IAEA
International Atomic Energy Agency
Atoms for Peace and Development

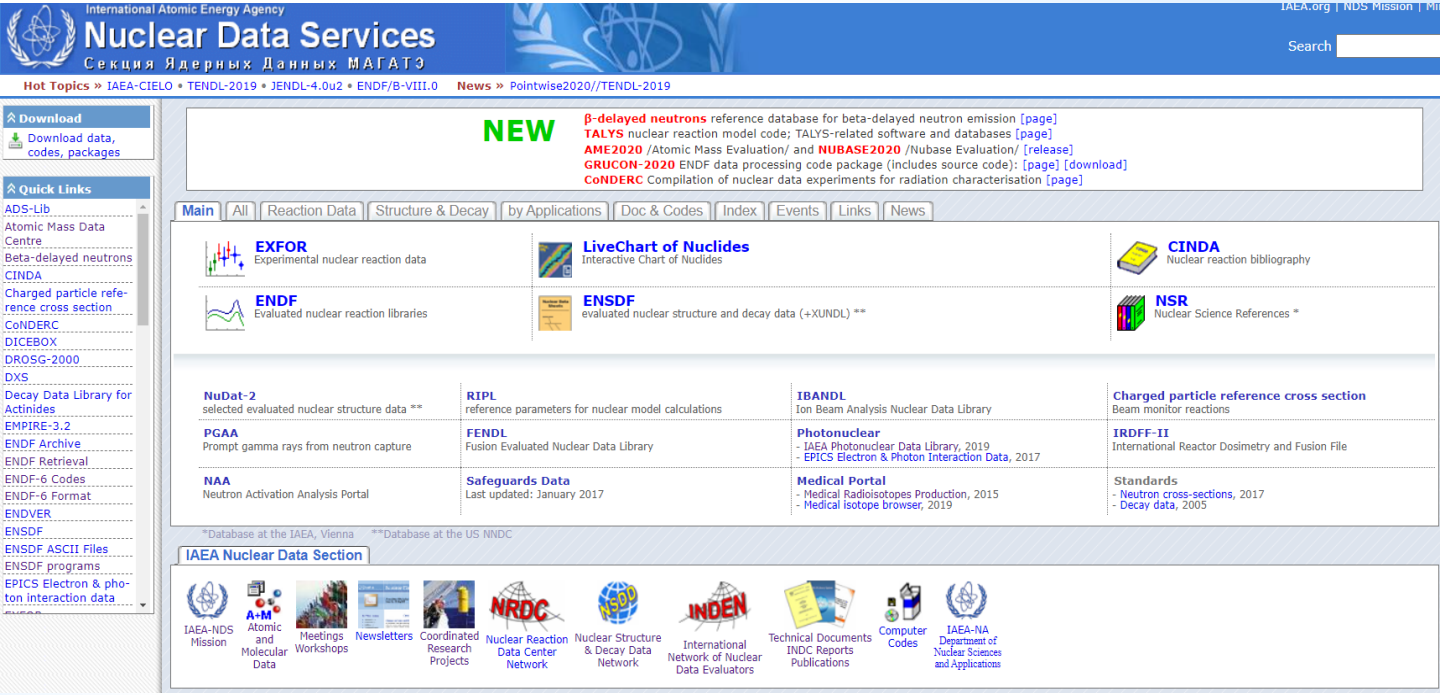
IAEA Technical Meeting on nuclear data for anti-neutrino spectra calculations and their applications, 23-26 April 2019

Paraskevi (Vivian) Dimitriou
Nuclear Data Section, Division of Physical and Chemical Sciences,
International Atomic Energy Agency

IAEA Meeting

- Goals
- Structure
- Achievements and Outstanding issues
  - Reactor anti-neutrino flux and spectrum measurements
  - Reactor anti-neutrino flux and spectrum calculations
  - Nuclear Data & Reactor parameters
- Future perspectives and Recommendations

Nuclear Data Section



www-nds.iaea.org

IAEA dissemination

Structure and Decay Data

NSR
Nuclear Science References *

ENSDF
evaluated nuclear structure and decay data (+XUNDL) **

NuDat-2
selected evaluated nuclear structure data **

LiveChart of Nuclides
Interactive Chart of Nuclides

Decay Data Library for Actinides
Evaluated data with detailed comments and decay schemes

