Nuclear Data Needs in Nuclear Energy Application

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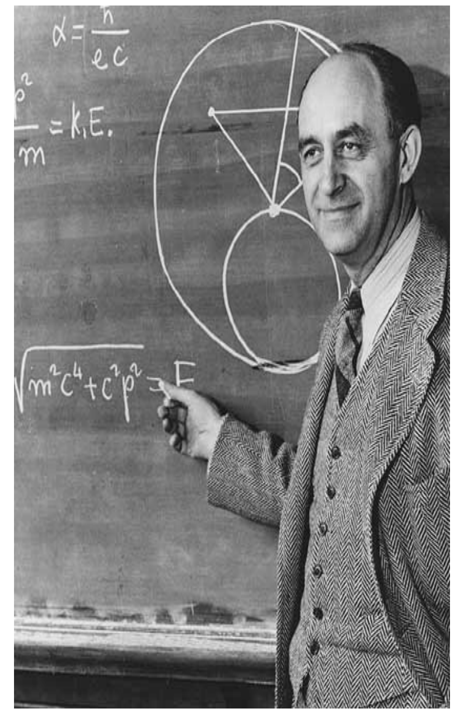
Data needs and uncertainty reduction

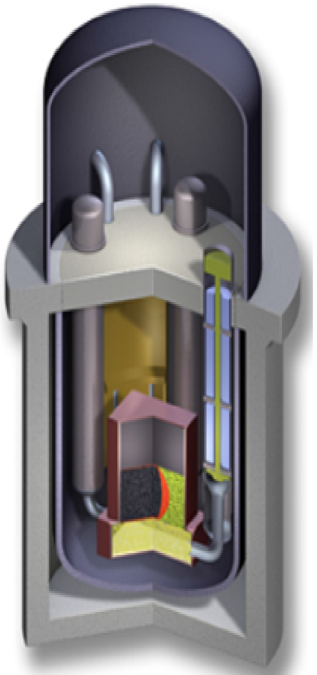
- Despite the spectacular success of reactor physics to help operate the present power park, crucial problems have still to be solved in order to:
  - *Reduce margins and optimize concepts, thus improving the economical viability of present and future systems*
  - *Assess the feasibility of innovative options, in particular allow a robust safety assessment of evolutionary or advanced reactor and fuel cycle systems*
- Neutron cross sections in current libraries (ENDF/B for US, JEFF for Europe, JENDL for Japan) perform quite well. However, this performance is the result of large compensations among different parameters. This can induce unexpected biases and large uncertainties



1- Impact of uncertainties on reactor systems design and analysis

- Uncertainties have multiple and sometimes unexpected, impacts on reactor design and on fuel cycle assessments.
  - Over the last decades, several significant cases have been identified.
  - Moreover, tight design target accuracies, required to meet safety and optimization requirements and objectives, can only be achieved if very accurate nuclear data are used for a large number of isotopes, reaction types and energy ranges.
- Areas of nuclear systems assessment where uncertainties play a crucial role:
  - Advanced fuels, cladding, and structural Materials
  - Advanced modeling and simulation – code validation support
  - Innovative reactor core configurations and heat removal systems
  - Advanced fuel cycle demonstration

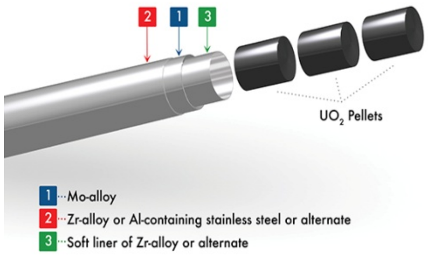
- With regard to advanced reactors, the uncertainty analysis performed using current covariance data shows that the present integral parameters uncertainties resulting from the assumed uncertainties on nuclear data are probably acceptable in the early phases of design feasibility studies.
- However, in the successive phase of preliminary conceptual designs and in later design phases of selected reactor and fuel cycle concepts, there is the need for improved data and methods, in order to reduce margins, both for economic and safety reasons.
- It is then important to prioritize as soon as possible the issues, i.e. which are the nuclear data (isotope, reaction type, energy range) that need improvement, in order to quantify target accuracies and to select a strategy to meet the requirements (e.g. by some selected new differential measurements and/or integral experiments).



