Application of rigorous two step method to Proton activation of ISIS targets

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Science & Technology Facilities Council

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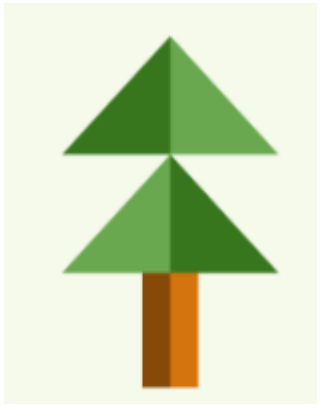
- M Flemming, UKAEA
- FISPACT team – JC Sublet, M Gilbert et al.
- The TENDL team – Koning, Rochman et al.
- PYNE team



Outline

- **Activation calculations**
  - **Current method**
  - **Possible method**

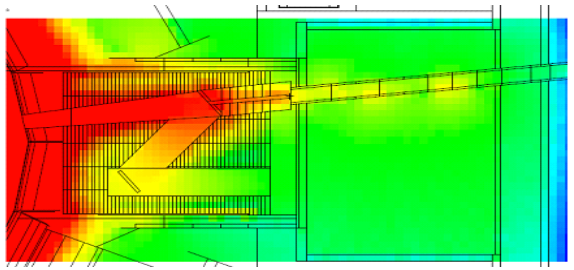
- **Nuclear data**
  - **TENDL Nuclear data**
  - **Preliminary extended TENDL data**
  - **Validation of nuclear data**

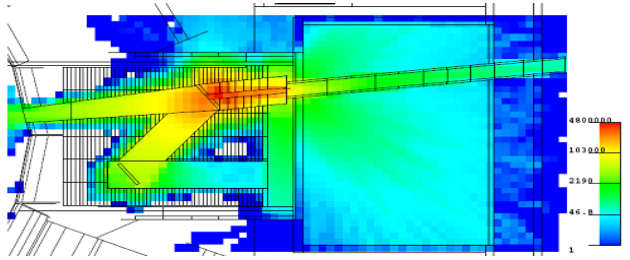
- **Target analysis**
  - **Particle energy spectra**
  - **Activation results**

Activation calculations

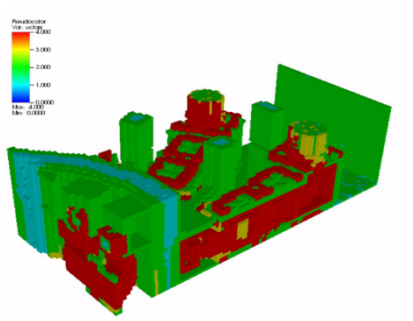
Need activation calculations in spallation for:

- He/H appm production
- Poison burn up
- Material change
- Decay heat
- Waste classification
- Shutdown dose rate
- Shielding design

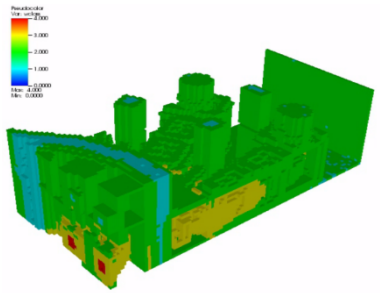




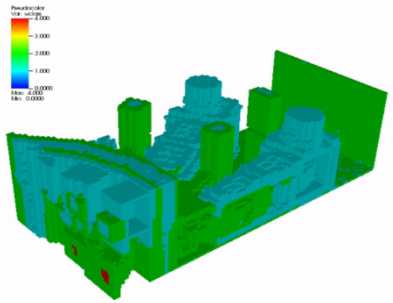
Davis et al., Fus. Eng. Des. ***85*** *(2010) p87*