Nuclear Electromagnetic Moments
Experimental and recommended nuclear moments

MIB
Medical isotope browser

Beta-delayed neutrons
Reference Database for Beta-Delayed Neutron Emission

Main | All | Reaction Data | Structure & Decay | by Applications | Doc & Codes | Index

Database Retrieval Systems

ENDF
Evaluated nuclear reaction libraries

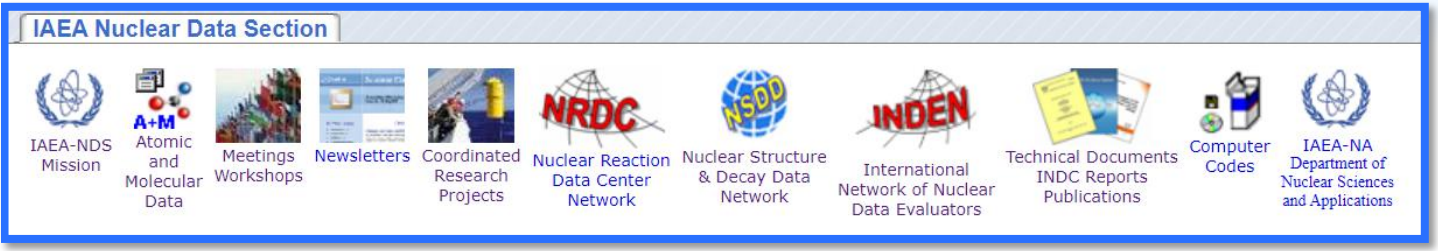
EXFOR
Experimental nuclear reaction data

CINDA
Nuclear reaction bibliography

Data Libraries for download

NGATLAS - atlas of neutron capture cross sections
IBANDL - Ion Beam Analysis Nuclear Data Library
FENDL - Fusion Evaluated Nuclear Data Library
Minsk Actinides Library - evaluated neutron reaction data (Maslov et al.)
IRDFF-II - International Reactor Dosimetry and Fusion File
Charged particle reference cross section - Beam monitor reactions
PADF 2007 - Proton Activation Data File
Tendl2019 - processing results for a subset of TENDL-2019 for incident neutrons: 630 materials
POINT - Pointwise data of ENDF/B-VII.1, processed into temperature dependent form
Standards - Neutron Cross-section Standards 2017
RNAL - Reference Neutron Activation Library
Various Specialized Evaluated Data Libraries in ENDF and other formats -
ADS-Lib - Application test library in ACE and MATXS format for ADS neutronics design
ENDF Archive - Download evaluated data in original ENDF (4,5,6) format
Thin Layer Activation - Thin Layer Activation (TLA) Technique for Wear Measurements
PIGE - Reference Database for Particle Induced Gamma-ray Emission

IAEA meetings, networks, projects



Meeting Webpage

http://www-nds.iaea.org/index-meeting-crp/Antineutrinos/

Participants

Leendert Hayen
Jun Cao
Liangjian Wen
Yufeng Li
Zeyuan Yu
Fengpeng An
Liang Zhan
Cecile Jollet
Muriel Fallot
Madalina Wittel
Karl-Heinz Schmidt
Tadashi Yoshida
Soo-Bong Kim
Sunny Seo
Marek Karny
Marzena Wolinska
Dmitry Svirida
Alejandro Algora
Jose Tain
Antonin Vacheret
Alejandro Sonzogni
Toshihiko Kawano

Technical Meeting on Nuclear Data for Anti-neutrino Spectra and Their Applications

23-26 April 2019, IAEA Headquarters, Vienna, Austria

The Nuclear Data Section of the International Atomic Energy Agency is holding a Technical Meeting on Nuclear data for anti-neutrino spectra and their applications, from to 26 April 2019.

