The n_TOF Collaboration, www.cern.ch/n_TOF

AccApp 2013

Eleventh International Topical Meeting on Nuclear Application of Accelerators

The n_TOF Facility at (CERN): neutron data for applications

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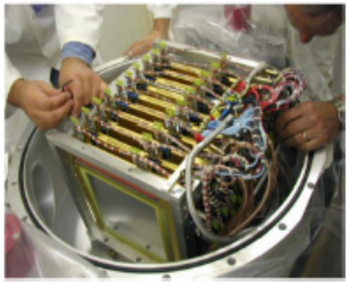
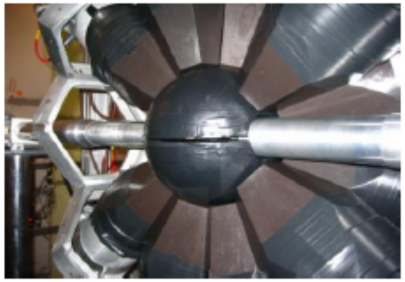
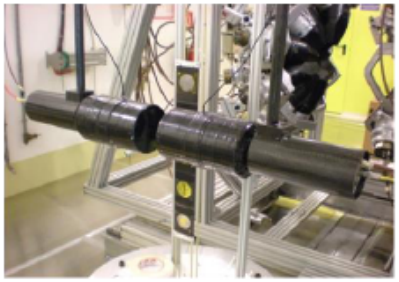
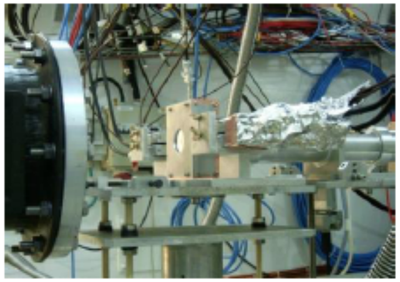
Istituto Nazionale Fisica Nucleare, Sezione di Bari

Outline

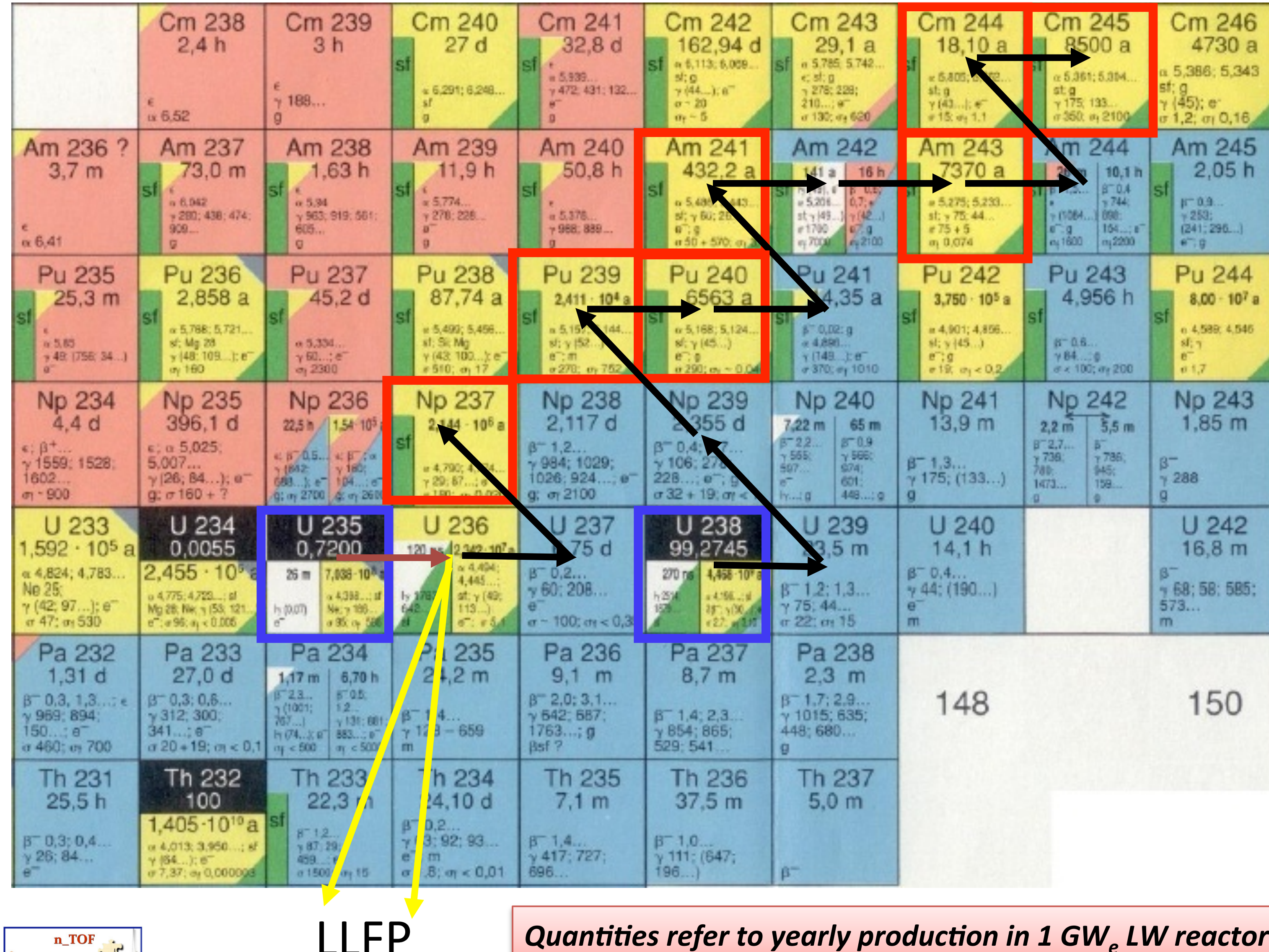
- Motivations
- The n_TOF facility
- The experimental program
- Persectives
- Conclusions

The n_TOF Collaboration

(~100 Researchers from 30 Institutes)

CERN	
Technische Universitat Wien	Austria
IRMM EC-Joint Research Center, Geel	Belgium
Charles Univ. (Prague)	Czech Republic
IN2P3-Orsay, CEA-Saclay	France
KIT – Karlsruhe, Goethe University, Frankfurt	Germany
Univ. of Athens, Ioannina, Demokritos	Greece
INFN Bari, Bologna, LNL, Trieste, ENEA – Bologna	Italy
Univ. of Tokio	Japan
Univ. of Lodz	Poland
ITN Lisbon	Portugal
IFIN – Bucarest	Rumania
CIEMAT, Univ. of Valencia, Santiago de Compostela, University of Cataluna, Sevilla	Spain
University of Basel, PSI	Switzerland
Univ. of Manchester, Univ. of York	UK

