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JAEA/JRC collaboration

Development of active neutron NDA

Peter Schillebeeckx

International Symposium on Technology Development
for Nuclear Non-proliferation and Nuclear Security
10 February 2016, Tokyo, Japan

European Commission

EC – JRC – IRMM

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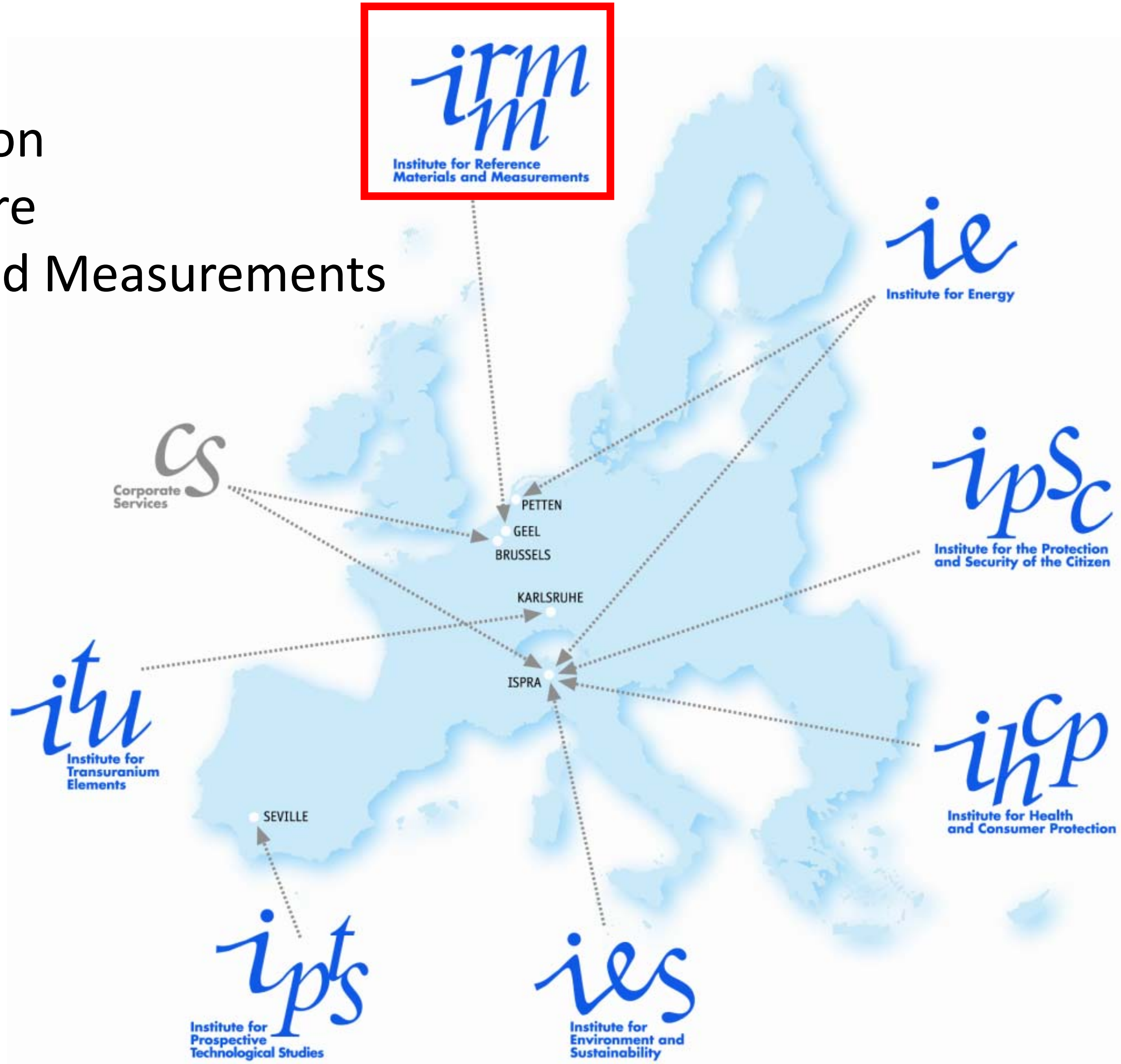

JAEA – JRC Collaboration

- Action Sheet – 1 (2012 – 2015)

  Neutron Resonance Densitometry (NRD)
  for characterization of debris of melted fuel

- Action Sheet – 7 (2015 – 2018)

  Development of active neutron NDA techniques
  for Nuclear Non-Proliferation, Security and Safety

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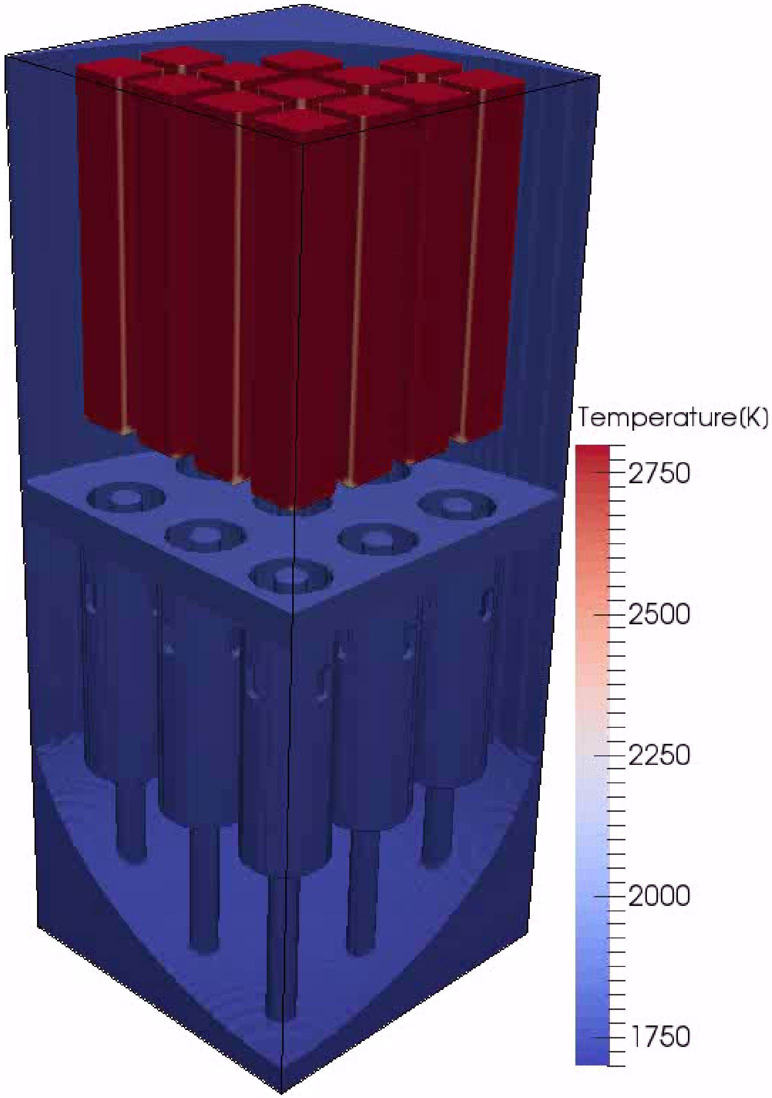
AS – 1: Method to characterize melted fuel from a nuclear accident

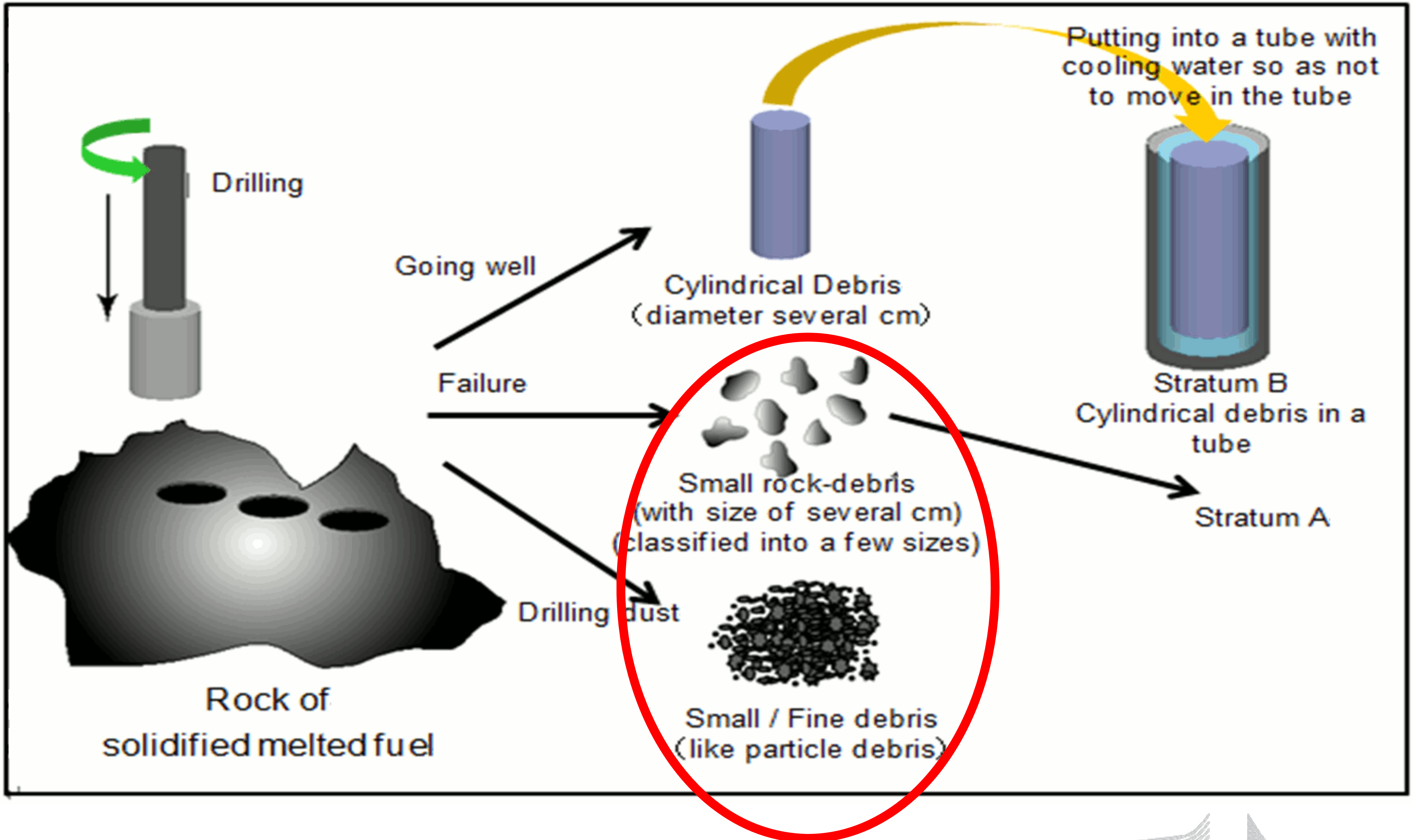
Earthquake followed by a Tsunami (15 m)

core meltdown (units 1,2,3)



Melted fuel:
Complex mixture of materials in fuel and control/safety rods,
i.e. U, Pu, fission products, structural materials and neutron absorbers (^{10}B)

