GEDEON GROUPEMENT DE RECHERCHE
CEA - CNRS - EDF - FRAMATOME

GEDEON WORKSHOP

ON

NUCLEAR DATA RELATED TO INNOVATIVE OPTIONS FOR TRANSMUTATION

SESSION 2A
EXPERIMENTS UNDERWAY AND NEW PRIORITIES

INTEGRAL EXPERIMENTS : THE PHYSICS APPROACH

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1. General introductory remarks relative to nuclear data uncertainties

2. The role of integral experiments as a validation tool and as a complement to differential experiments

3. Conclusion

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1. General introductory remarks relative to nuclear data uncertainties

- **The nature and quality (accuracy) of the data** required by the nuclear engineer for studying a particular nuclear **system depend on the type of study** he/she is doing : scoping, conceptual, design, licensing, operation, safety studies require different types of nuclear data with different levels of accuracy. Consequently, the effort (cost) required for obtaining the relevant data may vary substantially between studies.

- In principle, for any application, the nuclear engineer **should assess the data accuracy** he/she needs to meet the specified objective and performance (characteristic output value G + maximum uncertainty + allowable margins of variations) of the system, even if, in practice, this can be difficult as objectives are complicated functions of many variables often subject to constraints.

- There are **various sources of errors** affecting the performance (G) of a given system. Uncertainties in nuclear data are only one of several components contributing to the total uncertainty in G. Others include manufacturing tolerances, uncertainties in the physical, chemical, or mechanical properties of the constituents, calculation/modelling errors, etc.

All should be estimated. Basic nuclear data are often the dominant source of errors ; however, one should not lose sight of the other components as, in some cases, they may become dominant, making the improvement of nuclear data beyond a certain level useless.

- The specified performance of the system (G) should be translated into **target uncertainties for the various basic parameters**, P, including nuclear data. This can be done by using standard error propagation formulas, provided **sensitivity profiles** ($S=P/G \times \partial G/\partial P$) **and correlation information** on the P's are available.

- A **cost/benefit analysis** can then be made : The efforts needed for improving various parameters (ΔP) can be compared in terms of their relative contributions to the total uncertainty in G, ΔG. Unfeasible, unnecessary, or inconsistent work can then be avoided. On the other hand, the analysis may provide a strong incentive for reducing the uncertainties in some particular parameter.

- Regarding nuclear data, the parameters P should in principle be taken as the basic nuclear physics parameters of each nuclide. However, in practice, effective microscopic group cross sections σ are generally used instead as they are easier to relate to G. As covariance data are essentially missing from the evaluated files (which is a serious problem), covariance matrices of group cross sections must be estimated.

- By the above procedure, one can in principle determine the impact of parameter uncertainties on the system performance, and therefore determine whether design or performance criteria can be satisfied or improved (economic gain or added safety margin).

2. The role of integral experiments as a validation tool and as a complement to differential experiments

- **Integral experiments** consist in accurate measurement of neutron-spectrum-averaged quantities such as critical mass or reaction rates in carefully-designed configurations representative of a system of interest.

- Whereas differential measurements provide high-resolution information on a particular nuclide and reaction in some narrow energy range, integral measurements usually provide low-resolution information sensitive to several nuclides and reactions over a large energy domain.

- Integral experiments are useful for neutronics code « **validation** » purposes, i.e., for estimating the **uncertainties** to be assigned to the neutronics code predictions as a result of errors in the data files used.

  Additionally, measurements from fundamental-type integral experiments can be analysed by sensitivity studies to infer valuable **information on nuclear data**.

  Finally, uncertainties obtained from integral experiments can be **extrapolated** to real operating systems, which can be extremely valuable whenever integral measurements in the actual system are not available, inaccurate or impossible.

- Two types of integral experiments are usually distinguished :
    - ♦ **“Fundamental” experiments**, as “clean” as possible

      Aim is physics, nuclear data

      Ex : PROFIL in PHENIX, OSMOSE in MINERVE

      Simple configurations, well-characterised spectrum ⇒ calculations free from biases → feedback on nuclear data *via* sensitivity analyses of C/E
    - ♦ **“Mock-up” experiments**, as “representative” as possible

      Aim is validation of a particular concept

      Ex : COSMO in MASURCA, ECRIX in PHENIX

      More complicated modelling, requires numerical + experimental validation studies → assessment of performance from C/E

- Following an integral experiment, the measured (E) value of some integral quantity G is compared with the corresponding calculated value (C) obtained by some reference method (negligible method biases), for some well-characterised reference configuration (negligible modelling errors) representative of the system under consideration. The **discrepancy C/E** can then be **unambiguously attributed to errors in the nuclear data**.

- This (small) discrepancy ΔG is analysed by **sensitivity studies**. Sensitivity profiles are computed and used to split ΔG into contributions Δσ from the various nuclear data, σ.

- This procedure can be repeated for various configurations and measurable integral quantities G of interest. It can be further extended to other configurations and integral quantities which, although not of immediate interest for assessing the system performance, are chosen so that they are sensitive to a wide variety of parameters. In this manner, a large **integral database** can be constructed in which the parameter space is extensively spanned.

- Assuming that covariance information on integral measurements is available (which is usually the case), a **statistical adjustment procedure** can be applied to the various results of such analyses, from which deficiencies in some nuclear data (trends) can be identified. This procedure consists in minimising a χ^2 function of the nuclear data, equal to the sum of the weighted deviations of the microscopic data and the weighted deviations of the integral data.

- Following the diagnostic on nuclear data and pending improvements in the evaluated files, under certain conditions and assumptions, corrections $\Delta\sigma$ can be applied to the nuclear data to compensate the identified biases and to reduce the uncertainties. **Adjusted nuclear data libraries** thus built can be used for obtaining improved code performance. In fast spectrum reactor studies, such adjusted libraries have proved to be powerful tools for accurate predictions of critical mass and power distributions.

- Note that the extent and “representativity” of the integral validation database are essential as they condition the **range of validity** and the **level of uncertainties** associated to the code predictions.

3. Conclusion

- For a given type of system study (scoping, design,...), a systematic assessment of the nuclear and other basic data accuracy needed to meet the required objective and performance of the system should be made. This assessment should help determine if efforts on improving some nuclear data are necessary or not.

- Integral experiments not only provide the required information for validating theoretical predictions (uncertainty estimation), but also constitute a useful complement to neutron reaction differential measurements, which are still incomplete and insufficiently accurate (in level) today. Statistical adjustment procedures based on large integral databases can help reduce nuclear data uncertainties.

- Several high-value-added integral experiments are ongoing or planned at CEA for the coming 4-6 years : OSMOSE in MINERVE, PROFIL and ECRIX in PHENIX, COSMO and MUSE in MASURCA,

  all aimed at improving our basic knowledge of neutron physics and nuclear data.