The nuclear waste problem



$^{244,245}Cm$
1.5 Kg/yr

^{241}Am: 11.6 Kg/yr
^{243}Am: 4.8 Kg/yr

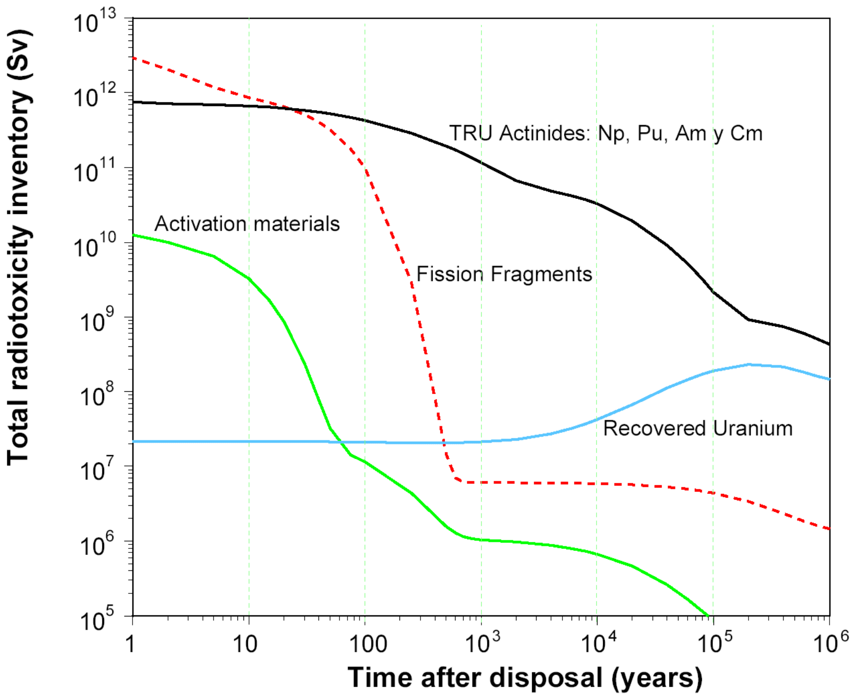
^{239}Pu: 125 Kg/yr

^{237}Np: 16 Kg/yr

LLFP
76.2 Kg/yr

Quantities refer to yearly production in 1 GW$_e$ LW reactor

The actinide problem

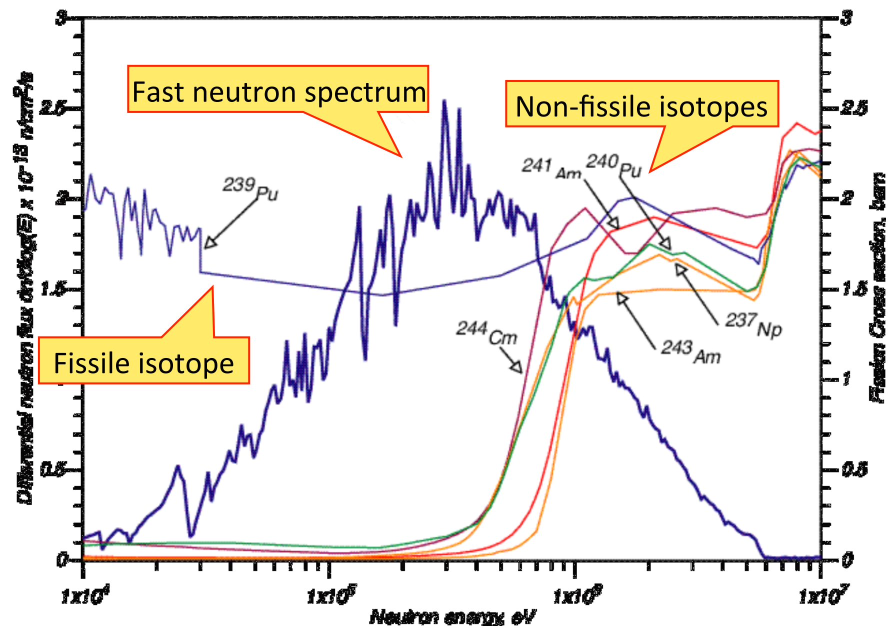


Main problem in the nuclear waste are the **transuranic actinides**: Np, Pu, Am, Cm, …

At present, only solution to high-level nuclear waste is storage in **geological repositories**

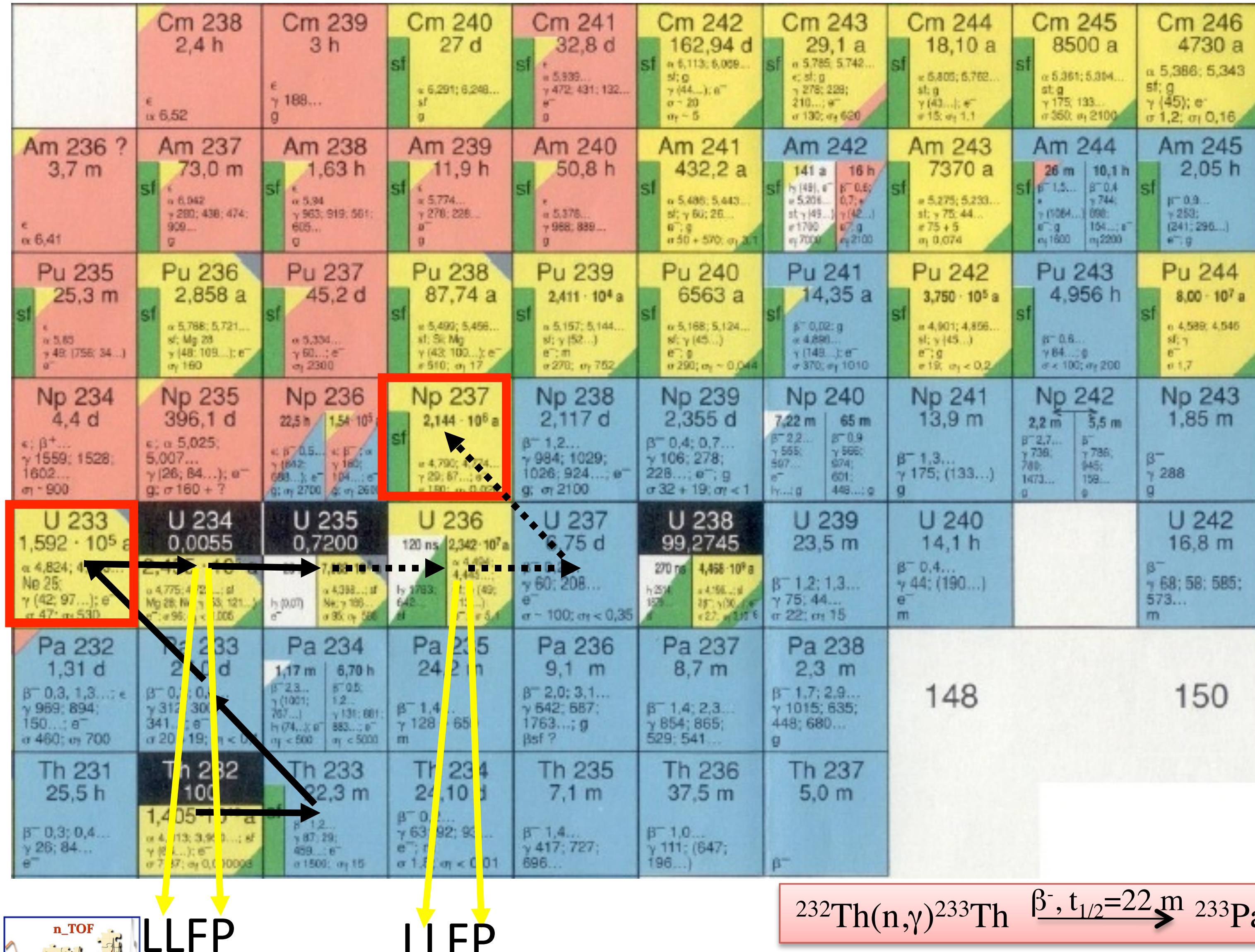
A more appealing solution: **nuclear waste incineration** by means of **neutron-induced reactions** (mostly fission).

Most **minor actinides** are not fissile (fission threshold around 1 MeV). **Incineration** requires a **fast neutron spectrum** (E_n>10 keV).



Generation IV fast reactors and **dedicated burners** (Accelerator Driven Systems) are being proposed as a possible solution.

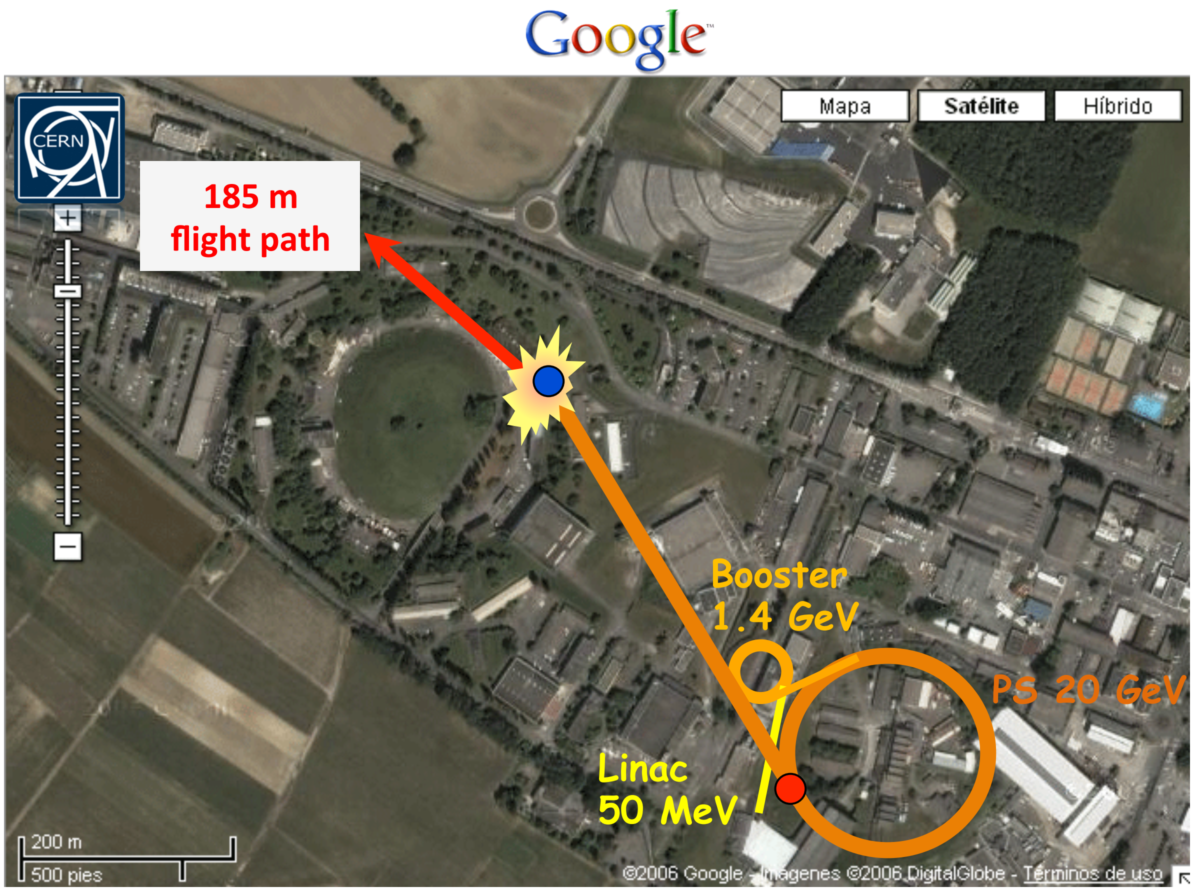
The Th/U fuel cycle



$$^{232}Th(n,\gamma)^{233}Th \xrightarrow{\beta^-,\ t_{1/2}=22\ m} {}^{233}Pa \xrightarrow{\beta^-,\ t_{1/2}=27\ d} {}^{233}U$$

The n_TOF facility at CERN

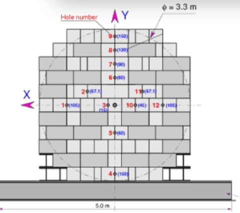
Data on a large number of isotopes are needed for Nuclear Astrophysics, for design of advanced systems and for improving safety of current reactors.



n_TOF is a **spallation** neutron source based on **20 GeV/c protons** from the CERN PS hitting a **Pb block** (~360 neutrons per proton).

