EU nuclear data projects for more sustainable nuclear energy and waste transmutation

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Final Scientific EFNUDAT Workshop

CERN, Geneva (Switzerland)

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INTRODUCTION

EU efforts to improve long term sustainability of energy generation:

SET Plan (Strategic Energy Technologies) : Technological Platforms + EII

For Nuclear Energy: SNETP + ESNII (Fast systems: GEN-IV and ADS)

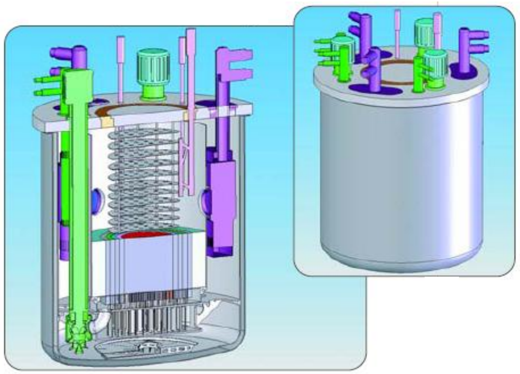
Sustainability:

- Security of supply
- Economical competitivity
- Maximize resource utilization : U+Pu multi-recycling in Fast reactors
- Minimize long lived nuclear waste: U, Pu and M.A. Transmutation

Technologies schedules:

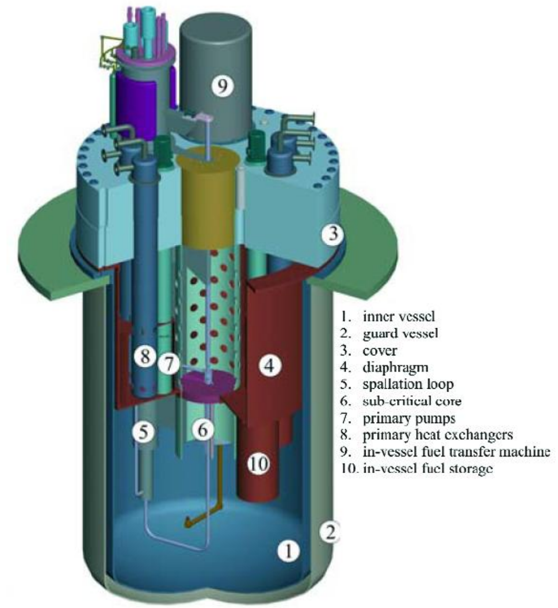
- LWR of Gen II (with Life extension) , Gen III & Gen III+ as long as there is available and cheap enriched Uranium
- Closing the cycle to limit waste production: Partition &Transmutation (middle to end of XXI century)
- Breeding Pu from U in fast reactors when enriched Uranium becomes expensive (middle to end of XXI century)

Fast Reactors for Gen IV and ADS systems for transmutation

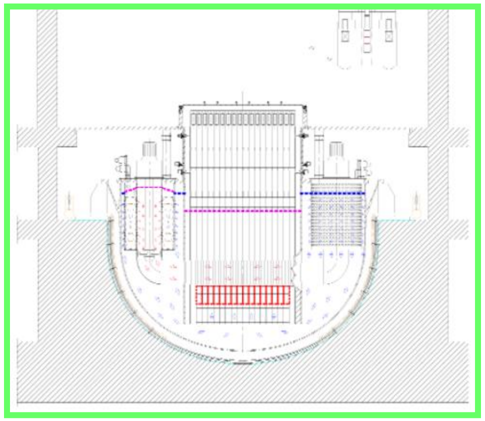


Sodium: ASTRID
7FP EU **CP-ESFR**

Gas: ALLEGRO
6 y 7FP EU **ALLEGRO, GoFastR**



ADS: MYRRHA/XT-ADS
6 y 7FP EU **EUROTRANS, CDt, FREYA**



LEAD: ELSY
7FP EU **7PM EURATOM LEADER, CDT, HeLiMnet**

Fast Reactors & ADS:
- Cooled by Sodium, Lead (alloys) or Gas (He)
- Coupling to Accelerator for ADS

Fuels:
- High Pu content
- High M.A. content
- Low U and inert matrices proposed for transmutation

Multiple Recycling:
- Evolution of HLW isotopic content
- Buildup of high mass Minor Actinides

INTRODUCTION

T o study these systems, today, high precision simulation is often cheaper and faster than the actual experiments, and normally provides much more details of the process – But it needs accurate basic (nuclear) data and always needs some experimental validation of its absolute accuracy.

The important role of simulation and basic data is in the Strategic Research Agenda of SNETP.

New problems,

New concepts,

New materials and/or

New procedures

will need efforts in nuclear data and dedicated experimental validation.

… but What data is really needed/directly useful for applications?

Steps to identify data needs

- All technologies can profit from better data:
  Gen II, Gen III(+), Gen IV and P&T
- Industrial, Exp. Reactors and Fuel Cycle
- **Identify relevant parameters and target precision** and priorities on those parameters

End Users Group
Designers, Builders and Utilities.
Strategic choices.
Simulation tools
Internat. Coop/ NEA / IAEA

- Identify present uncetainties
- **Identify relevant basic data**:
  Isotopes, reactions, energy range

Uncertainty evaluation
(M.C., Linear Deriv.)
Sensitivity analysis

Required precision for the data
Priorities for different data

Estimate Experimental feasibility and timely availability of experim. facilities

Global optimization and **evaluation of required measurements / evaluations and needed accuracies**

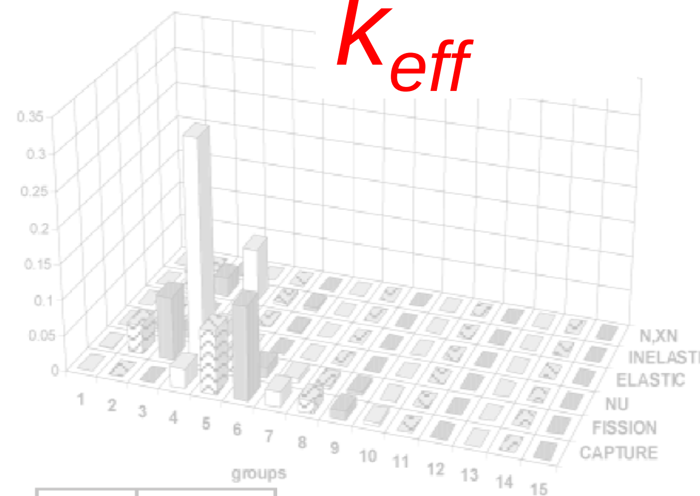
Need for complete and reliable uncertainties and correlations.

Coordinate needs from different technologies/fuel cycle
Reevaluation of priorities and accuracies

Sensitivity analysis – ADS for Transmutation

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	$\sigma_{n,2n}$	Total[a]
^{238}Pu	0.01	0.11	0.02	—	—	—	0.11
^{239}Pu	0.04	0.51	0.11	—	0.04	—	0.53
^{240}Pu	0.05	0.18	0.05	—	0.02	—	0.19
^{241}Pu	0.04	0.30	0.03	—	0.01	—	0.31
^{242}Pu	0.01	0.05	0.02	—	0.01	—	0.06
^{237}Np	0.24	0.70	0.21	—	0.14	—	0.78
^{241}Am	1.32	1.12	0.38	—	0.22	—	1.79
^{242m}Am	0.01	0.09	0.03	—	0.01	—	0.10
^{243}Am	0.74	0.59	0.21	—	0.60	—	1.14
^{242}Cm	—	—	—	—	—	—	—
^{243}Cm	—	0.05	0.01	—	—	—	0.05
^{244}Cm	0.13	1.09	0.18	—	0.07	—	1.11
^{245}Cm	0.01	0.41	0.08	—	0.01	—	0.42
^{246}Cm	—	—	—	—		—	—
^{56}Fe	0.03	—	—	0.05	0.49	—	0.50
^{57}Fe	—	—	—	—	0.06	—	0.06
^{52}Cr	0.01	—	—	0.01	0.03	—	0.03
^{58}Ni	—	—	—	—		—	—
Zr	0.03	—	—	0.03	0.07	—	0.09
^{15}N	—	—	—	0.19	0.01	—	0.19
Pb	0.02	—	—	0.10	0.41	0.02	0.43
Bi	0.04	—	—	0.11	0.49	0.03	0.50
Total[a]	1.54	1.97	0.54	0.25	1.05	0.04	2.77

k_{eff}



Group	(MeV)[a]
1	19.6
2	6.07
3	2.23
4	1.35
5	4.98e−1[c]
6	1.83e−1
7	6.74e−2
8	2.48e−2
9	9.12e−3
10	2.04e−3
11	4.54e−4
12	2.26e−5
13	4.00e−6
14	5.40e−7
15	1.00e−7

a) Upper limit of the group

NEA/WPEC-26.

One possible optimization for target accuracy for innovative systems using recent covariance data evaluations (BOLNA).
 M. Salvatores and R. Jacqmin (Eds), NEA/WPEC-26.
ISBN 978-92-64-99053-1

Similar tables for each present or proposed future reactor

Still serious dependence on the reactor and fuel models and on the transmutation model (homogeneous) can slightly modify the target accuracy and details on the priority order

Table 30. ADMAB: uncertainty reduction requirements needed to meet integral parameter target accuracies

Isotope	Cross-Section	Energy range	Uncertainty (%) Initial	Required λ=1	Required λ≠1 [a]
Pu238	σ_{fiss}	6.07 - 0.498 MeV	20	3	3
	ν	1.35 - 0. 183 MeV	7	3	3
Pu239	σ_{capt}	498 - 2.03 keV	12	4	3
	σ_{inel}	6.07 - 0.498 MeV	25	5	6
Pu240	σ_{capt}	183 - 67.4 keV	14	6	6
	σ_{fiss}	2.23 - 0.498 MeV	6	2	2
	ν	1.35 - 0.498 MeV	4	2	2
Pu241	σ_{capt}	1.35 - 0. 183 MeV	20	7	7
	σ_{fiss}	6.07 MeV-22.6 eV	15	2	2
Pu242	σ_{capt}	24.8 - 9.12 keV	35	10	10
	σ_{fiss}	6.07 - 0.498 MeV	20	4	4
Np237	σ_{capt}	498 - 0.454 keV	6	3	3
	σ_{fiss}	6.07 - 0.183 MeV	8	2	2
	σ_{inel}	2.23 – 0.183 MeV	25	5	6
Am241	σ_{capt}	1.35 MeV- 0.454 keV	8	2	2
	σ_{fiss}	6.07 – 0.183 MeV	10	1	1
	ν	6.07 - 1.35 MeV	2	1	1
	σ_{inel}	6.07 – 0.183 MeV	25	4	5
Am242m	σ_{fiss}	1.35 MeV- 9.12 keV	17	5	5
Am243	σ_{capt}	1.35 MeV- 0.454 keV	10	2	2
	σ_{fiss}	6.07 - 0.498 MeV	10	2	2
	σ_{inel}	6.07 MeV- 24.8 keV	40	2	3
Cm242	σ_{fiss}	6.07 MeV- 67.4 keV	55	26	26
Cm243	σ_{fiss}	1.35 MeV- 67.4 keV	50	8	8
Cm244	σ_{capt}	498 -9.12 keV	20	6	6
	σ_{fiss}	6.07 MeV- 67.4 keV	45	2	2
	ν	6.07 – 0.183 MeV	10	1	1
Cm245	σ_{fiss}	6.07 MeV- 0.454 keV	45	3	3
Fe56	σ_{capt}	183 - 0.454 keV	12	5	3
	σ_{inel}	6.07 - 0.498 MeV	20	2	2
Zr90	σ_{inel}	6.07 - 2.23 MeV	18	3	4
N15	σ_{el}	2.23 MeV - 67.4 keV	5	1	1
Pb	σ_{capt}	9.12 - 2.03 keV	20	20	14
	σ_{inel}	6.07 - 2.23 MeV	12	3	4
Bi209	σ_{inel}	2.23 - 0.498 MeV	34	3	3

[a] See Table 24 for λ ≠ 1, case A

Important isotopes for Transmutation Fuel Cycles: The multi-recycling point of view

Report of the Numerical results from the Evaluation of the nuclear data sensitivities, Priority list and table of required accuracies for nuclear data. E. Gonzalez-Romero (Ed), NUDATRA Deliverable D5.11 from IP-Eurotrans

Isotopes	Uncertainty in the abundance %			Important for:			
	Burnup (GWd/t)						
	150	500	800				
^{234}U	4.6	16.1	32.4	T	DH		
^{235}U	13.1	18.4	15.5	T			
^{236}U	1.8	7.6	12.6	T			
^{237}Np	6.3	23.7	28.1	T			
^{238}Pu	4.3	10.8	19.3	T	DH		R
^{239}Pu	4.6	12.9	17.8	T	DH		R
^{240}Pu	2.0	7.0	14.4	T	DH		R
^{241}Pu	8.2	14.7	17.0	T			
^{242}Pu	2.1	7.9	16.2	T	DH		R
^{241}Am	7.2	20.7	26.0	T	DH		R
^{242m}Am	12.8	28.6	34.4	T			
^{243}Am	6.6	15.6	20.2	T	DH		R
^{242}Cm	10.7	7.7	15.6	T	DH		
^{243}Cm	23.3	32.6	35.7				
^{244}Cm	6.0	13.3	19.1	T	DH	N	R
^{245}Cm	13.3	18.8	16.3	T	DH		R
^{246}Cm	7.5	21.7	31.5	T	DH	N	R
^{247}Cm	15.4	27.2	31.6	T			
^{248}Cm	6.4	19.8	31.4			N	
^{250}Cf	31.9	28.9	36.9			N	
^{252}Cf	52.4	46.1	48.9			N	

T= Transmutation efficiency
DH= Decay Heat load
N = Neutron emission
R = Radiotoxicity

The research on Nuclear Data has received a broad attention in the EURATOM FP6/FP7 with following initiatives:

- **NUDATRA (DM5 of IP-EUROTRANS)**

  Improving nuclear data and simulation tools for transmutation
  Experimental measurements and theoretical developments

- **NUDAME**

  Access to IRMM Geel facilities to perform nuclear data measurements

- **EFNUDAT**

  Access to several EU facilities to perform nuclear data measurements
  Research to improve the nuclear data facilities and simulation tools

- **CANDIDE**

  C. A. on Nuclear Data for Industrial Development in Europe.
  Networking plus Road Map of data needs and paths to produce it.