Travelling Wave Concept

2- Examples of uncertainties reduction needs can be found in various reactor and fuel cycle design and analysis areas

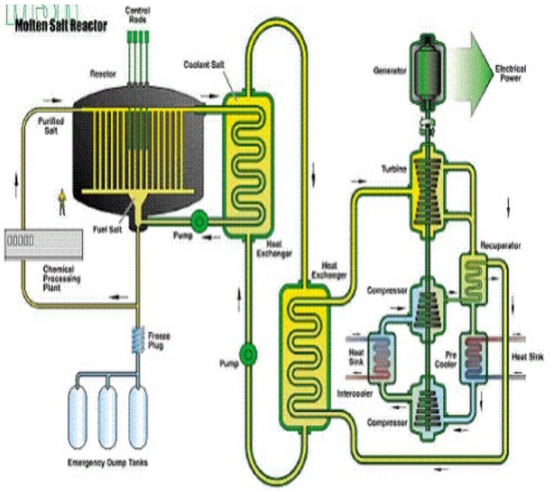
- High burn-up systems: Increased burn-up scenarios will put a larger emphasis on the quality of higher actinides and of fission products evaluations
  - Fission products cross sections, fission yields, and radioactive decay properties still need improvement
  - Absorption and fission cross sections, and even inelastic cross sections, of higher actinides (higher Pu isotopes, minor actinides) will play a much more crucial role in future fuel cycle optimization studies as foreseen by industry
- Advanced fuels and cladding materials for LWRs: Uncertainties can impact their choice and potentially their feasibility. Re-evaluation of uncertainties is certainly needed for materials considered accident tolerant fuels studies.



- Spent nuclear fuel pools (SFP): In the wake of the Fukushima events, a renewed in-depth assessment of the design and safety of SFPs was requested by all national regulators. The total pool heat load can result from compensating effects, and data uncertainty play a very relevant role, especially for high burnup fuels.
- LWR concepts based on Pu-Th fuels: The crucial void coefficient depends on the Pu vector; present uncertainties are strongly reducing the range of acceptable Pu feeds (low ^{240}Pu and ^{242}Pu content)