Experimental area at **185 m**.

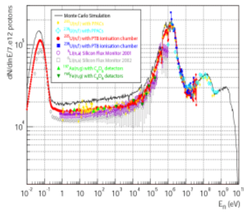
n_TOF time line



1995-1997 **TARC** experiment

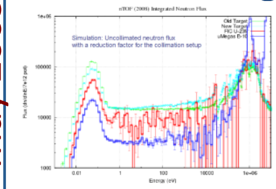
May 1998 **Feasibility** CERN/LHC/ 98-02+Add

2000 **Commissioning**



2008 **New Target** construction

May 2009 **Commissioning**



2009-2012 **Phase II**
Isotopes
Capture: 14
Fission: 6
(n,α): 2

July 2014 **Commissioning EAR2**

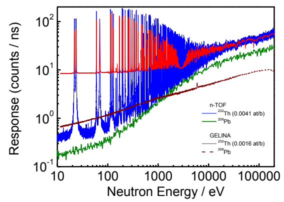
1996 — 2009 — 2014

1997 **Concept** by C.Rubbia
CERN/ET/Int. Note 97-19

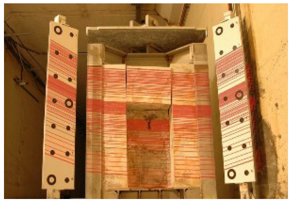
Aug 1998 **Proposal** submitted

1999 **Construction** started

2001-2004 **Phase I**
Isotopes
Capture: 25
Fission: 11



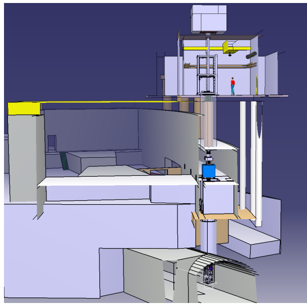
2004-2007 **Problem** Investigation



2009 **Phase II**

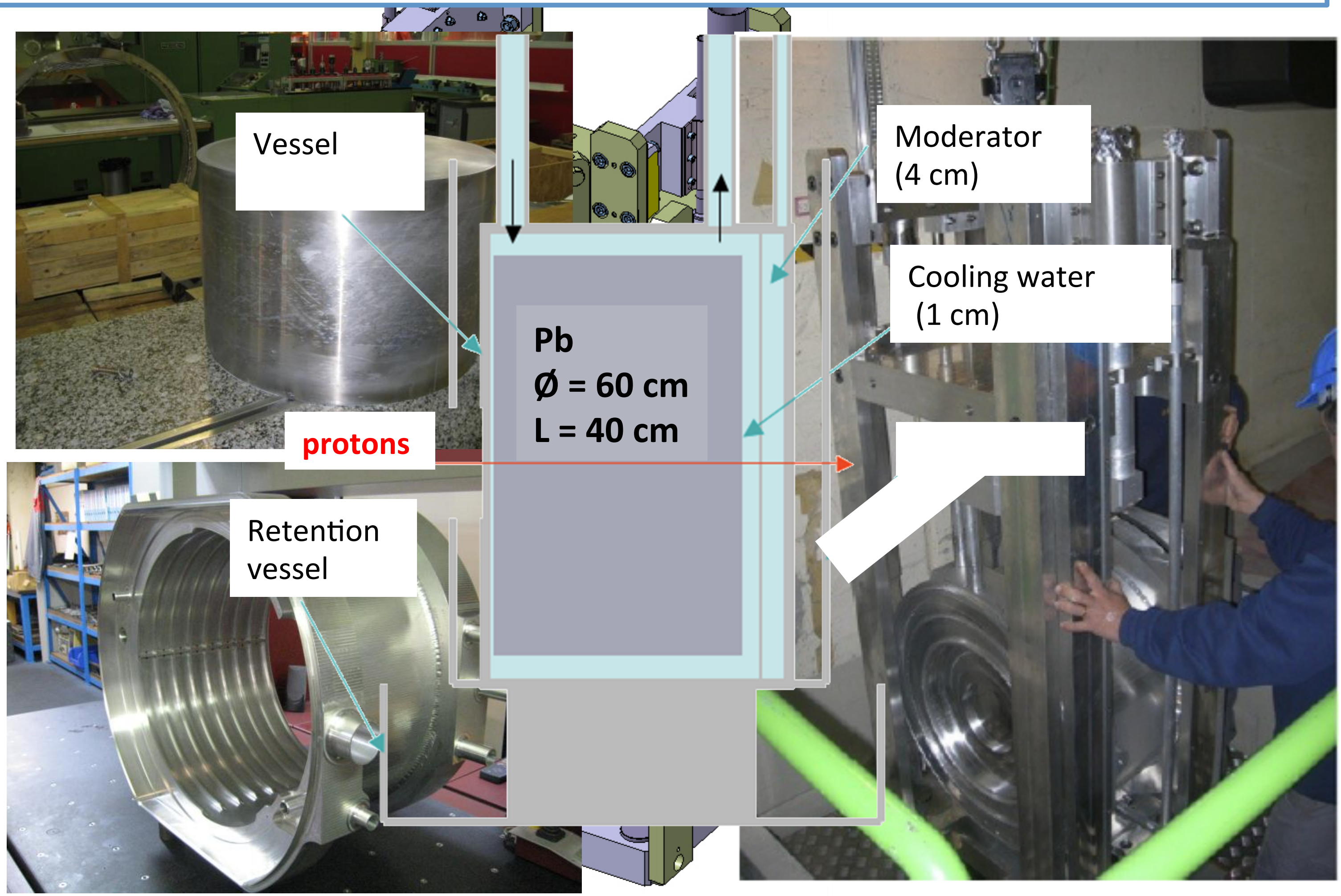
2010 **Upgrades:**
Borated-H_2O
Second Line
Class-A

2013-2014 **Construction** EAR2



The new spallation target

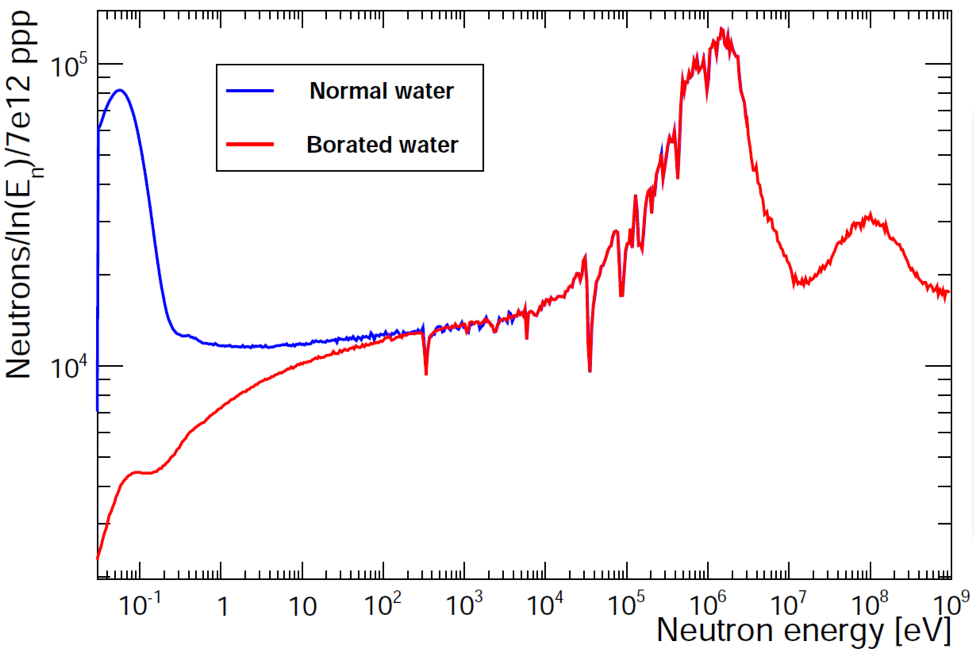
The cooling and the moderator systems in the target are separated, so to optimize neutron spectrum or minimize background



The facility

The n_TOF facility

Advantages of the **PS proton beam**: **high energy, high peak current, low duty cycle.**



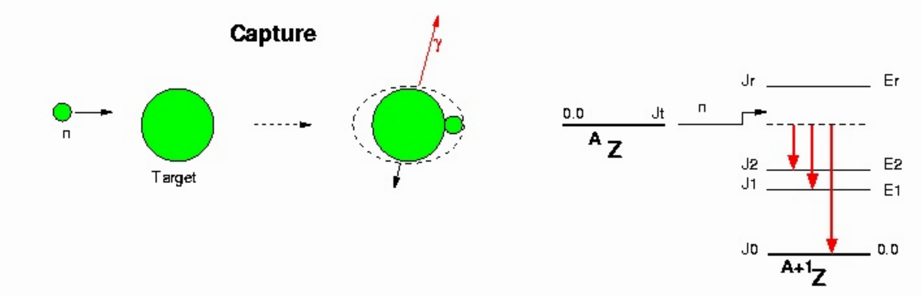
Main feature: **high instantaneous neutron flux** (*10^6 n/pulse*).

