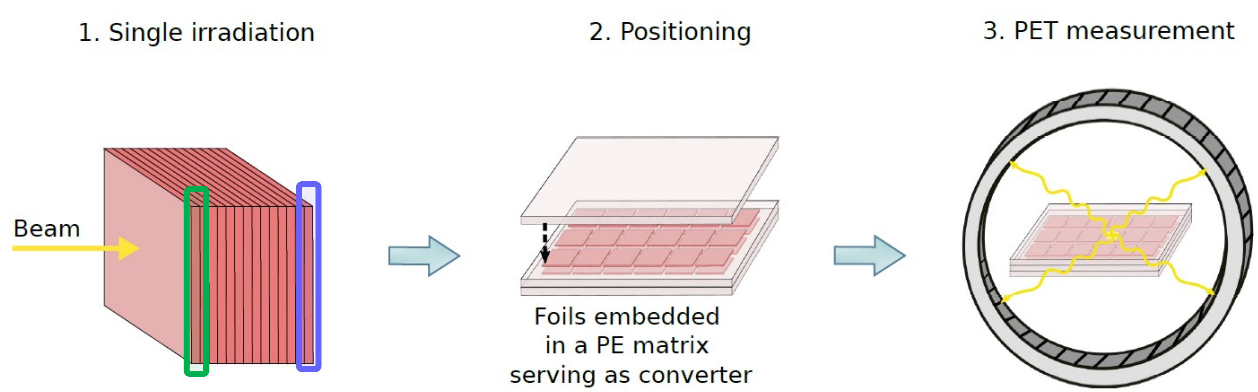
Characterisation of the sTED detectors

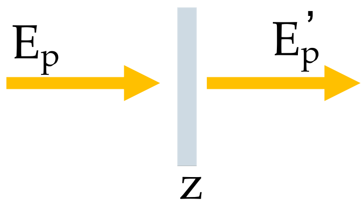
Experimental deposited energy spectra in one sTED module (Exp.-Back.) with background subtracted (Back.) and simulated with NuDEX+Geant4 (MC) for ^{197}Au(n,γ) cascades.

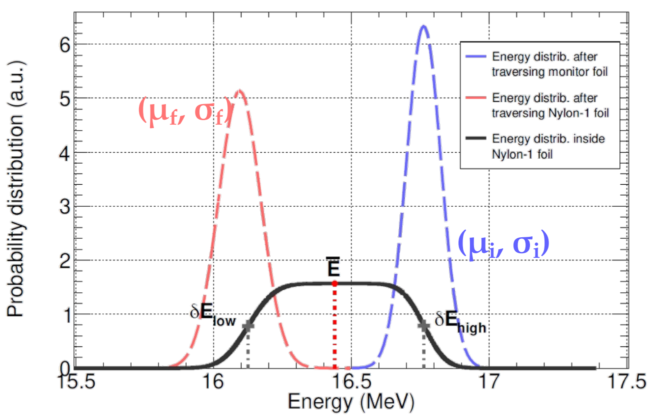
^{197}Au(n,γ)

