Modelling of Neutrino Production and Spectra From a Magnox Reactor

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Based upon paper from ANIMMA Conference
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NATIONAL NUCLEAR LABORATORY

Summary

Based upon presentation to ANIMMA

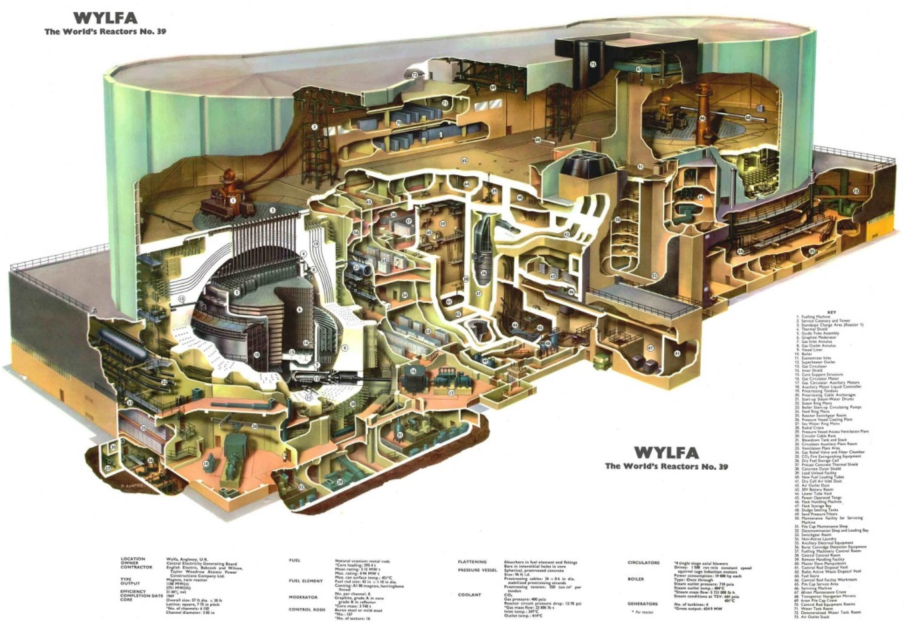
https://www.epj-conferences.org/articles/epjconf/abs/2018/05/epjconf_animma2018_07008/epjconf_animma2018_07008.html

- VIDARR detector deployed at Wylfa reactor in 2014/2015
- Detailed reactor operation information supplied
- Wylfa core modelled to estimate anti-neutrino flux and spectra
- Discussion of alternative calculation methods and comparison to experimentally determined spectra.

VIDARR: Above ground Reactor Monitoring
J Coleman, C Metelko, M Murdoch, Y Schnellbach, C Touramanis, R Mills, D. Mountford
Journal of Physics: Conference Series 1216 (1), 012007
https://iopscience.iop.org/article/10.1088/1742-6596/1216/1/012007/meta

Deployment at Wylfa

Wylfa Power Station –
Last of the Magnox stations



Reactor 2 – Shutdown 2012

Reactor 1 – Shutdown December 2015

Natural uranium metal fuel
49248 elements in 6156 channels
in Magnesium alloy clad Magnox©

- Largest Magnox 2x1.6 GW_{th} power
- Carbon dioxide cooled
- Graphite moderation
- On-load refuelling!

Image from :http://econtent.unm.edu/cdm/singleitem/collection/nuceng/id/41/rec/48

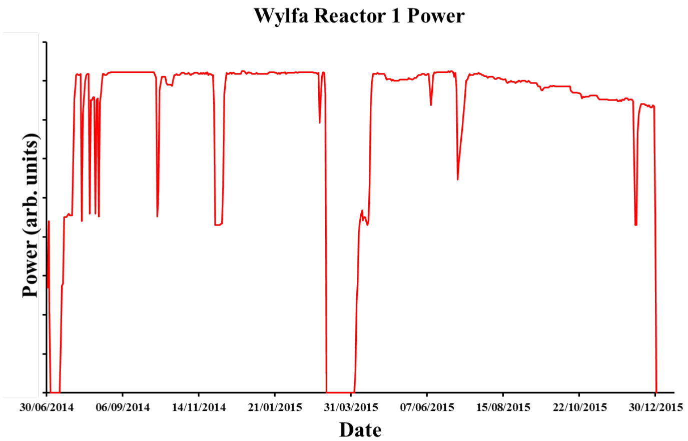
The necessary introductions for site access were facilitated by UK Government in response to an approach from the UK Support Programme to the IAEA*.