- very convenient for measurements of **radioactive isotopes** (maximizes signal-to-background ratio)
- ideal facility for **actinides** (nuclear technology)

Other features of the neutron beam:

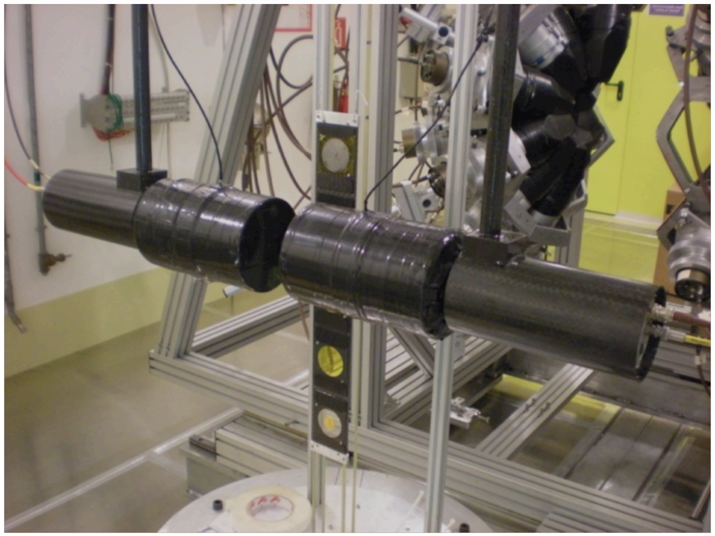
- high **resolution in energy** (*$\Delta E/E = 10^{-4}$*) .... study **resonances**
- wide **energy range** (*25 meV<E_n<1GeV*) .... measure **fission** from thermal to GeV
- low **repetition** rate (*< 0.8 Hz*) .... no **wrap-around**

Detectors for capture reactions …



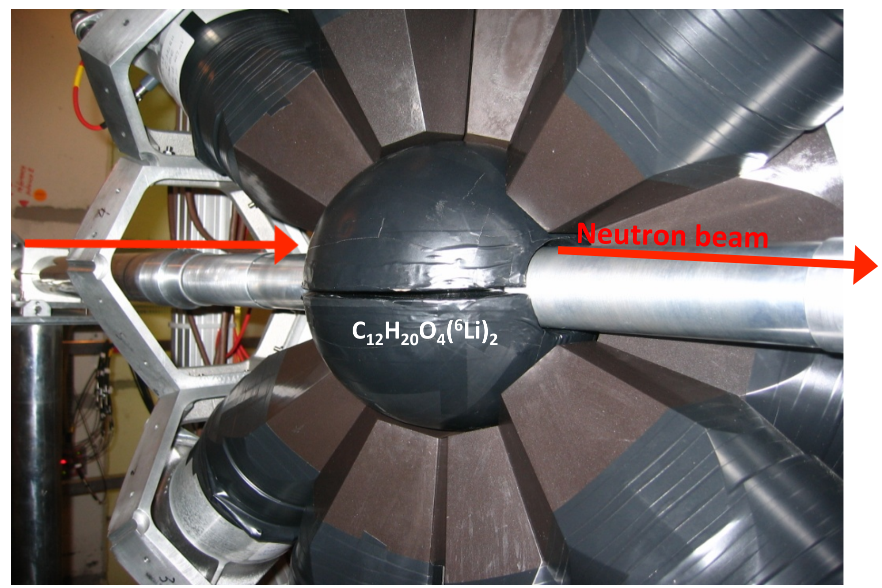
Capture reactions are measured by detecting γ-rays emitted in the de-excitation process.

At n_TOF, two detection systems are used, for different purposes.



C_6D_6 (deuterated liquid scintillators)
- low neutron sensitivity device
- used for low cross-section samples

Total Absorption Calorimeter (TAC)
- High-efficiency **4π** detector (40 BaF_2 scintillators with neutron shielding)
- mostly used for fissile isotopes (actinides)

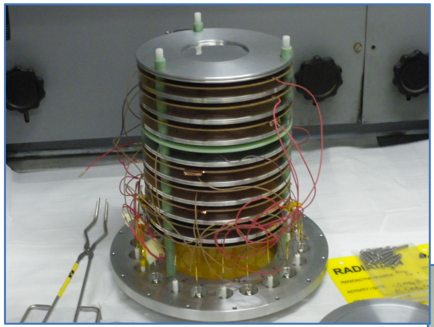


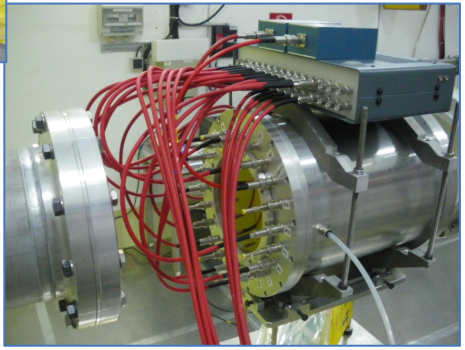
… and for fission

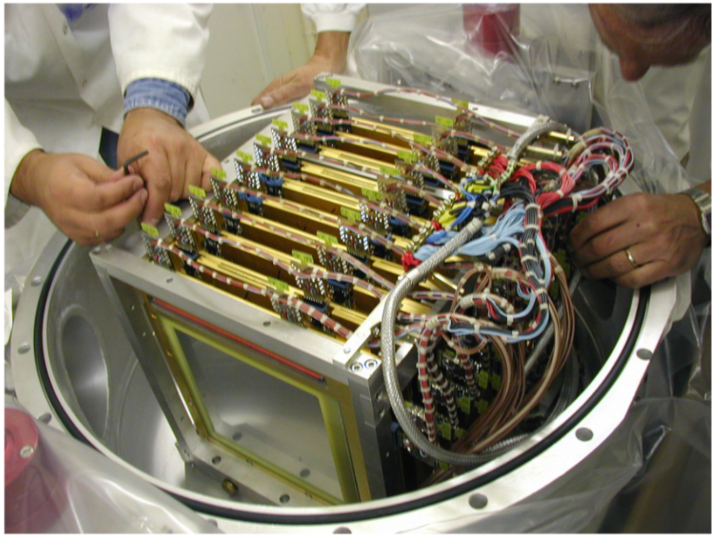
Several systems have been used for detecting fission fragments.
The main problem in fission measurements is the **background** due to **α-decay**.

Micromegas chamber

- low-noise, high-gain, radiation-hard detector







Parallel Plate Avalanche Counters (PPAC)

- Fission fragments detected **in coincidence**
- Very good rejection of α-background

The n_TOF measurements

Phase 1
(2001-2004)

Capture

^{151}Sm

^{232}Th

^{204,206,207,208}Pb, ^{209}Bi

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{186,187,188}Os

^{233,234}U

^{237}Np,^{240}Pu,^{243}Am

Fission

^{233,234,235,236,238}U

^{232}Th

^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

Phase 2
(2009-2012)

Capture

^{25}Mg

^{88}Sr

^{58,60,62}Ni,^{63}Ni

^{54,56,57}Fe

^{92}Zr,^{93}Zr

^{236,238}U

^{241}Am

Fission

^{240,242}Pu

^{235}U(n,γ/f)

^{232}Th, ^{234}U

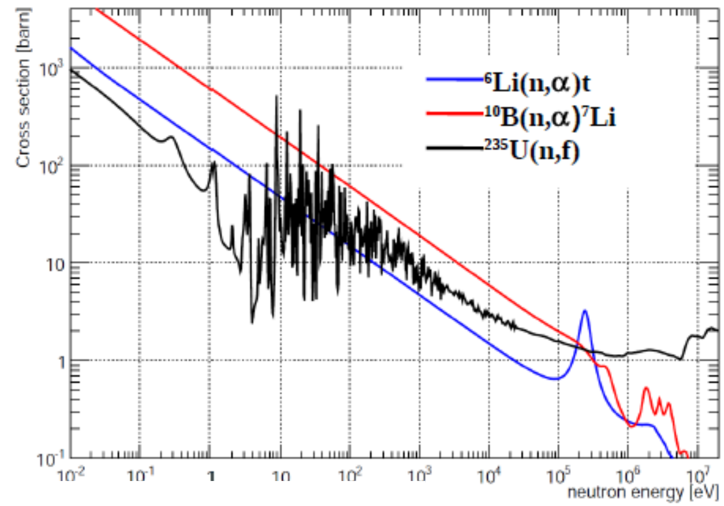
^{237}Np (FF ang.distr.)