Removal of melted fuel: substantial amount of debris



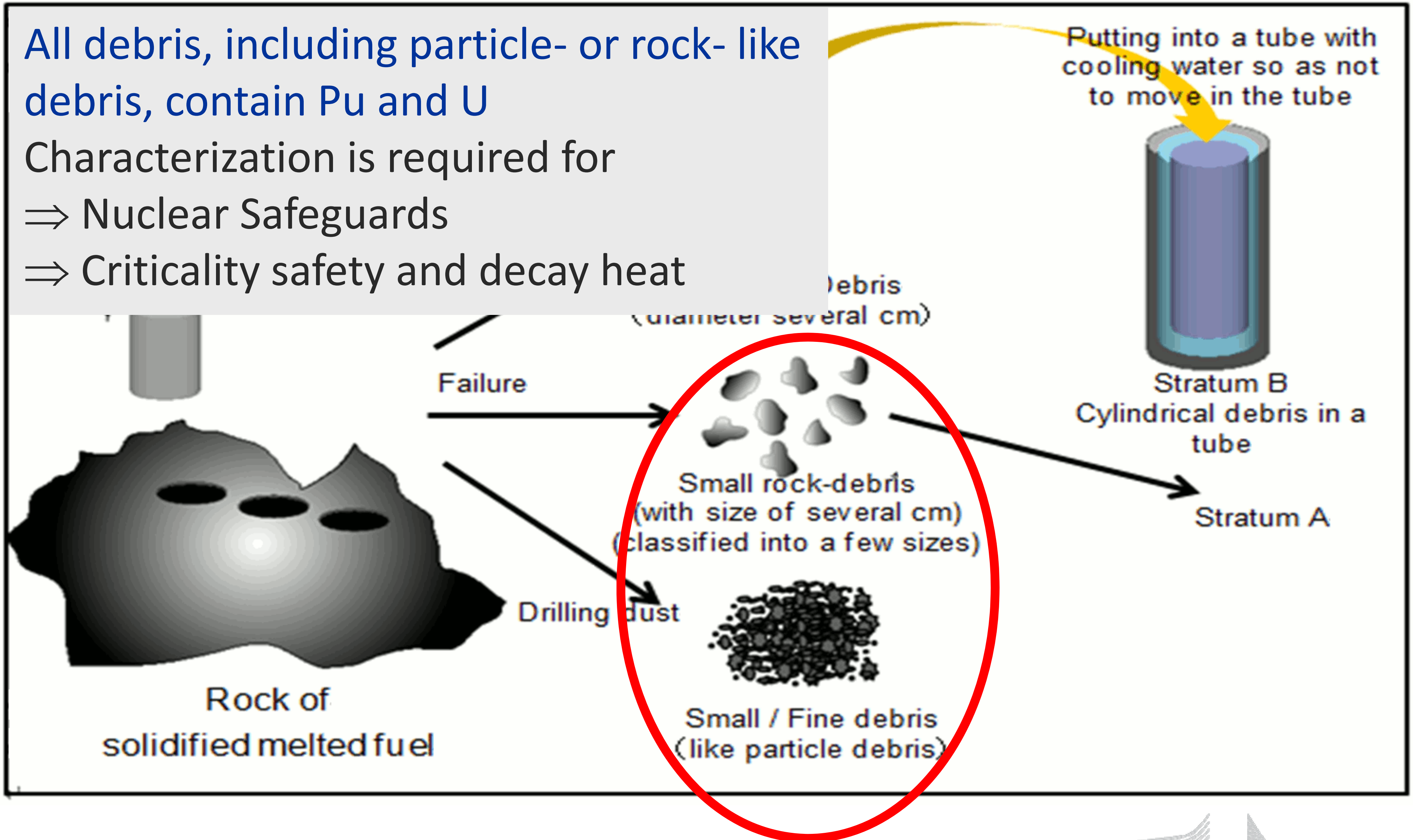
Removal of melted fuel: substantial amount of debris

All debris, including particle- or rock- like debris, contain Pu and U

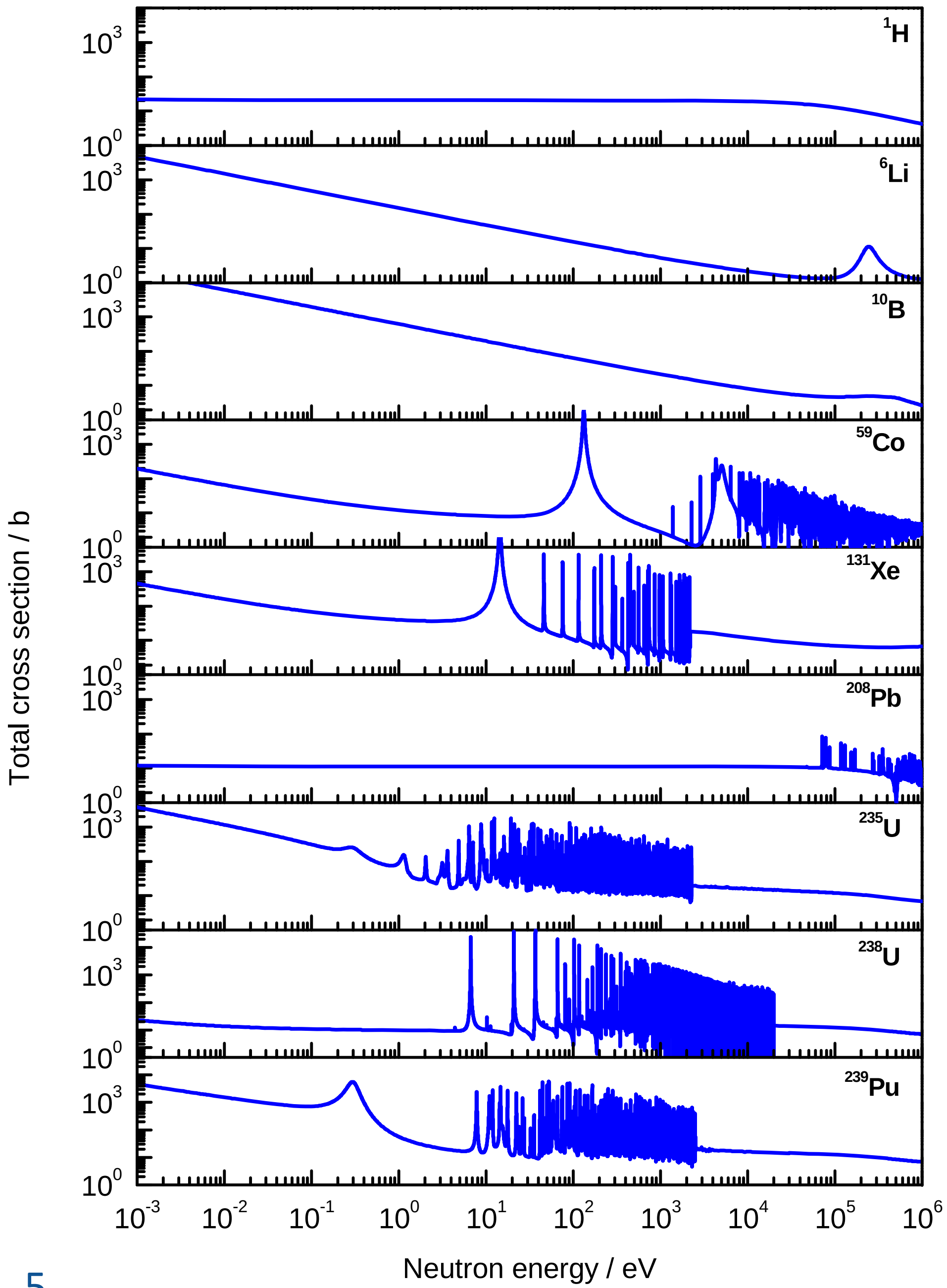
Characterization is required for

⇒ Nuclear Safeguards

⇒ Criticality safety and decay heat

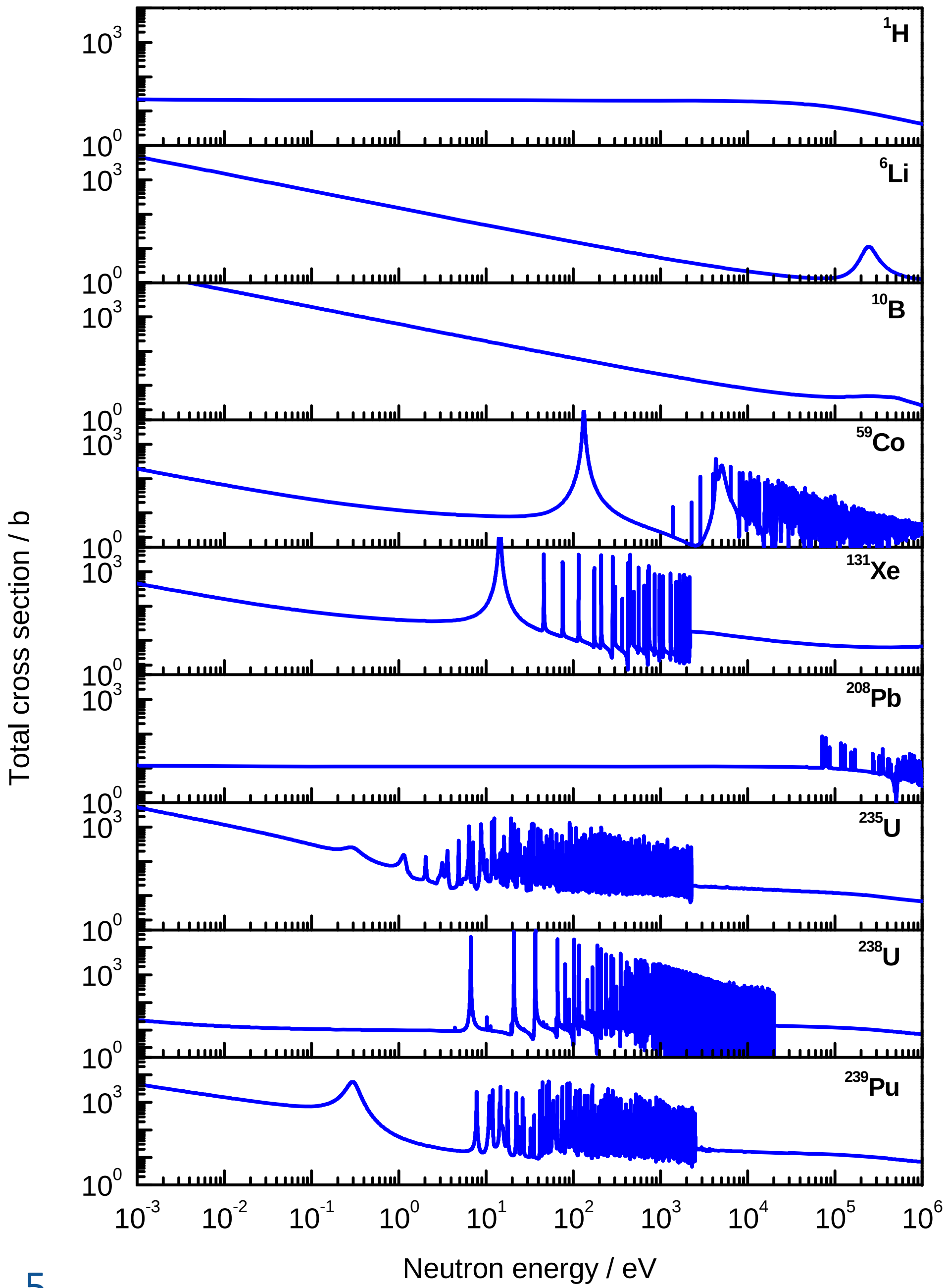


Neutron Resonance Analysis (NRCA&NRTA)



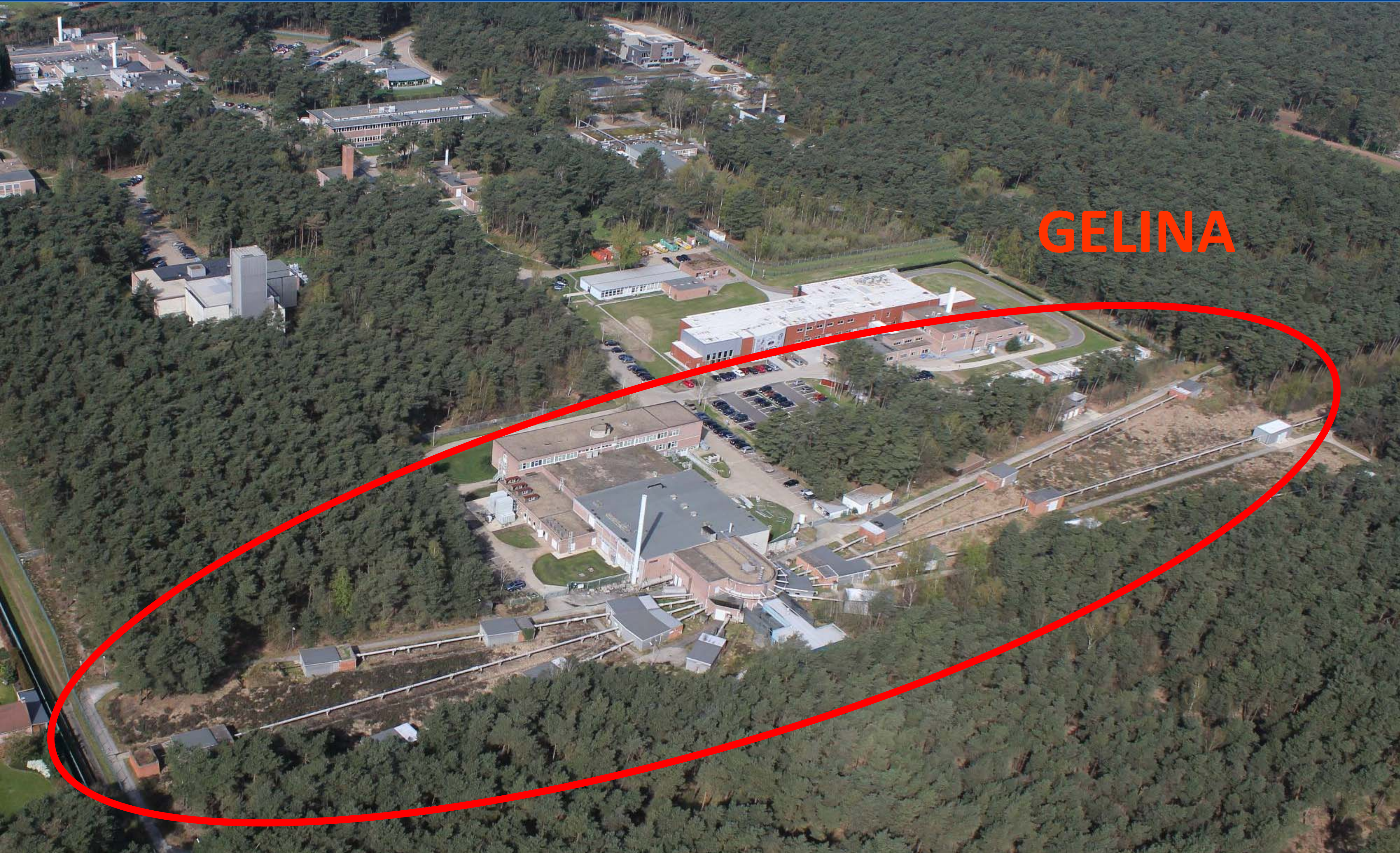
- Cross section is a measure for the interaction probability (symbol σ)
- Resonances appear at energies that are specific for each nuclide