- **EUFRAT (FP7)**

  Access IRMM European facility for innovative reactor and transmut. n data

- **ANDES (FP7)**

  Accurate Nuclear Data for nuclear Energy Sustainability

- **ERINDA (FP7 proposal)**

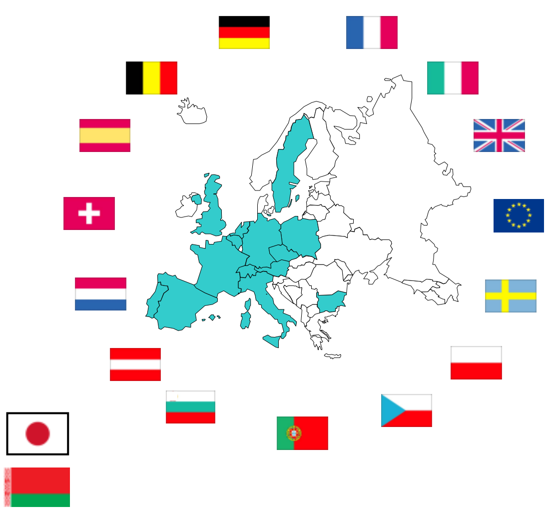
  Access European Research Infrastructures for Nuclear Data Applications

EUROTRANS/DM5: NUDATRA

(Nuclear DAta for TRAnsmutation)

General objective:

Improve nuclear data evaluated files and models which involves sensitivity analysis and validation of simulation tools, low and intermediate energy nuclear data measurements, nuclear data libraries evaluation at low and medium energies, and high energy experiments and modelling.



Participants: 13 Research Centers + 9 Universities

CEA (France), CIEMAT (Spain), CNRS (France), CSIC (Spain), FZJ (Germany), FZK (Germany), GSI (Germany), INFN (Italy), INRNE (Bulgaria), NRG (Netherlands), PSI (Switzerland), SCK-CEN (Belgium), JRC-Geel (EC)

Universities: AGH (Poland),TUW (Austria), KTH (Sweden), ULG (Belgium), UNED (Spain), USDC (Spain), USE (Spain), UU (Sweden), ZSR (Germany).

Publications: >35 Journal papers, >70 Conference contributions 7 PhD Thesis, 2 Master Thesis,

NUDATRA specific priorities

were adapted to the nuclear data needs for Advance fuel cycles with Nuclear waste transmutation and the use of ADS as actinide transmuters:

- **Sensitivity analysis of ETD advanced fuel cycles (and data needs)**
- **Pb-Bi cross sections: inelastic, (n,xn), (n, n+X), Po production (B.R.)**
- **Minor Actinide cross sections: Capture in ^{243}Am + Fission on ^{244}Cm**
- **TALYS improvements for M.A., Pb/Bi: Low Energy models and evaluation.**
- **High energy measurements: Gas (He) and Light Charged Particles production, Absolute Spallation product x-section**
- **High energy models improvement (INCL & ABLA)**
- **New transmutation simulation systems (models, validation, uncertainties)**

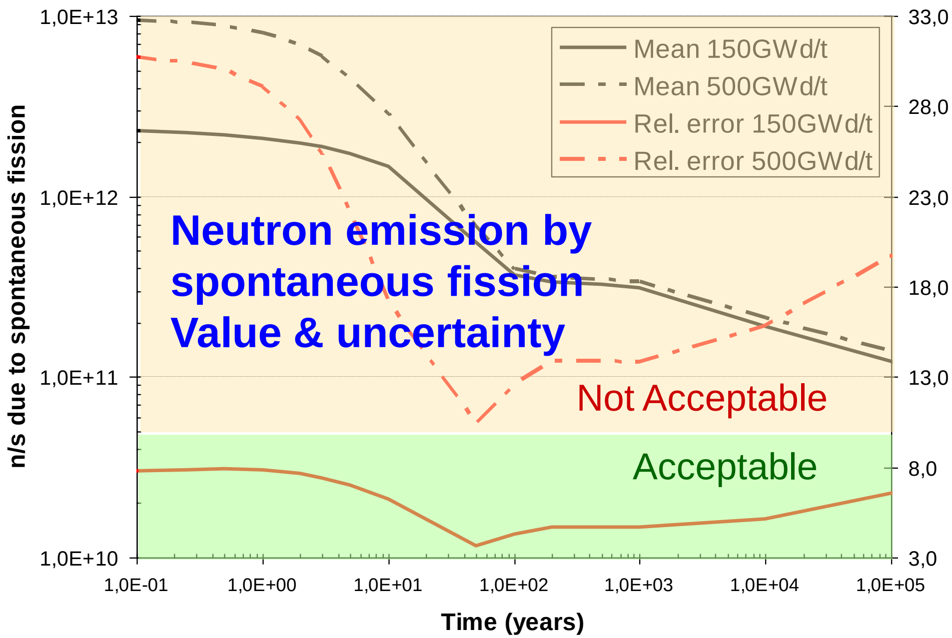
Transmutation Fuel cycle Sensitivity analysis (multi-recycling)

NUDATRA

Uncertainties
MC & Diff. Sensitivity,
Uncertaint. libr., Correlations effects.
Long burn-up consequences.
Critical isotopes & reactions
Optimization & required accuracies

Fuel cycle parameters:
Decay heat: 2, 10, 200 yr
Neutron emission: 2 yr
Radiotoxicity: 10, 100, 10000,yr …

New transmutation simulation systems and benchmarks.



31 critical cross sections (causing an uncertainty beyond the design target accuracies) in the fuel cycle parameters (Double Strata using ETD-like ADS)

U234	(n,γ)	CM242	(n,γ)
U234	(n,γ-M)	CM243	(n,fission)
U235	(n,fission)	CM243	(n,γ)
NP237	(n,γ)	CM244	(n,γ)
PU238	(n,fission)	CM245	(n,fission)
PU238	(n,γ)	CM245	(n,γ)
PU239	(n,fission)	CM246	(n,γ)
PU240	(n,γ)	CM247	(n,fission)
PU241	(n,fission)	CM247	(n,γ)
PU242	(n,γ)	CM248	(n,γ)
AM241	(n,γ)	BK249	(n,γ)
AM241	(n,γ-M)	CF249	(n,γ)
AM242M	(n,fission)	CF250	(n,fission)
AM242M	(n,γ)	CF250	(n,γ)
AM243	(n,γ-M)	CF251	(n,fission)
		CF251	(n,γ)

Pb-Bi cross sections: Measurements

NUDATRA

Very large improvement

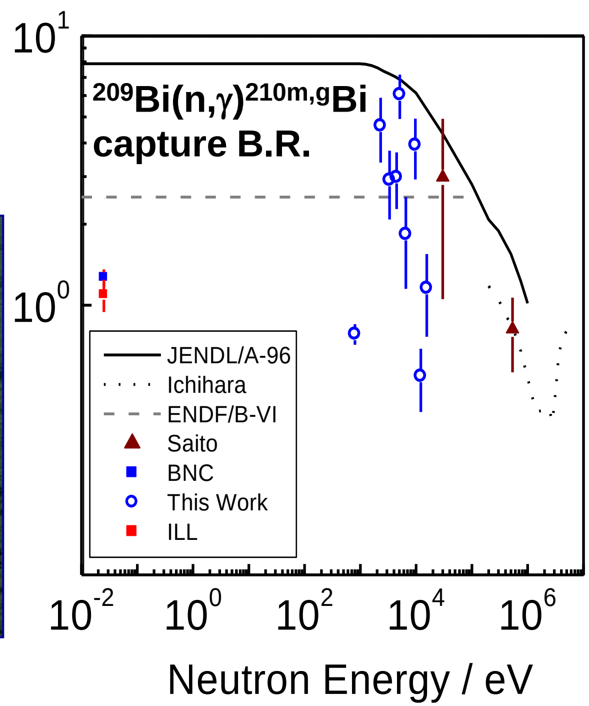
Inelastic: $^{206,\,207,\,208}$Pb and ^{209}Bi

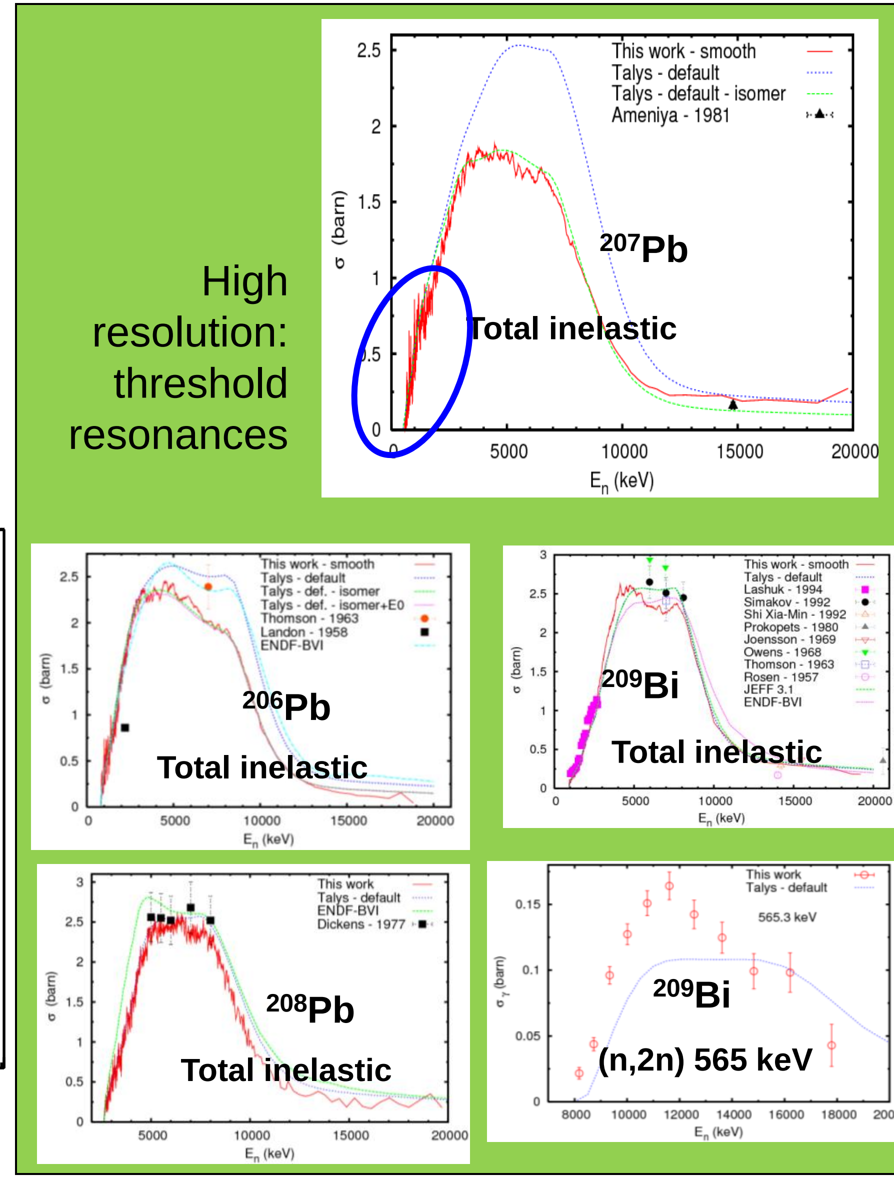
(n,xn): $^{206,\,207,\,208}$Pb(n,2nγ), ^{208}Pb(n,3nγ), ^{209}Bi(n,2nγ)

(n,n X): Pb (n,n'X) at 100 MeV

Po product.: ^{209}Bi(n,γ)^{210m,g}Bi capture B.R.

