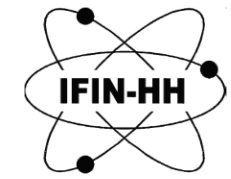


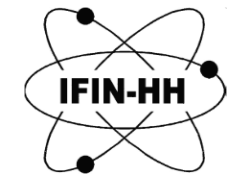
# **Neutron Inelastic cross section measurements** **of importance for new reactor concepts**

A collaboration between IPHC, Strasbourg and IFIN-HH, Bucharest

**A. Negret & Ph. Dessagne**



**Introduction:**  
**The collaboration between IPHC, Strasbourg and IFIN-HH**



## Short history of the last-decade collaboration between IPHC, Strasbourg and IFIN-HH

- 2008 – 2010 PICS (Projet International de Cooperation Scientifique) *In the frame of new reactor concepts, measurements of the  $(n,xng)$  cross sections on actinides.*
- 2008 – *today* One collaboration item within the IN2P3 – IFIN-HH Collaboration Agreement.

### FRENCH TEAM

Philippe Dessagne

Maelle Kerveno

Gregoire Henning

Eliot Party (PhD student 2016 - 2019)

Jean Claude Thiry (PhD student and postdoc 2007 - 2011)

Antoine Bacquias (postdoc 2011 - 2014)

### ROMANIAN TEAM

Alexandru Negret

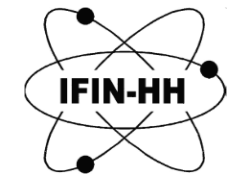
Catalin Borcea

Adina Olacel (PhD, then postdoc 2012 - today)

Marian Boromiza (PhD student 2014 - today)

Dana Deleanu (PhD student 2009 - 2013)

- The scientific activity is concentrated on measuring neutron inelastic cross sections of importance for the development of the next generation of nuclear reactors. Three experimental setups have been exploited:
  - The GRAPhEME setup at GELINA, JRC-Geel, Belgium
  - The GAINS setup at GELINA, JRC-Geel, Belgium
  - The gamma arrays available at the Tandem Accelerator of IFIN-HH.
- The two institutes have a coordinated participation to several FP7 projects:
  - ANDES (2010-2013)
  - ERINDA (2011-2013)
  - CHANDA (2013-2018)



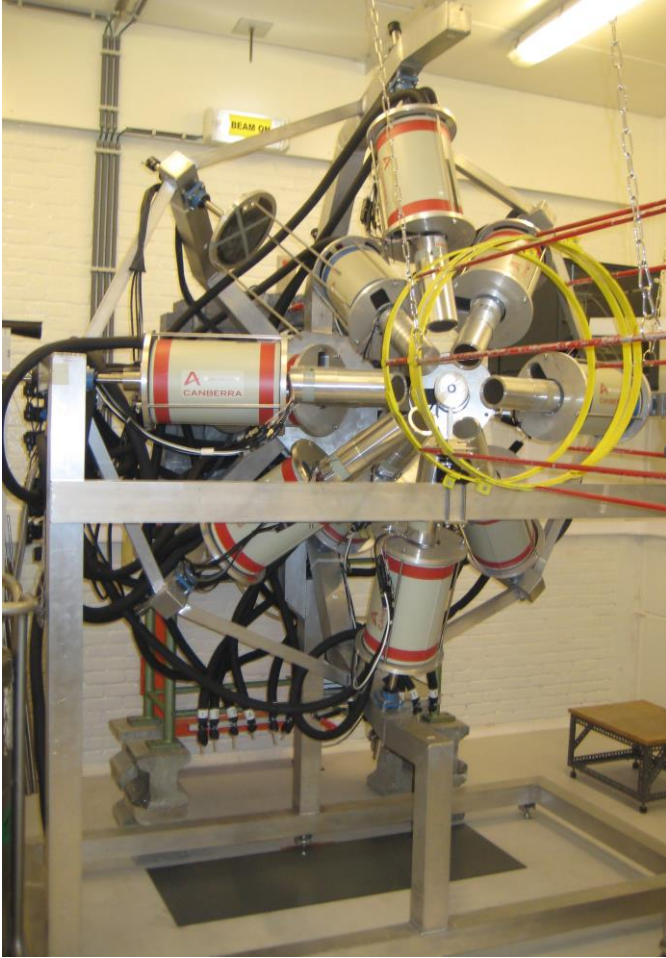
**Experiments**  
**performed at the neutron source GELINA of JRC-Geel**