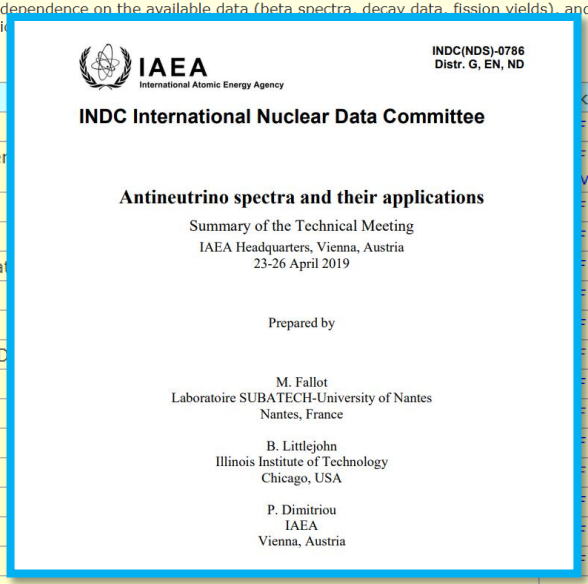
The idea is to bring together experts from the broad spectrum of physics, theory and measurements, related to anti-neutrino studies for basic sciences (mixing angle in neutrino oscillations) and for applications (reactor monitoring with anti-neutrino detection), to review the current status of:

-neutrino anomalies and the sterile neutrino hypothesis
-existing measurements of integral beta spectra
-recent Daya Bay, Double Chooz and Reno results on spectra measurements
-results from short baseline experiments Prospect, SoLid, Neutrino-4/DANSS, NEOS
-conversion method and uncertainties, corrections
-summation method and impact of nuclear data (beta decay data; fission yield data; uncertainties and correlations)
-nuclear data libraries (ENDF/B; JEFF; JENDL)

The goal is to (a) assess the sensitivity of the observations to uncertainties affecting large and short-baseline anti-neutrino measurements, (b) address the limitations an uncertainties of the theoretical methods (conversion vs summation), (c) estimate their dependence on the available data (beta spectra, decay data, fission yields), and finally (d) make recommendations for the existing measurements, theories and evaluati

Presentations

#	Author	Title
1	P. Dimitriou	Introduction
2	C. Jollet	Last Double Chooz results and observations with null nuclear power
3	B. Littlejohn	Daya Bay antineutrino flux measurements
4	L. Zhan	Daya Bay spectrum measurements
5	S.B. Kim	Precise Measurement of Reactor Antineutrino Yield and Spectrum at
6	J. Cao	TAO-JUNOS experiment
7	Y. Li	Global reactor flux analysis
8	J. Link	CHANDLER: A New Technology for Surface-level Reactor Neutrino D
9	S.-H. Seo	NEOS I & II
10	A. Vacheret	SoLiD
11	D. Svirida	DANSS experiment
12	K. Heeger	PROSPECT
13	N. Bowden	PROSPECT Applications
14	Y. Efremenko	Coherent elastic neutrino-nucleus scattering
15	P. Huber	Antineutrino spectrum prediction and nuclear data
16	A. Hayes	Current status of the reactor neutrino spectrum



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INDC(NDS)-0786
Distr. G, EN, ND

INDC International Nuclear Data Committee

Antineutrino spectra and their applications

Summary of the Technical Meeting
IAEA Headquarters, Vienna, Austria
23-26 April 2019

Prepared by

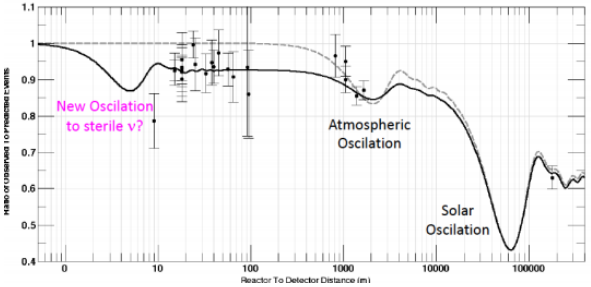
M. Fallot
Laboratoire SUBATECH-University of Nantes
Nantes, France

B. Littlejohn
Illinois Institute of Technology
Chicago, USA

P. Dimitriou
IAEA
Vienna, Austria

Historical background: starting in 2011

- New reference $\bar{\nu}_e$ flux/spectra from conversion of ILL measured beta spectra: Mueller et al, Phys.Rev. C83(2011) 054615
- Converted ν spectra = ~ +3% normalization shift with respect to old $\bar{\nu}_e$ spectra (235U, 239Pu, 241Pu) → flux anomaly