EU-JRC
IRMM Geel

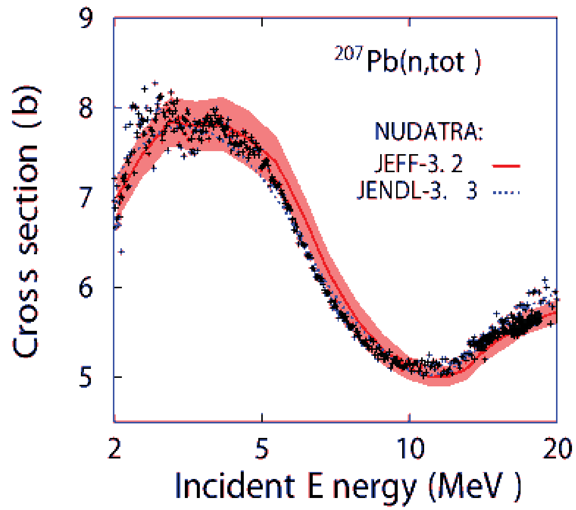


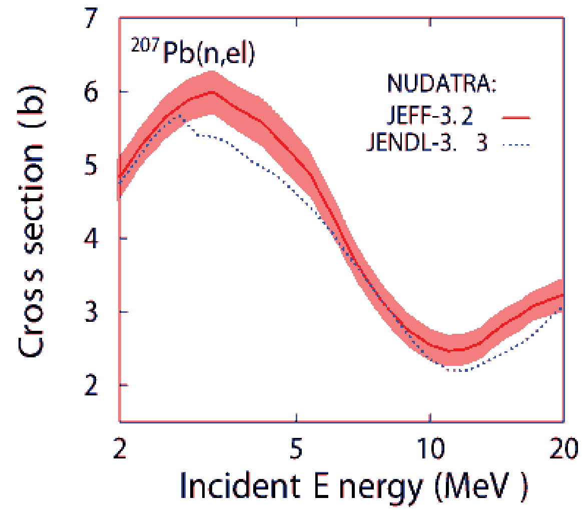


Pb-Bi cross sections: Evaluation (+ using TALYS)

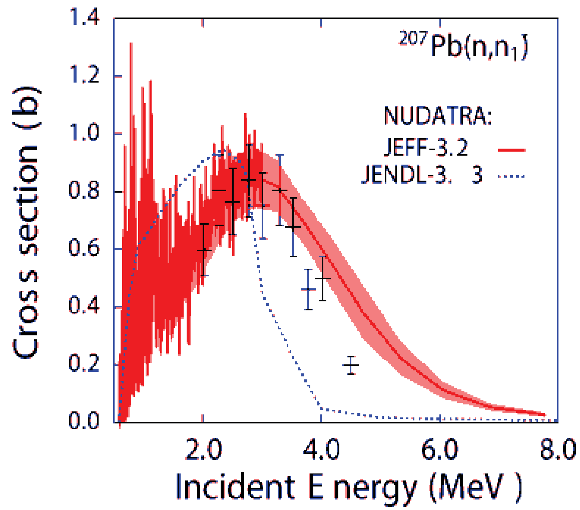
Complete data cycle:

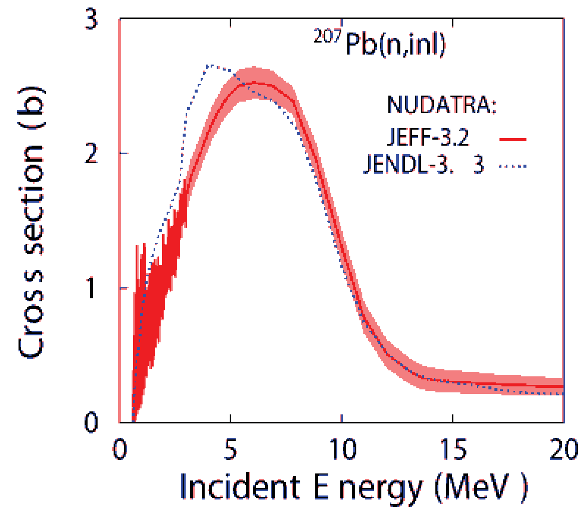
- Measurements,
- evaluation,
- dissemination to data libraries JEFF3.2 and
- validation with criticality benchmarks.





^{207}Pb evaluated cross section and uncertainty limits (orange area)





Pb-Bi cross sections: Validation

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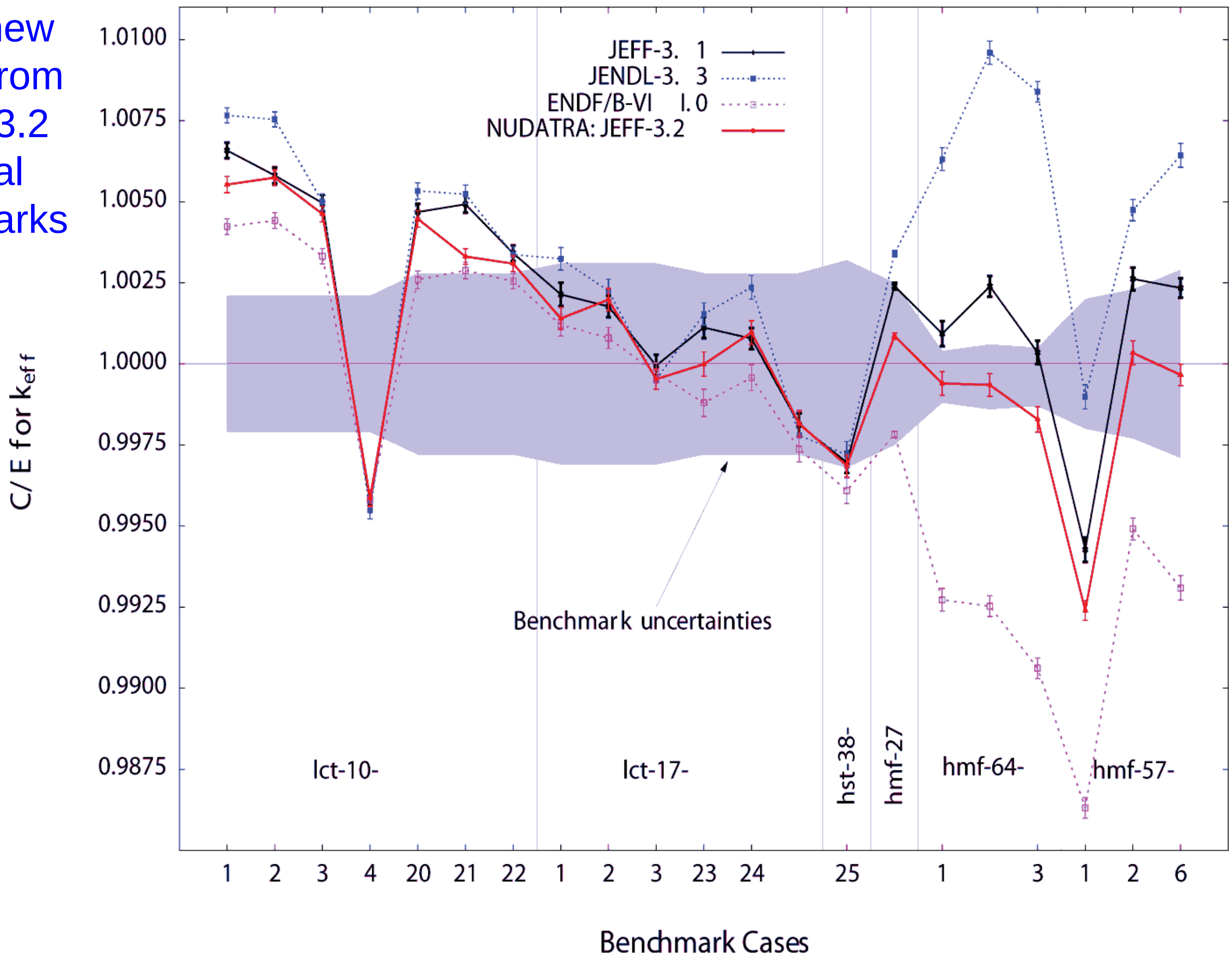
Validation of the new ^{207}Pb evaluation from NUDATRA to Jeff3.2 by the international criticality benchmarks

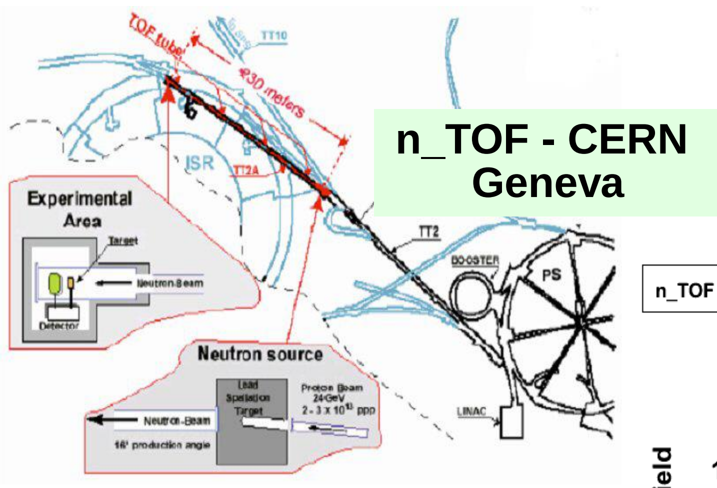


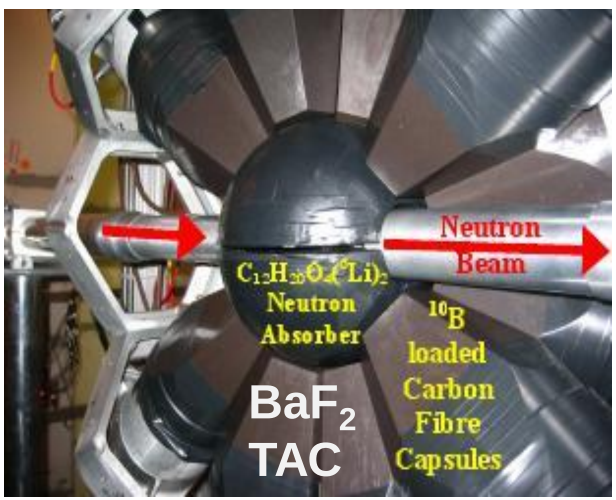
M.A. cross sections: ^{243}Am capture

^{243}Am is the door to ^{244,245,246,247}Cm production

Measurements at 2004, highly radioactive sample)

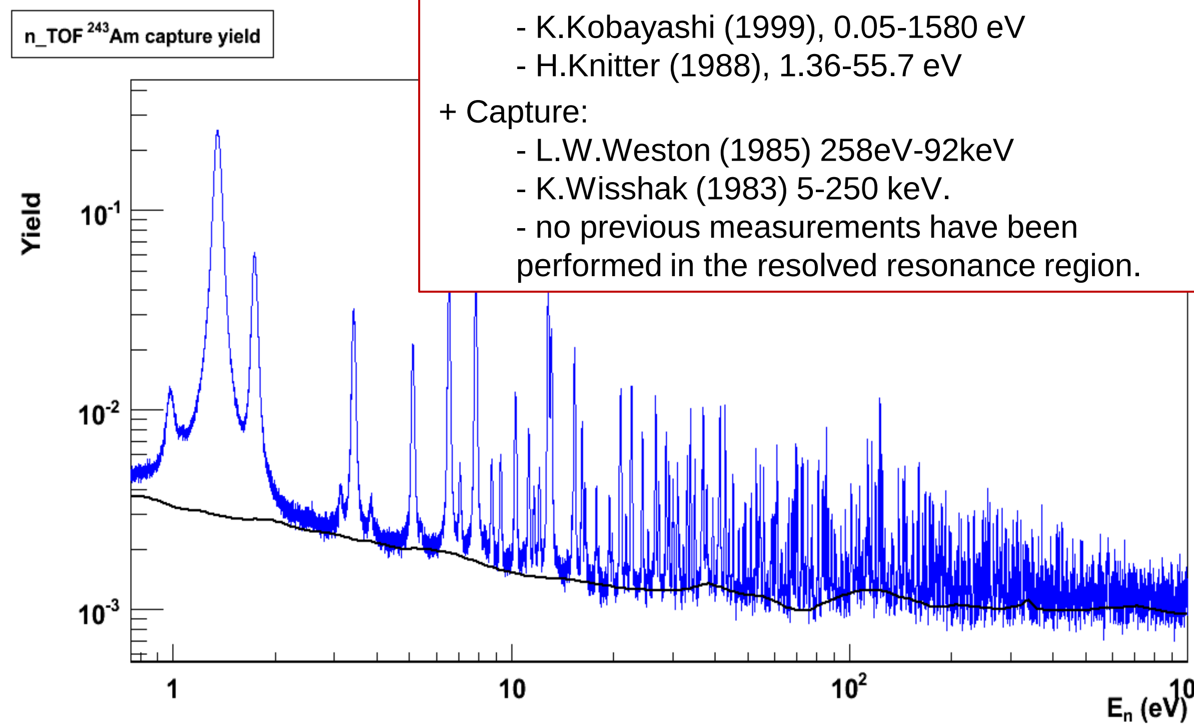
New analysis & background reduction+ mass determination at 2008-2010