1 day

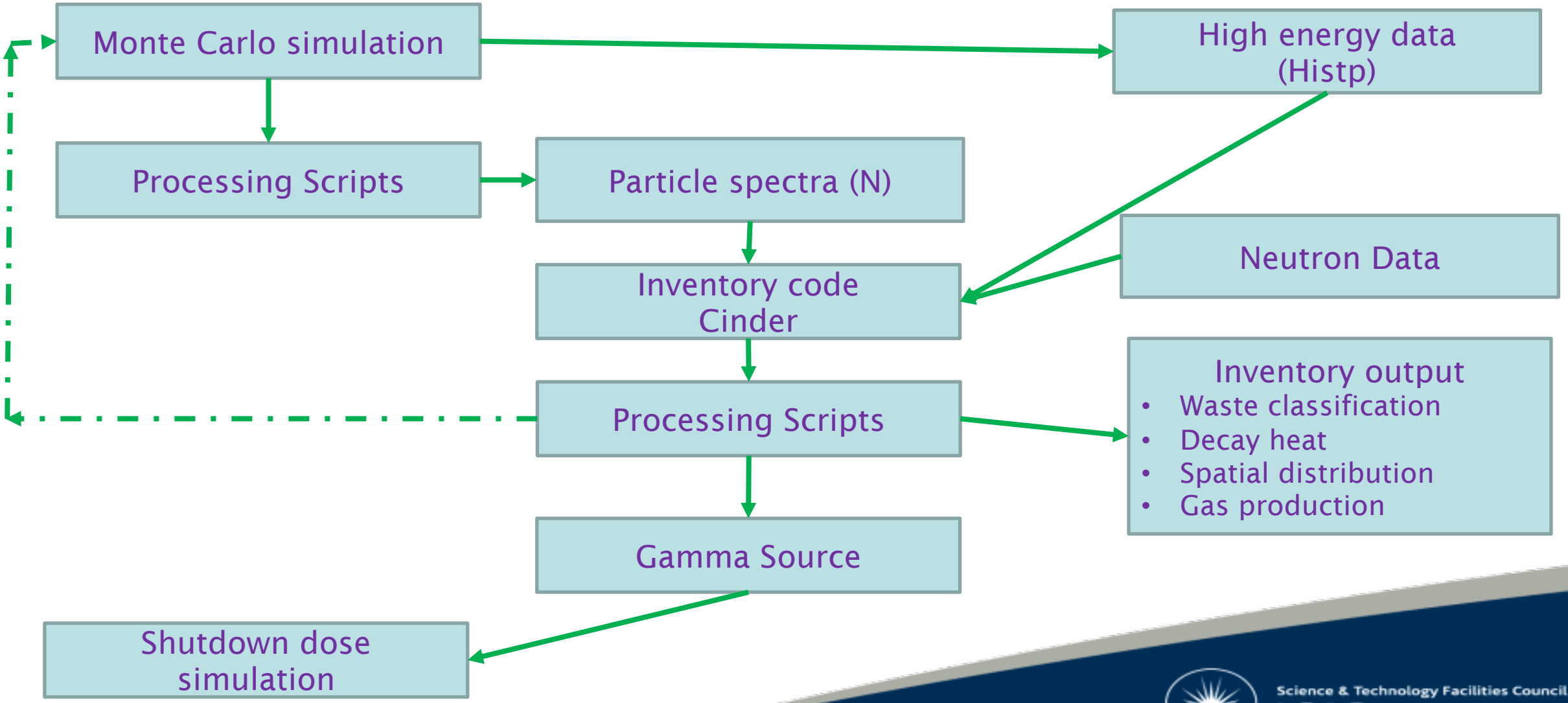


1 year

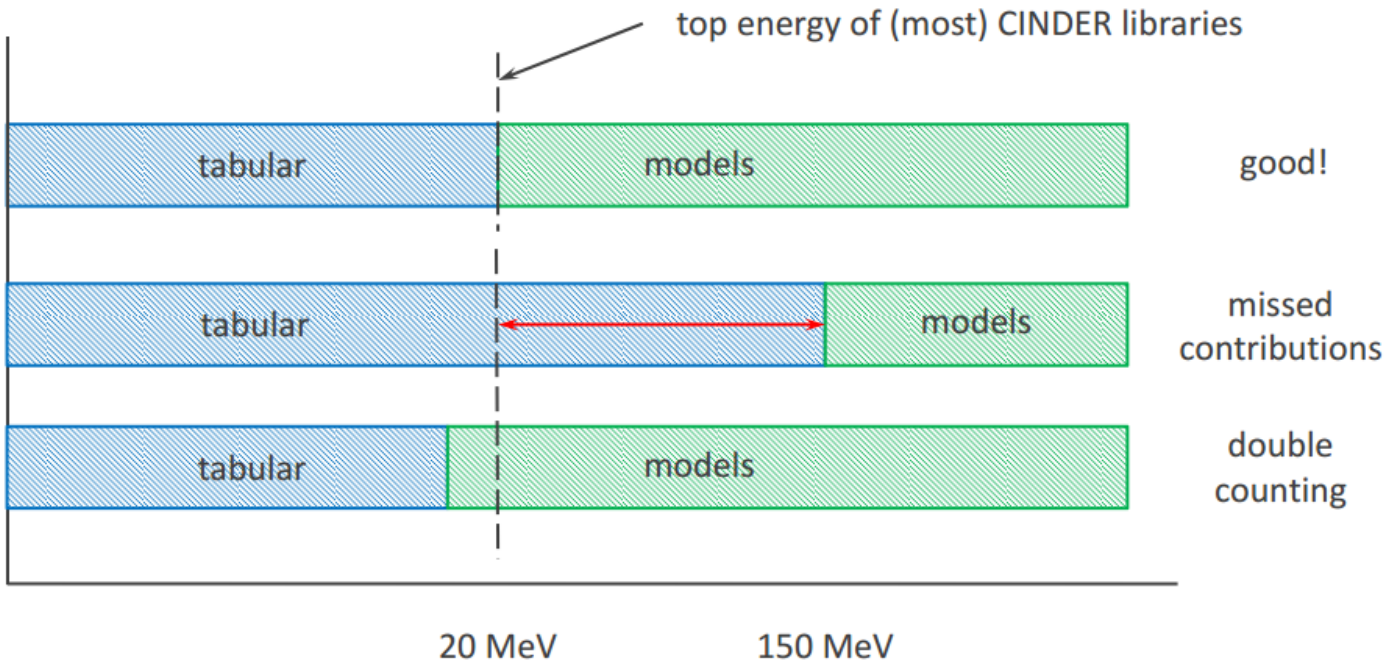


100 years

Current activation method



Current activation method



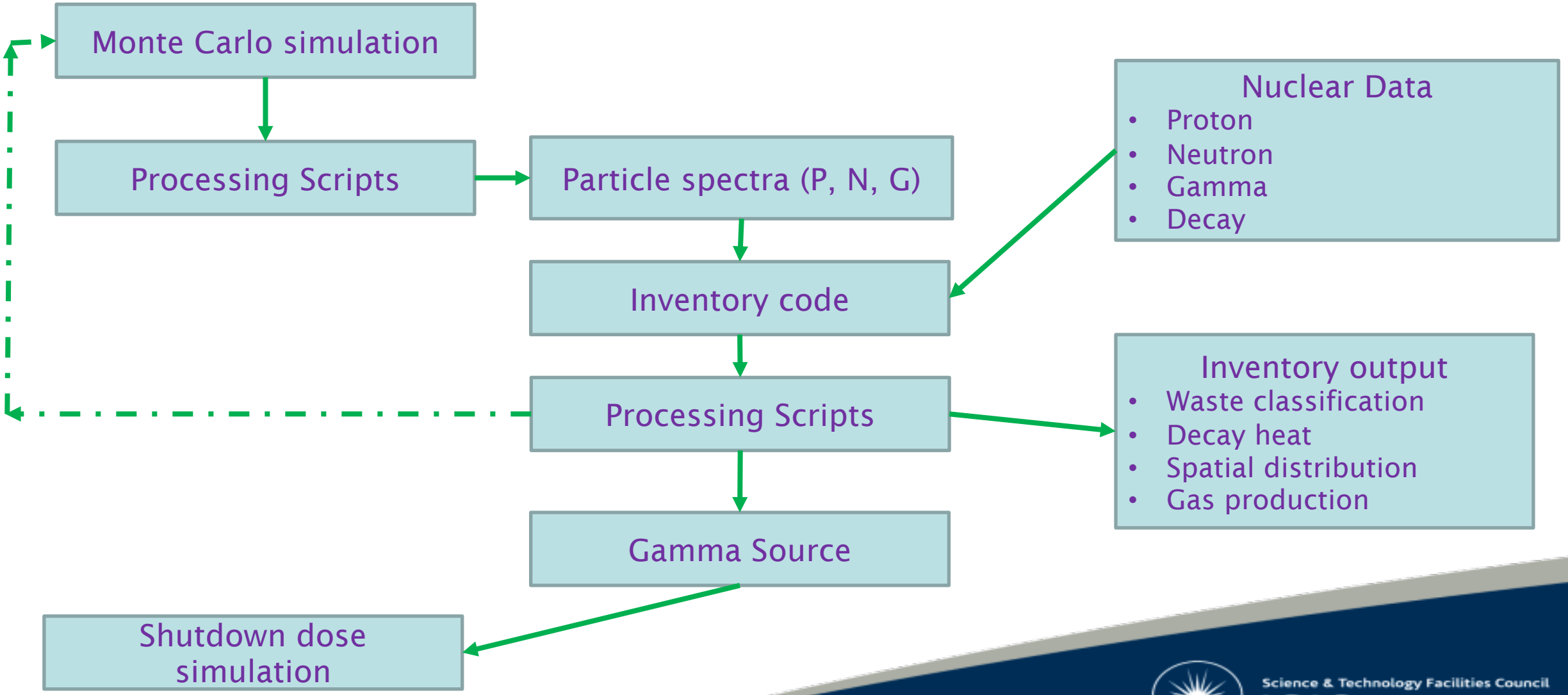
From Micklich, ARIA 2015

Need to ensure match of models and library data energy cut-offs,

In large simulations multiple data libraries might be used with different top energies.

Consistency of models and tabulated data

Possible method



Inventory codes

Bateman equation solvers, geometry independent, use nuclear data, some include self shielding, fission, pathway analysis, irradiation history, uncertainty analysis etc

$$\frac{dN_i}{dt} = -N_i(\lambda_i + \sigma_i\varphi) + \sum_{j \neq i} N_j(\lambda_{ij} + \sigma_{ij}\varphi)$$

Several different options

- ALARA
- FISPACT-II
- ACAB
- CINDER
- VESTA

- FISPACT-II most recent updated – able to use GENDF format nuclear data, for proton, neutron, Deuteron, Alpha, gamma