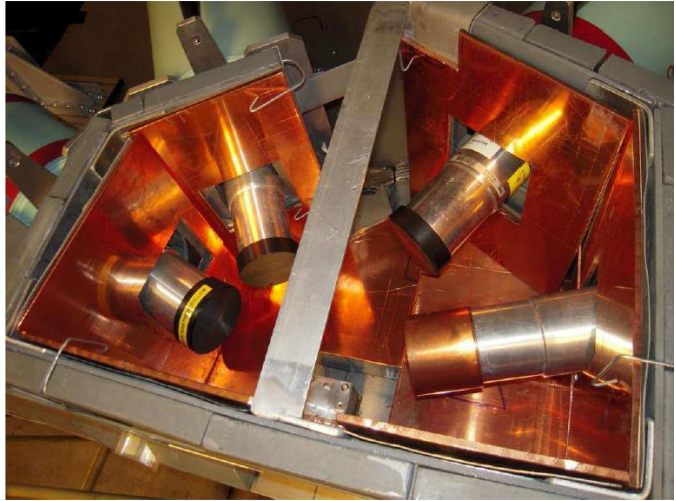
# Measurements at GELINA – experimental setup



GELINA  
Geel Linear Accelerator



GAINS  
Gamma Array for Inelastic  
Neutron Scattering



GRAPHEME  
GeRmanium array for Actinides  
PrEcise MEasurements



## Measurements at GELINA – the technique



**GAINS**

**GRAPhEME**

- Neutron source: GELINA  
(white flux 100 keV – 20 MeV), operated  
by EC-JRC-Geel, Belgium
  
- TOF technique (200 m flight path):  
Amplitude  $\Leftrightarrow$  gamma energy  
Time  $\Leftrightarrow$  neutron energy



## Measurements at GELINA – experimental setups



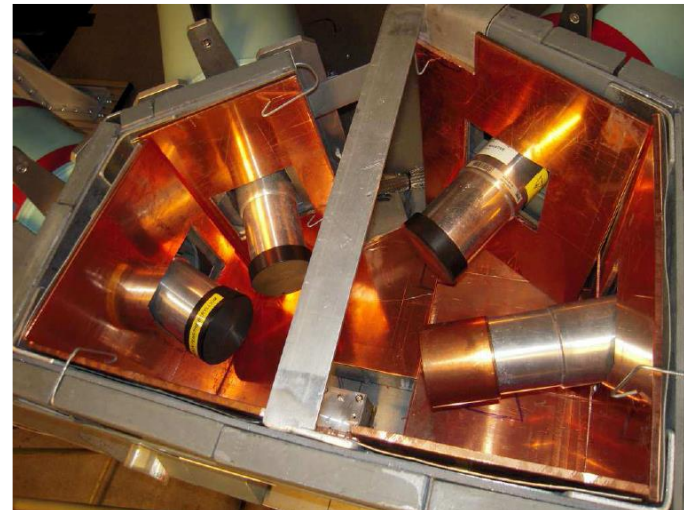
**GAINS**

FP3 – 200 m of GELINA

Mainly used to measure inelastic cross section for structural materials:

$^{206,208}\text{Pb}$ ,  $^{56,57}\text{Fe}$ ,  $^{28}\text{Si}$ ,  $^{24}\text{Mg}$ ,  $^{12}\text{C}$ ,  $^{16}\text{O}$ ,  $^{\text{nat}}\text{Ti}$ ,  $^{23}\text{Na}$ ,  $^{76}\text{Ge}$

- Array of 12 HPGe detectors ( $\epsilon=100\%$ )
- Beam monitoring:  $^{235}\text{U}$  Fission chamber