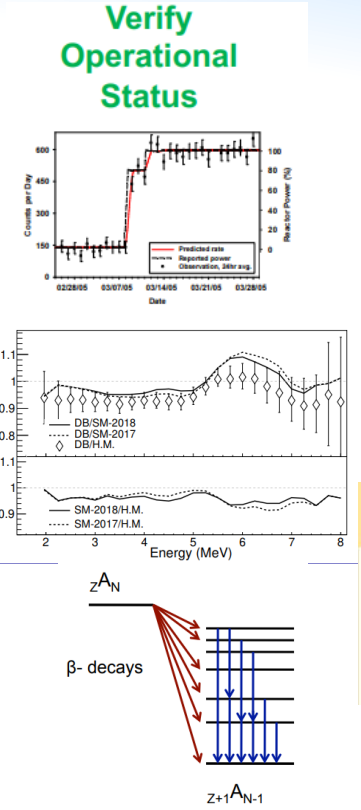
G. Mention et al. Phys. Rev. D83, 073006 (2011)

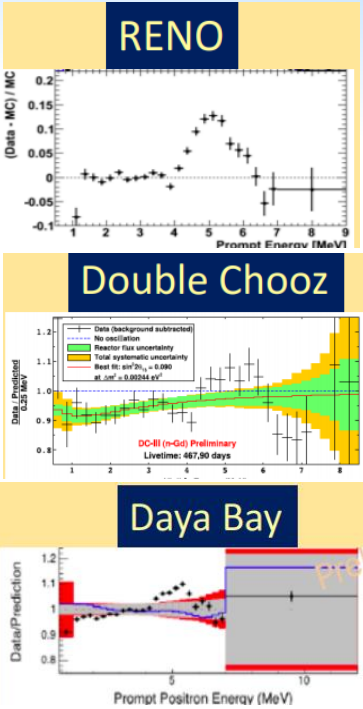
- Spectral distortion discovered in addition to flux deficit
- "Hunt" for sterile neutrinos to explain 'reactor anomaly': 6% deficit in flux, "bump" at 5-7 MeV
- In addition to campaigns to measure θ13 oscillation parameter
- Results from first campaigns:

Y. Abe et al Phys. Rev. LeO. 108, 131801, (2012) *Double Chooz*
F. P. An et al., Phys. Rev. LeO. 108, 171803 (2012) *Daya Bay*
J. K. Ahn et al., Phys. Rev. LeO. 108, 191802 (2012) *Reno*

Goals of the meeting

- Bring together representatives of major collaborations and groups from all over the world to discuss
  - Achievements and outstanding issues of measurements of reactor anti-neutrino flux and spectrum
  - Status of calculations of reactor anti-neutrino flux and spectrum [Conversion method, Summation method]
  - Impact of nuclear data, nuclear theory and reactor parameters
  - Make recommendations for future





Broad international participation

35 participants from 11 countries incl. IAEA

Reactor anti-neutrino measurements: representatives of almost all long- and short-baseline experiments attended	Daya Bay, Double Chooz, NEOS, RENO, TAO-JUNOS, PROSPECT, SoLiD, DANSS, CHANDLER, COHERENT
Reactor anti-neutrino flux and spectrum calculations	Conversion method, Summation method experts
Nuclear data and theory: experimental groups and evaluators/theorists attended	Decay data, TAGS, Fission Product Yields, beta-decay theory (first forbidden non-unique transitions)
Reactor parameters: the importance of collaborating with the nuclear reactor engineers was recommended at the meeting	In future meetings

Meeting Photo

Structure of the meeting

- Chair: A. Sonzogni
  Rapporteurs: M. Fallot, B. Littlejohn

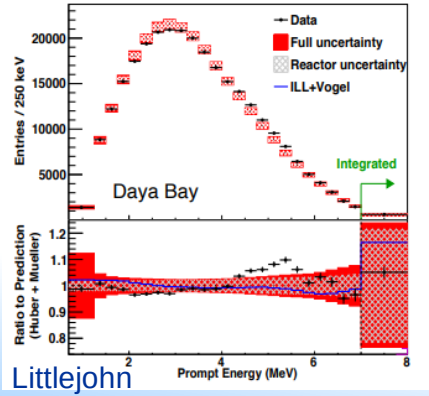
- Presentations: 2.5 days (28 presentations)
  - ample time for Q&A

- Roundtable Discussions: 2 days
  - 2 moderators: experiments - K. Heeger, calculations - P. Huber
  - Preparation of questions and discussion items
  - Minutes – joint statement including recommendations (B. Littlejohn, M. Fallot)

