Task 4.2:
FY and nuclear structure and decay data evaluation

A. Negret, M. Fallot, M. Kellett, S. Lalkovski, O. Serot, J. Timar

Task 4.2: Fission yields and nuclear structure and decay data evaluations
Task coordinator: IFIN-HH, partners: IFIN-HH, CEA/LNHB, CNRS/LPSC, Sofia, Atomki, CNRS/Subatech

Task 4.2.1: Evaluation of Fission yields
The analysis and evaluation of fission yields is also of prime importance for many applications (e.g. correct estimation of the content of spent nuclear fuel). The CEA/DEN, CNRS/LPSC have a large experience in measuring, analysing and evaluating thermal neutron-induced fission yields. In the framework of a collaboration between the Physical Studies Laboratory (LEPh) of the CEA (France), the Subatomic and Corpuscular Physics lab (LPSC of CNRS) of Grenoble (France) and others, a program of actinide fission yield measurements of interest for the current and innovative nuclear reactors has been initiated for several years. In this task, the proposed work will allow to deeply test some model assumptions used in the fission yield evaluations. The program will be based on the measurements of kinetic energy dependency of yields, isomeric ratios or isotopic distributions. It is defined in three parts: two experimental, and the last one dealing with the improvement of the modelling of the fission products used in the evaluations (e.g. modelling of the fission products from the FIFRELIN Monte Carlo code).

Task 4.2.2: Evaluation of nuclear structure and decay data
Together with the fission yields, evaluations of nuclear structure and decay data can have an important impact on specific applications, such as decay heat calculations. Additionally, it is important that the (cumulative) fission yields are evaluated together with decay data. In this context, a few experienced groups will join efforts to perform ENSDF (Evaluated Nuclear Structure Data File) evaluations. ENSDF constitutes the main source of nuclear structure information used in RIPL (The Reference Input Parameter Library), the major library used by TALYS and EMPIRE. It should be noted that some of these groups also have experimental and simulation programs which are combined with the evaluation efforts. For instance, new TAGS data will be analysed to develop the calculation of the experimental uncertainties associated to these experiments, in order to be able to provide nuclear databases with covariance matrices for beta decay data. These covariance matrices are mandatory for the propagation of decay data uncertainties on the decay heat, antineutrino spectra and beta-delayed neutron emission fractions of reactors (CNRS/Subatech). Evaluation activity will be performed by CEA/LNHB, ATOMKI, Sofia and IFIN-HH: theoretical calculations, evaluations, modern evaluation tools (and training) and nuclear data library production (e.g. evaluated decay scheme), to improve the next version of the JEFF Radioactive Decay Data Library and the Evaluated Nuclear Structure Data File.

Task 4.2:
Evaluation of nuclear structure/decay and FY

- Fission Yields evaluation (and measurements)
- Nuclear structure evaluation for ENSDF and DDEP
- Decay data evaluation with TAGS data

Fission Yields

FY measurement Collaboration :

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2 CEA, DES, IRESNE,DER, SPRC, LEPh, Cadarache center, F-13108 Saint Paul lez Durance, France
3 Institut Laue-Langevin, F-38042 Grenoble Cedex 9, France
4 CEA, DSM, IRFU, SPhN, LEARN, Saclay center, F-91191 Gif-sur-Yvette, France

Task 4.2.1:
Tests of some model assumptions used in the FIFRELIN code

Directly linked to the LOHENGRIN measurements (ILL) described in WP 2

FIFRELIN (developed at CEA-Cadarache) = Monte-Carlo code for

- Calculating fission observables: spectra and multiplicities of the prompt neutron and gamma particles; energies released; **fission yields**…)
- Investigating correlations between fission observables

- The activity carried out by the CNRS/LPSC (Grenoble) in collaboration with the CEA-Cadarache, was completed in 2021;
- PhD Thesis: Jehaan NICHOLSON, “Determination of fission fragment angular momentum from isomeric ratio measurement”, September 2021, University Grenoble Alpes, France

Nuclear structure and decay data evaluation (ENSDF)