Neutron Resonance Analysis (NRCA&NRTA)

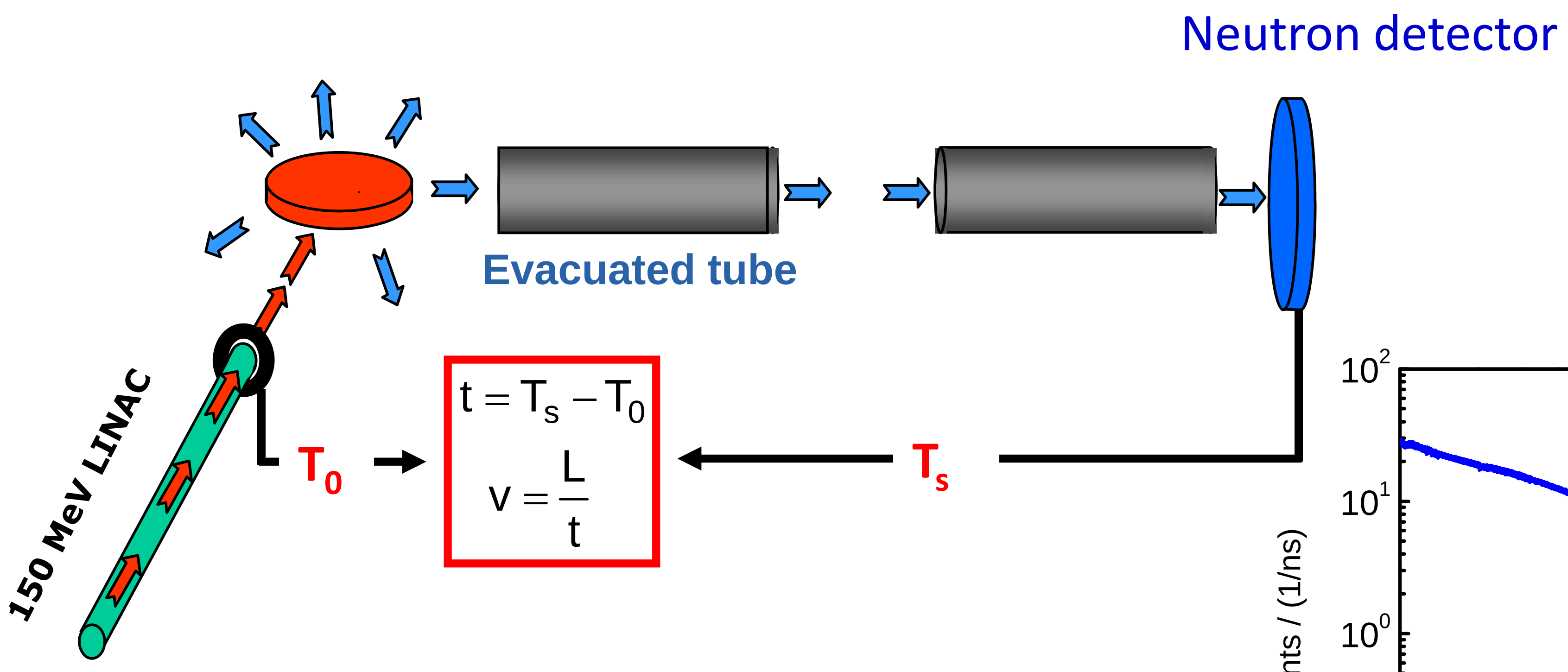


- Cross section is a measure for the interaction probability (symbol σ)
- Resonances appear at energies that are specific for each nuclide
- Position and amplitude of resonances can be used as fingerprints to
  - identify and quantify nuclides
  - elemental & isotopic composition
- Neutron Resonance Analysis (developed at JRC)
  - Non-Destructive Analysis (NDA)
  - sensitive to almost all nuclides (except light)
  - no sample preparation required
  - **requirements:**
    TOF-measurements at a white neutron source

Time – of – flight facility GELINA at JRC - IRMM

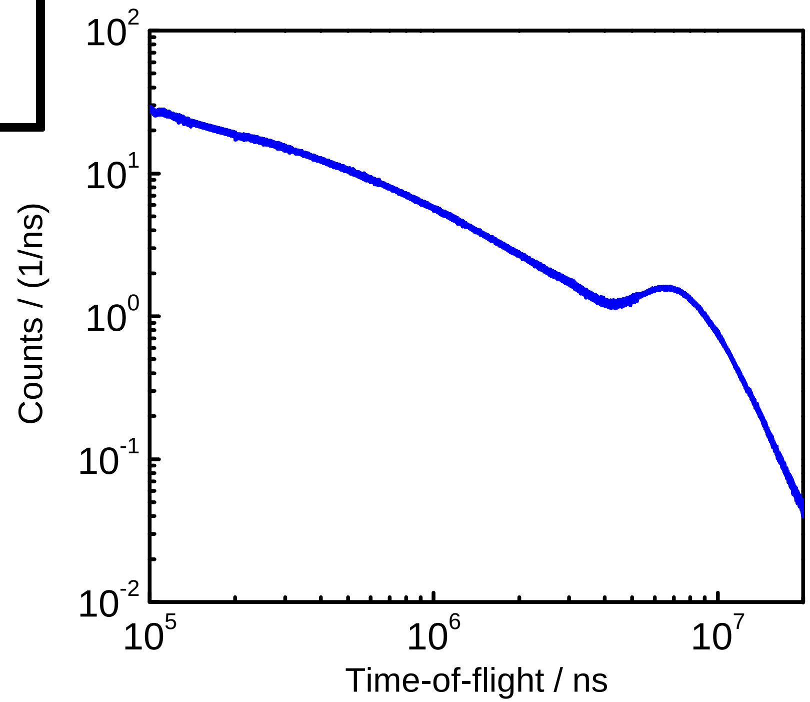


Neutron resonance transmission analysis (NRTA)

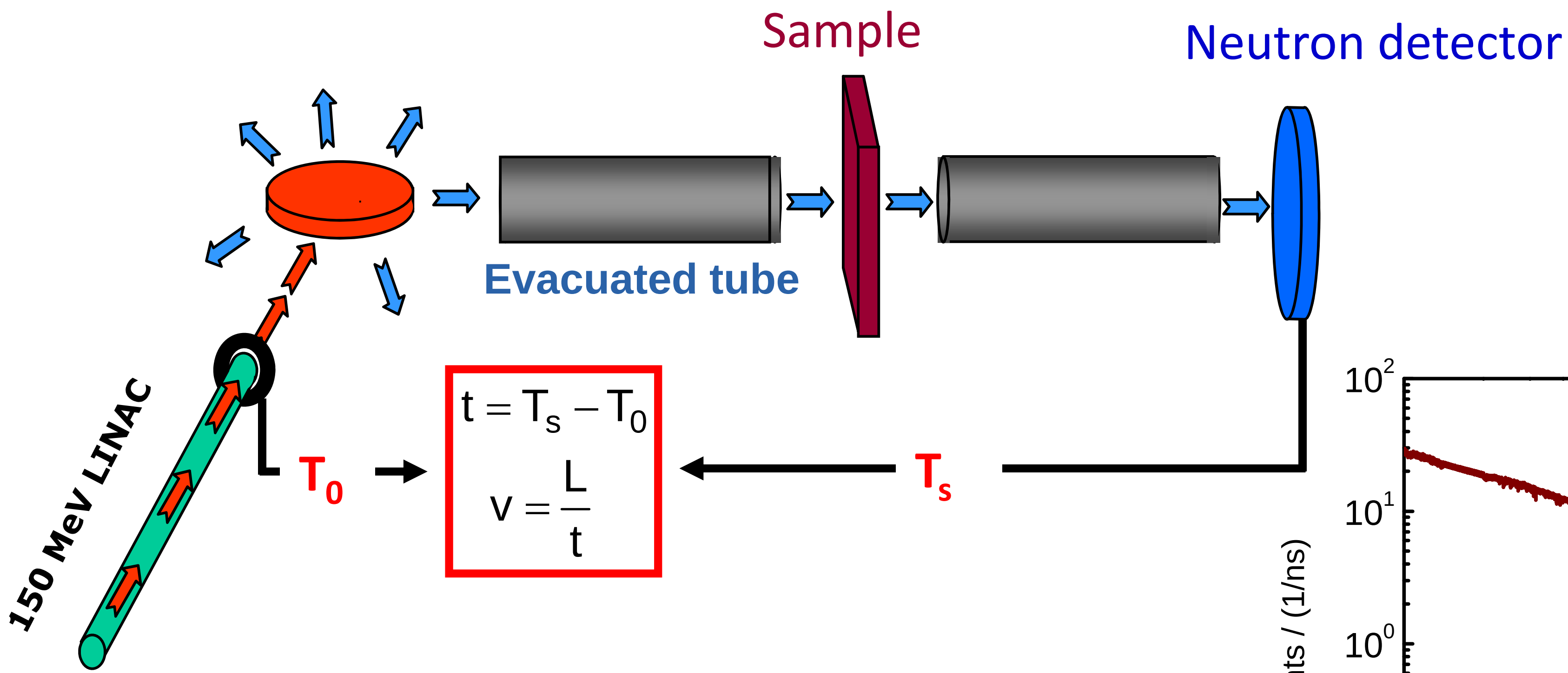


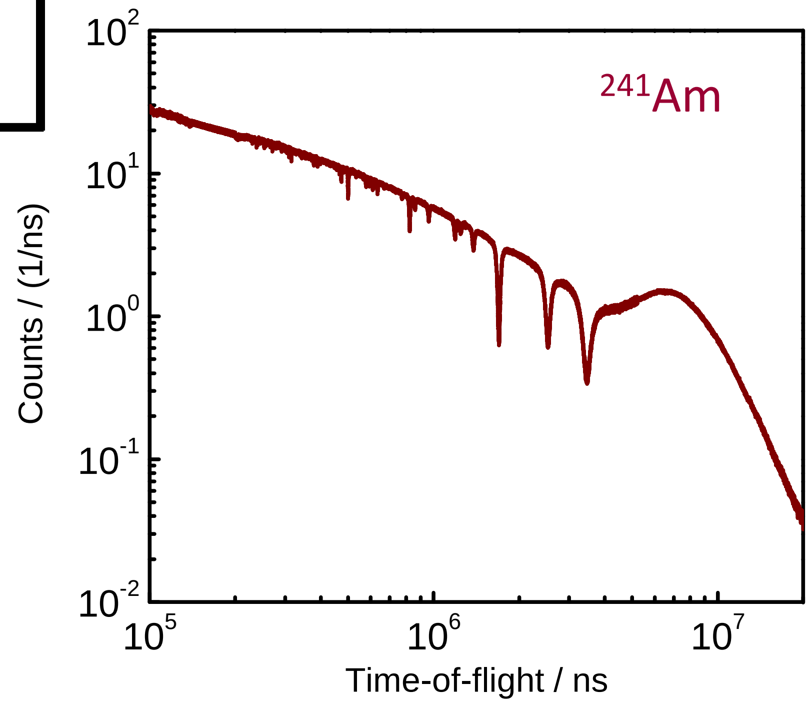
L : distance between target and detector

t : time-of-flight



Neutron resonance transmission analysis (NRTA)





L : distance between target and detector

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Characterization of debris of melted fuel by NRTA : challenges

Target value: uncertainty on Pu and U content $\leq$ 2%

Challenges due to the material characteristics:

- **Inhomogeneity of the samples**: due to diversity in shape and size of the particle - & rock-like debris samples
- **Impact of impurities**: structural material and neutron absorbers, i.e. ^{10}B (control rods and borated water)
- **Complex transmission spectra due to fission products**

Solutions have been studied and validated by experiments at GELINA as part of a JRC/JAEA collaboration

Workshop on Neutron Resonance Densitometry

Joint EURATOM / JAEA workshop

4 – 5 March 2015

JRC-IRMM, Geel, Belgium

Report on progress made

- Presentations on progress made
- Demonstration of NRD performance

50 participants

- Extensive delegation from Japan
  (JAEA, Univ. Kyoto & Nagoya)
- DG-ENER, JRC
- EU Member states
- IAEA, US (DOE, LANL, LLNL, ORNL)

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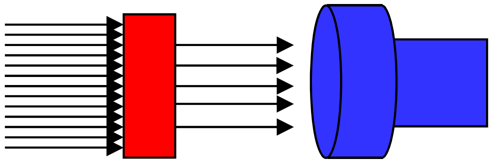
NRTA on homogeneous samples

Transmission is a non-linear function of n

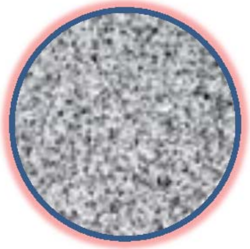
– Homogeneous sample : $T = e^{-n\sigma_{tot}}$



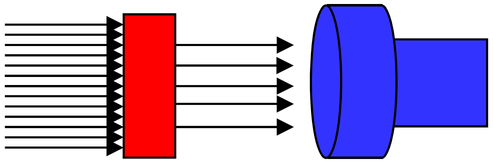
n is the quantity of interest

Impact of particle size distribution

Transmission is a non-linear function of n



- Homogeneous sample : $T = e^{-n\,\sigma_{tot}}$
- Heterogeneous sample : $\langle T \rangle = \langle e^{-n\,\sigma_{tot}} \rangle \neq e^{-\langle n \rangle\,\sigma_{tot}}$



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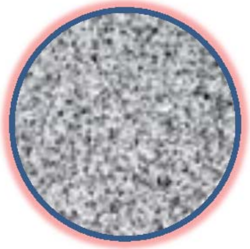

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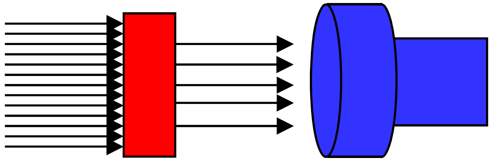

<n> is the quantity of interest

$\Rightarrow$ Dedicated model for debris samples is required to avoid bias effects

$\Rightarrow$ LP- Model (Levermore, Pomraning et al., J. Math. Phys. 27, 2526, (1986))

- Widely used for other problems dealing with radiation transport through stochastic media, e.g. scattering of sunlight in clouds
- **Validated by experiments at GELINA** (Becker et al., EPJ Plus 129 (2014) 58 – 9)

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NRTA demonstration experiment at GELINA

Samples

18 different samples

8 different elements

Black box: 8 slots

- B, Mn, Co, Cu, Nb, Rh, W, Au samples with different thicknesses
- Selection of samples by DG-ENER, IAEA and DOE representatives

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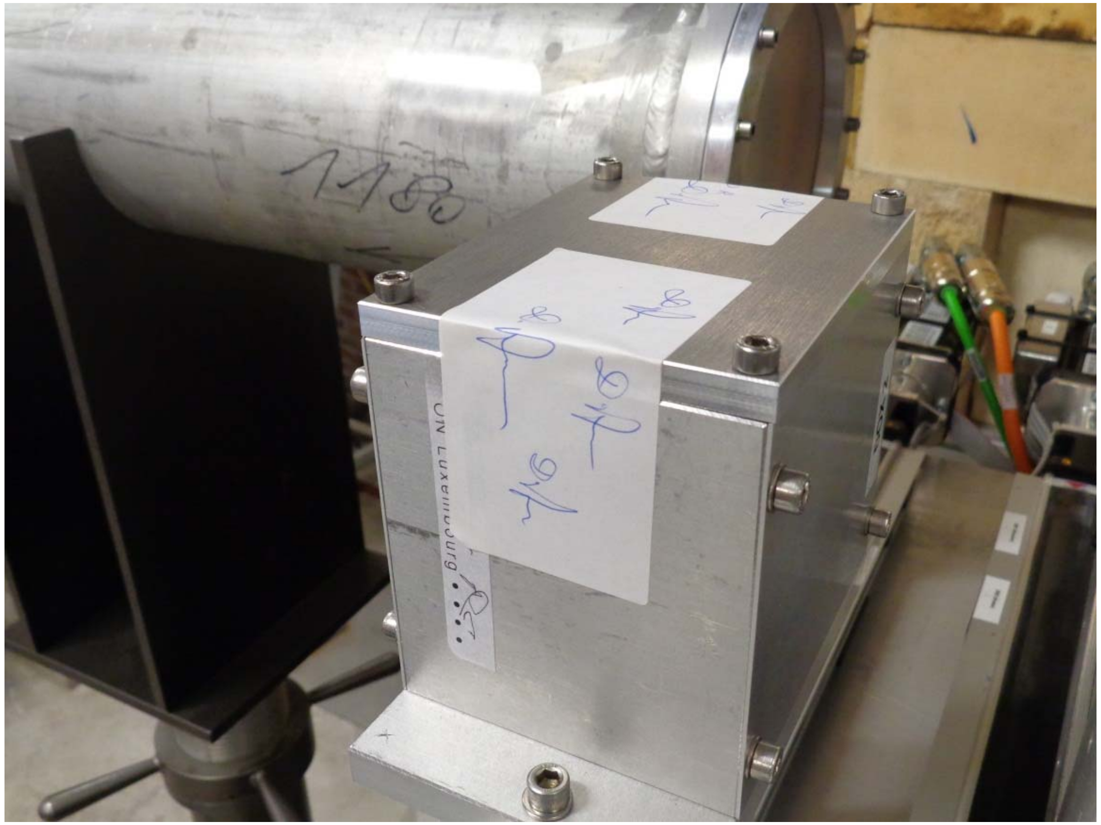
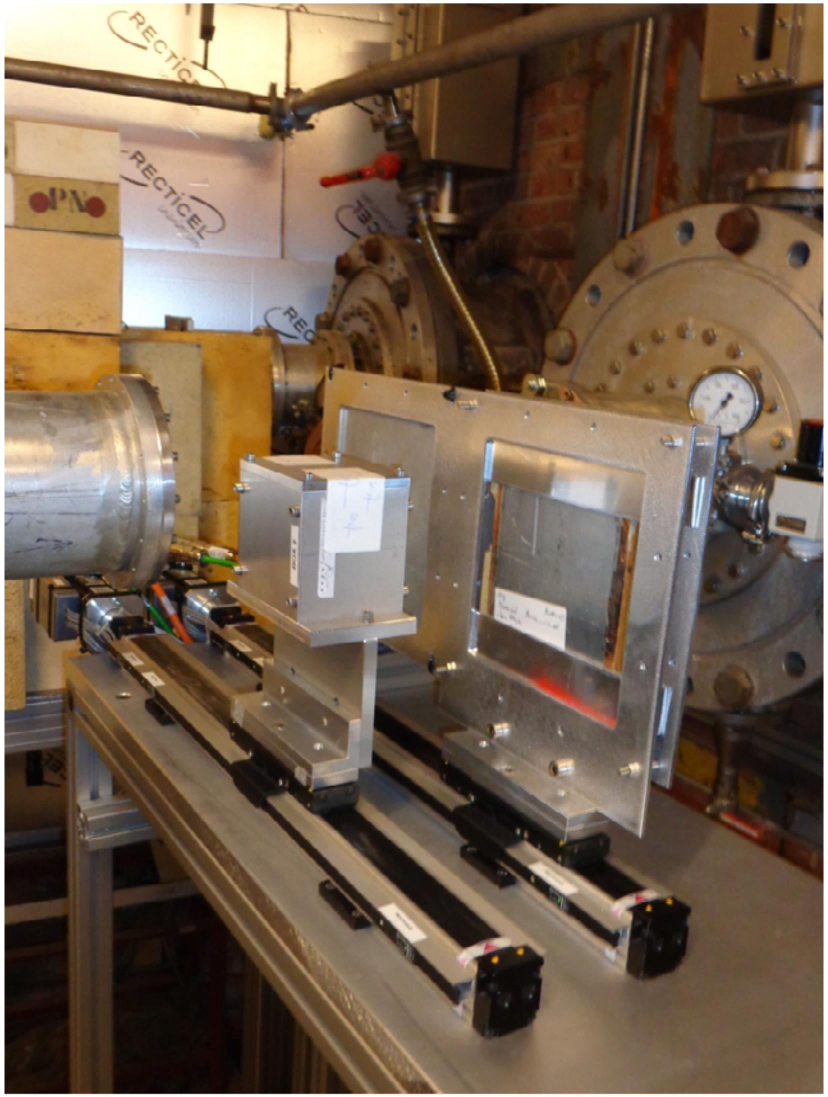
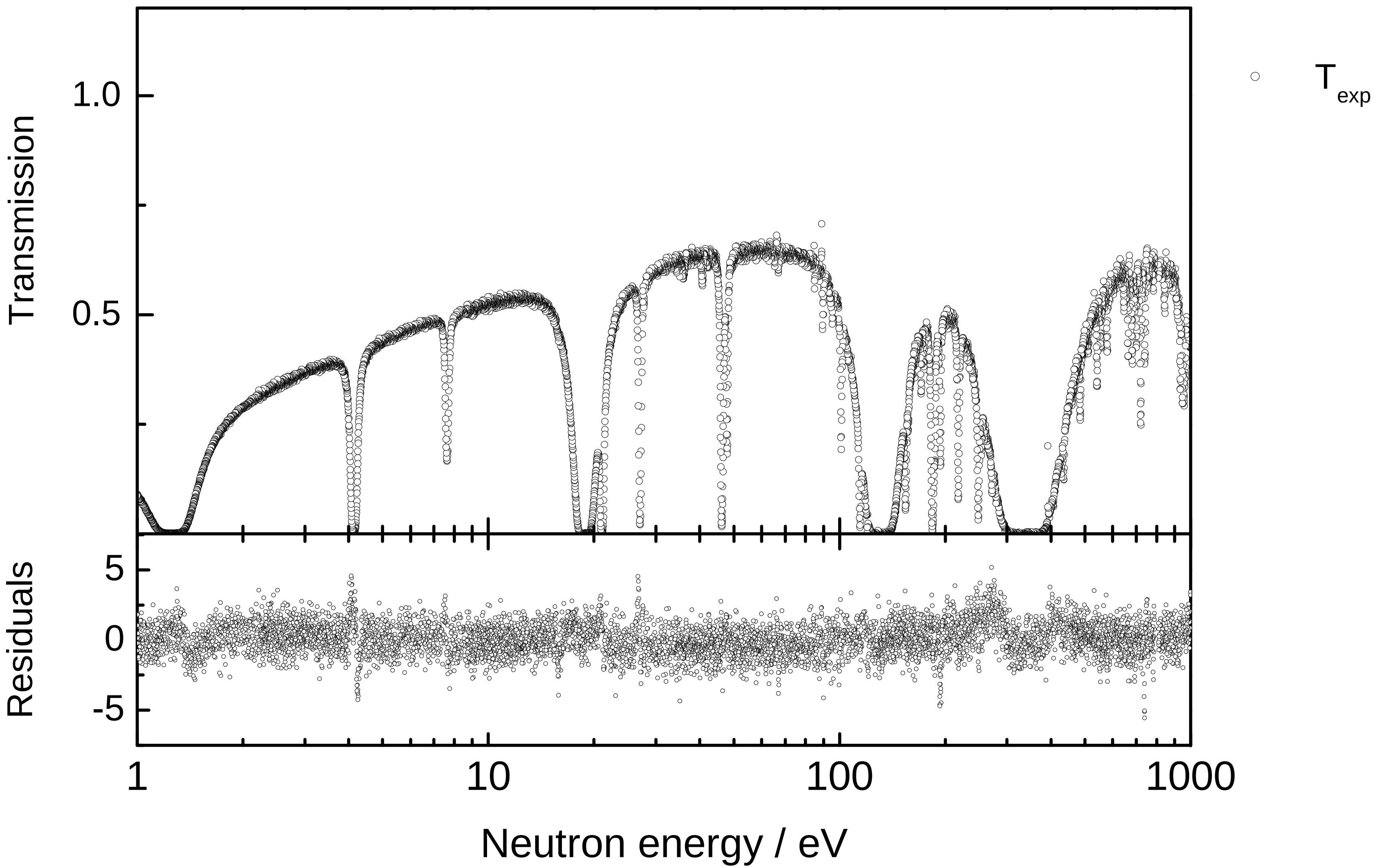
NRTA demonstration experiment at GELINA