(n,α)

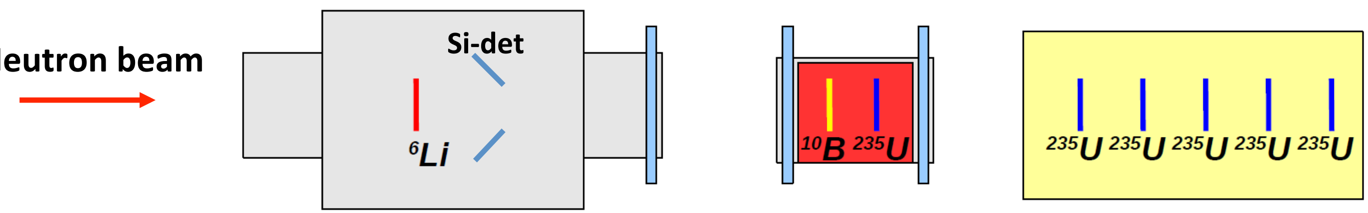
^{33}S,^{59}Ni

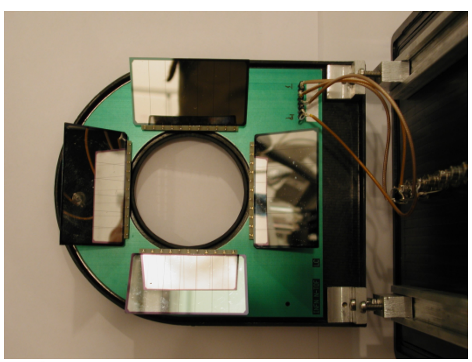
The neutron flux measurement

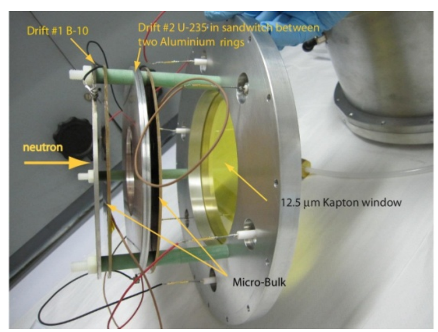
Reaction	Standard energy range
$H(n,n)$	1 keV to 20 MeV
^{3}He(n,t)	0.0253 eV to 50 keV
^{6}Li(n,α)	0.0253 eV to 1 MeV
^{10}B(n,α)	0.0253 eV to 1 MeV
^{197}Au(n,γ)	0.0253 eV and 0.2 MeV to 2.5 MeV
^{235}U(n,f)	0.0253 eV and 0.15 MeV to 200 MeV
^{238}U(n,f)	2 MeV to 200 MeV

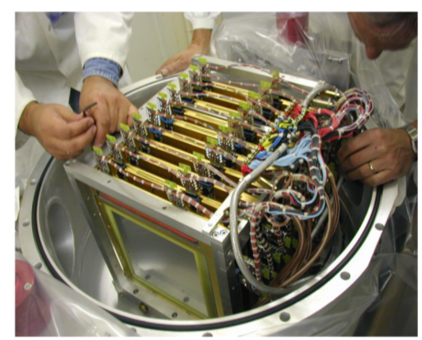


Neutron beam

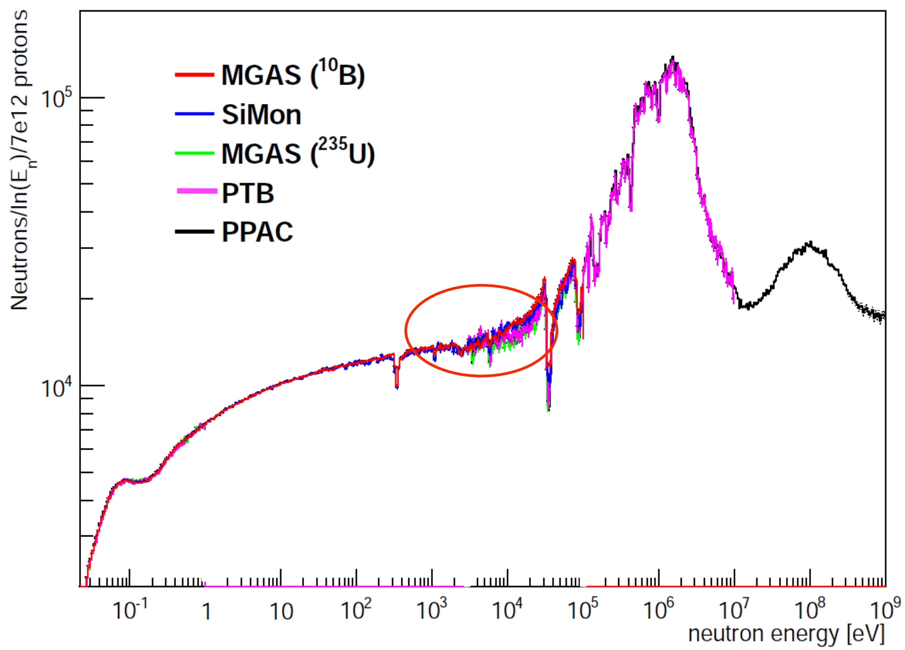








The neutron flux measurement



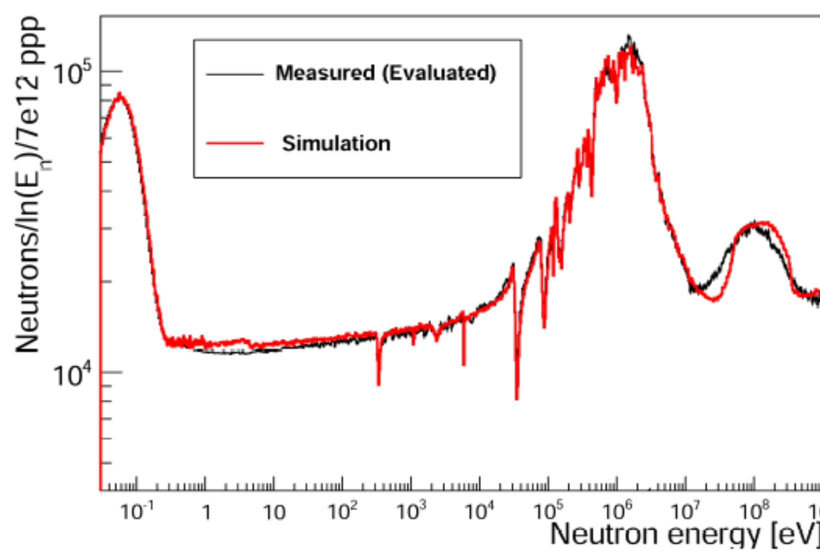
Agreement between various detectors from **1% (at low energy)** to **3% (at higher energy)**.

A large **discrepancy** observed between **10 and 30 keV**, we believe because of a problem in the **^{235}U(n,f)** cross section.

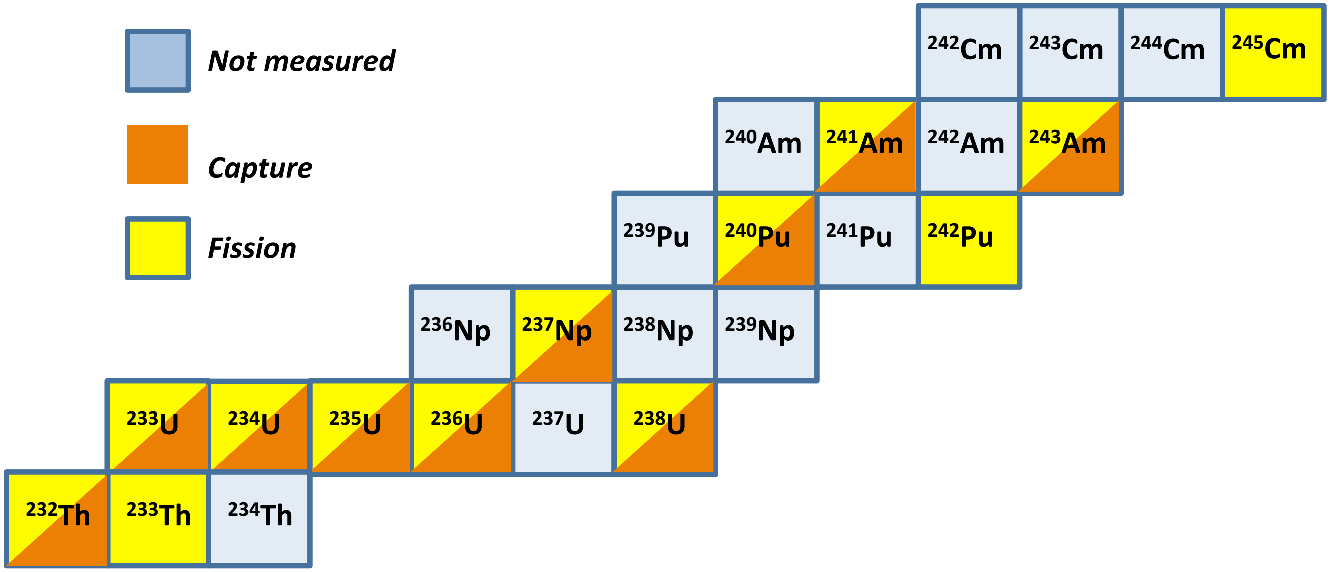
Simulations of the spallation process performed with **FLUKA** (down to 20 MeV neutron energy).

MCNPX used to transport neutrons from 20 MeV down.

Good agreement between measurements and simulations.