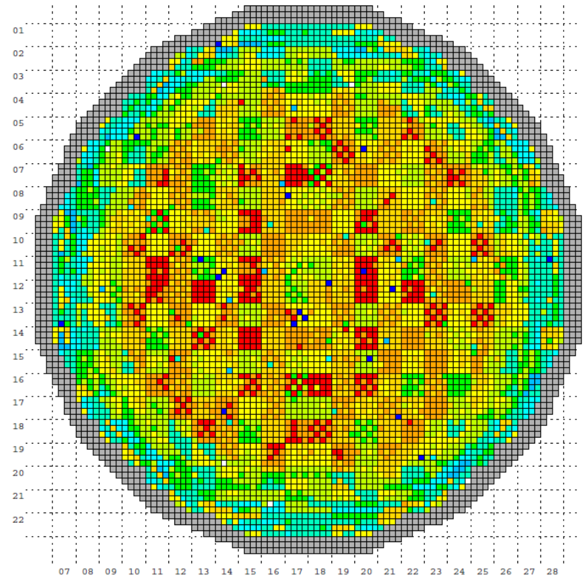
*The UK Support Programme is funded by the Department of Energy and Climate Change, to provide technical support to the IAEA Department of Safeguards. The Programme is administered by UKNNL

Modelling data supplied

Information supplied by operators

- Reactor R1 power July 2014 – December 2015
- At 18 dates given full-power “snapshots” of core consisting PANTHER calculations of whole core with:
  - **Power (MW) for each rod**
  - **Irradiation (GWd/t) of each rod**
  - **Enrichment of each rod (natural or 0.8 Wt% $^{235}U/U$)**
- PANTHER solves the thermal hydraulics and neutronic solutions
- Thus, depends on knowledge of nuclear data:
  - **Shielded fission and capture cross-sections (affects changes of nuclide number density with time) as well as fission rates**
  - **Neutron emission probabilities (prompt/delayed)**
  - **Energy release per fission (prompt/delayed)**
  - **Neutron transport (absorb/scatter cross-sections)**
  - **Fission product yields**
  - **Radioactive decay data**