- Recent work by Gilbert el al on PKA spectra using FISPACT-II

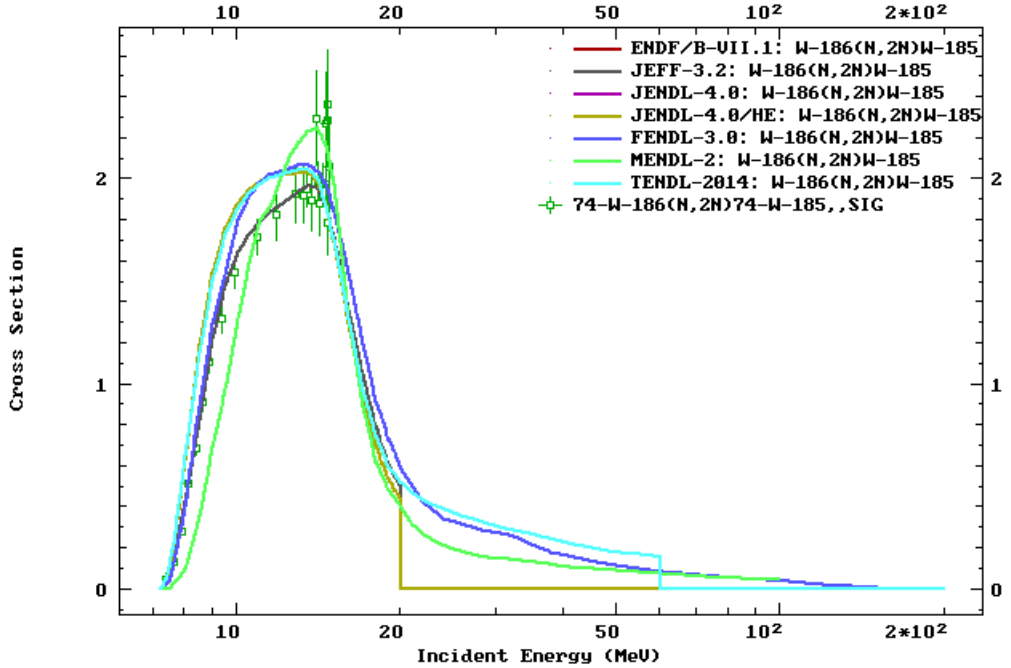
Nuclear data libraries

Traditional production of evaluated cross sections is very time consuming
Careful tuning of cross sections compared to experiments including integral experiments
Most libraries updated on 5 – 10 year timescale and then only some nuclides actually change

Typically two types of library
General purpose libraries
- ENDF BVII
- JEFF
- CENDL
- JENDL

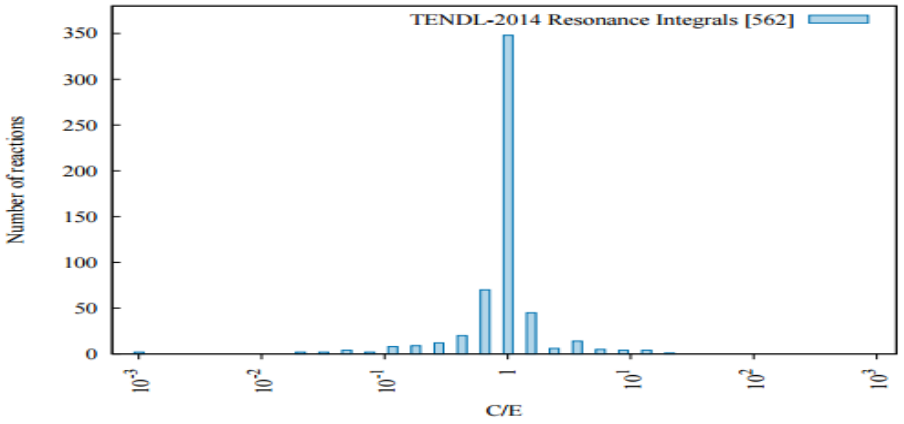
Special purpose libraries
- FENDL
- IRDFF
- EAF

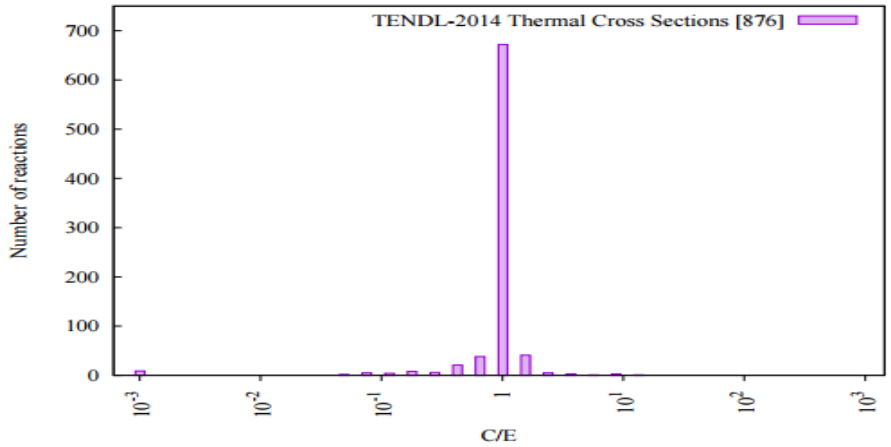
Majority have upper energy cut off of
20 or 60 MeV



TENDL- Talys Evaluated Nuclear Data Library

- T6 & Talys – uses theoretical models such as optical models, break up models etc.
- Updated on yearly basis
- Up to 200MeV
- Low Z nuclides from best available evaluations – Talys unable to model
- Includes libraries for Proton, Neutron, Deuteron, Triton, He3, Alpha, Gamma
- Nuclides with half life over 1second
- Approx 2800 Nuclides included
- Most important nuclides now have custom parameters
- Increasing Validation suite – Sublet, Flemming et al.