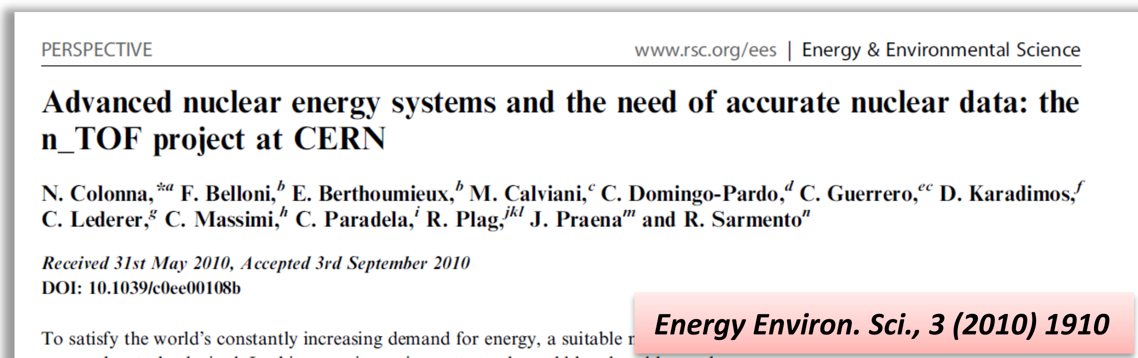
Results relevant to nuclear technology



In the two campaigns, measured **capture** and **fission** cross sections for most **long-lived actinides**.

Plans to measure also short-lived actinides at the new "high flux" experimental area

For more information see:


PERSPECTIVE www.rsc.org/ees | Energy & Environmental Science

Advanced nuclear energy systems and the need of accurate nuclear data: the n_TOF project at CERN

N. Colonna,[*a] F. Belloni,[b] E. Berthoumieux,[b] M. Calviani,[c] C. Domingo-Pardo,[d] C. Guerrero,[ce] D. Karadimos,[f] C. Lederer,[g] C. Massimi,[h] C. Paradela,[i] R. Plag,[jkl] J. Praena[m] and R. Sarmento[n]

Received 31st May 2010, Accepted 3rd September 2010
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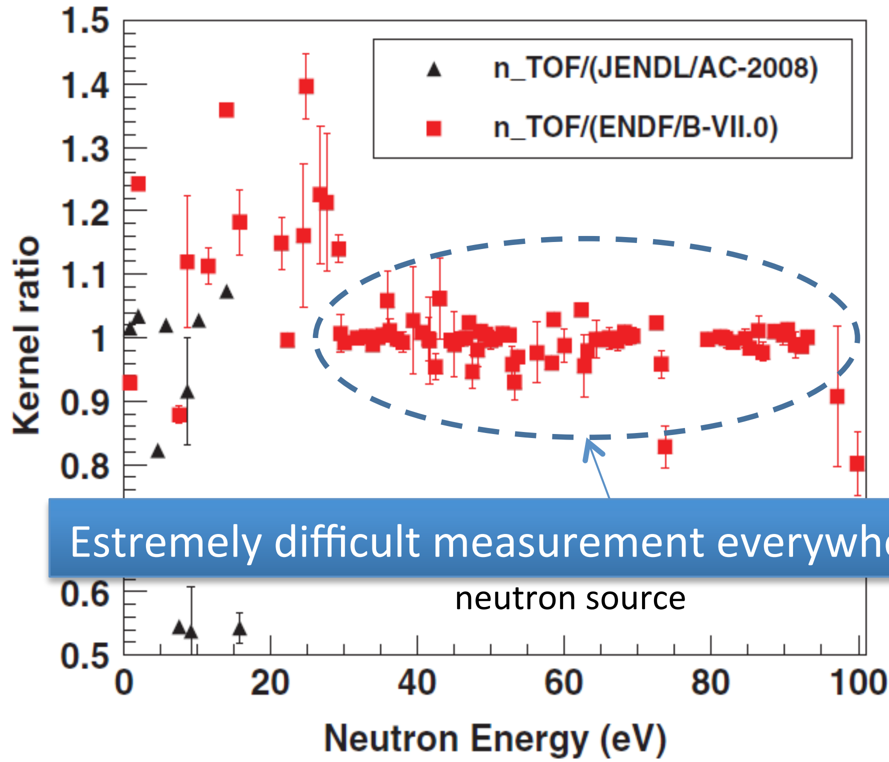
To satisfy the world's constantly increasing demand for energy, a suitable r... sources has to be devised. In this scenario, an important role could be played by nuclear energy.

Energy Environ. Sci., 3 (2010) 1910

The fission cross section of ^{245}Cm



Half-life: **8500 y**
Sample: **1.71 mg**
Activity: **87 MBq** (each sample)
Contamination (declared): **^{244}Cm 6.6% (18.1 y)**

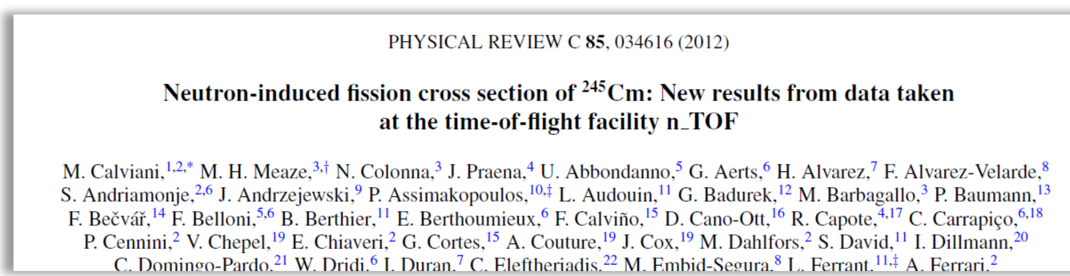
Estremely difficult measurement everywhere else (except at a nuclear explosion !)

Below 30 eV, two **(very old)** measurements exist, showing **large discrepancies**.

Above 30 eV, **only one** measurement exist, showing good agreement with n_TOF.

From thermal energy to 30 eV a **revision of the evaluations** is needed.

Above 30 eV, n_TOF confirm previous data and evaluations.

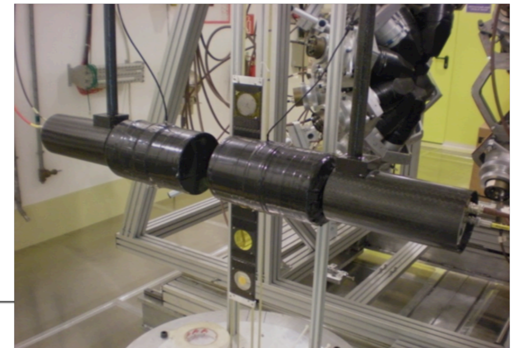

PHYSICAL REVIEW C **85**, 034616 (2012)

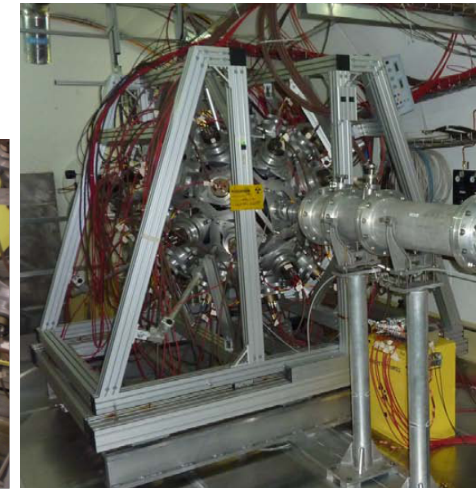
Neutron-induced fission cross section of ^{245}Cm: New results from data taken at the time-of-flight facility n_TOF

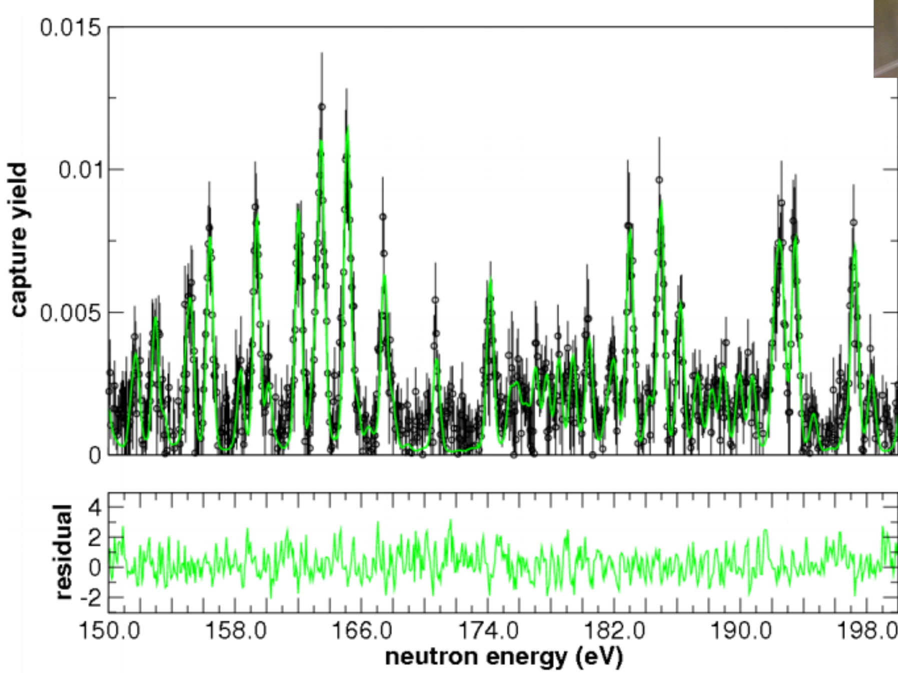
M. Calviani,[1,2,*] M. H. Meaze,[3,†] N. Colonna,[3] J. Praena,[4] U. Abbondanno,[5] G. Aerts,[6] H. Alvarez,[7] F. Alvarez-Velarde,[8] S. Andriamonje,[2,6] J. Andrzejewski,[9] P. Assimakopoulos,[10,‡] L. Audouin,[11] G. Badurek,[12] M. Barbagallo,[3] P. Baumann,[13] F. Bečvář,[14] F. Belloni,[5,6] B. Berthier,[11] E. Berthoumieux,[6] F. Calviño,[15] D. Cano-Ott,[16] R. Capote,[4,17] C. Carrapiço,[6,18] P. Cennini,[2] V. Chepel,[19] E. Chiaveri,[2] G. Cortes,[15] A. Couture,[19] J. Cox,[19] M. Dahlfors,[2] S. David,[11] I. Dillmann,[20] C. Domingo-Pardo,[21] W. Dridi,[6] I. Duran,[7] C. Eleftheriadis,[22] M. Embid-Segura,[8] L. Ferrant,[11,‡] A. Ferrari,[2]

$^{241}Am(n,\gamma)$: a difficult measurement

Half-life: **432 y**
Sample: **32.2 mg**
Activity: **3 GBq**







Measurements made with both **C_6D_6** and **TAC** detectors, to minimize systematic uncertainties.