NRTA station at 10 m





NRTA demonstration experiment at GELINA



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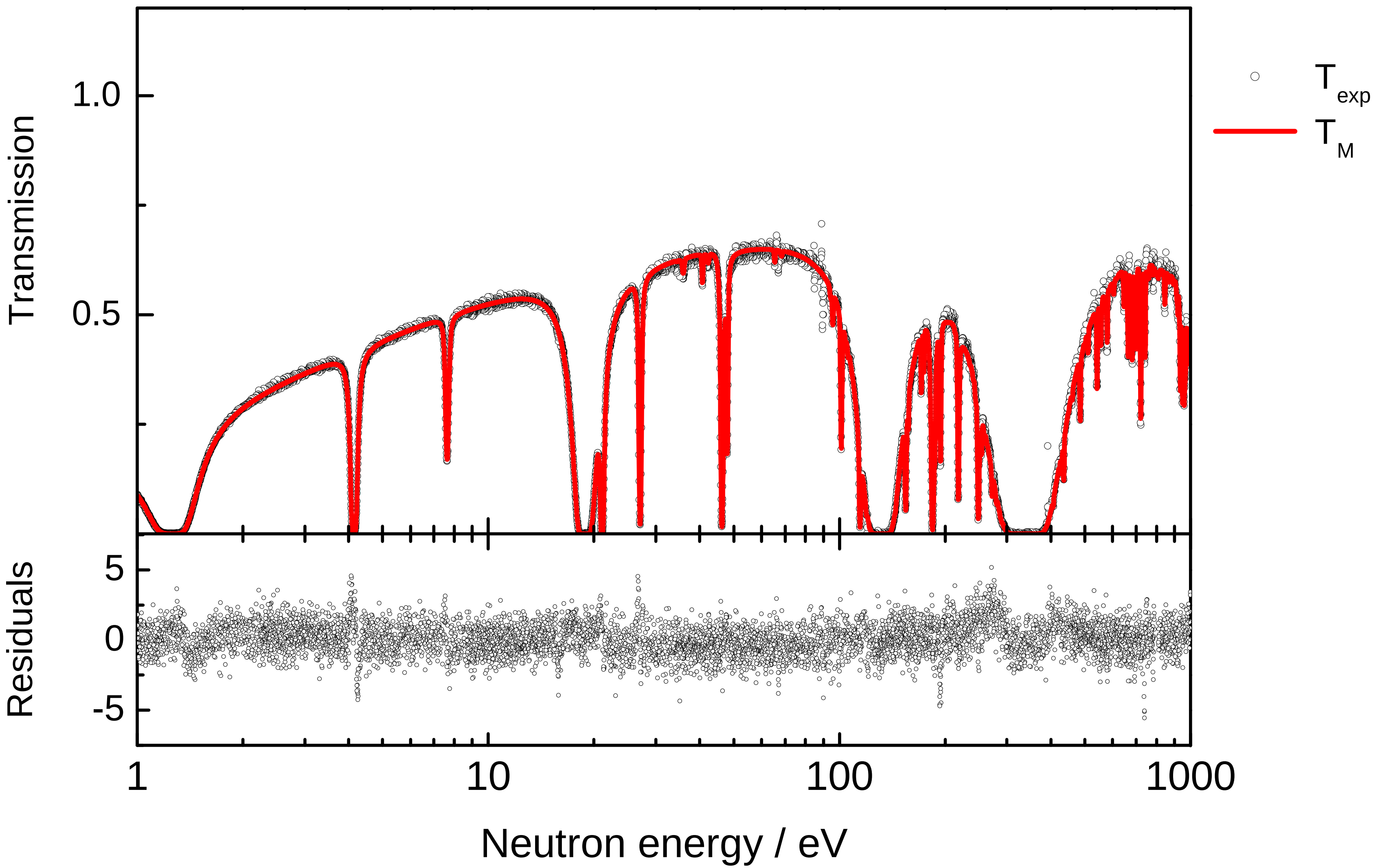

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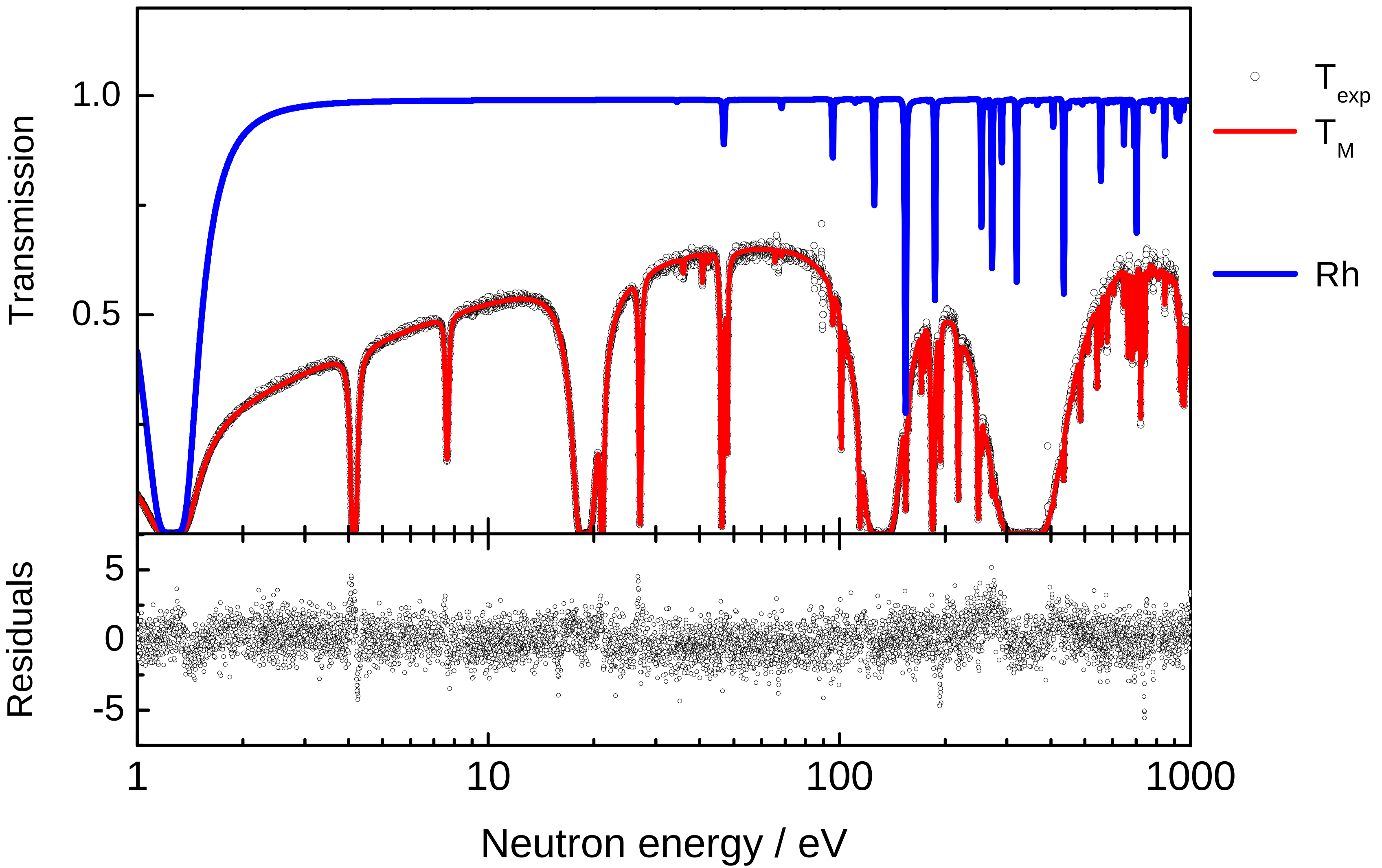

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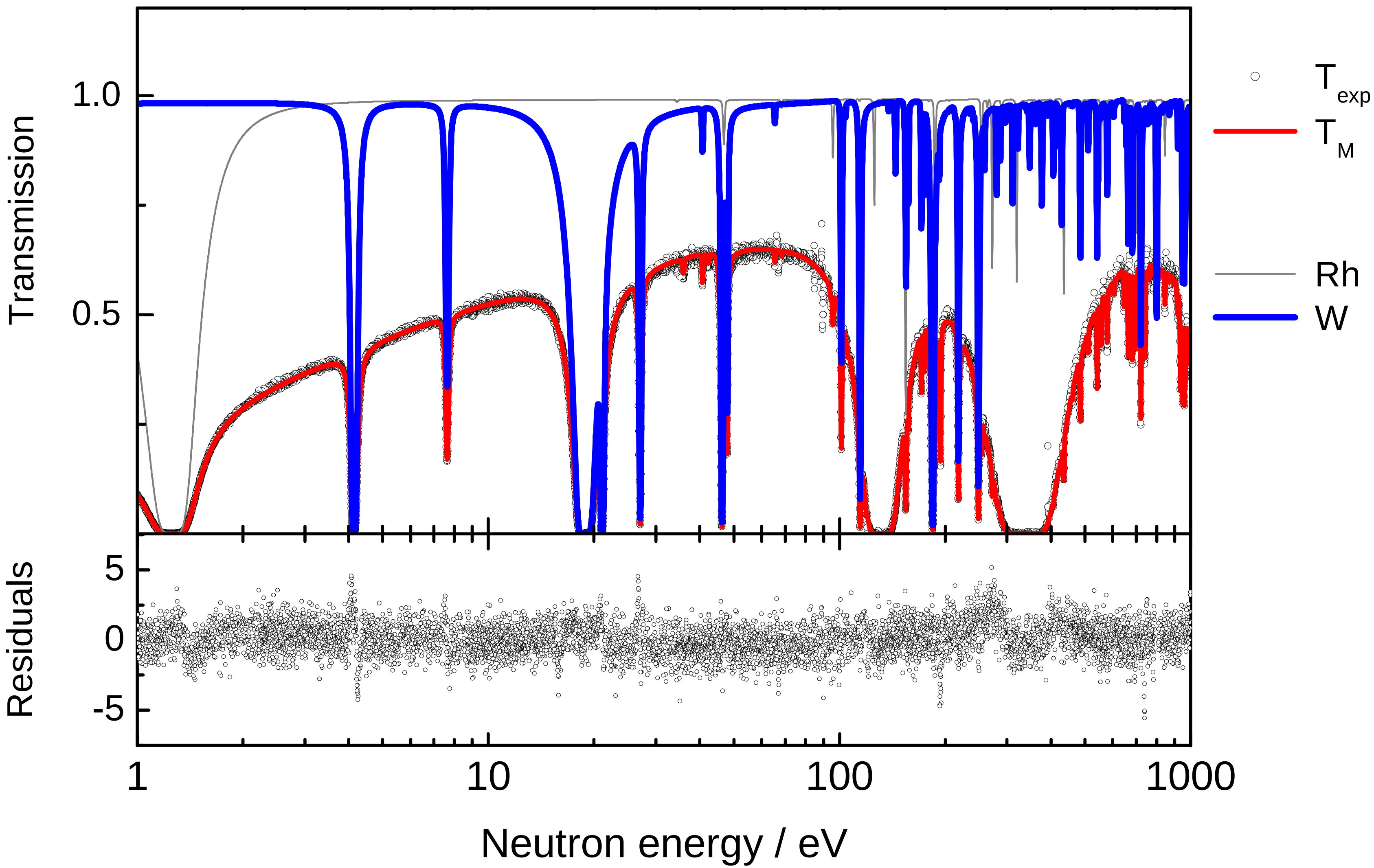