**GRAPhEME**

FP16 – 30 m of GELINA

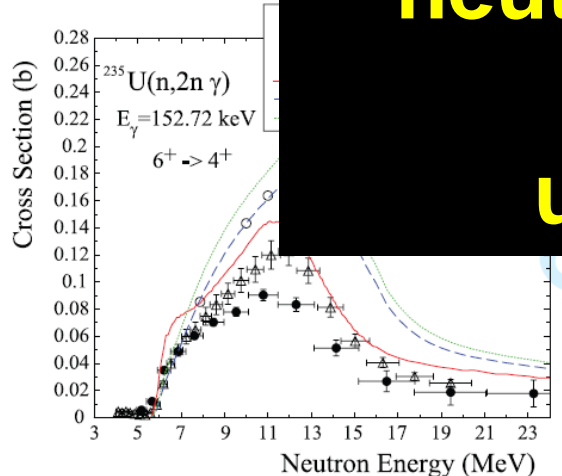
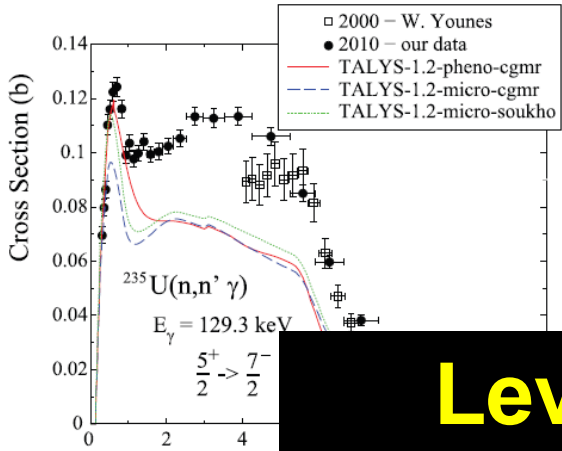
Mainly used to measure inelastic cross section for actinides:

$^{233, 235, 238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{182,183,184,186}\text{W}$ ,  $^{\text{nat}}\text{Zr}$

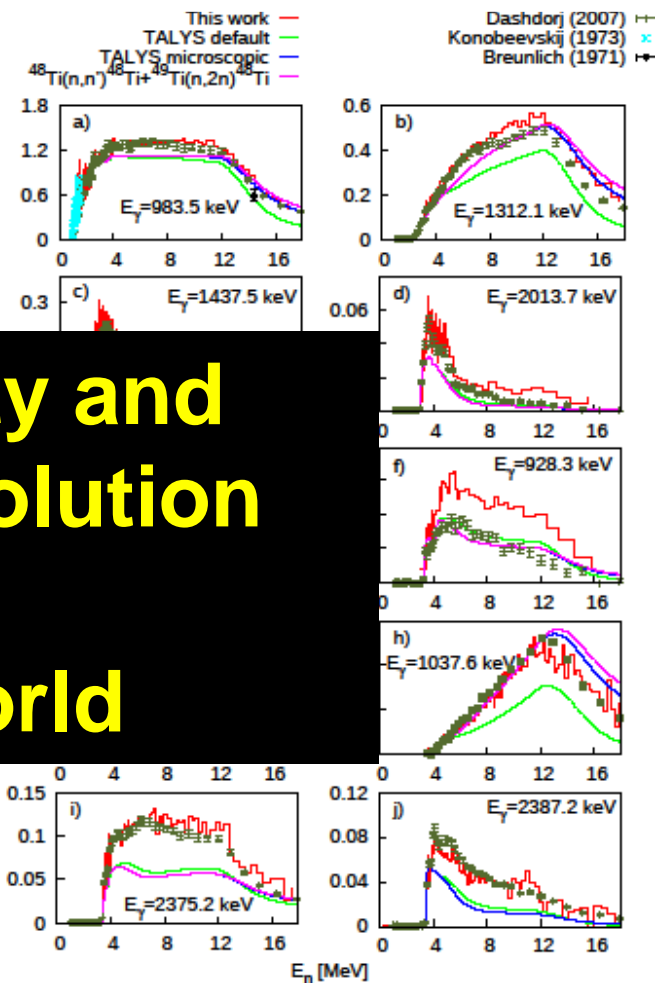
- 5 planar + 1 segmented HPGe detector,
- Heavy shielding both against EM and  $\gamma$  background,
- Beam monitoring:  $^{235}\text{U}$  Fission chamber



# Measurements using GAINS and GRAPHEME - results



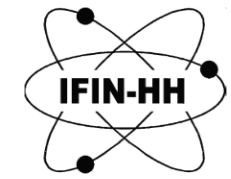
**Level of uncertainty and neutron energy resolution - unique in the world**



$\gamma$ -production cross sections in  $^{235}\text{U}(n, x n \gamma)$

$\gamma$ -production cross sections in  $^{48}\text{Ti}(n, n' \gamma)^{48}\text{Ti}$