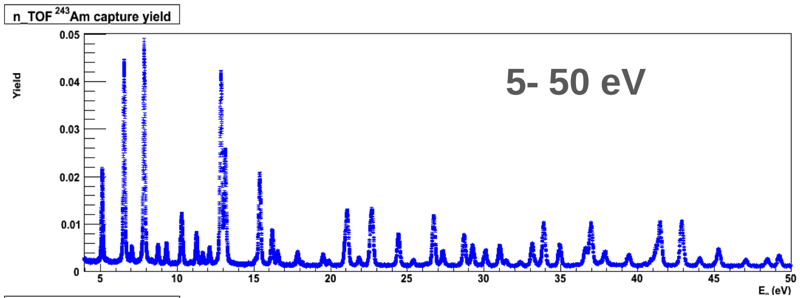
Previous experimental data

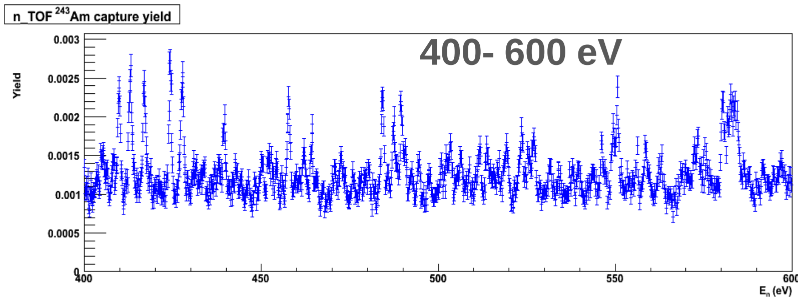
+ Transmission:
  - T.S. Bellanova (1976), 0.35-35 eV
  - *O.D. Simpson (1974), 0.5-1000 eV* (R.P.)
  - J.R. Berreth (1970), 0.008-25.6 eV
  - R.E. Cote (1959), 0.0014-15.4 eV
+ Fission:
  - K.Kobayashi (1999), 0.05-1580 eV
  - H.Knitter (1988), 1.36-55.7 eV
+ Capture:
  - L.W.Weston (1985) 258eV-92keV
  - K.Wisshak (1983) 5-250 keV.
  - no previous measurements have been performed in the resolved resonance region.

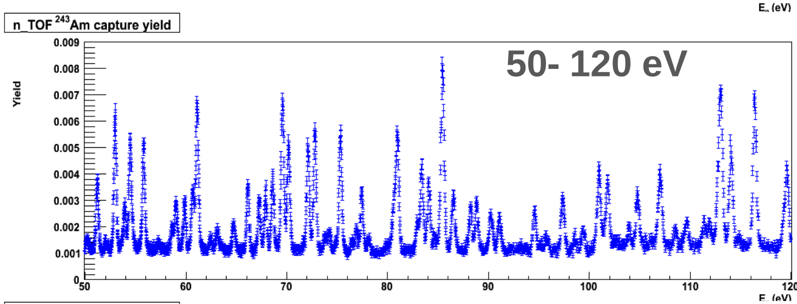


^{243}Am capture cross section (2010) with RR up to 1 keV

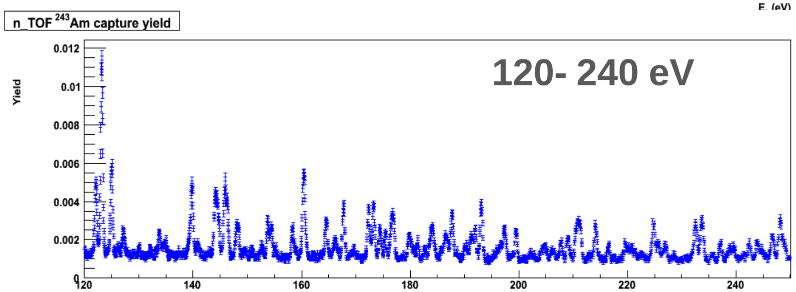
M.A. cross sections: ^{243}Am capture

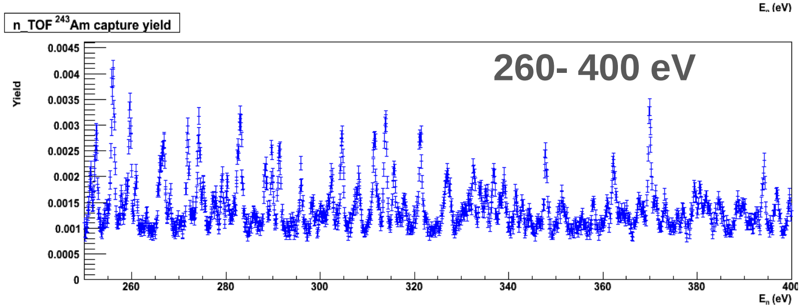


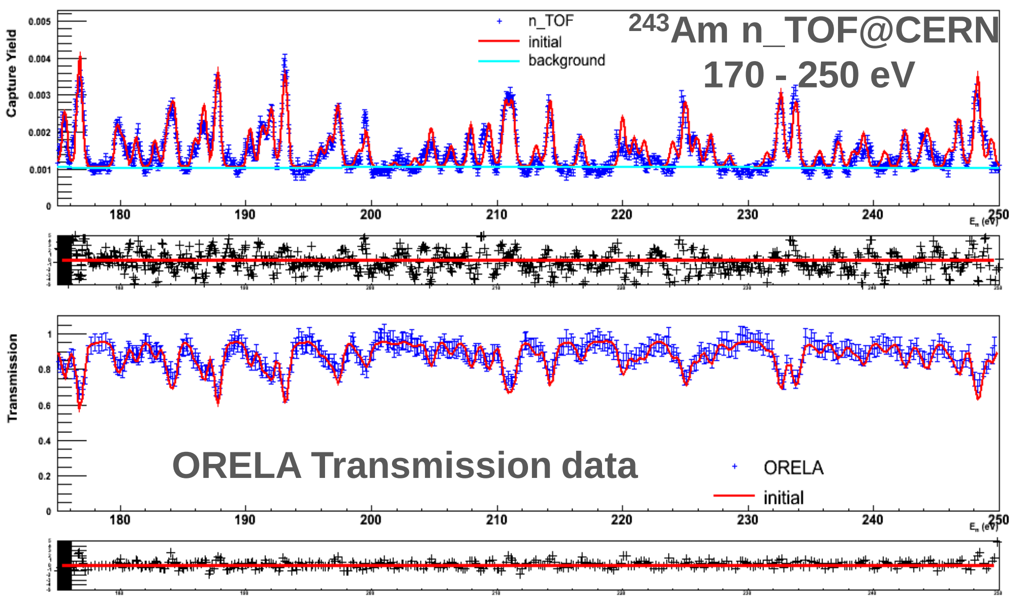




The data will be sent to EXFOR and when combined with available ORELA transmission data will provide a large improvement to the cross section libraries







M.A. cross sections:
Surrogate reaction- Fission

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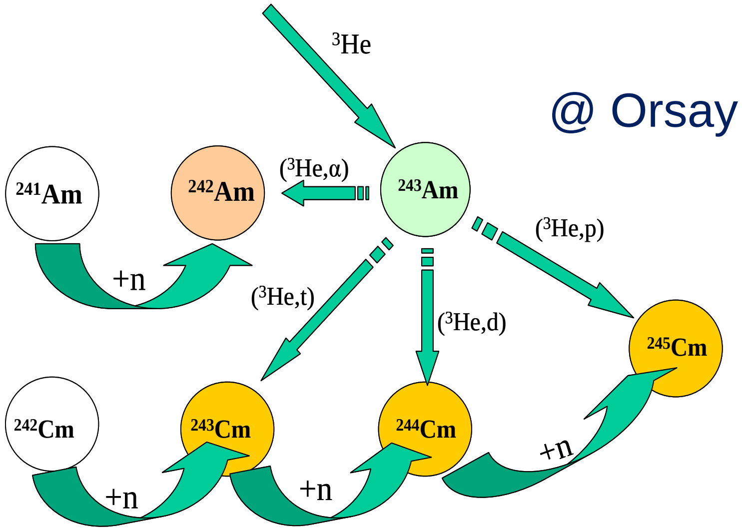
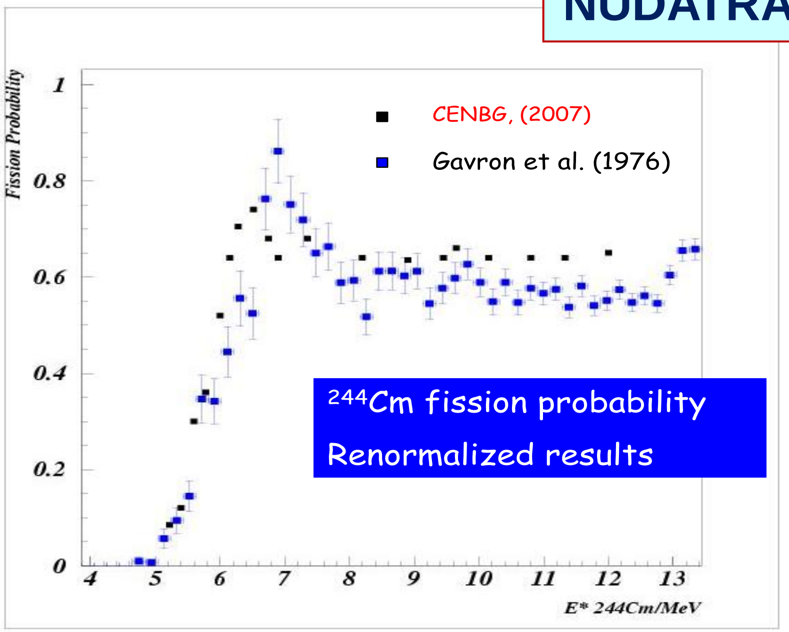
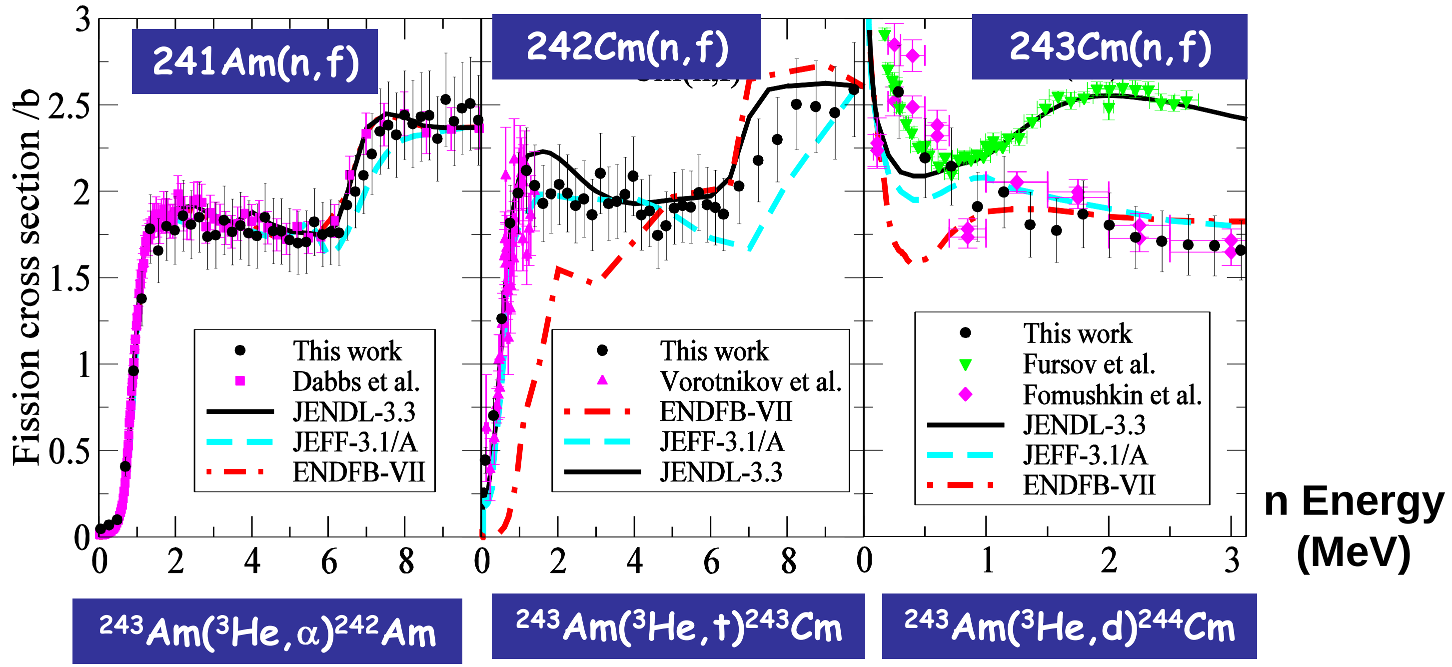