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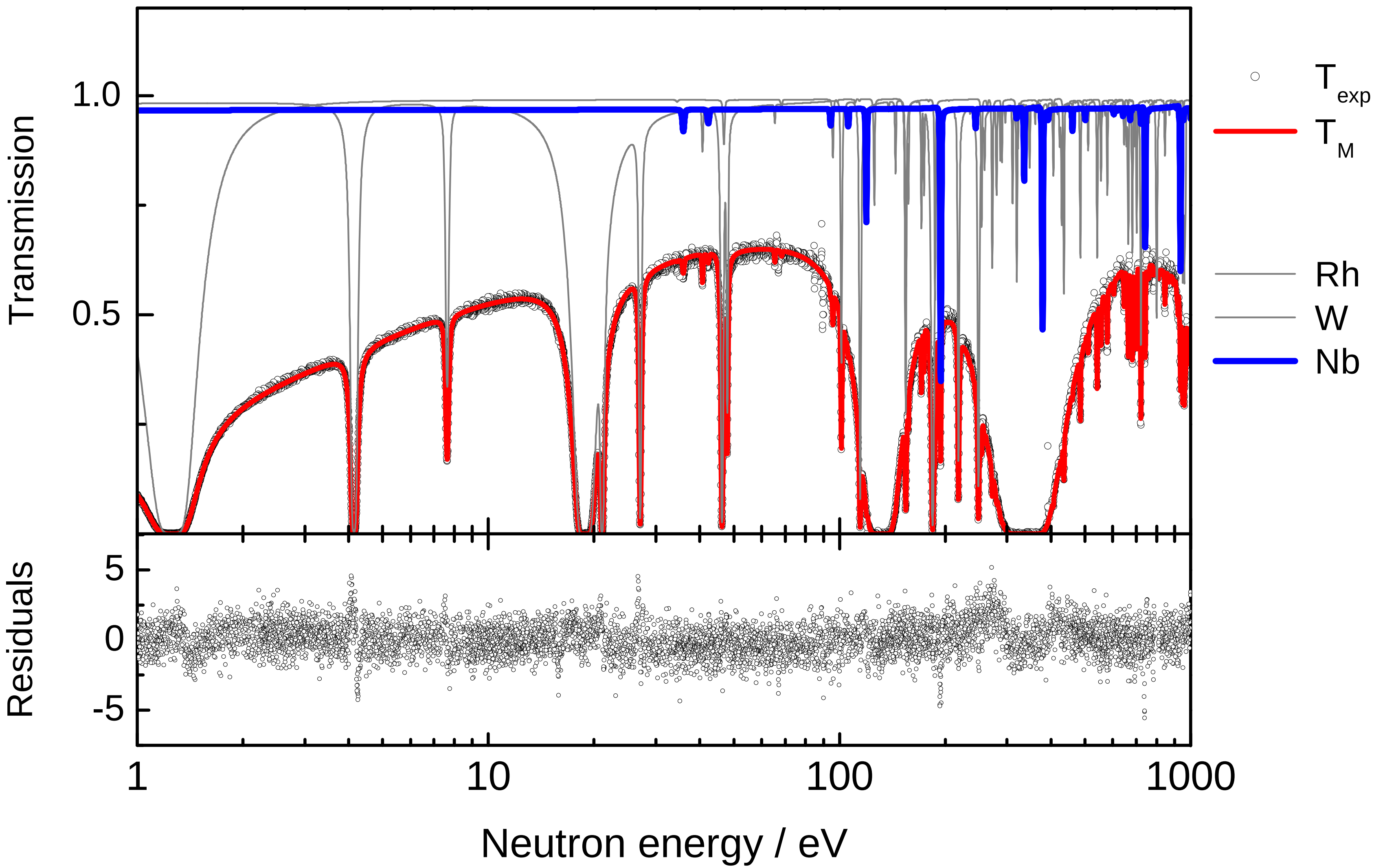

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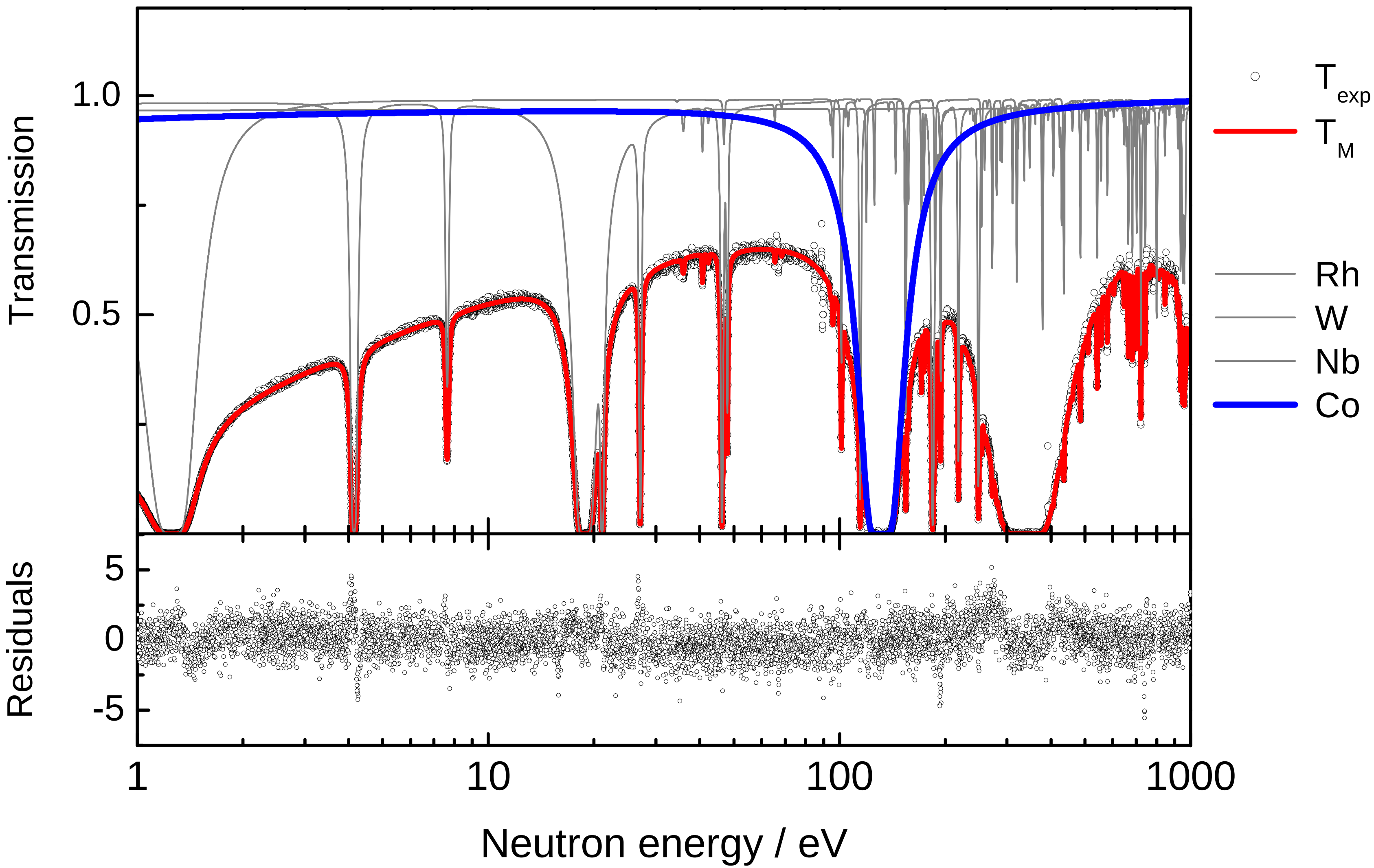

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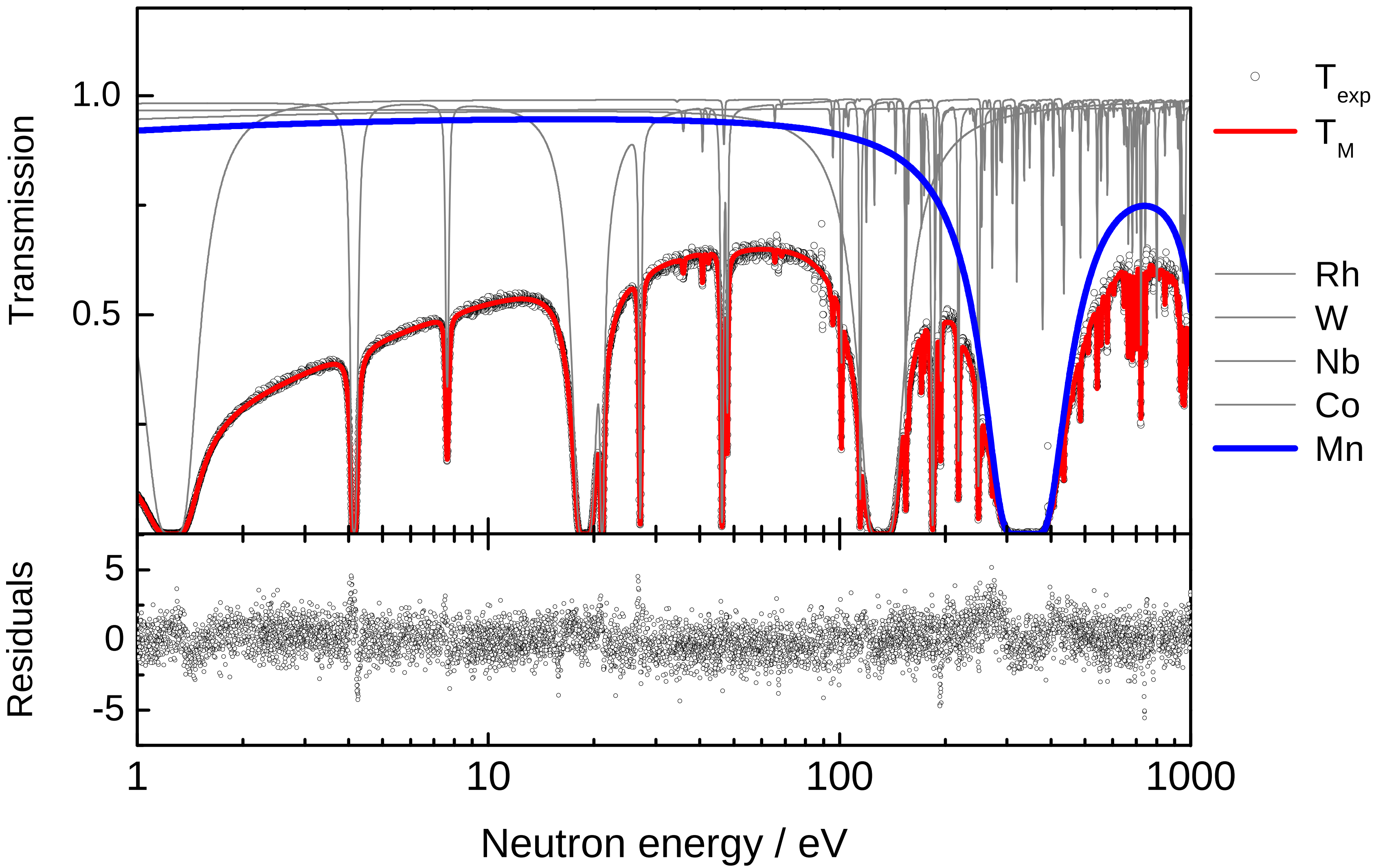