**Experiments**  
**performed at the Tandem accelerator of IFIN-HH, Bucharest**

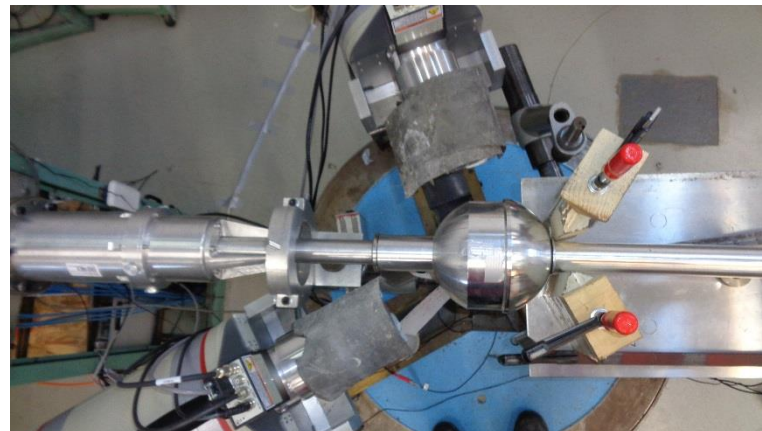


# Measurements at the Tandem accelerator of IFIN-HH – experimental setup

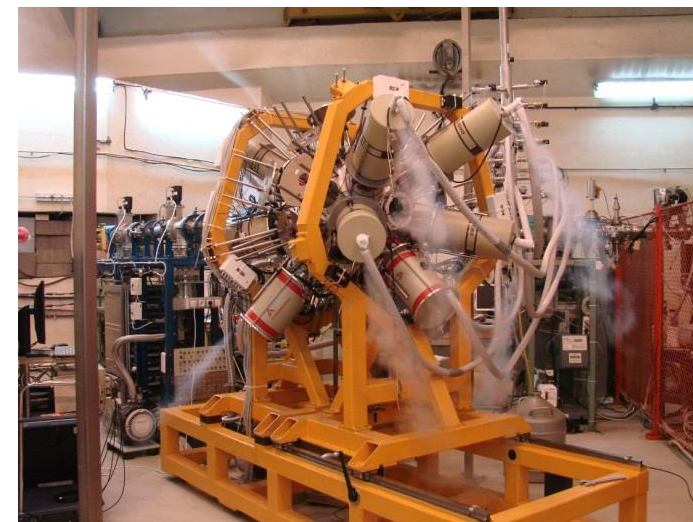


**The 9 MV Tandem Accelerator**

**Detection system:**  
from a simple configuration with 2 detectors...

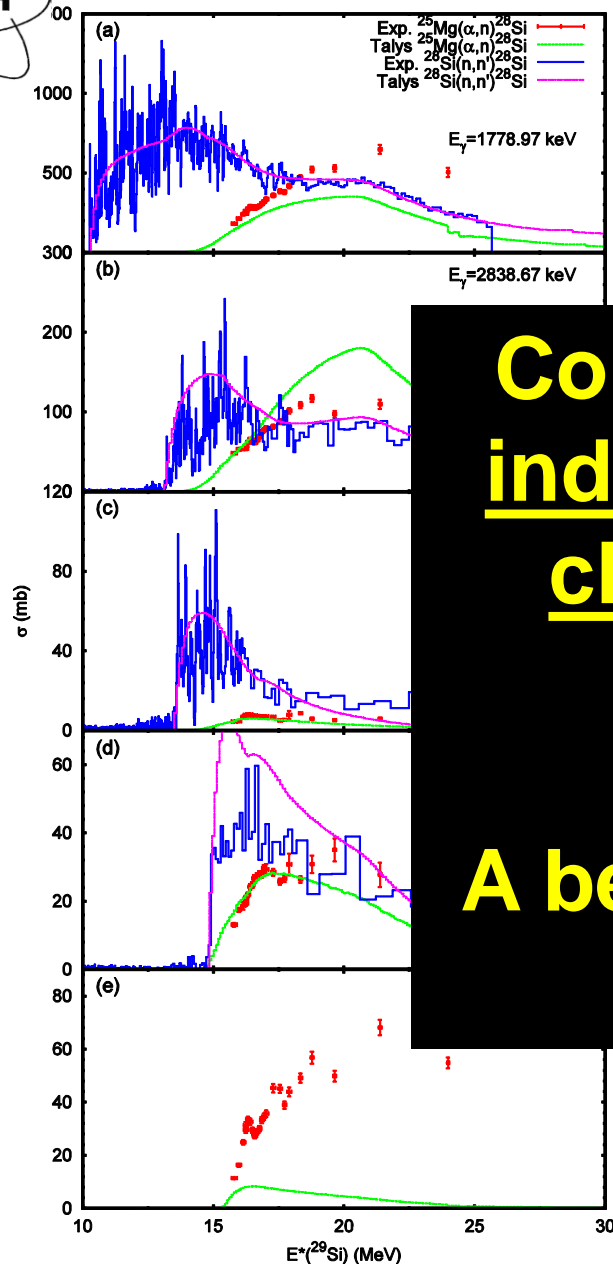


... to ROSPHERE





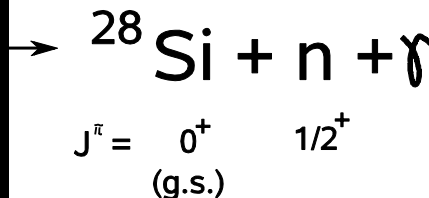
# Measurements at the Tandem accelerator of IFIN-HH - results