Evaluation (+TALYS improvements)

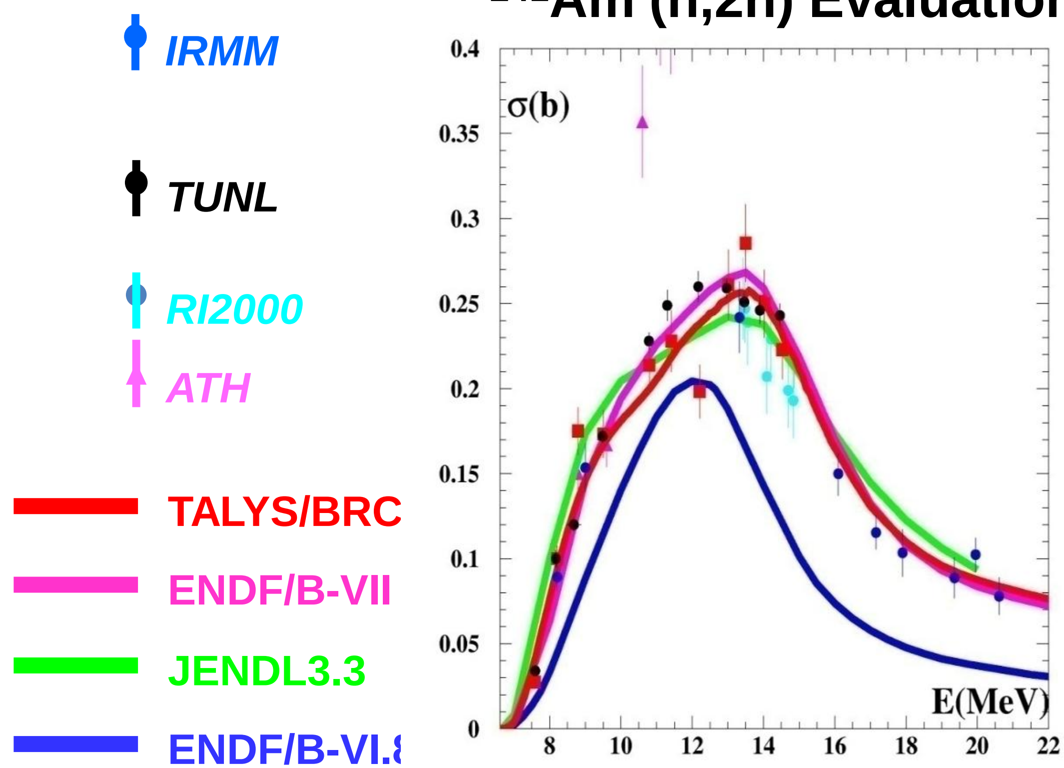
^{241}Am (n,2n) Evaluation

obtained by detailed models and parameters for fission, level densities and optical model

Improvement of TALYS-1.0 and associated evaluation tools for cross section evaluation and prediction:

- new physics and possibility to work with actinides and fission
- Analysis of evaluated ^{241}Am Level Spacing Distribution
- Optical model for actinides
- Theory and techniques for evaluation of covariance data
- Better uncertainty treatment

^{241}Am (n,2n) Evaluation



High Energy Measurements: Gas & LCP production

NUDATRA

High energy measurements:

Solving discrepancies: Large database
of Gas (He) and
Light Charged Part. Prod. x-sections,

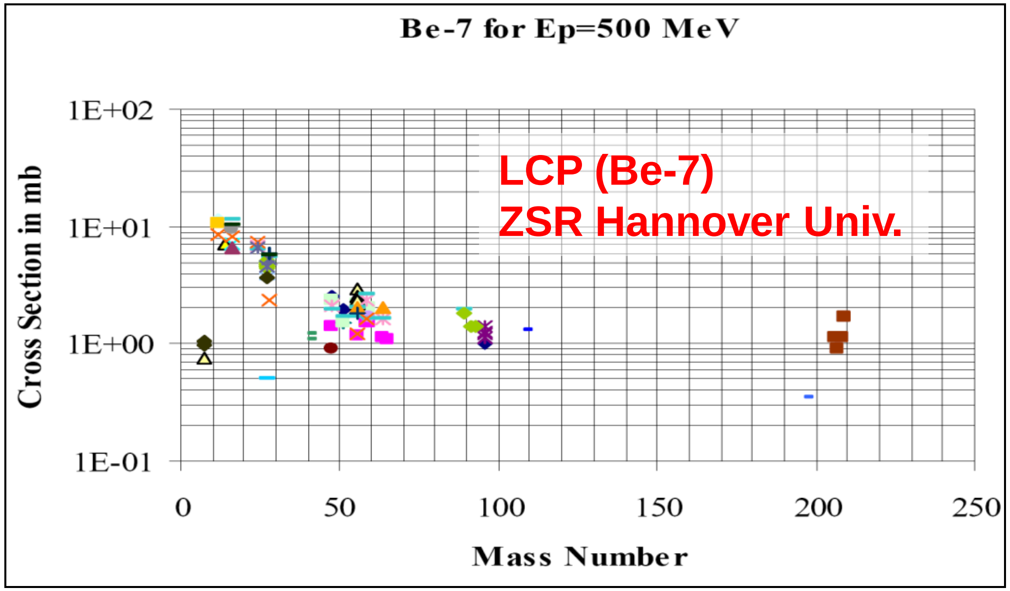
Absolute normalization of Spallation prod. x-section

Spallation x-section for intermediate energies
100-500 MeV

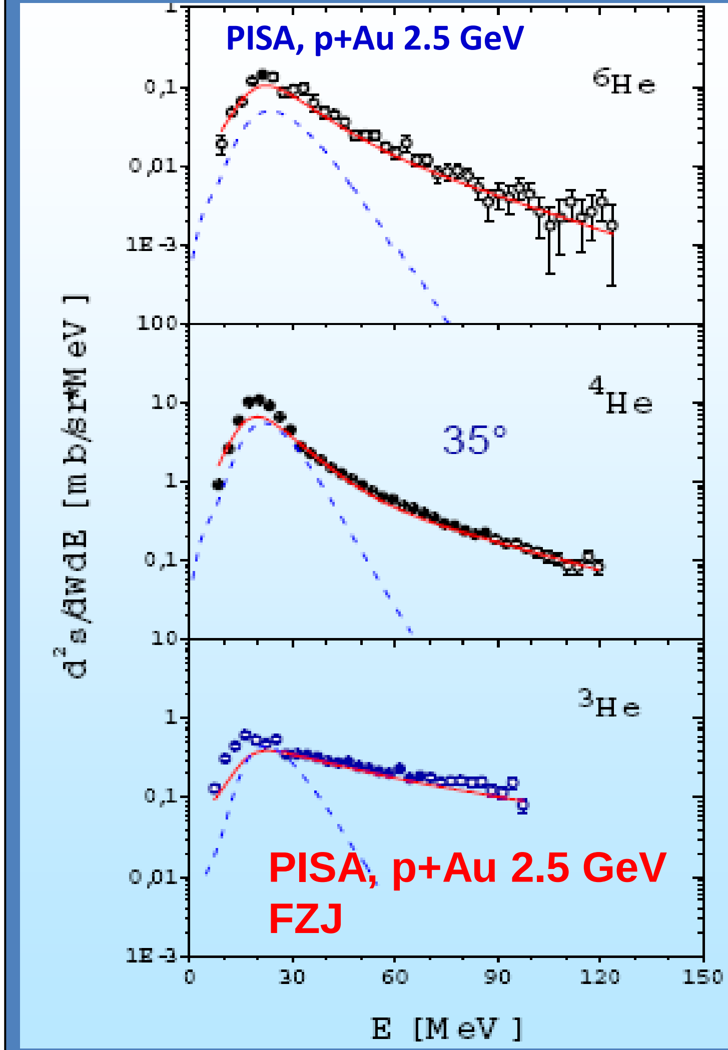
High energy models improvement Improved
versions of **INCL & ABLA** Coupling and implement.
in MCNPX, …

First validations

based on Megapie and other benchmark



Gas production

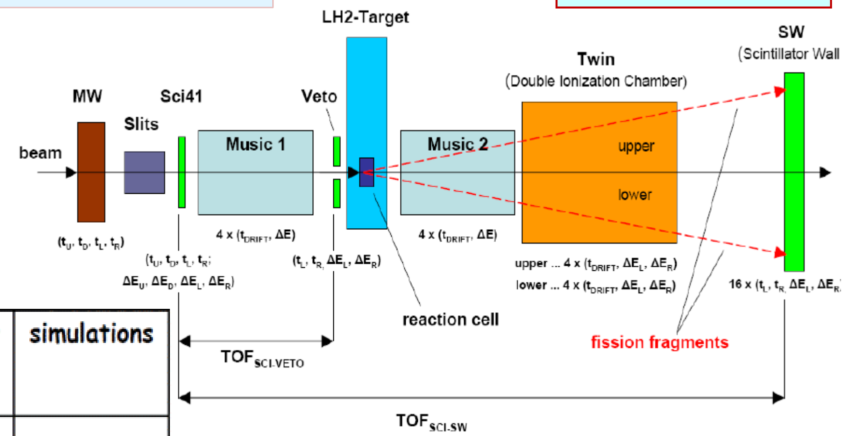


High Energy Measurements: Spallation

NUDATRA

New experimental campaigns at GSI

New absolute normalization of Spallation product cross-section (total production xs)

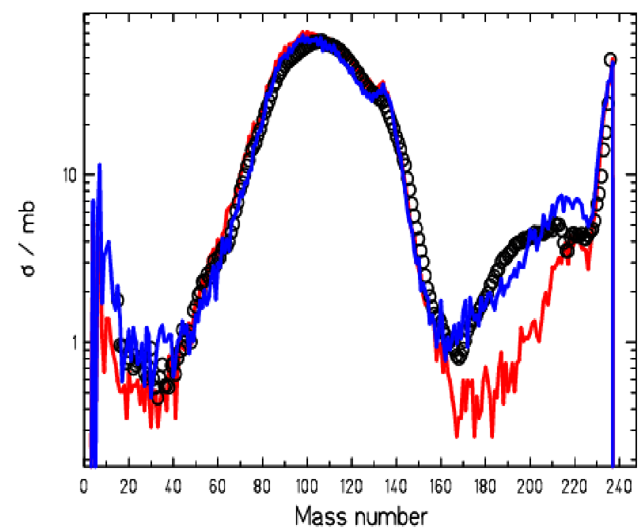


+ New data for Ta

Reaction	σ_{tot} (this work)	σ_{tot} (other works)	Prokofiev [1]	simulations
^{208}Pb (500 A MeV) + ^{1}H	146 ±7 mb	232 ±33 mb [ii]	112 mb	
^{208}Pb (1 A GeV) + ^{1}H		163 ±26 mb [iii]	116 mb	
^{208}Pb (500 A MeV) + ^{2}H	203 ±9 mb			
^{208}Pb (1 A GeV) + ^{2}H		169±14 mb [iv]		
^{238}U (505 A MeV) + ^{1}H		1.49 ± 0.08 b [2]	1.38 b	
^{238}U (545 A MeV) + ^{1}H	1.49 ±0.10 b		1.36 b	
^{238}U (935 A MeV) + ^{1}H	1.55 ±0.10 b		1.28 b	
^{238}U (1 A GeV) + ^{1}H		1.53 ±0.20 b [v] 1.48 ±0.06 b [2]	1.27 b	
^{238}U (1 A GeV) + ^{2}H		2.00 ±0.42 b [vi]		
^{181}Ta (1.0 A GeV) + H	(15.3 ±4.6) mb	preliminary		15.7 mb
^{181}Ta (0.8 A GeV) + H	(9.7 ±2.9) mb			5.3 mb
^{181}Ta (0.5 A GeV) + H	(8.0 ±2.4) mb			2.4 mb
^{181}Ta (0.3 A GeV) + H	(5.7 ±1.7) mb			1.2 mb
^{181}Ta (170 MeV) + H		1.91 ±0.28 b [3]		
^{181}Ta (166 MeV) + H		1.53 ±0.23 b [3]		