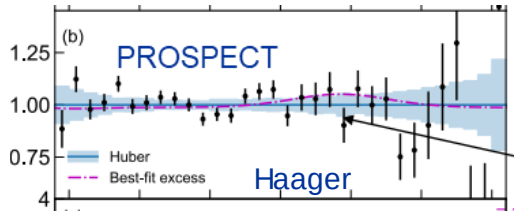
- Summary report: based largely on the Minutes
  INDC(NDS)-0786
  (download from meeting webpage)

Measurement of reactor $\bar{\nu}_e$ flux and spectrum

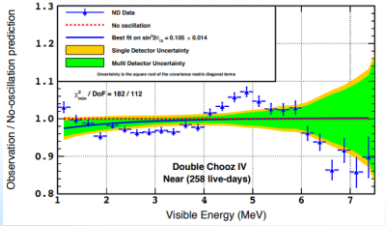
- Achievements
  - Precision measurements at LEU – systematics limited
  - Modern measurements at HEU – statistics limited
  - Demonstrated technology and capability of precision IBD measurements with surface-based detectors
  - Coherent neutrino scattering allows detection of $\bar{\nu}_e$ with larger cross sections
  - Ongoing R&D efforts towards surface based, field deployable, high signal-to-background detectors

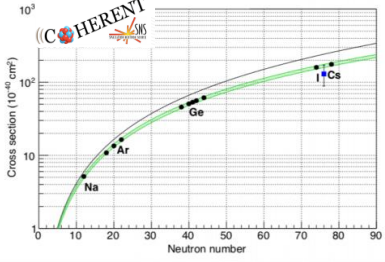


Littlejohn



Haager



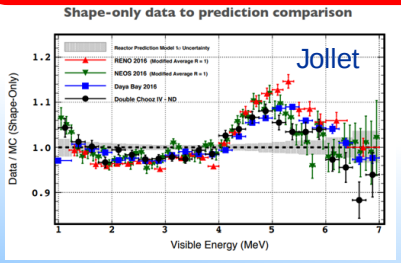


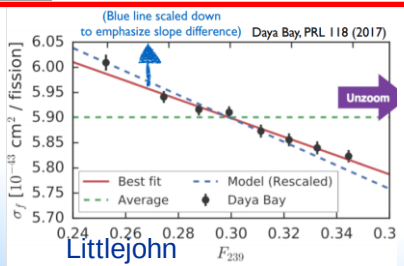
N^2 dependence of the CEνNS cross section.

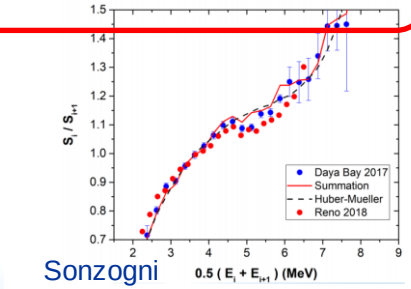
WoN

Measurement of reactor $\bar{\nu}_e$ flux and spectrum

- Outstanding issues
  - Origin of 'bump' in $\bar{\nu}_e$ spectra measured at LEU STILL NOT KNOWN
  - eV-scale sterile neutrinos still to be tested
  - Isotopic $\bar{\nu}_e$ yields and spectrum uncertainties are unknown at the level of several percent
  - Possible indication of fine structure
  - No measurements below IDB threshold 1.8 MeV
  - Secondary contributions from spent fuel, samarium poisoning, non-equilibrium and non-linear isotopes, not measured
  - Only LEU and HEU measurements
  - Not all published $\bar{\nu}_e$ data and supplementary materials are available in tabulated electronic form
  - Up-to-date summation antineutrino models are not easily accessible for use by neutrino experimentalists







Future $\bar{\nu}_e$ measurements

- High-resolution and high-precision measurements at LEU over several fuel cycles (preferably single reactor)
  - Reference spectrum
  - Benchmark for nuclear databases
  - Reliable isotopic IBD yields
  - Improve nuclear physics models for neutron-rich nuclides
- Deploy similar mobile detector systems at multiple reactor types (precision measurements)
  - library of templates for different reactor types useful for safeguards and reactor monitoring
  - validated technologies for safeguards and reactor monitoring
  - opportunity to validate model predictions for different reactor types and fissile vectors
- Perform measurements of spectrum below 1.8 MeV using coherent nuclear or electron scattering
  - New information for $\bar{\nu}_e$, nuclear and reactor models