Extending TENDL up to 1GeV

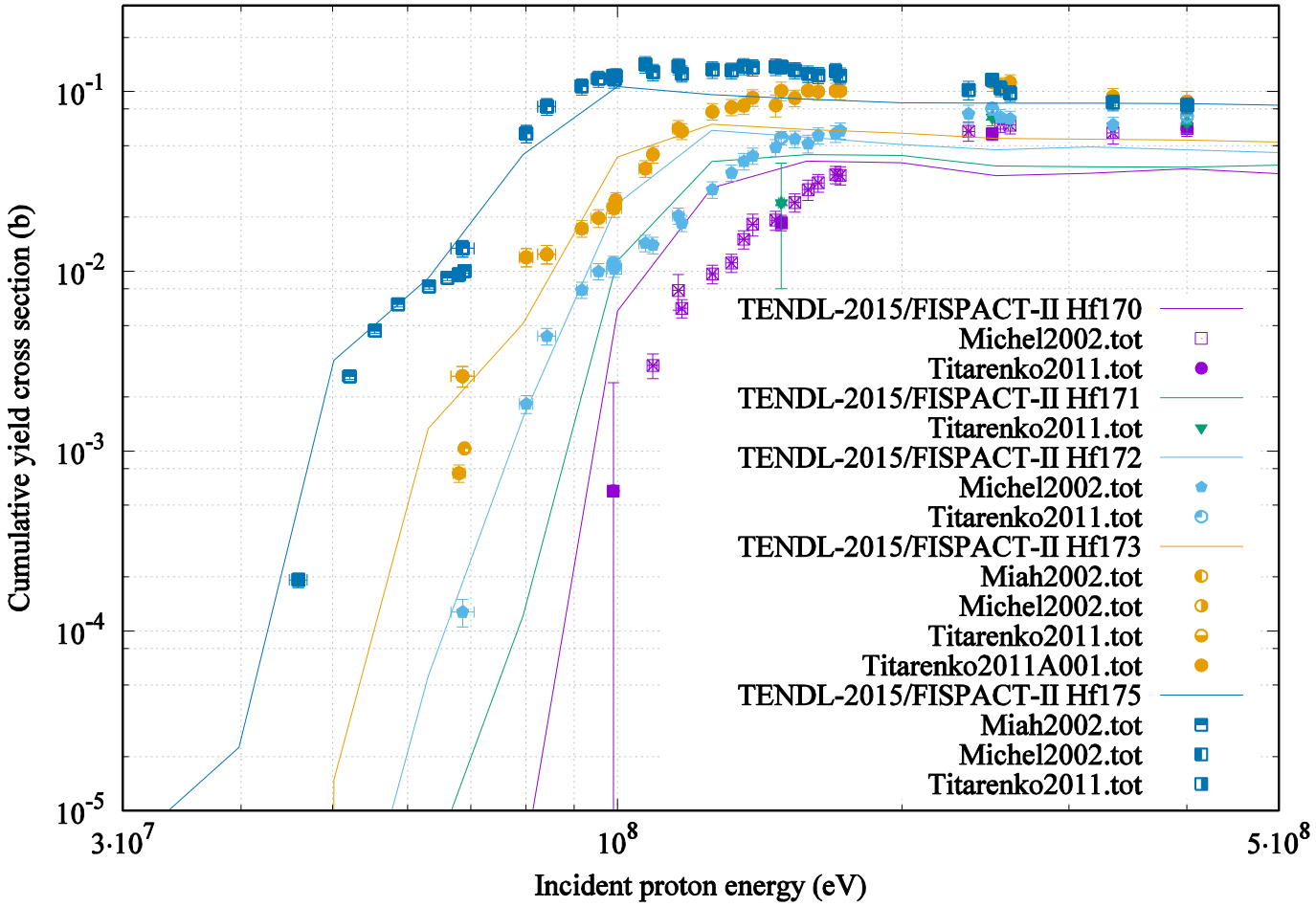
As it is derived from models it is reproducible, but also possible to change parameters and extend limits.
Therefore it is also possible to use Talys to produce libraries to higher energy.

So far produced test files for protons on tungsten up to 1GeV

But is it valid –

- Are all relevant models in Talys?
- Are parameters used to match data at low energy applicable to high energy ?
- Are all reactions included?

Data Validation

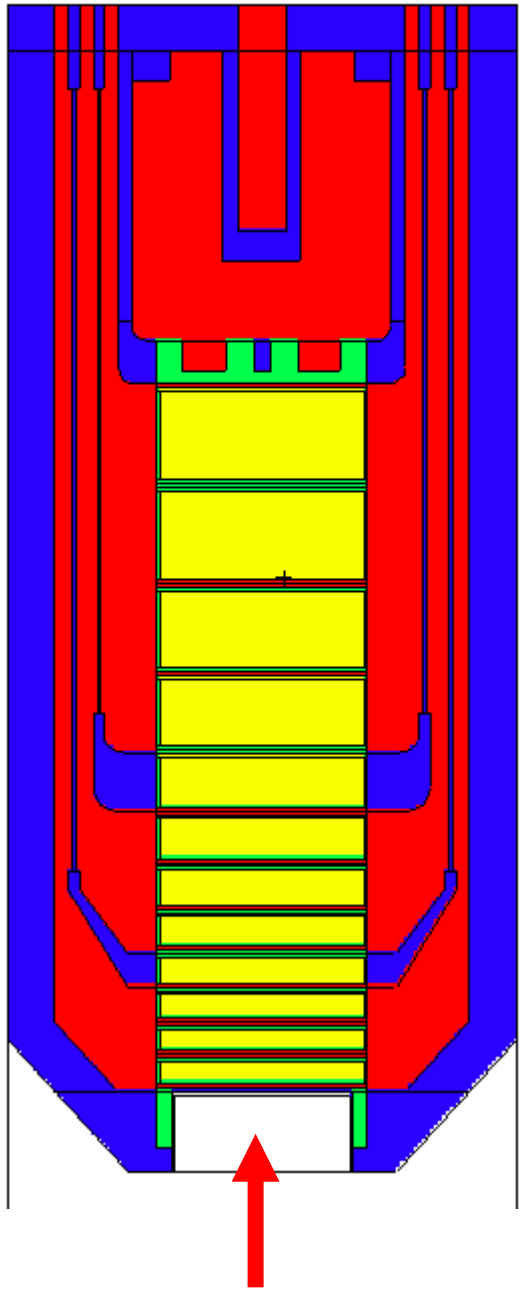


Predicted Total yield cross section compared with available data in EXFOR for Hf production from W