Improved Modeling with new INCL/ABLA

Mass distribution U + p, 1 A GeV

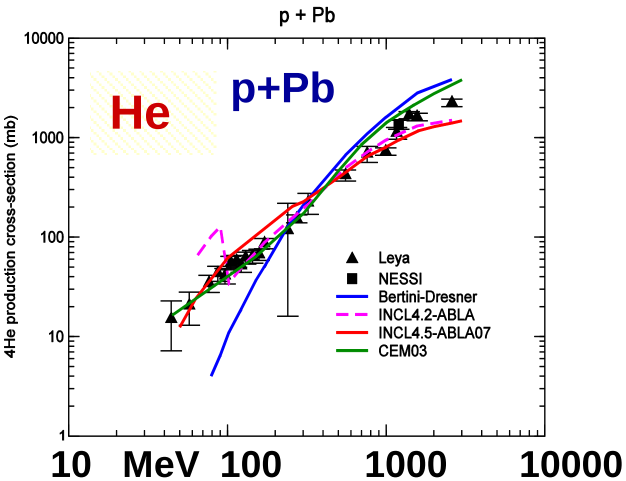


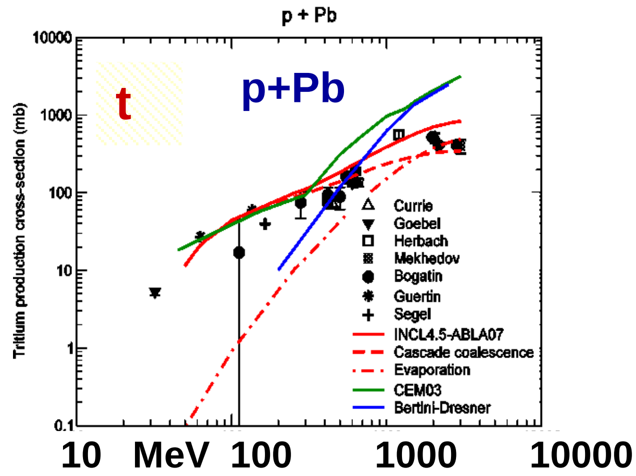
High Energy Measurements: Models INCL/ABLA

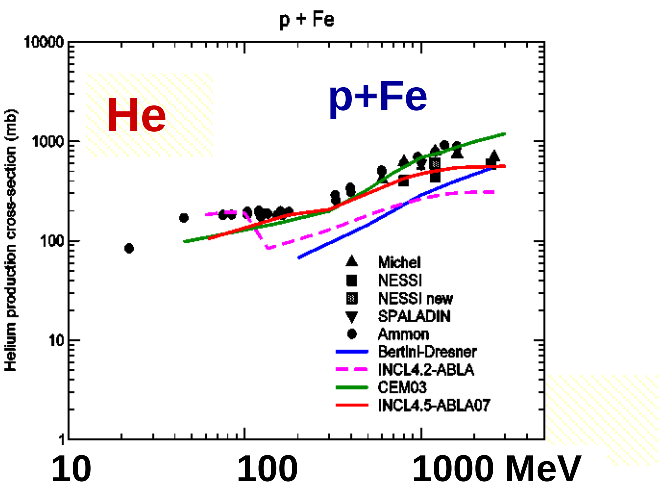
NUDATRA

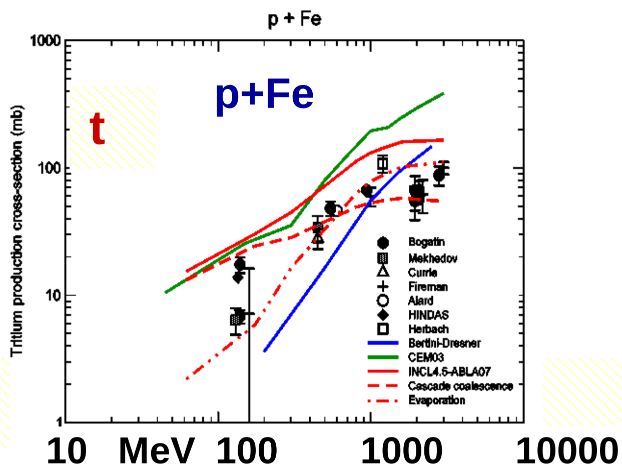
INCL4.5-ABLA07 models have been implemented into MCNPX

➥ will be available for for general users ~ end 2010









- **ABLA07 now produces t and ^{3}He**
- **Cluster emission during the INC stage very important for t and ^{3}He**
- **INCL4.5-ABLA07 gives a very good agreement with data all over the energy range, generally better than other models in MCNPX**

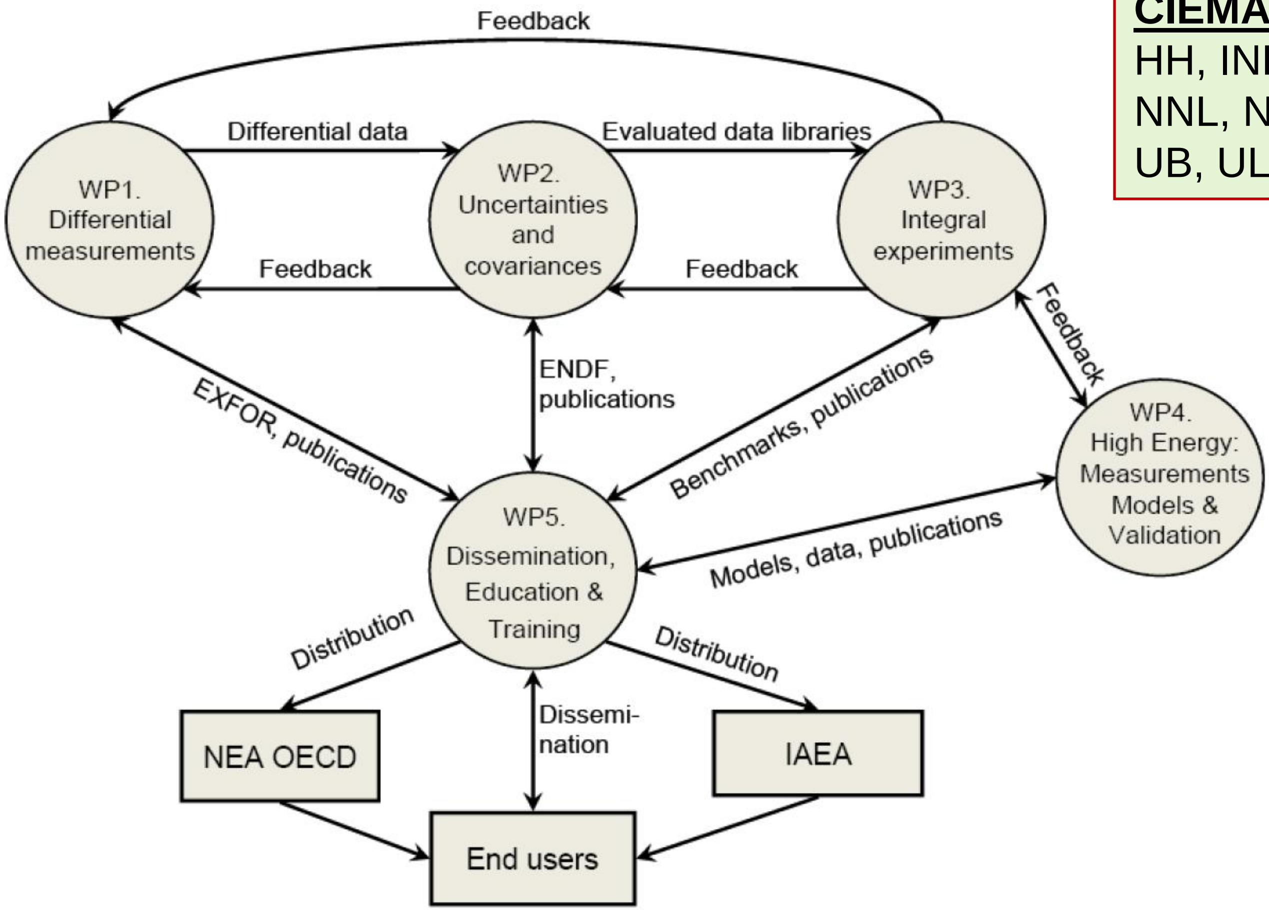
Improved modeling of helium and tritium production (NIMB 268 (2010) 581)

ANDES (FP7 project)

Accurate Nuclear Data for nuclear Energy Sustainability

20 partners + End User Group
Started on May 1st, 2010 (36 months duration)

ANDES Partners
CIEMAT, CEA, CNRS, GSI, IFIN-HH, INFN, ITN, JRC, JSI, JYU, NNL, NRG, PSI, SCK•CEN, TUW, UB, ULG, UPM, USC, UU

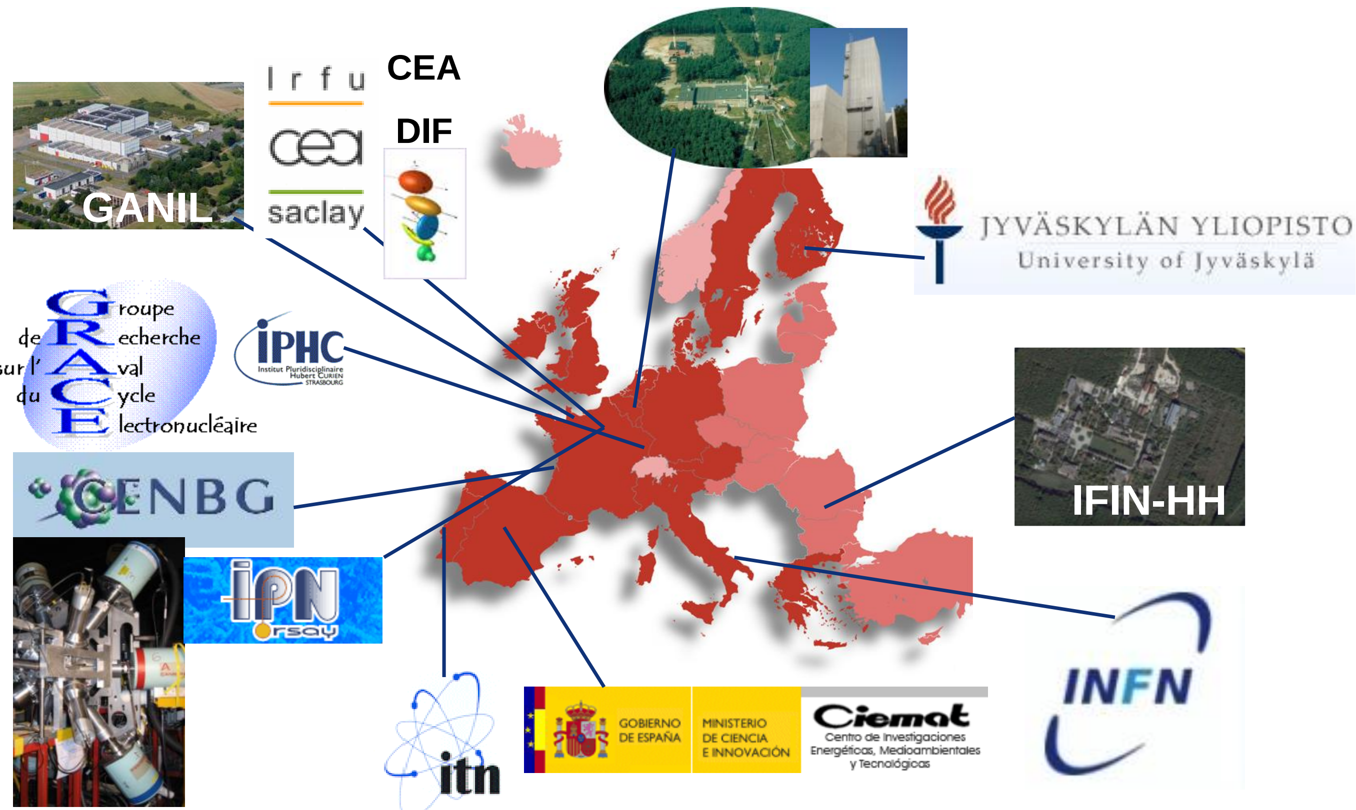


ANDES: Accurate Nuclear Data for nuclear Energy Sustainability

WP1: Measurements for advanced reactor systems

High accuracy inelastic, capture, fission, fission product decay heat,
^{238}U, ^{241}Am – ^{238,240,242}Pu(n,f),… - ^{23}Na, Zr, Mo - ^{88}Br, ^{94}Rb, ^{95}Rb,…
Best world facility combination

- **IRMM** neutron sources, both the e-linear and the Van de Graaff accelerators,
- The **n_TOF** spallation facility at CERN,
- The **Jÿvaskÿla** cyclotron and the IGISOL facility,
- The **CNRS/Orsay** accelerators,
- The **GANIL** accelerator complex



ANDES WP1 measurements

1. High accuracy measurements of neutron inelastic scattering cross sections.

- To improve with new measurements the cross sections for neutron inelastic scattering off **^{238}U**.
- To improve with new measurements the cross sections for neutron inelastic scattering off **structural materials and inert fuel components (**^{23}Na, Zr, Mo**)**.
- To provide **covariances and the limits of accuracy** for measurements with the (n,n'γ)-technique.