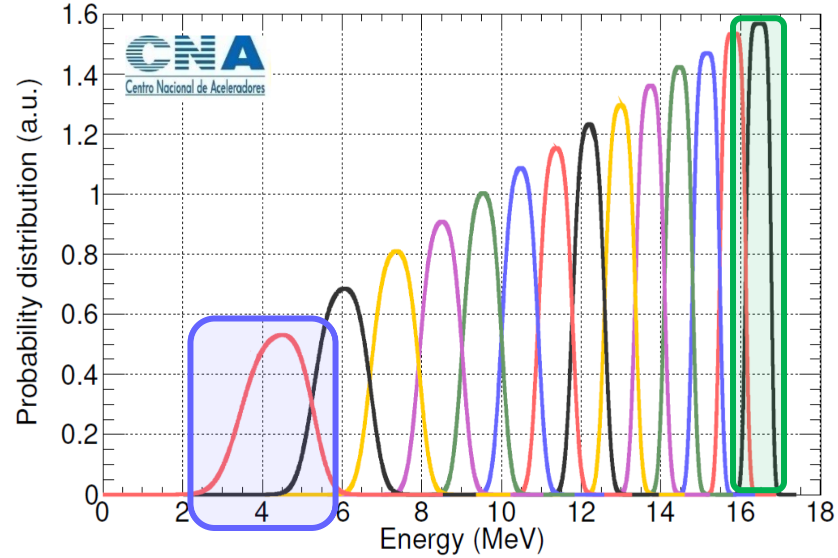


Multi-foil activation with PET scanner

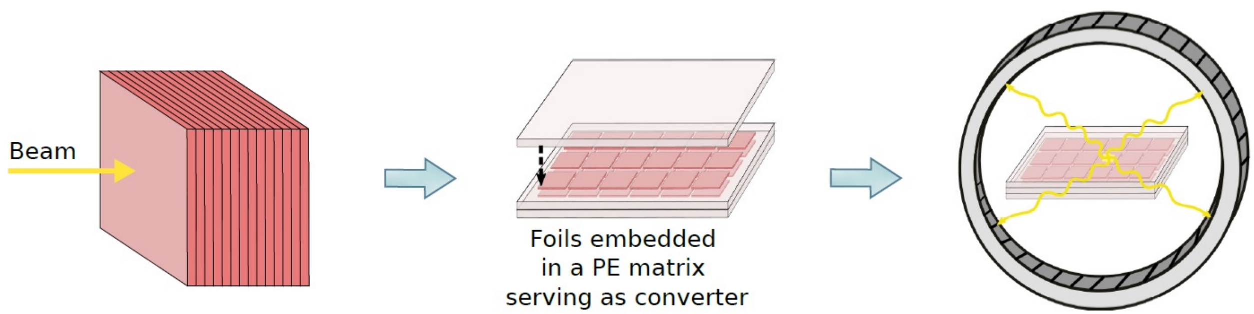


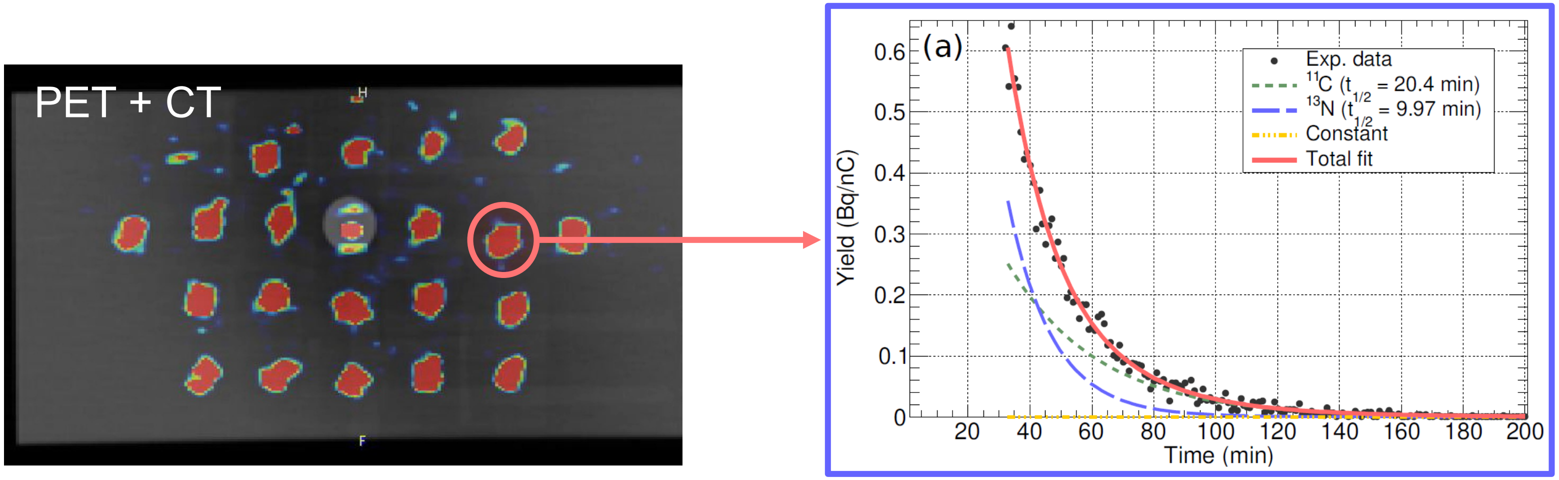




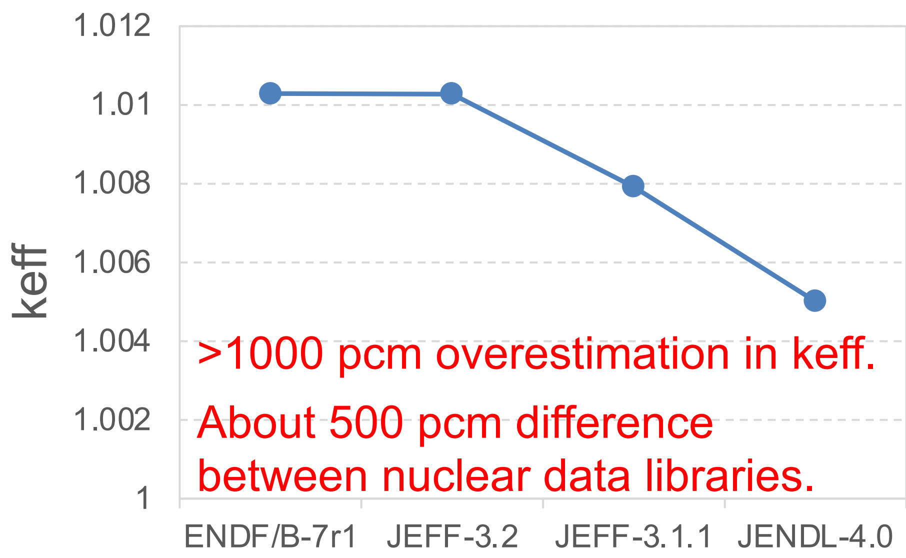


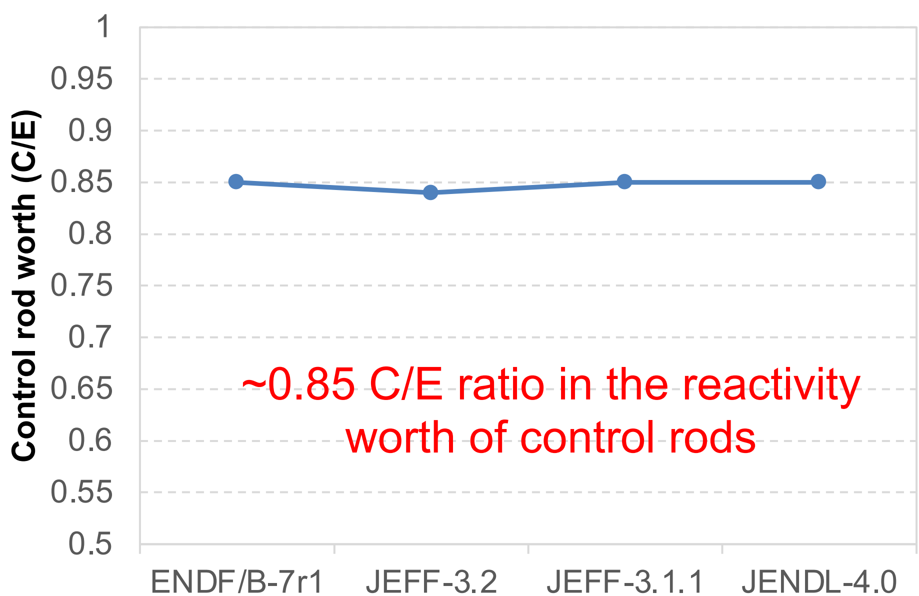