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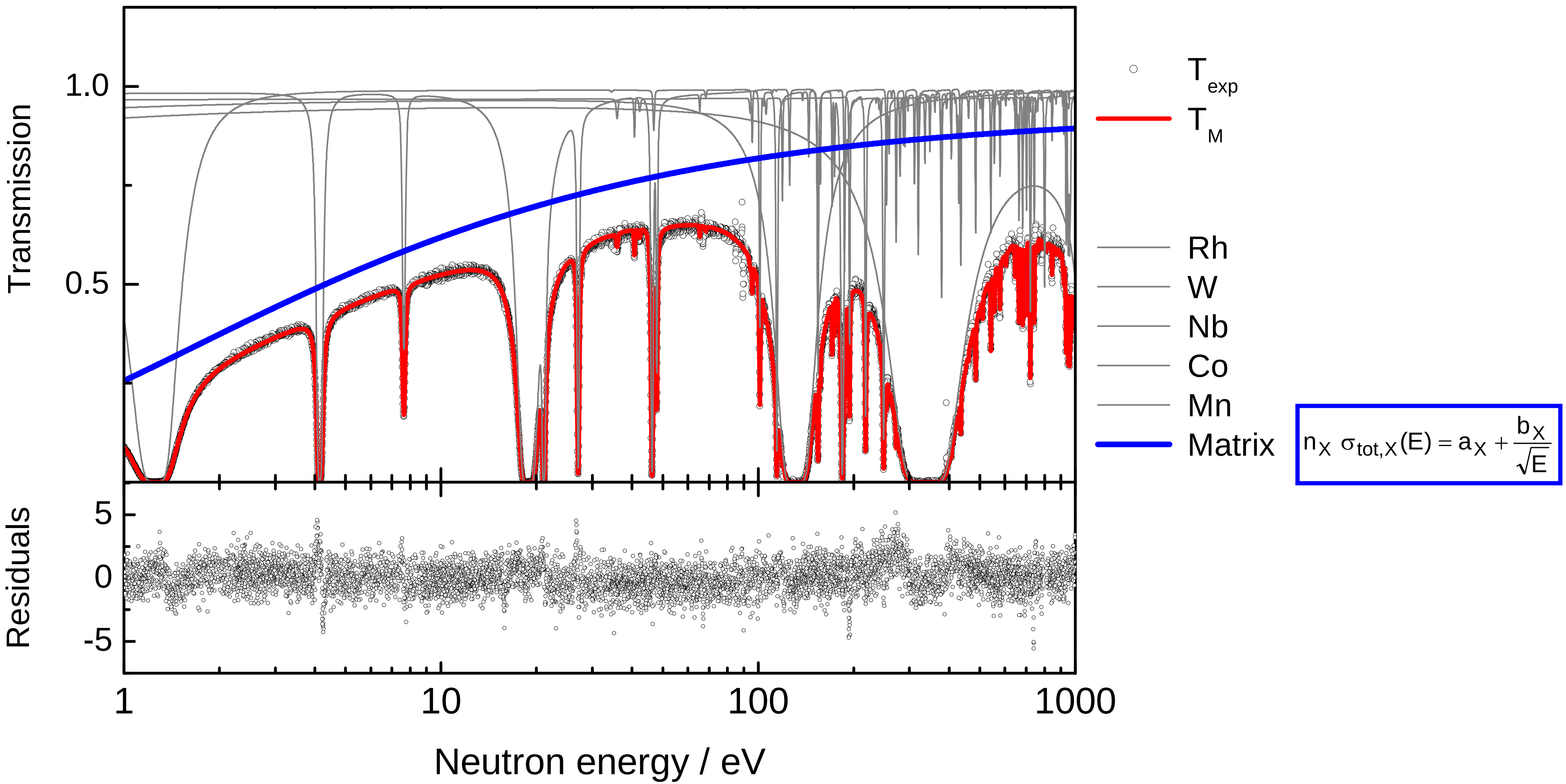
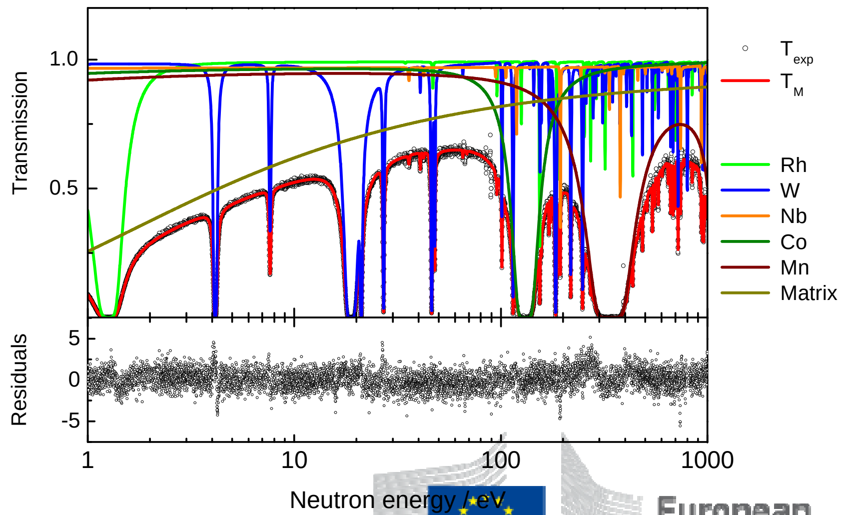


NRTA demonstration at GELINA : results

Element	Areal number density (at/barn)
	n_{NRTA}
Mn	$(1.928 \pm 0.003) \times 10^{-2}$
Co	$(4.509 \pm 0.015) \times 10^{-3}$
Cu	0
Nb	$(5.382 \pm 0.010) \times 10^{-3}$
Rh	$(1.891 \pm 0.003) \times 10^{-3}$
W	$(2.250 \pm 0.002) \times 10^{-3}$
Au	0



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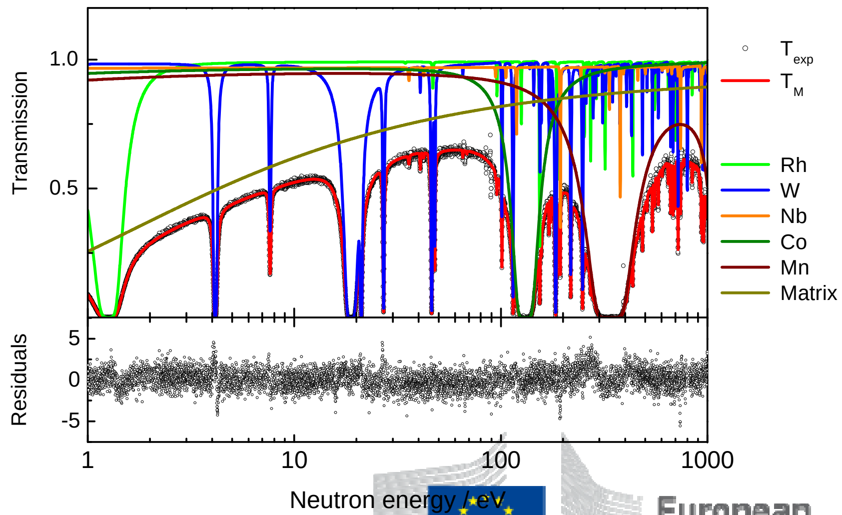
NRTA demonstration at GELINA : results

Element	Areal number density (at/barn) n_{Ref}	n_{NRTA}	n_{Ref}/n_{NRTA}
Mn	1.901×10^{-2}	$(1.928 \pm 0.003) \times 10^{-2}$	1.014 ± 0.002
Co	4.583×10^{-3}	$(4.509 \pm 0.015) \times 10^{-3}$	0.984 ± 0.003
Cu	0	0	
Nb	5.485×10^{-3}	$(5.382 \pm 0.010) \times 10^{-3}$	0.981 ± 0.002
Rh	1.856×10^{-3}	$(1.891 \pm 0.003) \times 10^{-3}$	1.019 ± 0.002
W	2.269×10^{-3}	$(2.250 \pm 0.002) \times 10^{-3}$	0.992 ± 0.001
Au	0	0	



NRTA demonstration at GELINA : results

Element	A … n_{Ref} …	n_{Ref}/n_{NRTA}
Mn	1.901 x …	1.014 ± 0.002
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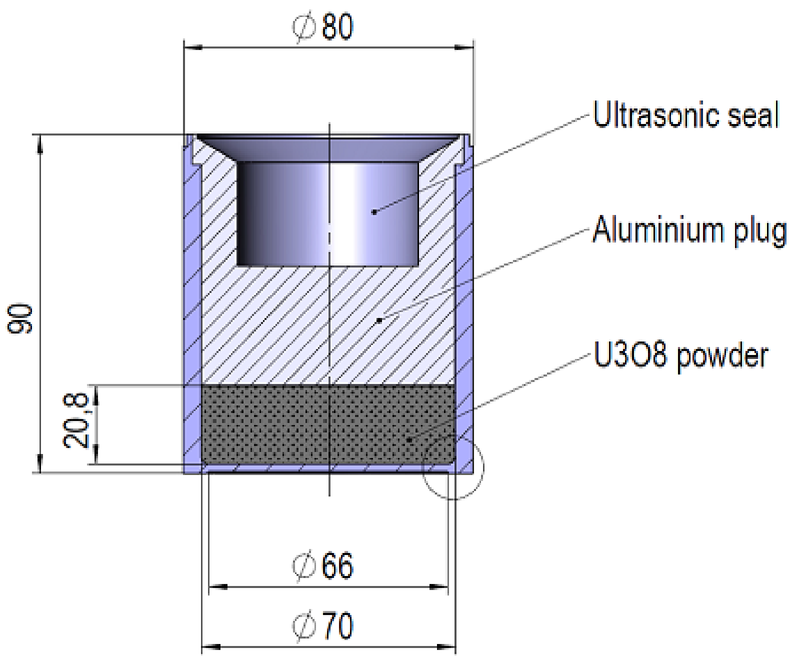
W	2.269 x …	0.992 ± 0.001
Au	0	