First time that complete region is covered **from thermal to MeV** in a single measurement.

Unprecedented resolution and statistics, to **extend RRR** above 150 eV

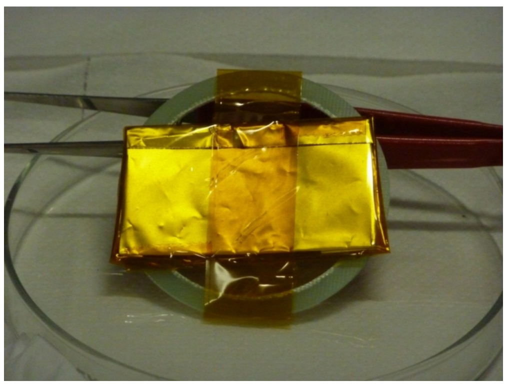
$^{238}U(n,\gamma)$ cross section: aiming at a very high accuracy

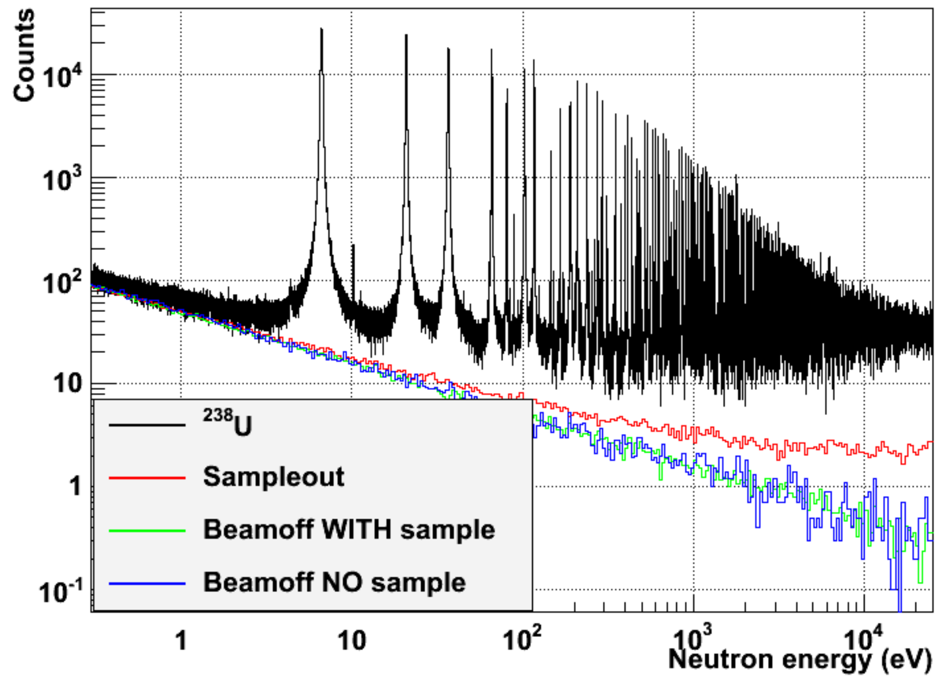
NEA request to measure $^{238}U(n,\gamma)$ cross section with 2% accuracy from 100 eV to 25 keV

Response from the community: measurements at n_TOF (x2), GELINA and LANSCE

^{238}U sample (provided by JRC-IRMM)

- 6.125 (2) g
- High purity (99.99%)
- Rectangular: 53.90 x 30.30 mm

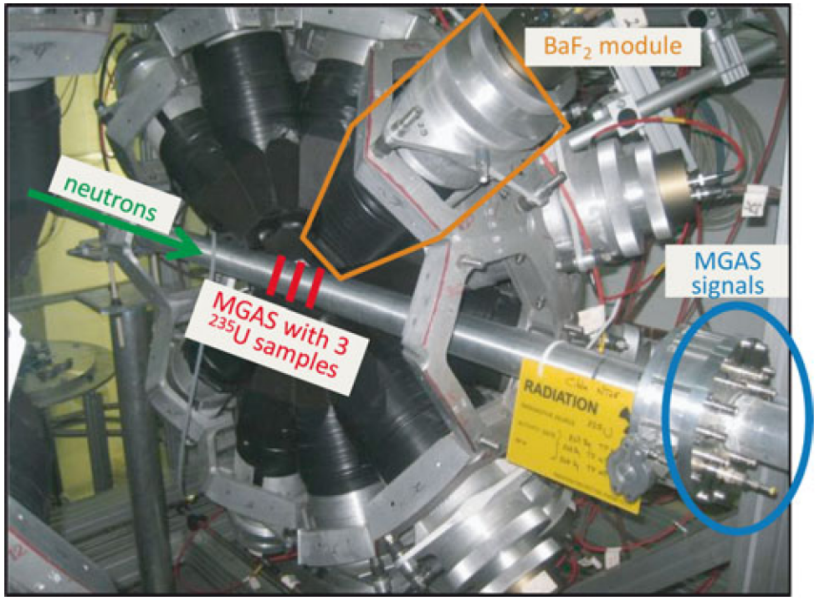


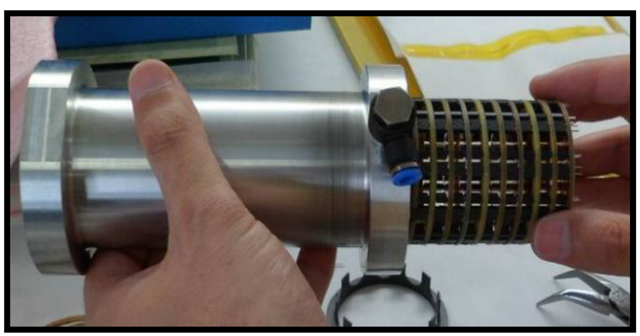


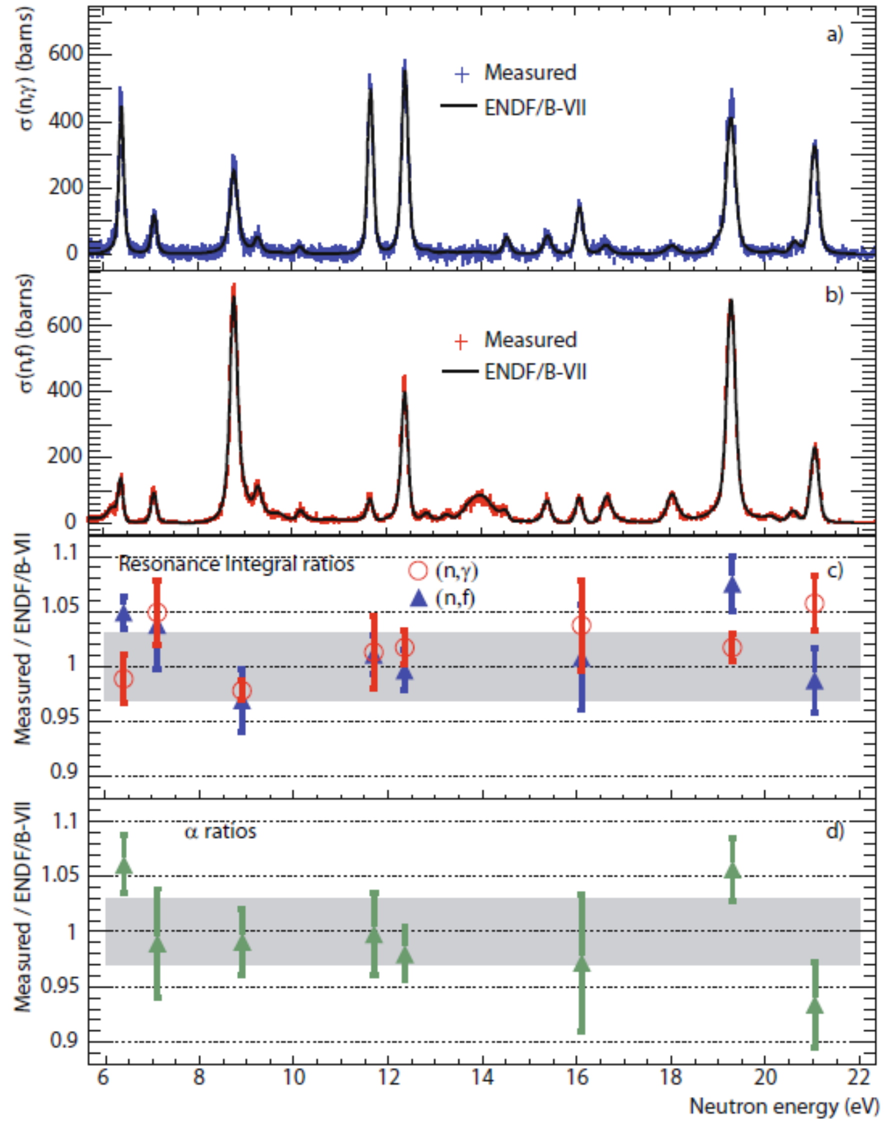
Used C_6D_6 and TAC to minimize systematic uncertainty related to detection effects