2. High accuracy measurements of neutron total and capture cross sections.

- To improve with new measurements the n+**^{238}U** radiative neutron **capture** cross sections.
- To improve with new measurements the n+**^{241}Am** radiative neutron **capture** cross sections.
- To assess the use of transfer reactions for the determination of neutron-induced capture cross sections for actinide targets.

3. High accuracy measurements of fission cross sections

- To improve with new measurements the neutron-induced **fission** cross section of **Pu isotopes (**^{238}Pu (TR), ^{240,242}Pu**)**.
- To improve with new experimental results the **fission cross** sections of the **minor actinides (**^{241,243}Am and ^{245}Cm**)**.
- To improve the experimental knowledge of the fast neutron induced **fission yields for isotopes of Np, Pu and Cm by surrogate neutrons and inverse kinematics**.

4. State of the art decay data measurements for reactor kinetics and decay heat

- To improve the experimental information for the **beta decay probability and strength functions** of relevant fission fragments (**^{88}Br, ^{94}Rb, ^{95}Rb and ^{137}I**).
- To improve the experimental information for the **delayed neutron emission probabilities** of relevant fission fragments (**^{88}Br, ^{94}Rb, ^{95}Rb and ^{137}I**).

ANDES WP1 measurements

Table 32. Summary of Highest Priority Target Accuracies for Fast Reactors

		Energy Range	Current Accuracy (%)	Target Accuracy (%)
U238	σ_{inel}	6.07 ÷ 0.498 MeV	10 ÷ 20	2 ÷ 3
	σ_{capt}	24.8 ÷ 2.04 keV	3 ÷ 9	1.5 ÷ 2
Pu241	σ_{fiss}	1.35MeV ÷ 454 eV	8 ÷ 20	2 ÷ 3 (SFR,GFR, LFR) 5 ÷ 8 (ABTR, EFR)
Pu239	σ_{capt}	498 ÷ 2.04 keV	7 ÷ 15	4 ÷ 7
Pu240	σ_{fiss}	1.35 ÷ 0.498 MeV	6	1.5 ÷ 2
	ν	1.35 ÷ 0.498 MeV	4	1 ÷ 3
Pu242	σ_{fiss}	2.23 ÷ 0.498 MeV	19 ÷ 21	3 ÷ 5
Pu238	σ_{fiss}	1.35 ÷ 0.183 MeV	17	3 ÷ 5
Am242m	σ_{fiss}	1.35MeV ÷ 67.4keV	17	3 ÷ 4
Am241	σ_{fiss}	6.07 ÷ 2.23 MeV	12	3
Cm244	σ_{fiss}	1.35 ÷ 0.498 MeV	50	5
Cm245	σ_{fiss}	183 ÷ 67.4 keV	47	7
Fe56	σ_{inel}	2.23 ÷ 0.498 MeV	16 ÷ 25	3 ÷ 6
Na23	σ_{inel}	1.35 ÷ 0.498 MeV	28	4 ÷ 10
Pb206	σ_{inel}	2.23 ÷ 1.35 MeV	14	3
Pb207	σ_{inel}	1.35 ÷ 0.498 MeV	11	3
Si28	σ_{inel}	6.07 ÷ 1.35 MeV	14 ÷ 50	3 ÷ 6
	σ_{capt}	19.6 ÷ 6.07 MeV	53	6

Items addressed by ANDES WP1 are marked

ANDES WP1 measurements

Table 30. ADMAB: uncertainty reduction requirements needed to meet integral parameter target accuracies

Isotope	Cross-Section	Energy range	Uncertainty (%) Initia
Pu238	σ_{fiss} ☑	6.07 - 0.498 MeV	20
	ν	1.35 - 0. 183 MeV	7
Pu239	σ_{capt}	498 - 2.03 keV	12
	σ_{inel}	6.07 - 0.498 MeV	25
Pu240	σ_{capt}	183 - 67.4 keV	14
	σ_{fiss} ☑	2.23 - 0.498 MeV	6
	ν	1.35 - 0.498 MeV	4
Pu241	σ_{capt}	1.35 - 0. 183 MeV	20
	σ_{fiss}	6.07 MeV-22.6 eV	15
Pu242	σ_{capt}	24.8 - 9.12 keV	35
	σ_{fiss} ☑	6.07 - 0.498 MeV	20
Np237	σ_{capt}	498 - 0.454 keV	6
	σ_{fiss}	6.07 - 0.183 MeV	8
	σ_{inel}	2.23 – 0.183 MeV	25
Am241	σ_{capt} ☑	1.35 MeV- 0.454 keV	8
	σ_{fiss} ☑	6.07 – 0.183 MeV	10
	ν	6.07 - 1.35 MeV	2
	σ_{inel}	6.07 – 0.183 MeV	25
Am242m	σ_{fiss}	1.35 MeV- 9.12 keV	17
Am243	σ_{capt}	1.35 MeV- 0.454 keV	10
	σ_{fiss} ☑	6.07 - 0.498 MeV	10
	σ_{inel}	6.07 MeV- 24.8 keV	40
Cm242	σ_{fiss}	6.07 MeV- 67.4 keV	55
Cm243	σ_{fiss}	1.35 MeV- 67.4 keV	50
Cm244	σ_{capt}	498 -9.12 keV	20
	σ_{fiss}	6.07 MeV- 67.4 keV	45
	ν	6.07 – 0.183 MeV	10
Cm245	σ_{fiss} ☑	6.07 MeV- 0.454 keV	45
Fe56	σ_{capt}	183 - 0.454 keV	12
	σ_{inel}	6.07 - 0.498 MeV	20
Zr90	σ_{inel}	6.07 - 2.23 MeV	18
N15	σ_{el}	2.23 MeV - 67.4 keV	5
Pb	σ_{capt}	9.12 - 2.03 keV	20
	σ_{inel}	6.07 - 2.23 MeV	12
Bi209	σ_{inel}	2.23 - 0.498 MeV	34

☑ Andes

(a) See Table 24 for $\lambda \neq 1$, case A

Important isotopes for Transmutation Fuel Cycles: The multi-recycling point of view

☑ Andes

Isotopes	Uncertainty in the abundance % Burnup (GWd/t) 150	500	800	Important for:			
^{234}U	4.6	16.1	32.4	T	DH		
^{235}U	13.1	18.4	15.5	T			
^{236}U	1.8	7.6	12.6	T			
^{237}Np	6.3	23.7	28.1	T			
☑ ^{238}Pu	4.3	10.8	19.3	T	DH		R
^{239}Pu	4.6	12.9	17.8	T	DH		R
☑ ^{240}Pu	2.0	7.0	14.4	T	DH		R
^{241}Pu	8.2	14.7	17.0	T			
☑ ^{242}Pu	2.1	7.9	16.2	T	DH		R
☑ ^{241}Am	7.2	20.7	26.0	T	DH		R
^{242m}Am	12.8	28.6	34.4	T			
☑ ^{243}Am	6.6	15.6	20.2	T	DH		R
^{242}Cm	10.7	7.7	15.6	T	DH		
^{243}Cm	23.3	32.6	35.7				
^{244}Cm	6.0	13.3	19.1	T	DH	N	R
☑ ^{245}Cm	13.3	18.8	16.3	T	DH		R
^{246}Cm	7.5	21.7	31.5	T	DH	N	R
^{247}Cm	15.4	27.2	31.6	T			
^{248}Cm	6.4	19.8	31.4			N	
^{250}Cf	31.9	28.9	36.9			N	
^{252}Cf	52.4	46.1	48.9			N	

ANDES: Accurate Nuclear Data for nuclear Energy Sustainability

WP2: Uncertainties and covariances of nuclear data

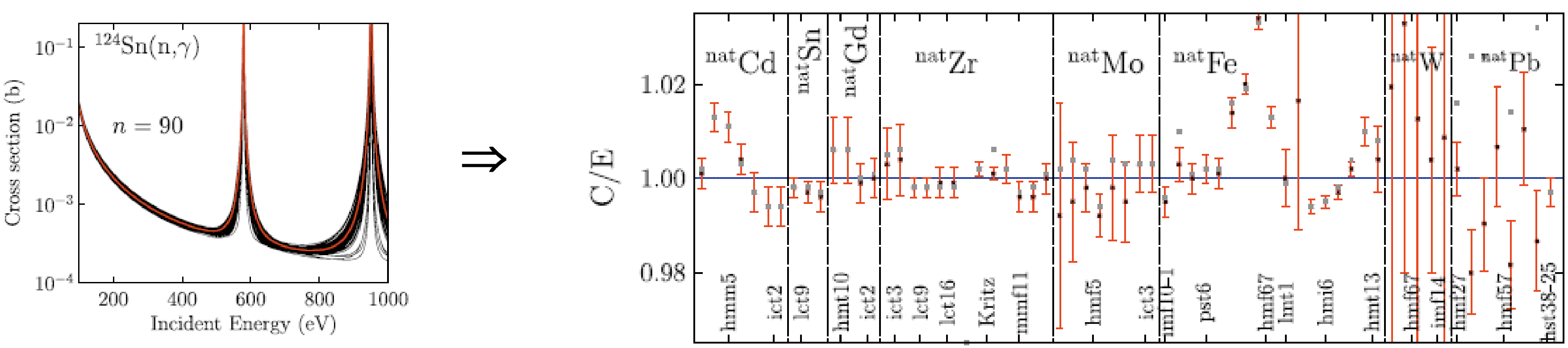
Develop tools to evaluate covariances (^{238}U/^{239}Pu, ^{241}Am)
Prepare simulation programs to use covariance information
Simulation results with the full uncertainty from data (not only statistics)

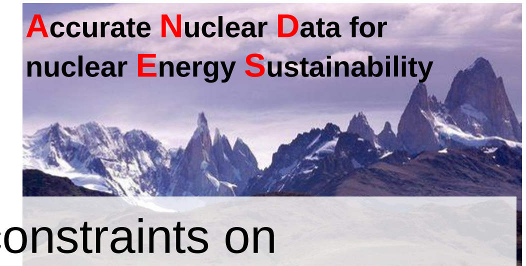
- Uncertainty/covariance evaluation of experimental data
- Uncertainty/covariance evaluation of data from nuclear reaction models
- A proper theoretical treatment and evaluation of nuclear reactions on actinides (especially fission models) and its relation with 1. and 2.
- Covariances for radioactive decay and fission yield data
- Use all of the above in processing, reactor and fuel cycle codes.

Participants: CIEMAT, CEA/DAM+DEN, NNL, NRG, TUW, UB, UPM

TALYS
GENEUS
CONRAD
ACAB
FISPIN
…

Uncertainty propagation from nuclear data to reactors

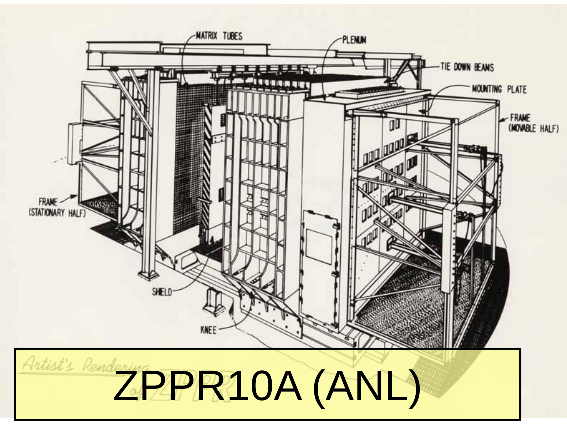




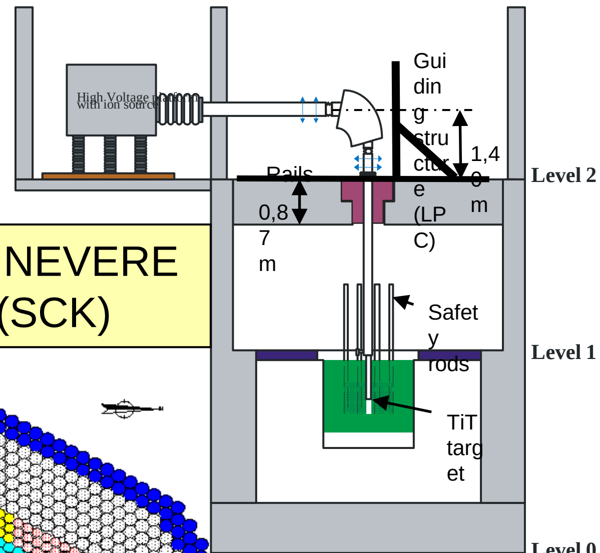
ANDES: Accurate Nuclear Data for nuclear Energy Sustainability

WP3: Integral experiments for validation of nuclear data and constraints on uncertainties Data from: MUSE, GUINEVERE, PROFIL, ZPPR10A ,SNEAK-7A and -7B, Nuclear data trends

Participants: CEA/CAD (F), NRG (NL), JSI (SL), CNRS (F), CIEMAT (E), SCK-CEN (B)



ZPPR10A (ANL)