Z. Elekes, S. Lalkovski, A. Negret, S. Pascu, J. Timar

Task 2.3: ENSDF evaluation

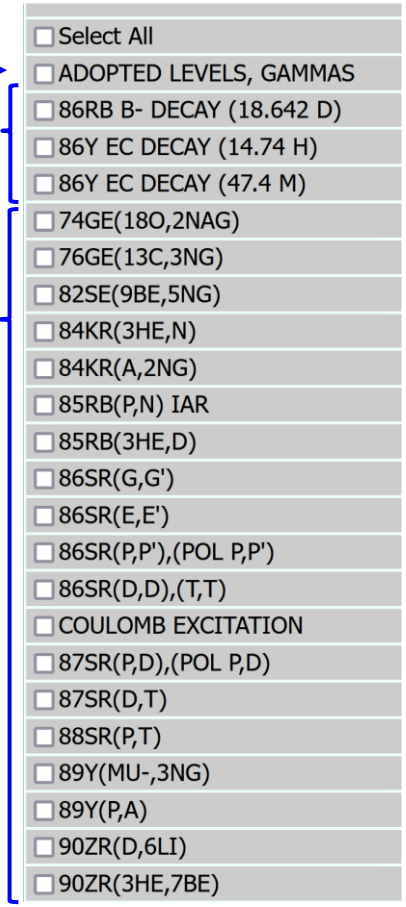
- Essential for research, applications, nuclear reactions, etc. All nuclear structure information from other databases (including RIPL) is based on ENSDF.
- Maintained by the Nuclear Structure and Decay Data Network, under coordination of IAEA. Only 3 Data Centres in Europe: Debrecen, Bucharest, Sofia. Most data centres in US, because there it is supported at the federal level.
- This is for the first time that ENSDF evaluation is funded through a European project.

Task 2.3:
More about ENSDF evaluation

^{86}Sr

For each nucleus:

- Adopted Levels, Gammas
- Decay datasets
  - Decay dataset 1
  - Decay dataset 2
  - …
- Reaction datasets
  - Reaction dataset 1
  - Reaction dataset 2
  - …



- Nuclear structure evaluators are experimentalists.
- Evaluation policies clearly defined.
- Evaluation techniques, evaluation software available.
- Mass-chain evaluations published in Nuclear Data Sheets and on the website; all evaluations are reviewed.

Task 2.3:
Status of ENSDF evaluation

Identification of nuclear structure data evaluation needs that serve

- The needs of the European projects: SANDA, JEFF, etc.
- The more general needs of ENSDF

IFIN-HH, Romania

1. Evaluation of isotopes of importance for monitoring applications, in collaboration with IAEA. An ongoing project is addressing the needs of the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization): - evaluation of the decay of ^{133}I and ^{140}La – sent for review
2. A new evaluation of several isotopes of the A=86 mass chain – 2022-2023.

ATOMKI, Hungary

1. A new evaluation the A=103 mass chain – ongoing (first half completed in 2021).
2. Evaluation of ^{47}Sc and ^{187}Re (medical applications) – 2022.

ATOMKI – IFIN-HH Collaboration

Joint evaluation the A=101 mass chain – completed in 2021, sent for review in 2022. Post-review effort to be performed within SANDA (2022-2023).

Sofia University, Bulgaria

1. A new evaluation the A=107 mass chain – ongoing (50% completed).
2. Evaluation of ^{117}Sn (medical applications) – ongoing (90% completed)