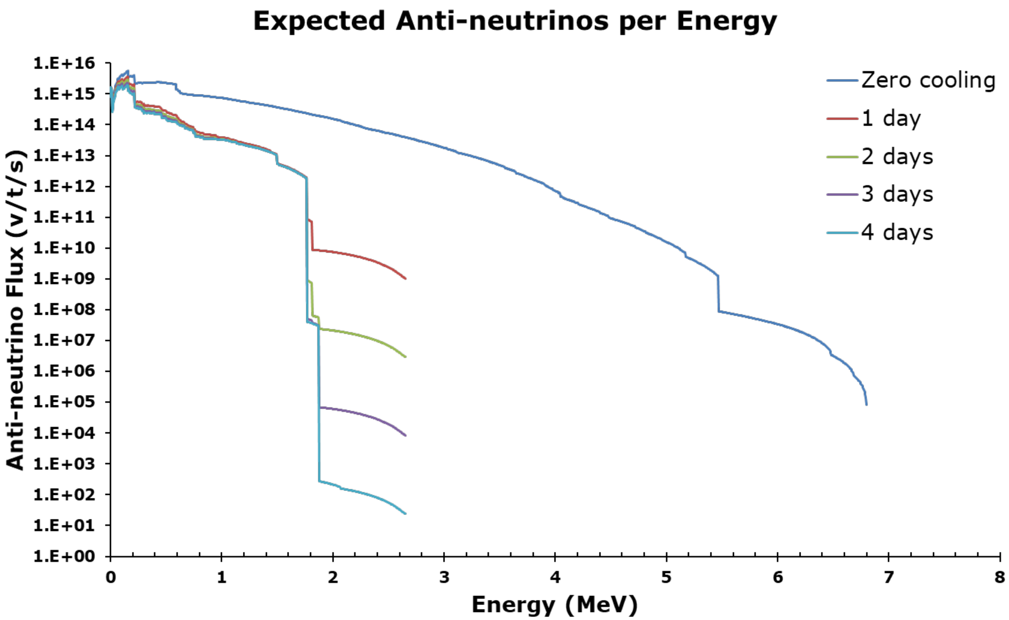
Calculation method

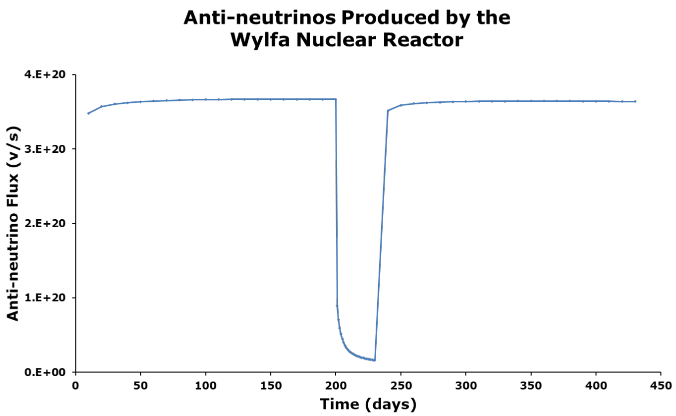
- Used "snapshots" and reactor power to determine history of each element.
- Modelled with FISPIN10A (UK fuel inventory code) for each element using JEFF-3.1.1.
- Combined the activities of each element to determine the total activities.
- Used BTSPEC to convert JEFF-3.1.1 ENDF formatted RDD into beta spectra, and as have each transition could calculate electron anti-neutron spectra. These spectra need to be multiplied by beta particles emitted by each decay.
- BTSPEC was used to generate 1500 bins of 10 keV width (i.e., maximum of 15 MeV) for all 670 β^- emitting nuclides available.
- Mathematical convolution of activities with spectra can be used to determine electron anti-neutrino particles produced and their spectra.

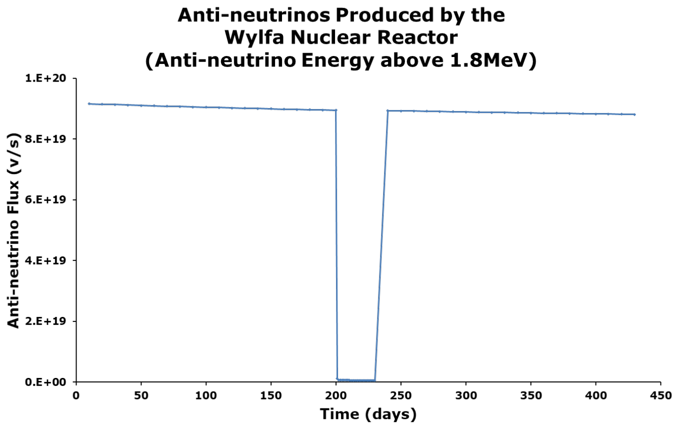
$$\frac{dN_i}{dt} = -\lambda_i N_i + \sum_i \lambda_j N_j B_{j,i} - \sum_l N_i \sigma_{i,d} \phi + \sum_m N_m \sigma_{m,i} \phi + \sum_k N_k \sigma_{k,f} \phi Y^i_{k,i},$$

Results

- Example of results for anti-neutrino during start of shutdown and showing results from whole core calculations.