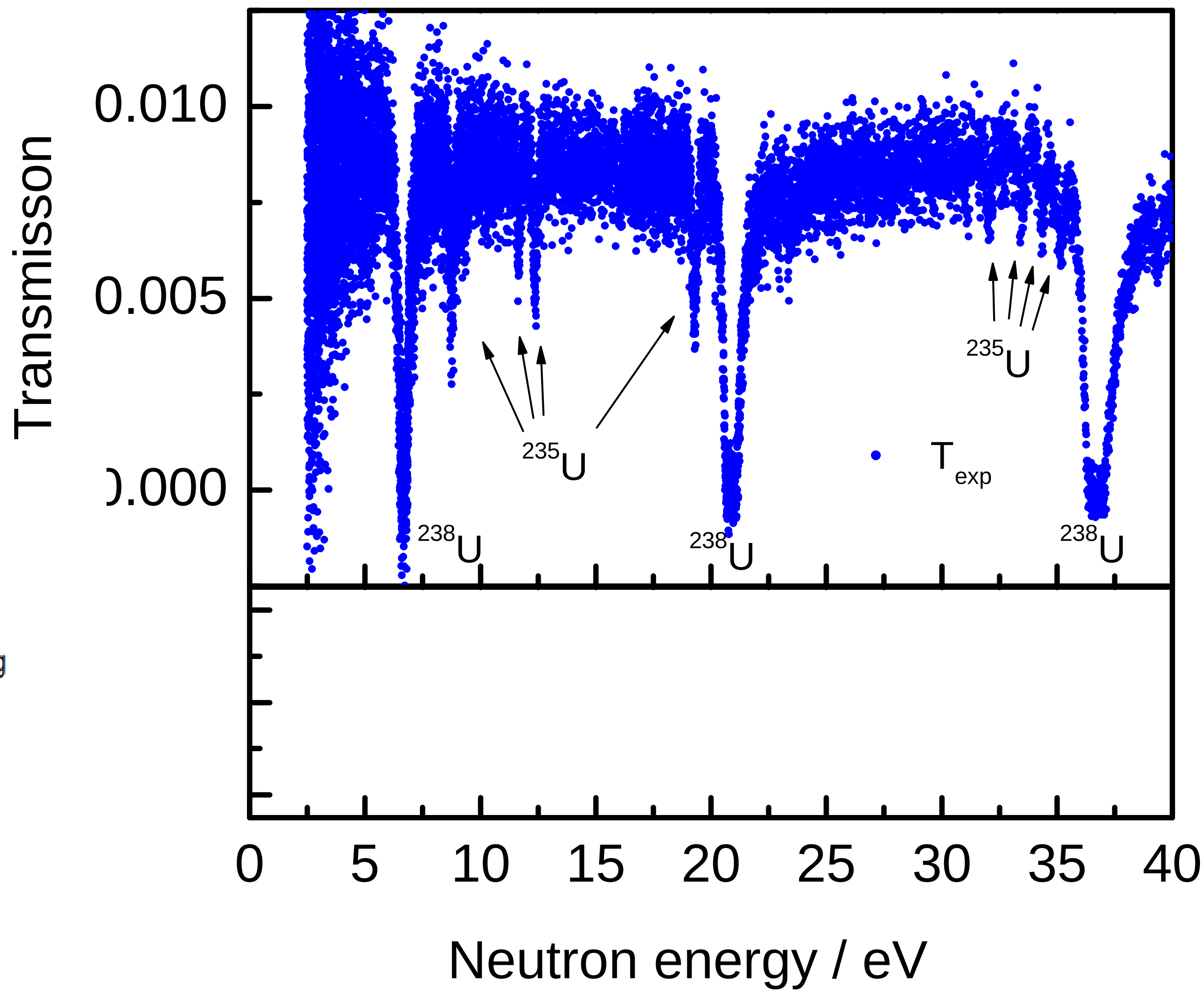
Bias $\leq$ 2%

NRTA of nuclear material GELINA

U_3O_8 reference sample
EC NRM 171

Beam attenuation
due to matrix
~ 99%



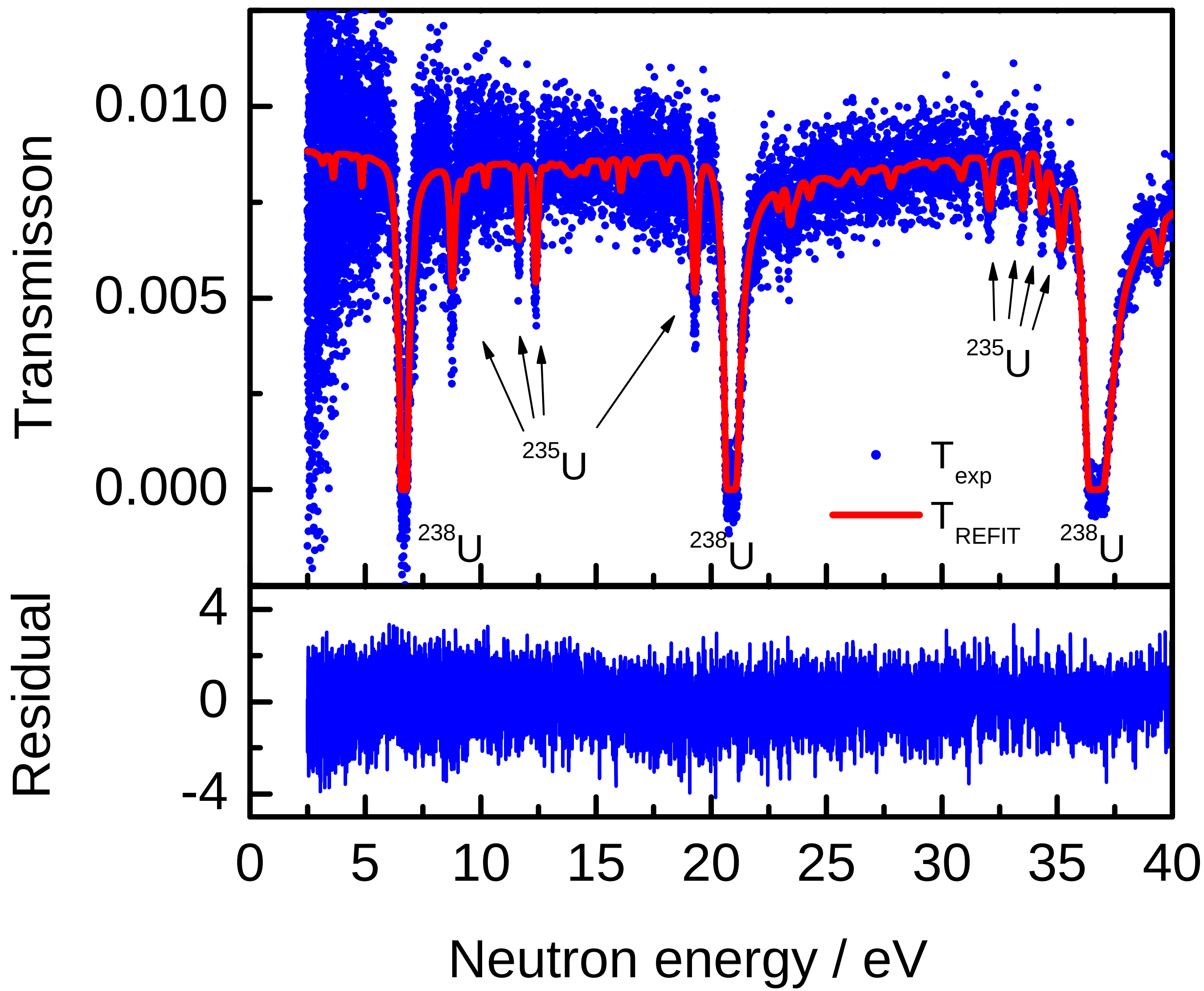


NRTA of nuclear material at GELINA

U_3O_8 reference sample
EC NRM 171

Beam attenuation
due to matrix
~ 99%

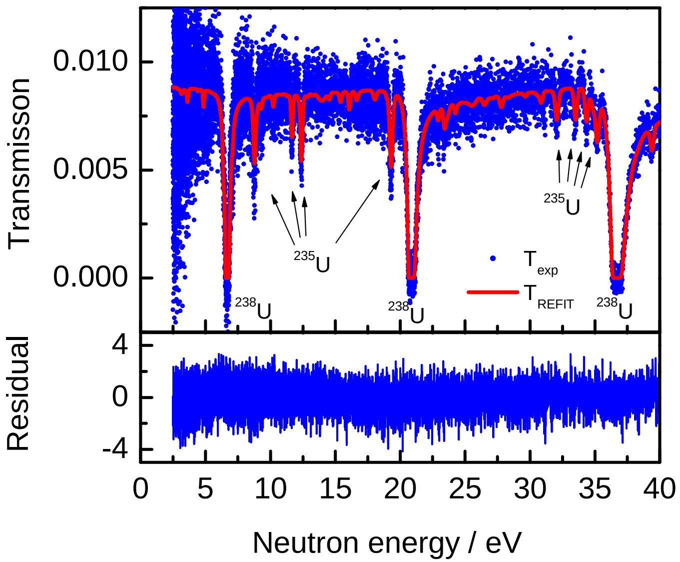
Fit for the amount of
^{235}U and ^{238}U



NRTA of nuclear material at GELINA

U_3O_8 reference sample
EC NRM 171

U-isotope	Areal number density (at/b)		Ratio
	Declaration	NRTA	
^{235}U	$(5.0326 \pm 0.0080) \times 10^{-4}$	$(5.063 \pm 0.09) \times 10^{-4}$	**1.006**
^{238}U	$(1.0628 \pm 0.0015) \times 10^{-2}$	$(1.062 \pm 0.01) \times 10^{-2}$	**0.999**



$\Rightarrow$ bias < 1.0 %

Schillebeeckx et al., JRC Science and Policy Report, EUR 26848 EN

Conclusions from Action Sheet - 1

NRTA is an analytical NDA technique to characterize nuclear material :

- Accurate absolute method
  (bias effects < 2%, accuracy depends on nuclear data)
- Sensitive to almost all nuclides (except for light nuclides)
- Applicable for high radioactive nuclear material
- No calibration requirements using representative calibration standards
- No sample preparation requirements
- No history requirements to determine U and PU content
- Performance of NRTA on complex materials such as debris of melted have been validated by experiments at GELINA

Intensify JRC – JAEA collaboration: Action Sheet - 7

- Active neutron NDA techniques for nuclear non-proliferation, security and safety
  - Neutron Resonance Transmission Analysis (NRTA)
  - Neutron Resonance Capture & Prompt Gamma Ray Analysis (NRCA &PGA)
  - Delayed Gamma Spectroscopy (DGS)
  - Differential Die Away (DDA)

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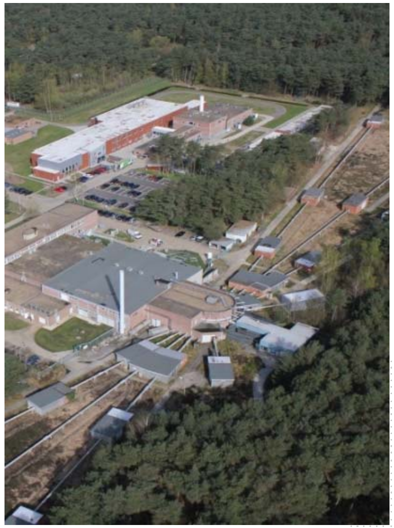
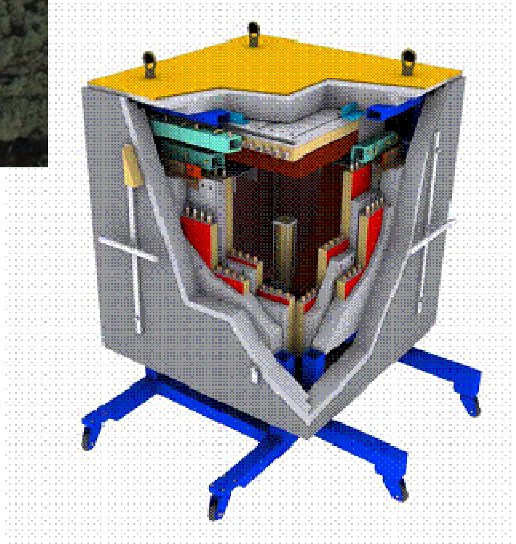
Intensify JRC – JAEA collaboration: Action Sheet - 7

- Active neutron NDA techniques for nuclear non-proliferation, security and safety
  - Neutron Resonance Transmission Analysis (NRTA)
  - Neutron Resonance Capture & Prompt Gamma Ray Analysis (NRCA &PGA)
  - Delayed Gamma Spectroscopy (DGS)
  - Differential Die Away (DDA)
- Strategy
  - Study and improve methodologies
  - Production of calibration and transfer standards
  - Experimental validation at existing facilities
- Use of nuclear facilities at JRC & JAEA
  - JRC Ispra : PUNITA
  - JRC Geel : GELINA, MONNET & Sample preparation
  - JAEA Tokai : TRP – PCDF
  - JAEA Tokai : NUCEF





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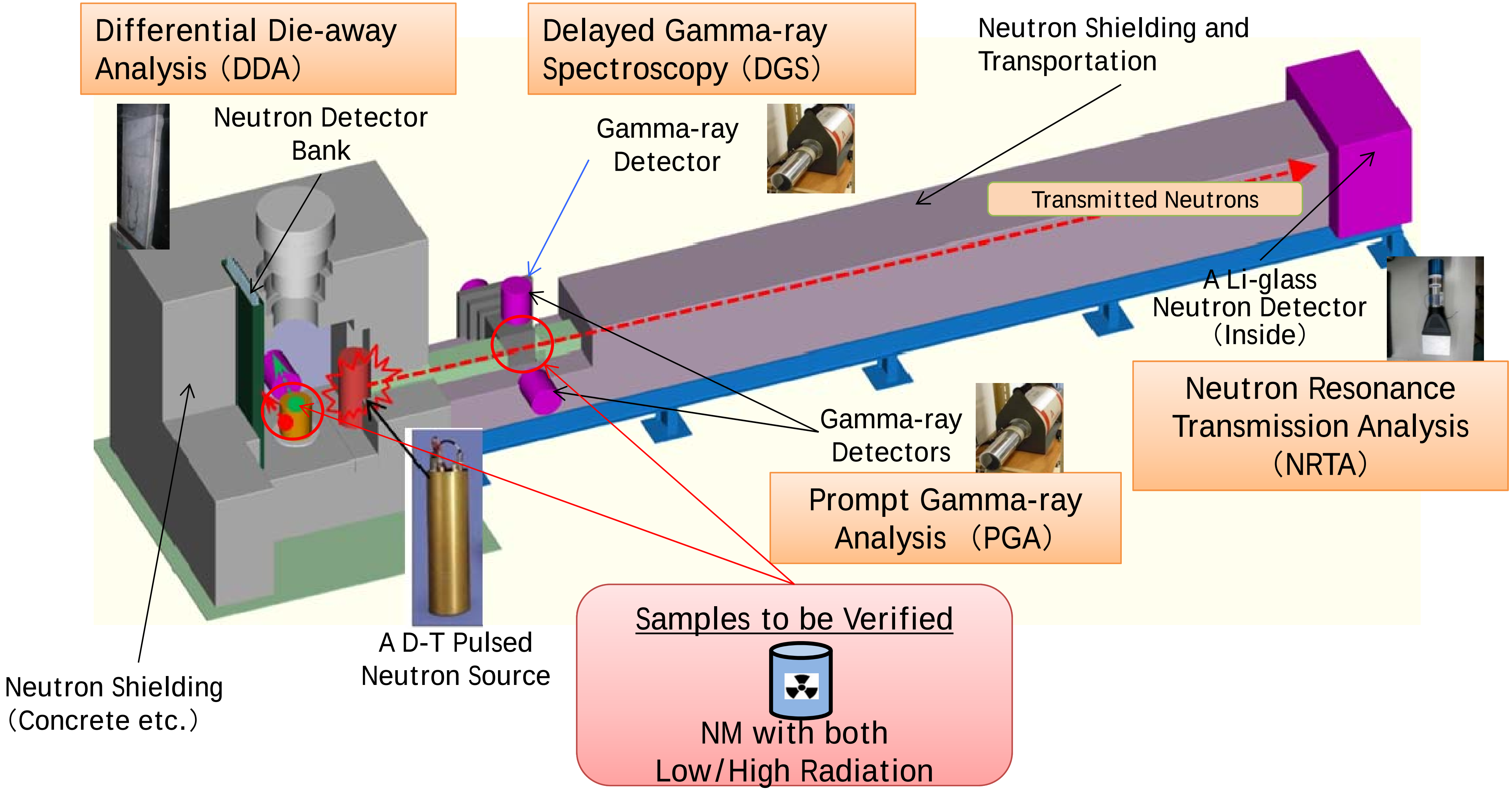
Active Neutron NDA Prototype: JAEA NUCEF



Development of a compact industrial NRTA facility

- Define and validate design parameters of a compact NRTA facility
- Develop and test a radiation resistant neutron detector
- Perform validation experiments with nuclear material (including spent fuel)
- Applications studies (analytical NDA technique with accuracy better than 2%)
  - Decommissioning (including melted fuel from nuclear accidents)
  - Storage and disposal of spent fuel
  - Reprocessing facilities
  - Innovative nuclear fuel cycles
  - Nuclear forensics

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Summary

- JAEA and JRC successfully demonstrated an innovative technique to characterize complex nuclear material (e.g. melted fuel from nuclear accident):
  - The technique is an absolute method to measure accurately the amount of U and Pu and fission products with a bias < 2%.

  - The technique can be applied for various applications in the nuclear fuel cycle

  Atomic Energy Society Japan award : Distinguished Technology Development

- Based on the success of the first collaboration project (AS-1) a new collaborative effort was defined (AS-7) to study and develop active neutron interrogation systems for nuclear non-proliferation, security and safety applications.

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Thank you

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