Decay data evaluation with TAGS data

A. Beloeuvre, E. Bonnet, M. Estienne, M. Fallot, L. Giot, R. Kean, A. Laureau and A. Porta

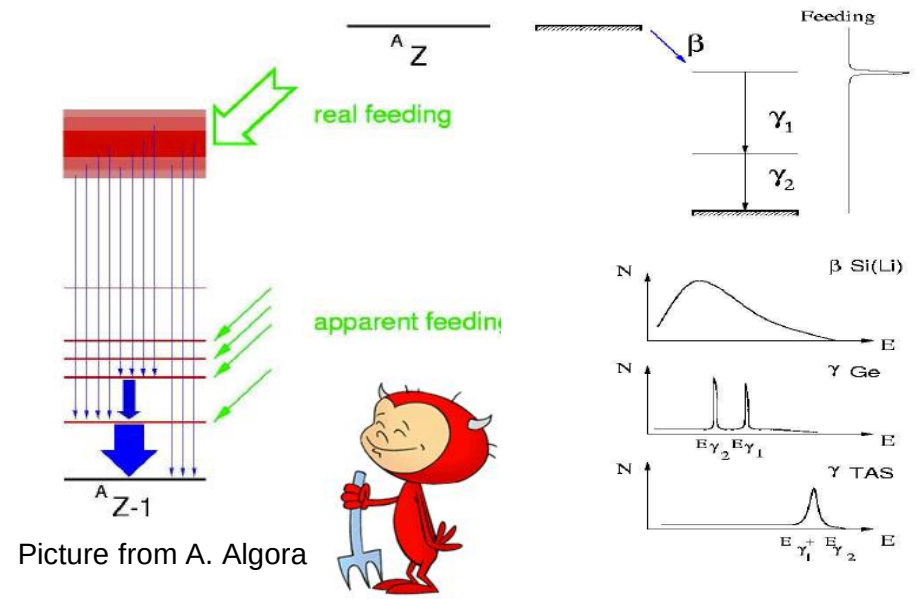
SUBATECH, Nantes, France

TAGS Solution to Pandemonium Effect

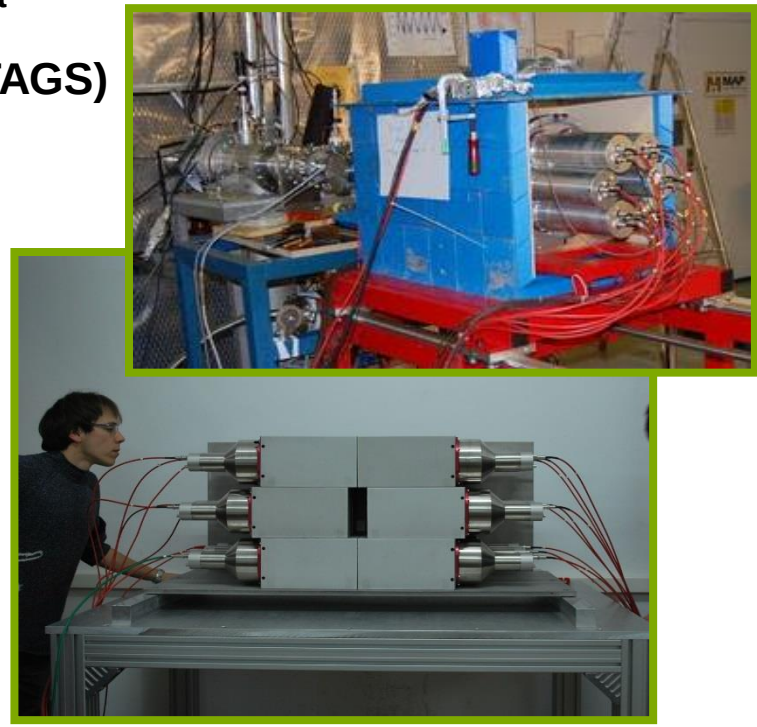
Pandemonium effect** :

Due to the use of Ge detectors to measure the decay schemes: lower efficiency at higher energy => underestimate of γ branches towards high energy excited states: overestimate of the high energy part of the FP γ spectra

⇒ Solution is Total Absorption γ-ray Spectroscopy (TAGS)
Big cristal, 4π => A TAGS is a calorimeter !



Picture from A. Algora



2 TAGS arrays developed by the Valencia team (Spain, B. Rubio, J.L. Tain, A. Algora et al.): Rocinante (12 BaF2) & DTAS (18 NaI)

** J.C.Hardy et al., Phys. Lett. B, 71, 307 (1977)

TAGS Experimental Campaigns

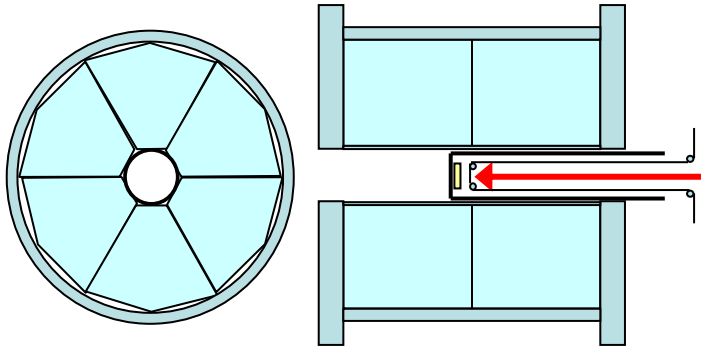
- **Decay Total Absorption Spectrometer (DTAS) for FAIR (IFIC Valencia): used in Jyväskylä in Feb. 2014 for our reactor antineutrino proposal:** 18 modules 15x15x25 cm^3 NaI(Tl) + 5" PMT
  - 12 nuclei for antineutrinos measured & 11 for decay heat
  - See V. Guadilla's talk at JEFF/CHANDA meeting in Nov. 2017