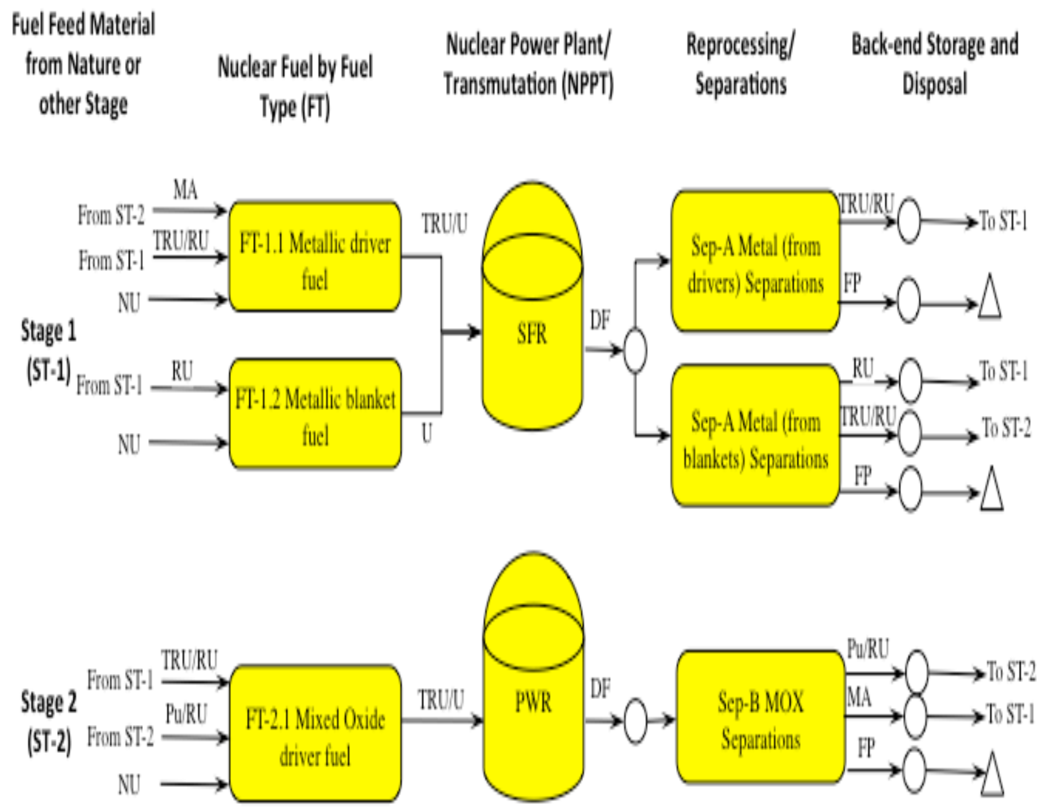
- Advanced fuel cycle concepts: TRU recycle and utilization concepts (i.e. high TRUs content fuels) are affected by severe uncertainties on decay heat at reactor shut-down (>10-20%) and on all reactivity coefficients (>30-40%) that can impact their feasibility
- Decay heat assessments, both for current and future reactors: Uncertainty propagation has to take into consideration the correlations among the data. The use of correlations, including those associated to experiments, can have a significant effect on the final decay heat uncertainty assessment.
- Reactivity coefficients: Their uncertainty can impact the safety case of advanced reactors, e.g., in a low sodium void fast reactor the objective of a zero sodium void coefficient cannot be achieved due to an uncertainty of 3 – 5 $.
- Gamma-ray heating: In advanced reactors, approximately 10% of the deposited heat is due to gamma-ray energy, from which about 40% is due to prompt fission gamma-rays. The uncertainty with respect to the heating should not exceed 7 – 8 % to adequately model these cores. Using the present evaluated data leads to an underestimation of the gamma-heating by up to ~30% for the main fissile isotopes ^{235}U and ^{239}Pu.

- The MSR concept can be temperature controlled since the large negative temperature coefficient could allow for control without control rods. However the temperature coefficient results from the sum of different components potentially of different signs and uncertainties of 10-15% (on Th Doppler coefficient, graphite moderation etc.) could impact the design and the safety case assessment.



▪ Fuel cycle options analyses

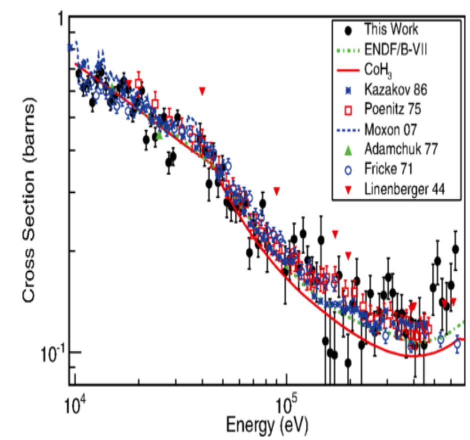
Large efforts have been invested to assess and inter-compare different options for future fuel cycles (see e.g. “Nuclear Fuel Cycle Evaluation and Screening – Final Report” by R. Wigeland et al.). Screening among fuel cycle options requires appropriate uncertainties (including nuclear data uncertainties) to be propagated in scenario codes. This is a fairly new need and no systematic approaches are yet available. Typical example of a scenario to which uncertainties need to be associated:



3- Role of experiments and new approaches

- For most of the previous examples, studies to quantify the impact of nuclear data uncertainties have been performed, using the newest data covariance information available.