Generally good agreement

At higher energies the plateau slight under prediction

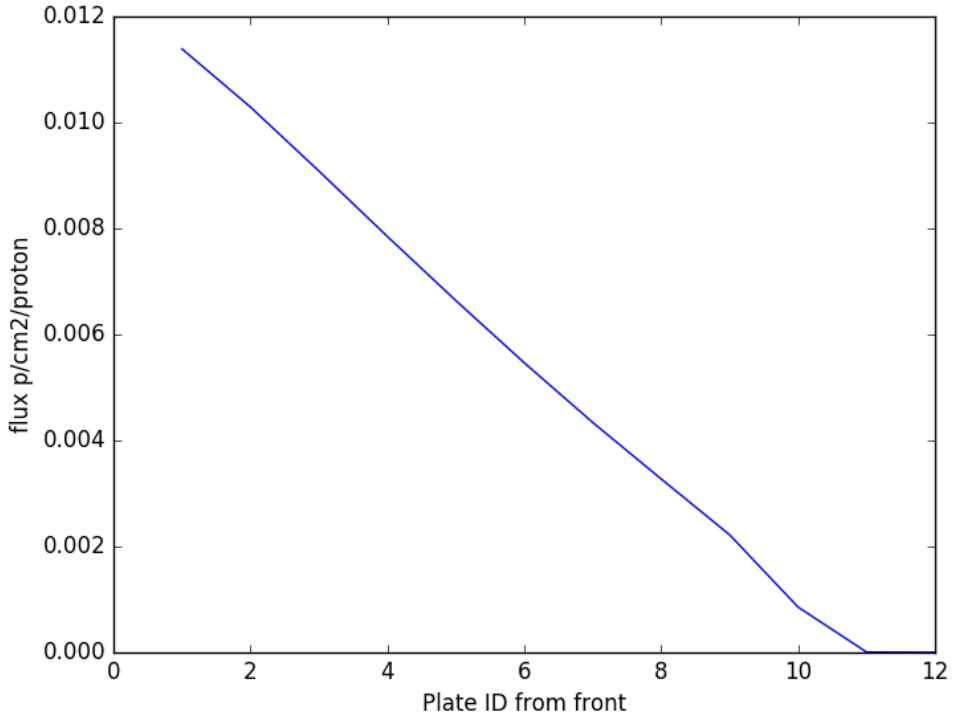
Courtesy of M Flemming, CCFE

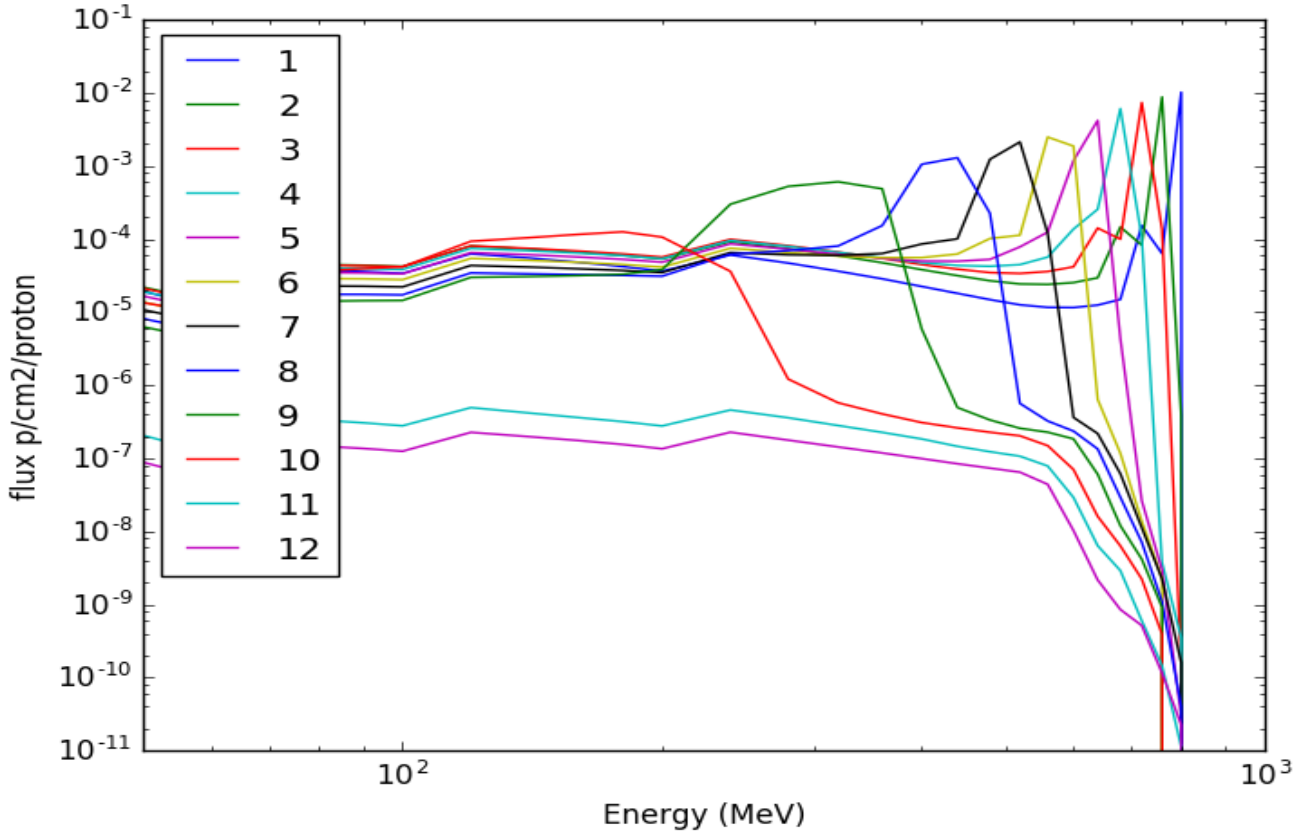


ISIS target model

- 12 Ta clad W plates varying in thickness
- Heavy water cooled (red)
- Basic design hasn't changed in over 20 years