Overall (expected): 2-3% systematic uncertainty (depending on E_n)

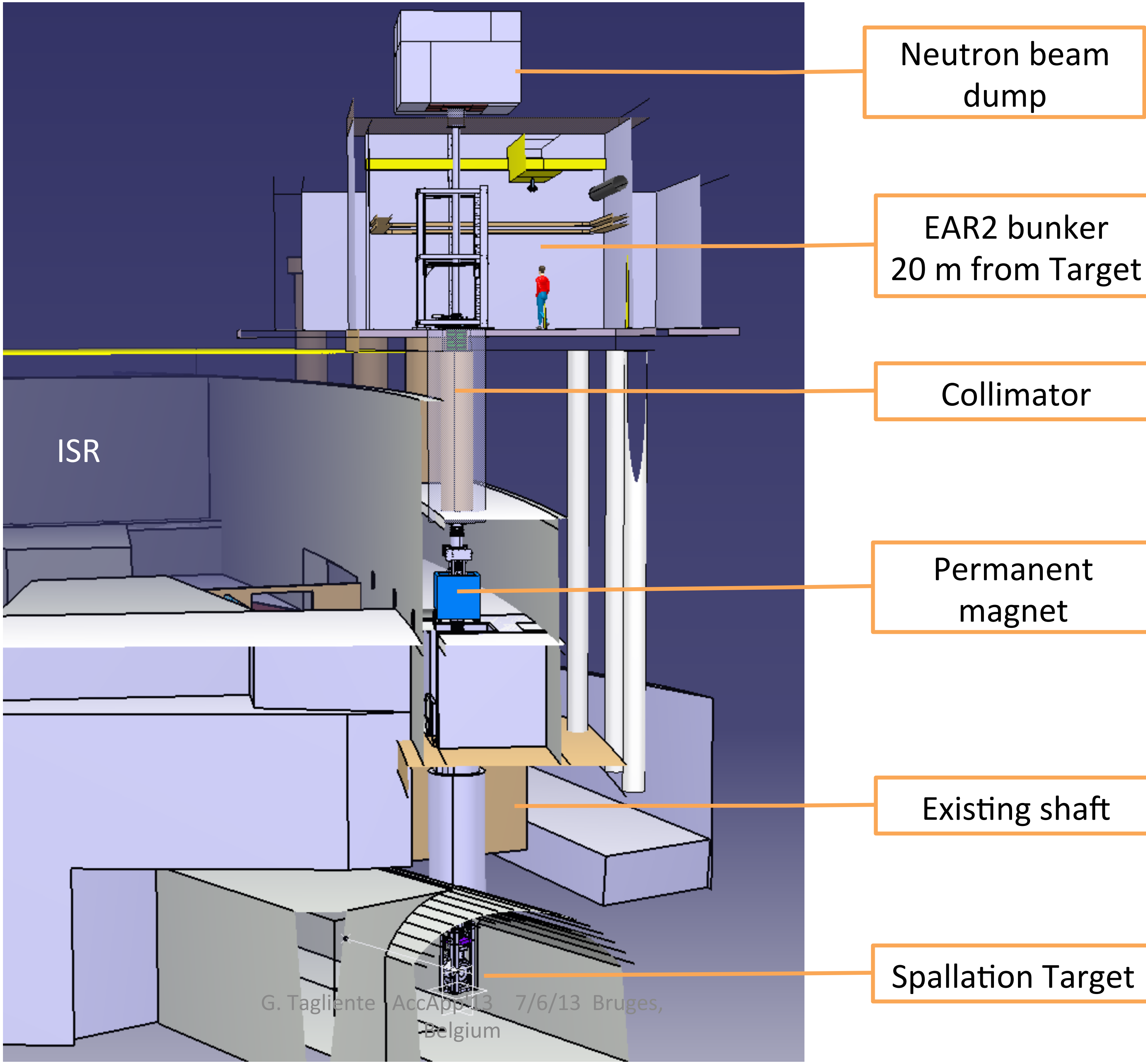
Simultaneous measurement of capture and fission cross section



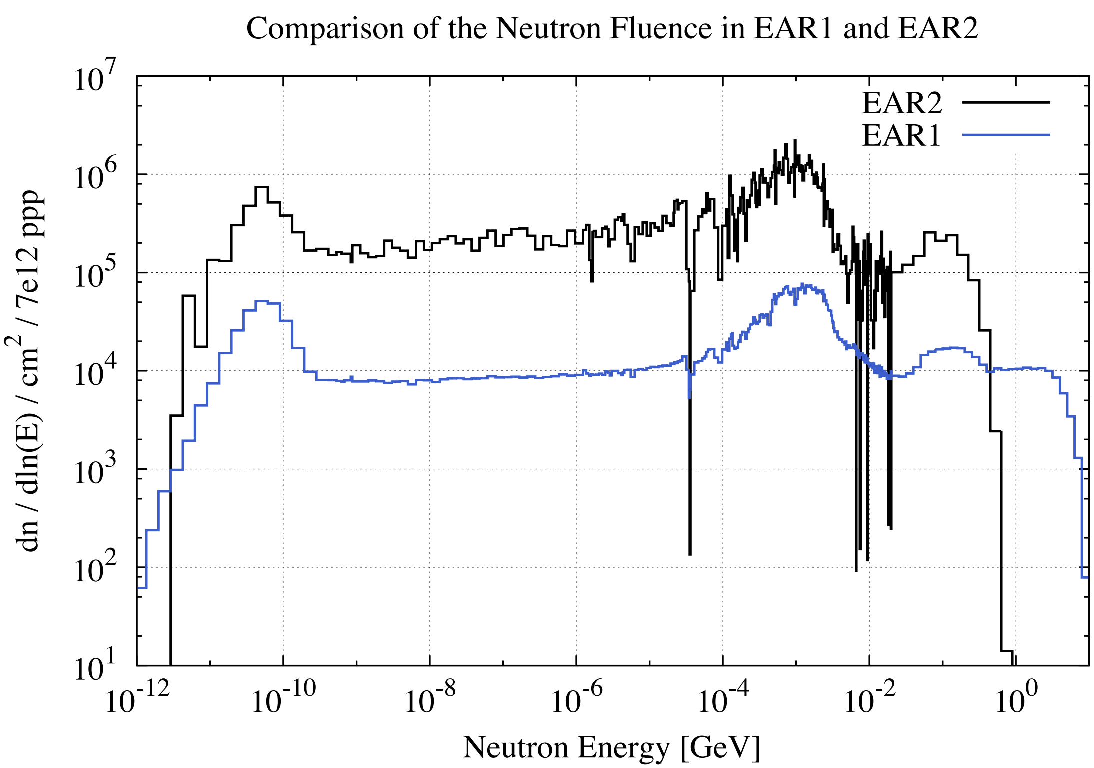




The second experimental area at n_TOF


Neutron beam dump
EAR2 bunker 20 m from Target
Collimator
ISR
Permanent magnet
Existing shaft
Spallation Target
G. Tagliente AccApp'13 7/6/13 Bruges, Belgium

Main features of EAR 2



Higher fluence, by a factor of 25, relative to EAR1.

The **shorter flight path** implies a factor of 10 smaller time-of-flight.

Global gain by a factor of **250 in the signal/background ratio** for radioactive isotopes!

The huge gain in signal-to-background ratio in EAR2 allows to measure radioactive isotopes with **half lives as low as a few years.**

The experimental program in EAR2

The EAR2 will allow to:

- measure samples of **very small mass (<1 mg)**
- measure **short-lived radioisotopes** (down to a few years)
- collect data on a much **shorter time scale**
- **measure (n,charged particle)** reactions with **thin samples**

Letter of intent for measurements in EAR2:

- **(n,p)** and **(n,α)** cross sections on **^{7}Be, ^{25}Mg, ^{26}Al**
- **Fission** cross sections of the **short lived actinides ^{232}U, ^{238,241}Pu and ^{244}Cm**
- **Capture** cross section of **^{79}Se, ^{245}Cm**
- Cross section and angular distribution of fragments from **^{232}U(n,f)**

Status of the EAR2:

- **Approved by CERN,** final design phase
- **Start construction** in May 2013
- **Beam ready** in mid-2014
- **Physics start** in 2015

Conclusions

- There is need of **accurate new data** on neutron cross-section both for **astrophysics and advanced nuclear technology.**
- Since 2001, **n_TOF@CERN** has provided an important contribution to the field, with an intense activity on **capture and fission measurements**.
- Several results of interest for **stellar nucleosynthesis** (Sm, Os, Zr, Ni, Fe, etc…).
- Important data on actinides, of interest for **nuclear waste transmutation.**
- To date, high resolution measurements performed in **EAR1** in optimal conditions (borated water moderator, Class-A experimental area, etc…).
- A second **experimental area at 20 m** for high flux measurements is in construction.
- The EAR2 (starting in 2015) will open **new perspectives** for frontier measurements on short-lived radionuclides.

Thank you