- *It has been attempted to set targets for uncertainty reductions, using information on the impact in terms of safety and economics of both uncertainties and extra margin requirements. In most cases it was concluded that the required accuracies on the nuclear data are difficult to meet using only differential experiments.*



- Innovative experimental techniques are developed: DANCE at LANL, at the Rensselaer Polytechnic Institute, the LINAC GELINA facility, at the CERN n_TOF facility, and at the GANIL facility in France.

- Moreover, growing efforts efforts in Japan and in China have produced some significant steps forward.

However, the physics limits on differential experimental uncertainties reduction require exploring other complementary paths.

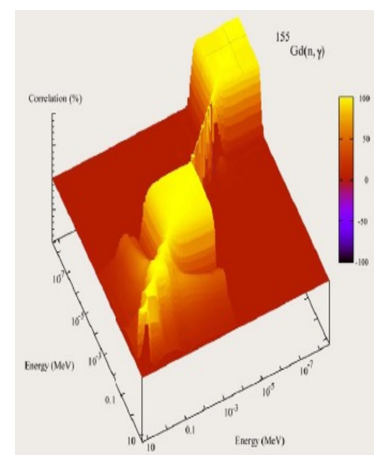
4- Integral experiments

▪The use of integral experiments has been essential in the past to ensure enhanced predictions for fast power reactor cores. In some cases, these integral experiments have been well documented and the associated uncertainties are well understood.

▪The combined use of scientifically based covariance data and of integral experiments can be made using advanced statistical adjustment techniques. These techniques can provide in a first step adjusted nuclear data for a wide range of applications, together with new, improved covariance data and bias factors (with reduced uncertainties) for the required design parameters, in order to meet design target accuracies.

▪The major new developments have been:

- ➢Definition of new science-based covariance data
- ➢Integral experiment covariance data assessment with improved experiments analysis
- ➢Ground-breaking critical approach to statistical data assimilation performance
- ➢Generalization of the data assimilation method itself, now applied to fundamental nuclear model parameters
- ➢Systematic use of well documented integral data bases (NEA DataBank, IRPhE project).