Proton flux





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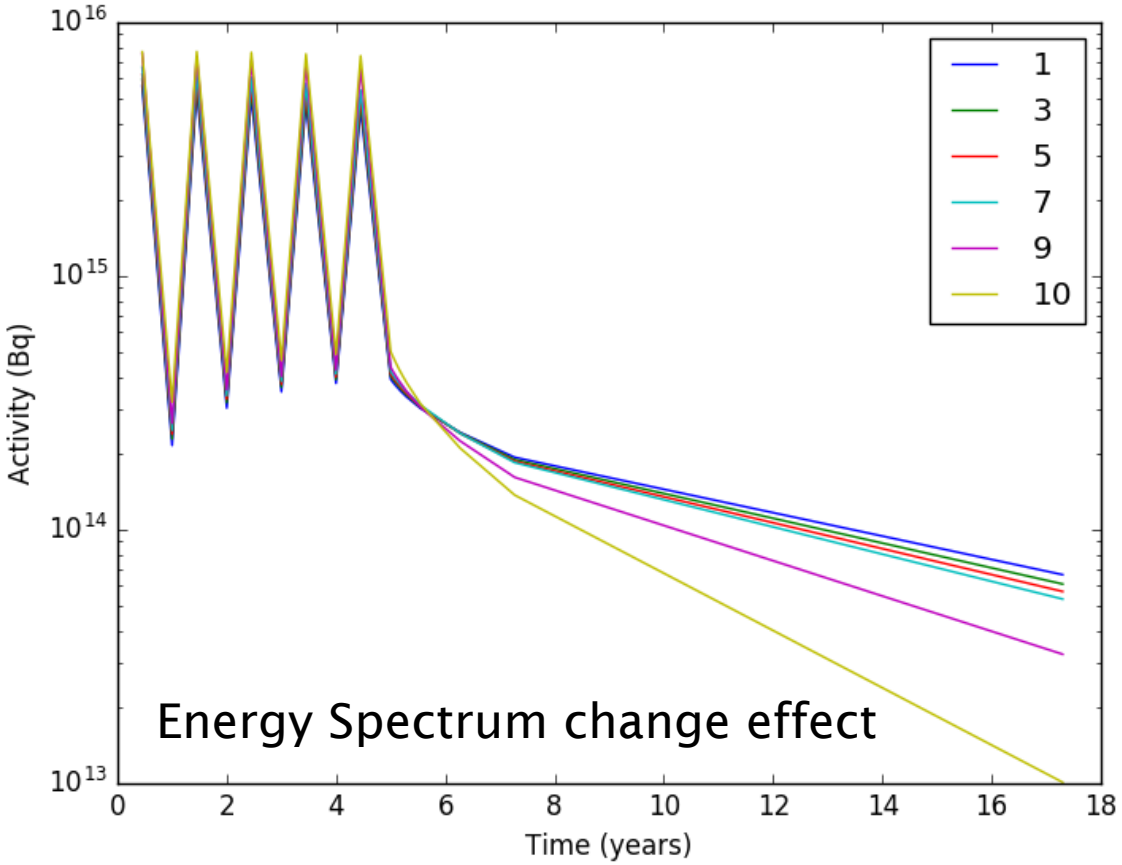
Inventory calculations



Interesting notes:

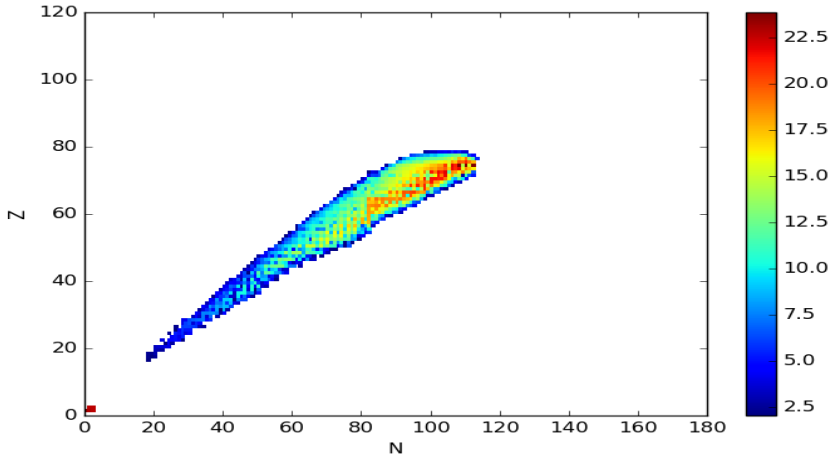
- APPM of He increases even after shutdown
- APPM of H factor of 10 higher than he
- After 10year H3 activity dominates if trapped