Data standardization and dissemination

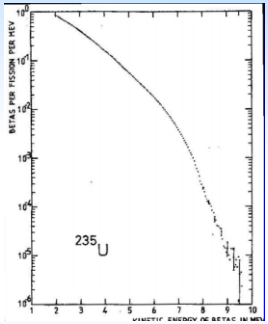
- Establish standard plots and formats for flux/spectrum data and inputs
- Encourage use of peer-reviewed, published data and results with tabulated data and supplementary materials references
- Establish standards, processes and locations for permanent public storage and access

Calculations of $\bar{\nu}_e$ flux and spectrum

- Conversion method

[relies on single measurement of the integral beta spectrum of 235U, 239Pu, 241Pu by Schreckenbach et al. at ILL, 1980s; beta decay models]

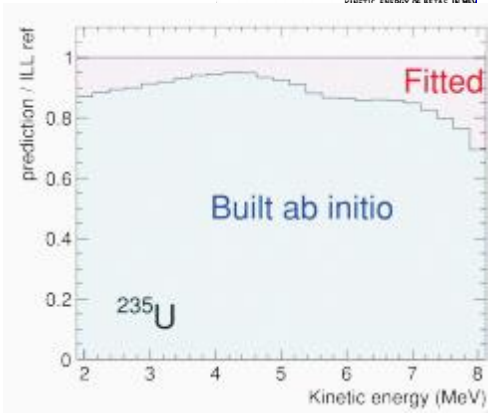
  - use of nuclear data for realistic beta branches, Z distribution of the branches
  - Th.A. Mueller et al, Phys.Rev. C83(2011) 054615; P. Huber, Phys.Rev. C84 (2011) 024617

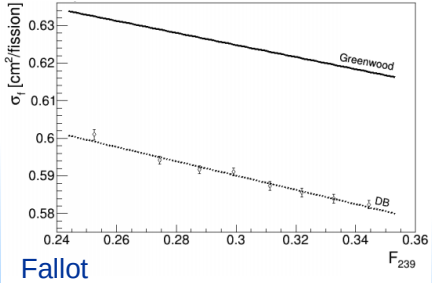


- Summation method

[relies on nuclear data: decay data, fission yield data]

  - First summation calculations: B.R. Davis et al. Phys. Rev. C 19 2259 (1979), to Tengblad et al. Nucl. Phys. A 503 (1989)136
  - First TAGS measurements: Greenwood et al, 1980s

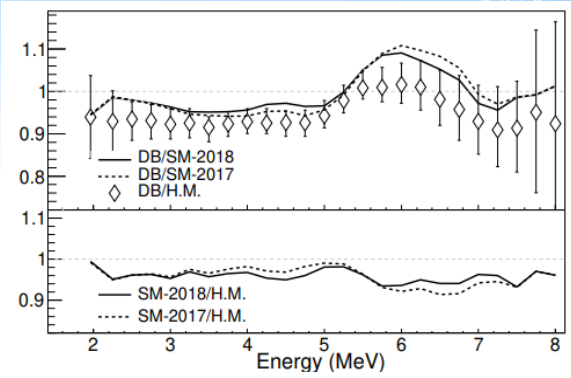




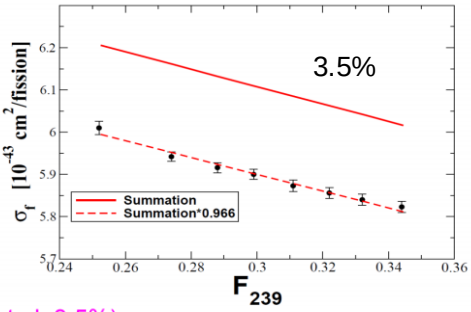
Achievements

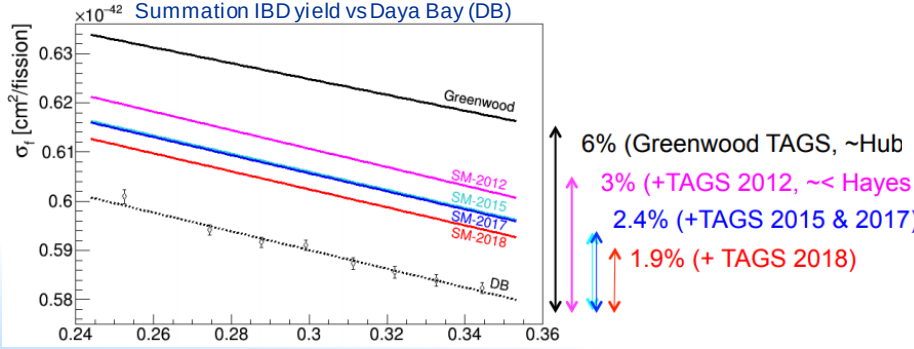
- Conversion and Summation method agree in spectral shape in 2-5 MeV
- Disagreement wrt measured at 2-5 MeV - 'bump' not explained (yet reduced)
- Differences between measured IBD yield and Summation dropped from 7% to 2%