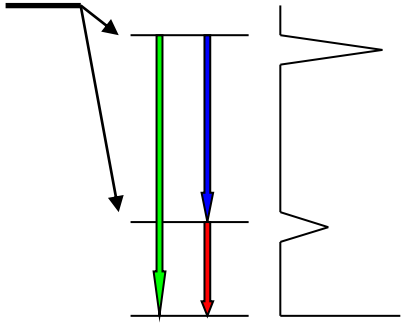
- **BAF_2 TAGS (Surrey-Valencia): used for the 2009 measurement at IGISOL-JYFLTRAP**: ^{86}Br, ^{87}Br, ^{88}Br, ^{91}Rb, **^{92}Rb, ^{93}Rb,** ^{94}Rb
  - ^{92,93}Rb results already shown at last meetings, see **A. Zakari-Issoufou et al., PRL 115, 102503 (2015)**
  - ^{87}Br, ^{88}Br**,** ^{94}Rb **E. Valencia et al. PRC 95 024320 (2017)**
  - ^{86}Br, ^{91}Rb **S. Rice et al. PRC 96 014320 (2017)**

Antineutrino Proposal in Jyväskylä: Subatech-IFIC collaboration

V.Guadilla et al.,, Nucl. Inst. and Meth. B, in press. Online (2015) : http://www.sciencedirect.com/science/article/pii/S0168583X15012628

Total Absorption Spectroscopy (TAS)
Big cristal, 4π => A TAS is a calorimeter





Observable:

β-intensity => β-strength:
An ideal TAS would give directly the β-intensity I_β which is linked with the β-strength S_β:

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}} \quad [s^{-1}]$$

$$I_i = \frac{f_i}{\sum_k f_k}$$

Statement of the problem:

Relation between TAS data and the β-intensity distribution:

$$d_i = \sum_j R_{ij} f_j \quad \Rightarrow \quad \mathbf{R_j} = \sum_{k=0}^{j-1} b_{jk} \mathbf{g_{jk}} \otimes \mathbf{R_k}$$

Deconvolution (Inverse problem) algorithms

Monte Carlo simulations + Nuclear statistical model

- Spectrum must be clean
- Response must be accurately known
- Solution of inverse problem must be stable

NIM A430 (1999) 333
NIM A430 (1999) 488

Objectives of the SUBATECH contribution

- **Compute covariance matrices associated to the TAGS analyses**
- **Include the TAGS data and their uncertainties in the evaluated databases**
  - ❑ **<u>To this purpose</u>: Start a new PhD co-supervised by Subatech – IFIC next year: accepted experiments @Jyväskylä are delayed due to the COVID-19 crisis: first 6 months delay, now most probably one year => Need of a prolongation of the SANDA project!**
  - ❑ **Interview of the PhD candidats March 2022, PhD will start around June 2022**
  - ❑ **Next TAGS experiment most probably in Sept. 2022 in Jyväskylä**
- **Discuss with evaluators to help evaluation process for the measured nuclei: collaboration on-going with the LNHB lab. (France)**
  - ❑ **Decay Data Evaluation Training Workshop in Saclay March 7- 9. 2022, organized by X. Mougeot et al. (LNHB). Subatech and IFIC participation**

Conclusions
and the impact of the pandemic

Task 4.2: Conclusions

- Progress during the last year:
  - FY evaluation: contribution from CNRS/LPSC (Grenoble) in collaboration with the CEA-Cadarache completed.
  - ENSDF evaluation: continues as expected (small delay)
  - TAGS data: PhD position available, interviews this month

- Impact of the COVID:
  - The evaluation is less impacted than the experimental activity. Yet, difficulties arise from: difficult communication, scientific visits not possible, conferences/workshops delayed, etc.

  - The experimental activity related to the present task suffers from a delay caused by the pandemic of about 1 year.

Acknowledgements:

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