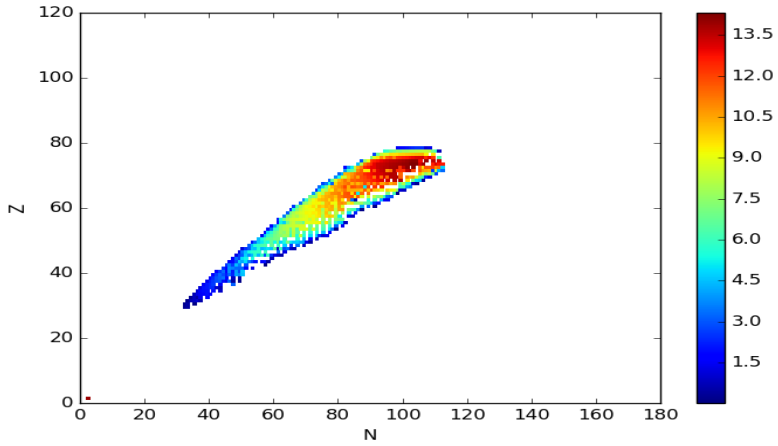
- 10^{th} plate H3 production significantly less than other plates

Proton only
5 years operations (45% on time)
$1x10^{15}$ protons per second

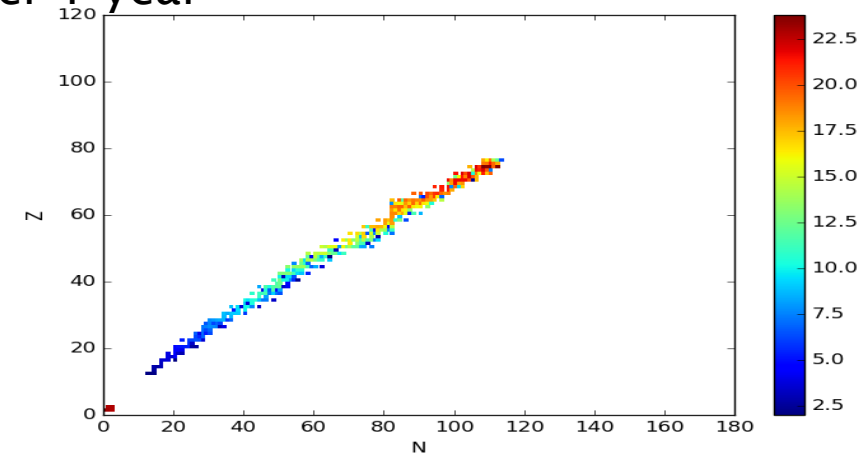
Nuclide results

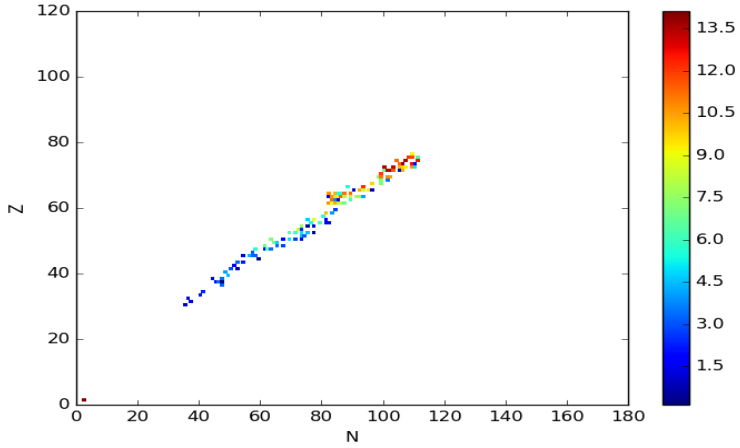
At shutdown





After 1 year





Atoms

Activity

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Automating the process - PYNE

Python for nuclear engineering –

- Open source project lead by University of Wisconsin
- Stop reinventing the wheel
- Lots of tools for nuclear data reading, materials, simple transport solvers, input/output processing
- Has an R2S method for unstructured meshes – compatible with UW DAGMCNP and ALARA
- In development – fispact output reader, cell based R2S

https://github.com/pyne/pyne

Future work

- Further test files to be produced – Ta, Re, Os
- Identify which reactions and which parameters work
- Generate co-variance matrices
- Finish automation in Pyne
- Need experiments/data for validation.
- Comparisons against other codes – Cinder, FLUKA, PHITS
- Comparison with JENDL2007-He library

Summary

- TENDL data and recent development in inventory codes make it possible to perform all transmutation in the inventory codes
- This could reduce issues with high energy models and matching table data
- Extensive validation is required – but the amount of experimental data is limited compared to low energies.

- Initial work suggests this method has potential benefits and builds on work performed in fusion neutronics.