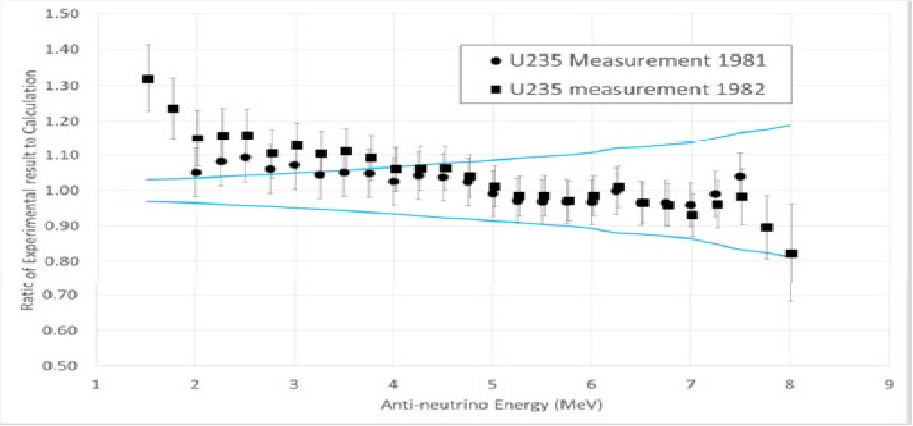


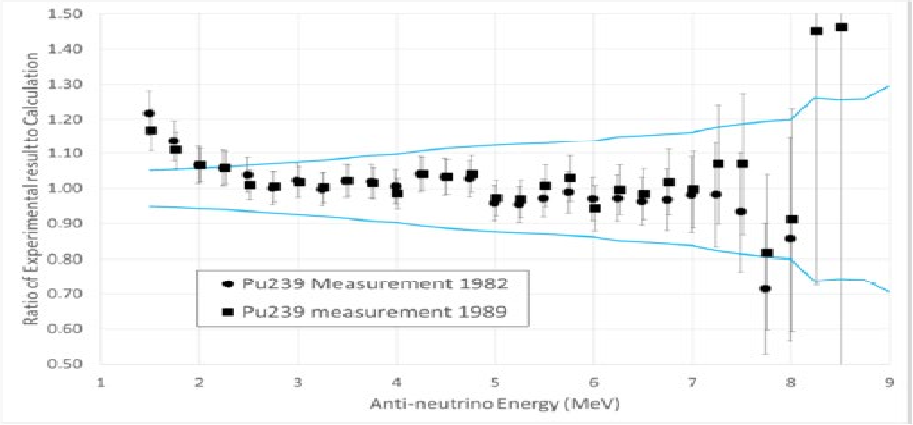
Simpler method based (1/2)

Alternatively, the fission product yields can be used directly with decay data.

As at constant fission rates and equilibrium product concentration, short-lived fission product activities equal the cumulative yield multiplied by the fission rate for the fissioning nuclide. Note that this ignores effects of neutron capture of fission products and issues with longer-lived fission products that are not in equilibrium.

If we compare these results with those published by





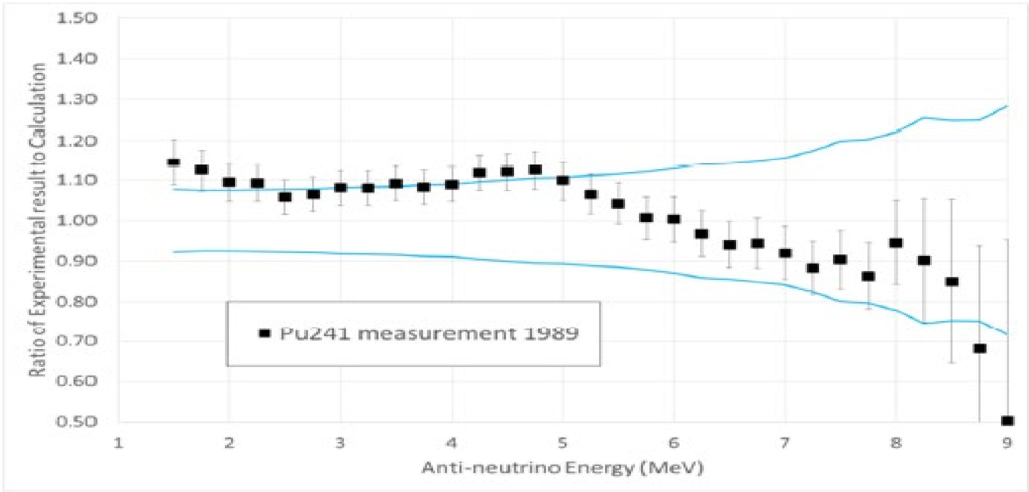
Schreckenbach, K., Faust, H.R., Feilitzsch, F. von, Hahn, A.A.,Hawrkamp, K. and Vuilleumier J.L. “Absolute measurement of the beta spectrum from 235U fission as a basis for reactor antineutrino experiments” (1981)
PHYSICS LETTERS Volume 99B, number 3