$$J^\pi = 0^+ \quad 1/2^+$$

**Comparison of the neutron-induced cross sections with charged-particle induced cross sections**

**A better understanding of the reaction mechanisms**



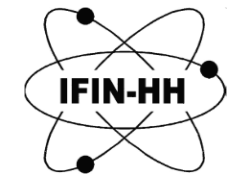
604 (2013)

neutrons on  $^{28}\text{Si}$  and comparison reaction

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 du Loess, 67037 Strasbourg, France  
 Materials and Measurements, B-2440 Geel, Belgium

(Received 29 May 2013; published 11 September 2013)

The inelastic scattering of neutrons on  $^{28}\text{Si}$  was investigated using the  $(n, n'\gamma)$  technique. The  $\gamma$  production cross sections were measured and the level and total inelastic cross sections were determined with high accuracy.  $^{28}\text{Si}$  was also excited through the  $^{25}\text{Mg}(\alpha, n\gamma)^{28}\text{Si}$  reaction and a comparison of the  $\gamma$  production cross sections determined for various incident energies was performed.



## Conclusions



## Conclusions: a very productive collaboration

A. Negret, L.C. Mihailescu, C. Borcea, Ph. Dessagne, K.H. Guber, M. Kerveno, A.J. Koning, A. Olacel, A.J.M. Plompen, C. Rouki, G. Rudolf

*Cross section measurements for neutron inelastic scattering and the  $(n, 2ng)$  reaction on  $^{206}\text{Pb}$*

**Phys. Rev. C91, 064618 (2015)**

M. Kerveno, A. Bacquias, C. Borcea, Ph. Dessagne, G. Henning, L.C. Mihailescu, A. Negret, M. Nyman, A. Olacel, A.J.M. Plompen, C. Rouki, G. Rudolf, J.C. Thiry

*From  $\gamma$ -emissions to  $(n, xn)$  cross sections of interest: the role of GAINS and GRAPHEME in nuclear reaction modelling*

**Eur. Phys. J. A51, p167 (2015)**

A. Negret, C. Borcea, Ph. Dessagne, M. Kerveno, A. Olacel, A. J. M. Plompen, M. Stanoiu

*Cross-section measurements for the  $^{56}\text{Fe}(n, xn\gamma)$  reactions*

**Phys. Rev. C 90, 034602 (2014)**

A.Olacel, C. Borcea, P. Dessagne, M. Kerveno, A. Negret, A. J. M. Plompen

*Neutron inelastic cross-section measurements for  $^{24}\text{Mg}$*

**Phys. Rev. C 90, 034603 (2014)**

A.Negret, C. Borcea, D. Bucurescu, D. Deleanu, Ph. Dessagne, D. Filipescu, D. Ghita, T. Glodariu, M. Kerveno, N. Marginean, R. Marginean, C. Mihai, S. Pascu, A. J. M. Plompen, T. Sava, L. Stroe

*Cross sections for inelastic scattering of neutrons on  $^{28}\text{Si}$  and comparison with the  $^{25}\text{Mg}(\alpha, n)^{28}\text{Si}$  reaction*

**Phys. Rev. C88, 034604 (2013)**

A.Negret, C.Borcea, A.J.M.Plompen

*Neutron inelastic scattering measurements for background assessment in neutrinoless double beta decay experiments*

**Phys. Rev. C88, 027601 (2013)**

M.Kerveno, J.C.Thiry, A.Bacquias, C.Borcea, P.Dessagne, J.C.Drohe, S.Goriely, S.Hilaire, E.Jericha, H.Karam, A.Negret, A.Pavlik, A.J.M.Plompen, P.Romain, C.Rouki, G.Rudolf, M.Stanoiu

*Measurement of  $^{235}\text{U}(n, n'g)$  and  $^{235}\text{U}(n, 2ng)$  reaction cross sections*

**Phys. Rev. C87, 024609 (2013)**

Can LIA supplement the continuously decreasing support we got over the years from the IN2P3 –  
IFIN-HH Collaboration Agreement?