Estienne et al., Phys. Rev. Lett. 123, 022502 (2019)



A. C. Hayes et al. PRL 120 (2018) 022503





6% (Greenwood TAGS, ~Hub

3% (+TAGS 2012, ~< Hayes et al. 3.5%)

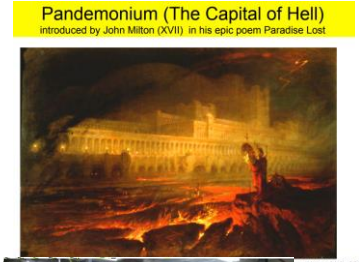
2.4% (+TAGS 2015 & 2017)

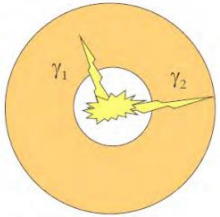
1.9% (+ TAGS 2018)

Phys. Rev. Lett. 123, 022502 (2019)

Major factor has been effort in nuclear data

- Total Absorption Gamma-ray Spectroscopy (TAGS) combined with High-Resolution Gamma-ray Spectroscopy (HRGS)





DTAS (IFIC-Valencia)

About 100 decays have been measured since 2010:

Nantes-SUBATECH group: Fallot et al.
IFIC-Valencia: Algora, Tain et al.
ORNL- Univ. Warsaw: Ryksaczewski, Karny et al.

+

HRGS @ ANL:
Decay Data for anti-neutrino applications (ATLAS & CARIBU)
(F. Kondev et al.)

Priority TAGS lists have been covered extensively:

A. A. Sonzogni, E. A. McCutchan, and A. C. Hayes Phys. Rev. Lett. 119, 112501

IAEA Meetings: TAGS measurements for decay heat AND anti-neutrino spectra calculations, INDC(NDS)-676

Outstanding issues I

- Conversion method: correct treatment of uncertainties (previously underestimated)
  - Average spread of effective Z
  - Treatment of high-Q non-unique forbidenness
  - Other corrections (weak magnetism etc.)
- Integral data: basis of all flux models remains the single measurement of integral beta spectra by Schreckenbach et al (1980s):

Recommendation: new measurements of the integral beta energy spectra for the main actinides

Outstanding issues II

- Summation method: realistic estimates of the uncertainties including correlations
  - Fission yield data: improve measurements, theory and evaluations

IAEA Coordinated Research project on Updated Fission Yields for Applications (2020-2024)

  - Non-unique forbidden transitions (shape factors): need to improve the models
    - New models should be validated against measured shape factors
    - New measurements of shape factors are needed[targeted lists exist]
  - Beta-decay theory: improving predictive power to complement evaluated data in the absence of experimental data

Outstanding issues III

- Reactor parameters:
  - Non-equilibrium effects, structural aluminium, Sm poisoning of the reactor core
  - Energy release per fission: discrepancies between calculated and literature values
  - Impact of different fuels (MOX, VTR)

Recommendation: to engage reactor physicists/engineers in discussions and meetings

General concluding remarks

- The meeting brought together experts from reactor neutrino experimental groups, theory/data groups applying the conversion and summation methods, nuclear theory, experimental nuclear physics and nuclear data

Belgium, China, France, Germany, Japan, Korea, Poland, Russia, Spain, UK, USA,

Discussions benefited from international coordination

Recommendations to IAEA

- Create an international working group (Antineutrino Flux Working Group)

Scope:

- standardized antineutrino data
- standardized models
- Antineutrino model input nuclear data and experiment

- Hold similar meetings every 2 years

Future

- Follow-up IAEA Technical Meeting in 2022
  - Technical advances
  - International working group
  - Standardization, data storage and access

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*Material taken from meeting presentations and summary report

Thank you!