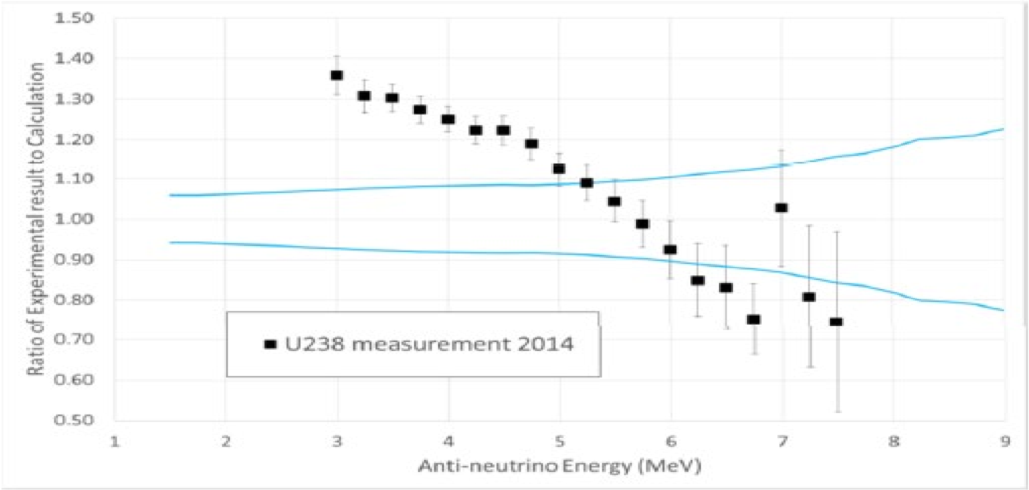
Feilitzsch, F. von, Hahn A.A. and Schreckenbach, K., “Experimental beta-spectra from 239Pu and 235U thermal neutron fission products and their correlated antineutrino spectra” (1982) Physics Letters, Volume 118B, number 1

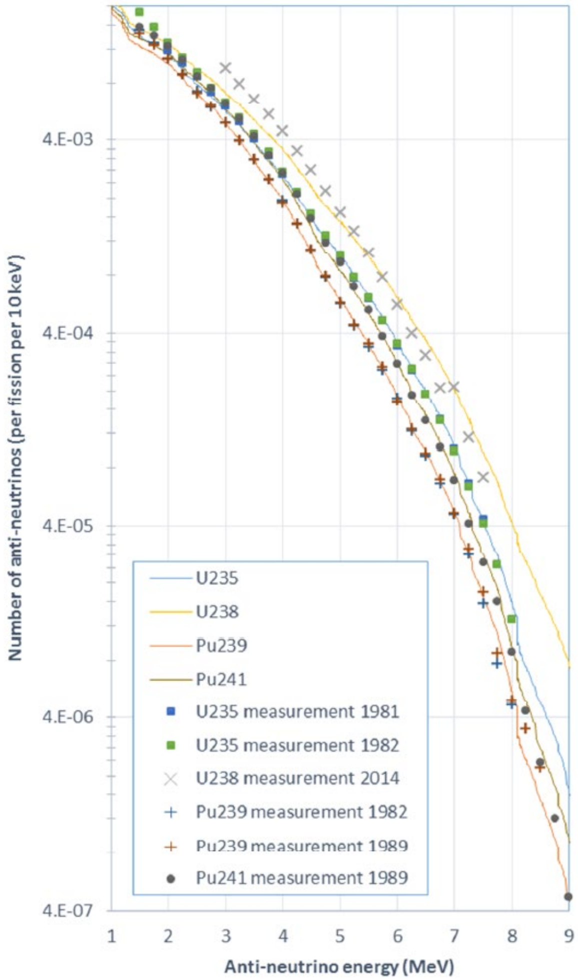
Hahn A.A., Schreckenbach, K., Gelletly, W., Feilitzsch, F. von, Colvin, G. and Krusche, B. “ANTINEUTRINO SPECTRA FROM 241Pu AND 239Pu THERMAL NEUTRON FISSION PRODUCTS” (1989) Physics Letters B Volume 218, number 3

Haag, N., Gütlein, A., Hofmann, M., Oberauer, L., Potzel, W., Schreckenbach, K., Wagner, F.M. “Experimental determination of the antineutrino spectrum of the fission Products of U 238” (2014) Physical Review Letters, 112

Simpler method based (2/2)







Conclusions and future work

Nuclear Data

- There is the datasets to calculated anti-neutrino emission but depends on a lot of quantities with accuracy and uncertainty correlations.
- No anti-neutrino emission measurement to directly compare.
- Fission yield distributions have the largest uncertainty, but beta shape is also of concern. Emission dominated by short-lived nuclides further away from stability.
- Dominated by ^{235}U and ^{239}Pu fission rates, which validation suggest end of life concentrations known to within ~5-10% from LWR post-irradiation analyses.

Reactor information

- To accurately model the emissions will need a lot of operational information – unless can justify a simplification simplify.

Future work

- Studies with JEFF-3.3 FY and ENDF-VIII RDD in progress using multiple methods.
- Also studying method simplifying the determination of whole core fractional fission rates.
- Within WATCHMAN plan to model an AGR using a similar approach.

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