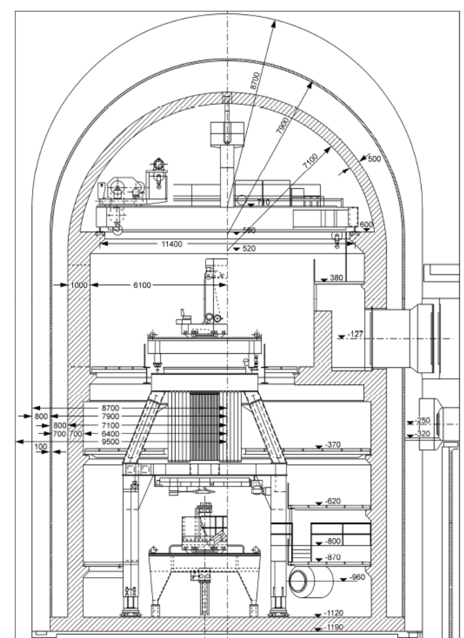


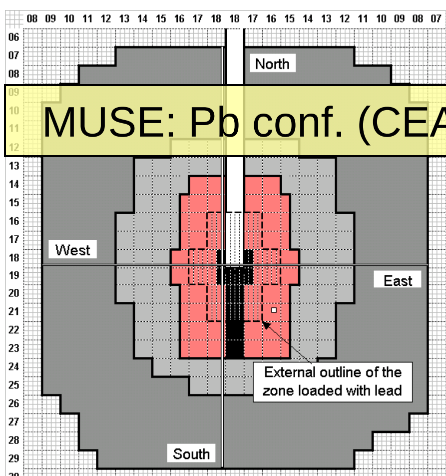
GUINEVERE (SCK)

SNEAK 7A AND 7B

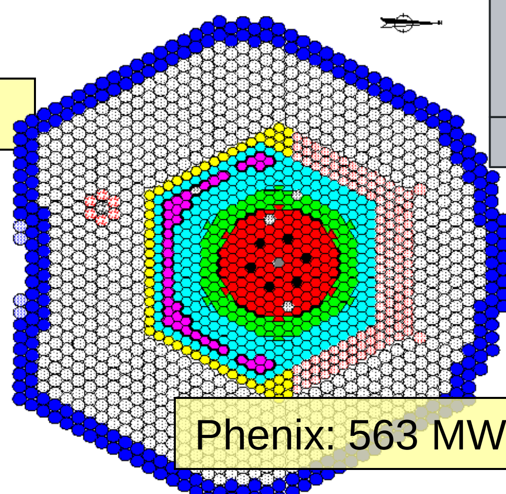
KARLSRUHE FAST CRITICAL FACILITY

SNEAK-LMFR-EXP-001
CRIT-BUCK-SPEC-COEF-KIN-RRATE-MISC





MUSE: Pb conf. (CEA)



Phenix: 563 MW (CEA)

ANDES WP3: Integral experiments for validation of nuclear data and constraints on uncertainties

Integral experiments data:

MUSE Ref Core characterization

- This experiment is available via the **MUSE** project of **FP5 of EURATOM**
- **Neutronic behaviors :** Keff, Spectral indices, reaction rates of Na cooled Fast reactor with **steel reflector**.

ZPPR10A experiment proposed in IRPHE data base of NEA data Bank

- This experiment is available **IRPHE of the NEA data bank**
- **Neutronic behaviors :** Keff, Spectral indices, and **sodium void effects**.

PROFIL experiments made in PHENIX on separate isotopes irradiation

- This experiment is available **via CEA**
- **Neutronic behaviors :** separated irradiated samples of different isotopes, **Actinides and Minor Actinides**, Post irradiated chemical analysis of the samples, information on Capture cross sections.

A large criticality and shielding benchmark used for validation of JEFF-3.1 from ICSBEP

- These experiments are available via **ISCBEP data bank**
- **Neutronic behaviors :** Keff, Spectral indices

A problem based on data GUINEVERE VENUS-F experimental facilities at SCK-CEN

- These experiments are available via project **EUROTRANS of EURATOM**
- **Neutronic behaviors :** Keff, Spectral indices, … of a **lead cooled uranium core**.

ANDES: Accurate Nuclear Data for nuclear Energy Sustainability

WP4: High energy model validation in the 150-600 MeV energy domain

Improving of the predicting capabilities of the models in the 150-600 MeV

New measurements at 500 Mev (p+Pb)- Validation with MEGAPIE - PIE

Participants: CEA/DSM-DAM, CNRS, GSI, NRG,PSI, ULG, USC, UU

Evaluation of the state-of-the-art of high-energy model predicting capability in the 150-600 MeV domain

- use of conclusions of the Benchmark of Spallation models presently organized by IAEA + specific comparisons of the models to the available elementary data (from HINDAS and NUDATRA) in the 150-600 MeV energy domain

Improving of the predicting capabilities of the models to reduce the uncertainties on the demonstration facility spallation target

- Improving the high-energy models starting from present versions of INCL-ABLA
- High-Energy Evaluated Nuclear Data Files generated from the TALYS+BRIC reaction codes

Validation on the results from the post irradiation analysis of MEGAPIE samples

- Analysis of samples from the MEGAPIE liquid Pb-Bi target irradiated during 4 months at SINQ and from ISOLDE
- Isotopes: $^{208/209}Po$, ^{194}Hg , ^{108m}Ag , ^{60}Fe, ^{53}Mn, ^{59}Ni , ^{26}Al, ^{36}Cl, ^{10}Be, ^{129}I, ^{10}Be, ^{55}Fe

Measurements

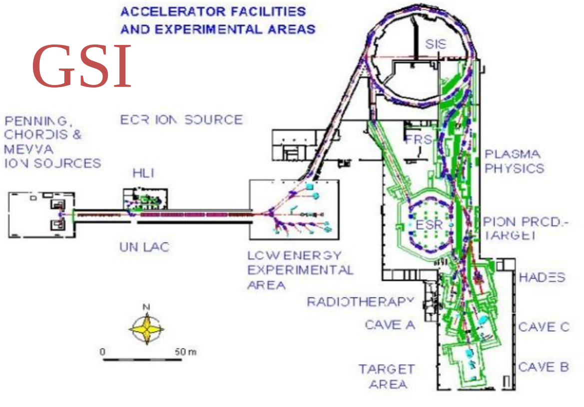
ANDES WP5 Measuerments: SPALADIN p+Pb at 500 MeV: measurement of the fission fragments and evaporation residues in coincidence with light ions

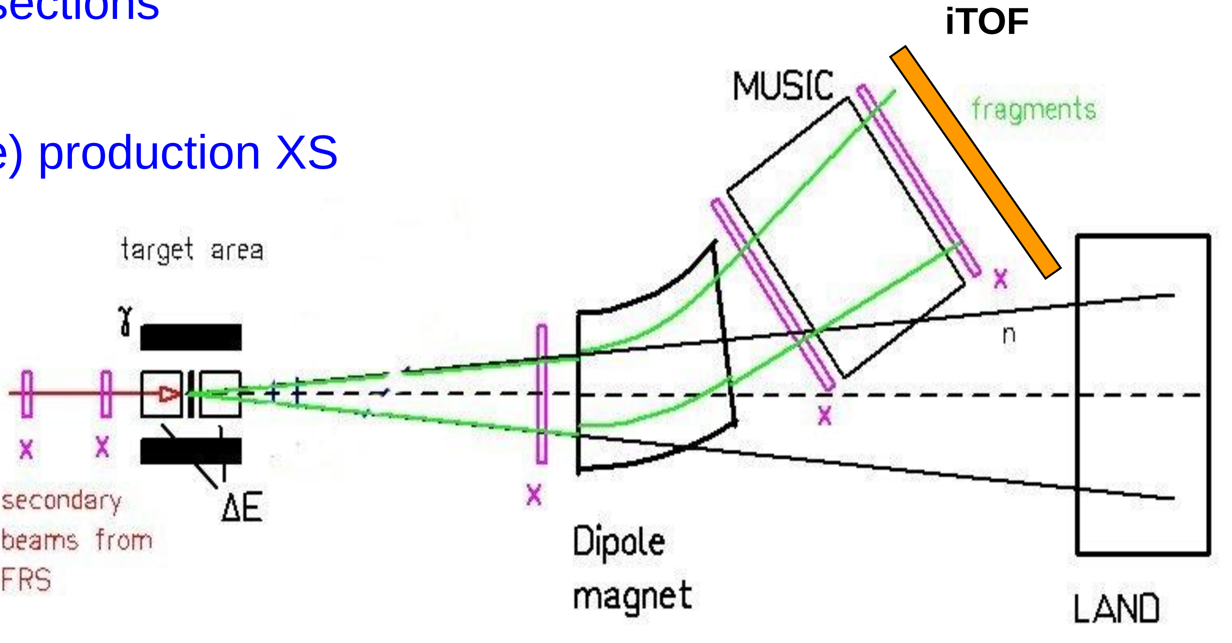
Importance of predicting gases from the liquid target: He, t, volatile elements from fission, Hg

Discrepancies between different sets of data, difficulty for models to predict data at different energies

New generation experiment in inverse kinematics were both fission fragments are indentified and measured in coincidence with neutrons and light-charge particles.

- Total fission cross-sections
- charge distribution
- helium and IMF (Be) production XS





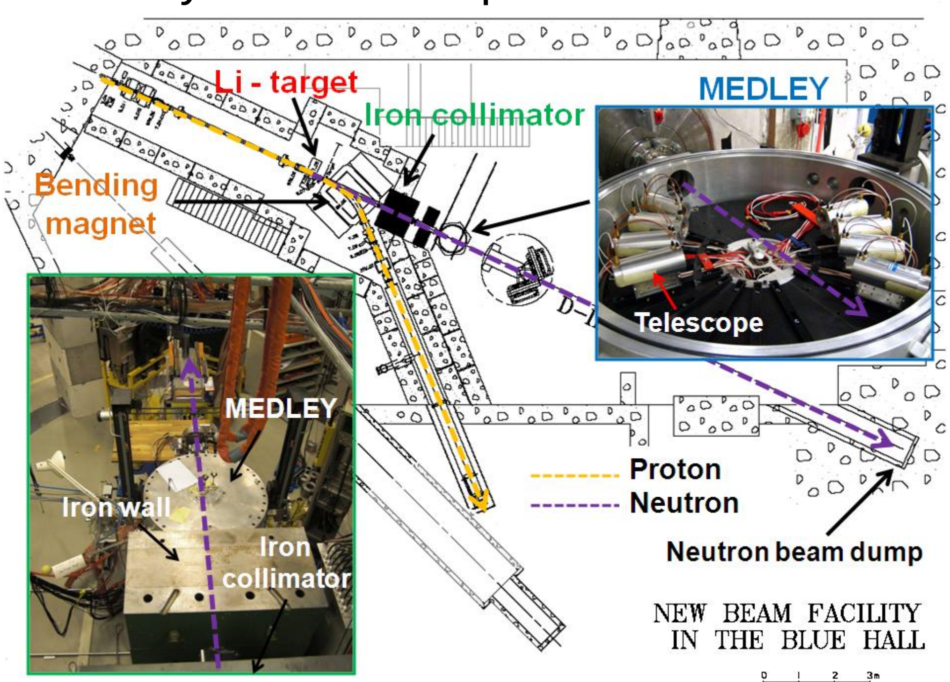
ANDES WP5: Measurement of neutron-induced light ion cross-sections at 175 MeV on Fe, Bi and U

- Importance of predicting light ion cross-sections (helium, tritium)
- Data around 150-200 MeV scarce, region between data library and nuclear models
- Constraints on TALYS calculations
  - Blind TALYS calculation: uncertainty ≈ 40-50%

    ⇨ Reduction by a factor 2 expected

Neutron beam @ TSL

UPPSALA UNIVERSITET



- detect and identify light ions: *p*, *d*, *t*, ^{3}*He* and α
- use the ΔE-ΔE-E technique – wide dynamic range
- low threshold for PID: 2,5 MeV p, 4 MeV α

ddx data for *X(n,light ions)* and deduced $d\sigma/d\Omega$, $d\sigma/dE$, yields, etc.

ANDES: Accurate Nuclear Data for nuclear Energy Sustainability

WP5: Dissemination, education & training

Education and training activities.

- Promote that R&D results into PhD and Master theses
- one open training course specialized in Nuclear Data for Sustainable Nuclear Energy (new edition of EXTEND?)

Cooperation with NEA and IAEA and Dissemination activities

- Dissemination of data
- WEB (temporarily: http://fachp.ciemat.es/andes)

End Users Group

- selected European universities, representatives of R&D organisations, responsibles of experimental reactors and nuclear facilities, international nuclear data agencies OECD/NEA and IAEA, industries involved in design or exploitation activities: Gen-IV and ADS system designs (CDT, ESFR,…), Utilities, regulatory bodies, education representatives.
- Early access to the results produced in the project
- One general meeting per year will be organized with support for the participation of End-Users
- Feedback for ANDES and future nuclear data activities

All participants are warmly invited to joint the ANDES End User Group