Multi-foil activation with PET scanner

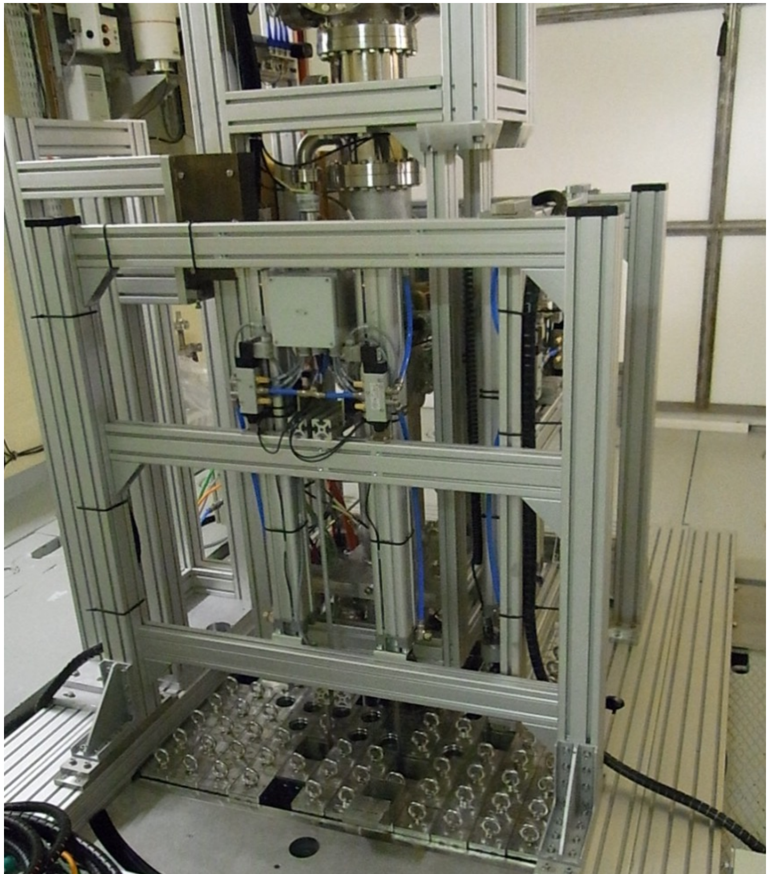




Pb nuclear data







VENUS-F mockup reactor during the FREYA project

V. Bécares y D. Villamarín, Resultados experimentales del proyecto FREYA dedicados al diseño y licenciamiento de MYRRHA/FASTEF.