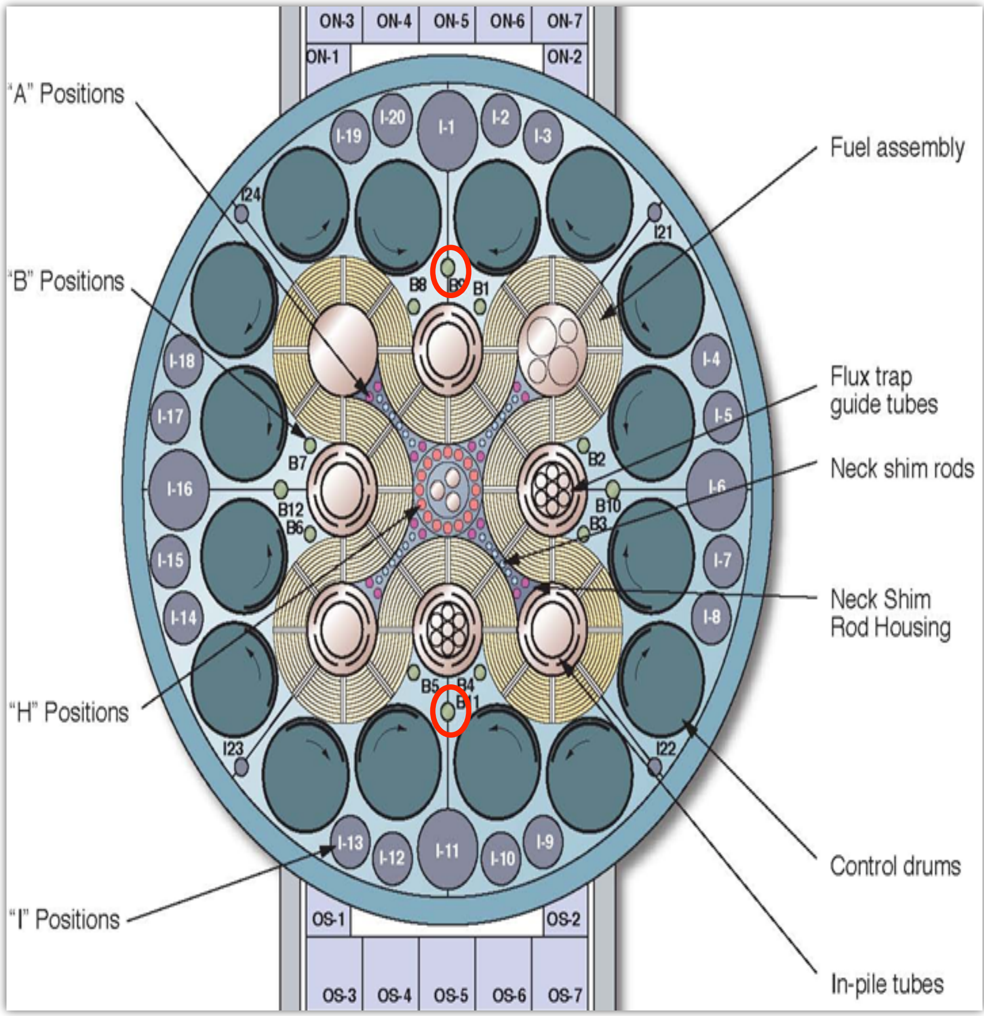


5- New physics experiments?

- In the case of future fuel cycles, the impact of nuclear data and of their associated uncertainties can be crucial in order to further explore an option, or to reject it. In fact, decay heat and doses (gamma and neutron) of spent fuel impact both the design of unloaded fuel maintenance systems, the proliferation risks mitigation and, in general, the geological storage characteristics. Minor actinide and higher Pu isotope data impact both safety and reactivity coefficient assessment.
- A very innovative experiment (MANTRA: Measurement of Actinide Neutronic Transmutation Rates with Accelerator mass spectroscopy) has been conceived to meet the performance requirements of future fuel cycles for advanced systems in terms of basic data.
- The MANTRA experiment, conceived at INL, has been performed in collaboration with ANL and ISU. It utilizes three major facilities
  - ATR reactor at INL (various neutron spectra are simulated using appropriate neutron filtering devices)
  - Accelerator Mass Spectroscopy (AMS) capabilities of the Argonne Tandem Linac Accelerator System (ATLAS) at the Argonne National Laboratory
  - Multi-Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS) at INL, providing very sensitive measurements of the different actinides that are built up during the irradiation, up to the highest mass isotopes
- The first results have confirmed the potential of this original experimental approach

MANTRA

Samples irradiation in ATR



Two Positions: B9 and B11

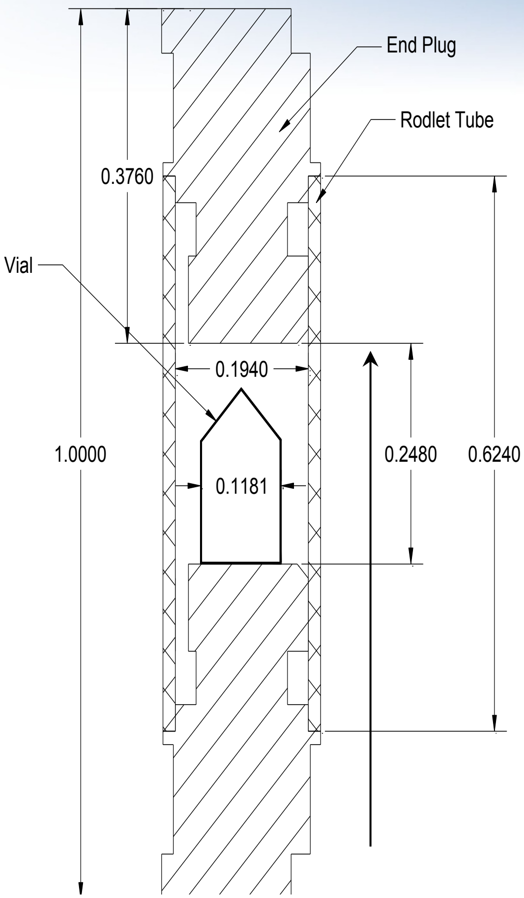
Three Neutron Filters:
→ 1 mm Cadmium
→ 5 mm Boron (70% ^{10}B)
→ 10 mm Boron (70% ^{10}B)

Irradiation in ATR:
→ 3/2012 to 1/2013 (5 mm B)
→ 11/2012 to 1/2013 (Cd)
→ 11/2013 to 1/2014 (10 mm B)

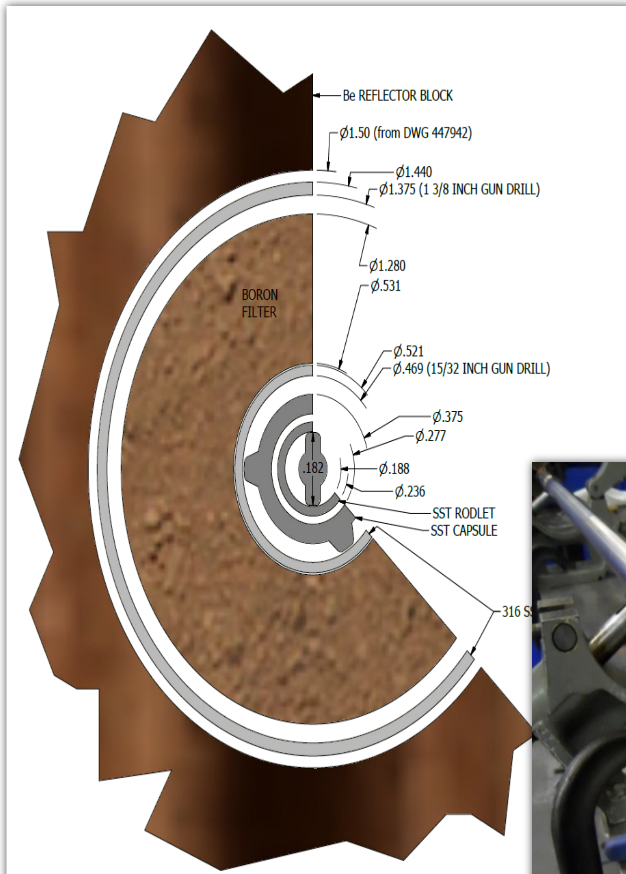
Irradiation Time:
→ 55 days for Cd-filtered
→ 110 days for B-filtered

NB: From May to November ATR 2012 was either shut-down for maintenance or operated only at zero power for physics testing. Most experiments were unloaded.

Samples irradiation in ATR:
Boron filter



Actinide sample



MANTRA

Multi-Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS)

- Brought online in MFC's Analytical Lab in April 2013
- Leap above the DOE and industry standard for accurate measurements of isotopic ratios, which relied on Thermal Ionization Mass Spectrometer (TIMS) technology
- Provides a faster and more accurate method to determine how much of which elements and isotopes are present in any given sample.
- Much faster turnaround times for MC-ICPMS for a given sample (few hours) than for TIMS.

6- Conclusions

- Next generation and advanced systems (core and associated fuel cycles) require improved data to meet safety and economy design requirements

- Expanded and more robust covariance data (e.g. cross correlations), improved evaluations (NEA initiative underway, CIELO)

- More extensive use of sensitivity analysis and of target accuracy requirements. Methods exist, but should be systematically used

- Possibly, a few selected new differential and integral experiments could be needed

- However, new paradigms in planning/performing science-oriented experiments (e.g. MANTRA): separated effects, basic phenomena understanding

- Science based approaches in data assimilation should be developed (initiatives underway at NEA, SG39)