Nuclear data for fission and fusion : status and synergies

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Summary

Since the drawn of the nuclear era it has been very clear the importance that accurate nuclear data have on the successful design and development of nuclear systems. Extensive measurements of nuclear data were made from the 1950s to the 1980s. Since then, computational modeling and simulations of nuclear systems have quickly developed thanks to development of computers and computational tools (e.g. CAD → 3D geometry → Code input). Computational tools are more and more important in the present days since sustainable energy production depends on high-level modelling capabilities for the reliable and cost effective design and safety assessment of fission and fusion nuclear systems. Furthermore, with the increase of the complexity of advanced nuclear systems the design and realization of experiments, mock-up and prototypes are more and more expensive it is thus necessary to develop calculation tools and sets of nuclear data that allow for very reliable simulation of the fission and fusion nuclear systems. High quality nuclear data are essential for the modelling capabilities and the interpretation of key benchmark experiments needed for performance and safety evaluations of the nuclear systems. The implementation of nuclear data files requires the complete and accurate information about the different nuclear reactions taking place in fission and fusion reactors. Therefore, for historical reasons fission and fusion nuclear systems have developed independently (even within the same country) and so the nuclear data files used for the design and analysis of these systems. However, in the attempt to improve the nuclear data files and to reduce costs in the recent years there has been increasing synergy between fission

and fusion communities. Indeed, fission and fusion nuclear analysis share a common energy range (the one extending from thermal neutron energy up to 10 MeV) and thus some quantities such as e.g. total and scattering cross sections, (n,x) reactions (where x is a charge particle), resonance parameters, kerma values, dpa cross sections, nuclear decay data, gamma-rays data, etc., can be jointly evaluated for a number of elements or isotopes.
The synergic effort so far pursued to merge into common libraries, extending at least up to 20 MeV, the fission and fusion nuclear data led to the production of extended nuclear data files such as e.g. ENDF/B, JEFF, JENDL, CENDL, TENDL etc., which in their latest release are able to cover and meet most of the needs for both fission and fusion nuclear systems. Therefore, effort is needed for extensive validation of these files and to extend them up to 50-60 MeV, to the range of interest to IFMIF/DONES. The latter is the intense neutron source for radiation damage study for fusion plants. Extension to higher neutron energies of the available nuclear data files is also of interest to the emerging new fission technologies such as the Accelerator-Driven Systems (ADS). ADS usually are sub-critical systems operated through a neutron source driven by an accelerator. The latter uses a beam of high energy protons to generate neutrons via spallation reactions. Despite the average energy of these neutrons can be as low as 1-2 MeV a tail of high energy neutrons (> 20 MeV) is present. This provides a common neutron energy range with IFMIF/DONES.

Cross sections above several MeV neutron energy are relevant to fusion for better evaluating high energy threshold cross sections (e.g. (n,a), (n,2n), (n,d), etc.) as well as their double differential cross sections. These data are useful also for calculating the induced *neutron damage* (dpa) in materials relevant to form the the main components of the reactor such as the first wall or the divertor. In next generation fusion devices dpa as high as tens of dpa are foresee, so even small uncertainty in the dpa cross section can introduce large error on the dpa evaluation and thus on the plant safety. Therefore, the information on dpa cross sections can be of importance also to ADS and fast nuclear reactors where the high energy component of the neutron spectrum is not to be neglected and in any case impact on the safety of the plant.

Up to now the measurements of dpa cross sections has represented one big issue since was requiring high neutron fluence at high energy. In the very recent years new experimental techniques based on *positron-annihilation lifetime-spectroscopy* (PALS) has allowed to measure the dpa cross section with neutron fluence of the order of $10^{\wedge 14}$ n/cm^2, several orders of magnitude lower than previous techniques. This allows to measure and/or re-measure (e.g. near the threshold) dpa cross sections for the most important elements forming the structural materials. This would result beneficial also for fission plants and ADS.

Last, but not least, in the latest years an increasing interest has grown also on hybrid fission-fusion (HFF) systems. In a HFF system a fusion device is used as neutron source to operate sub-critical fission reactors with the main goal not only to produce safely electric energy but also to burn spent fuel and actinides so to reduce the nuclear waste, a common goal shared also with ADS which, in turn, can use spent or not proliferation fuel too. The ADS and hybrid systems can play an important role to bridge the gap between fission and fusion communities and can be thus beneficial also to nuclear data implementation.

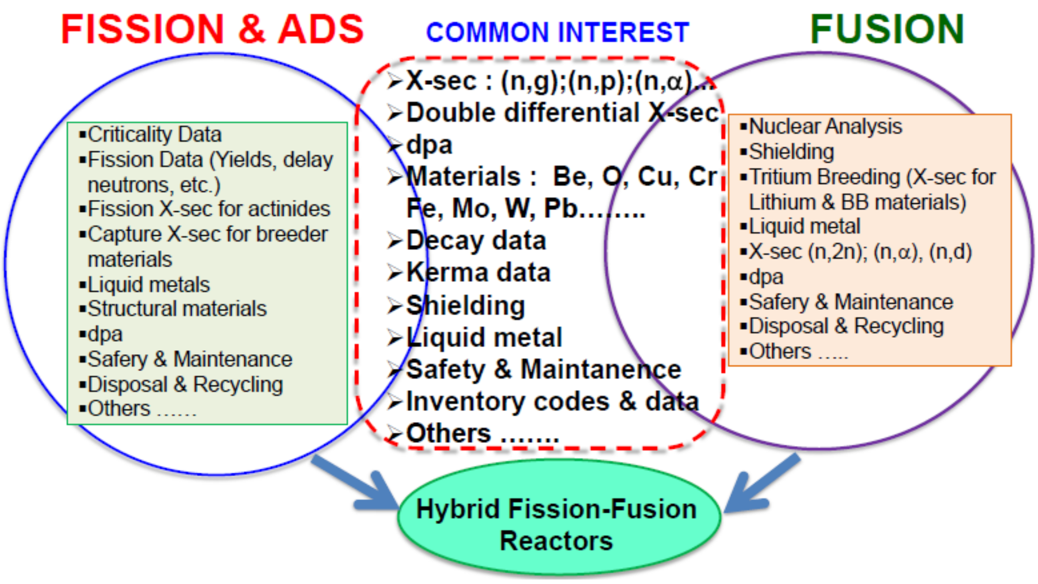
A fundamental part of the design of any nuclear system is the so called ***nuclear analysis*** which is used for the nuclear design of nuclear systems. The nuclear analysis serves not only to define the nuclear parameters and quantities of the system but also e.g. to evaluate the doses to materials, electronics, personnel (during both operational and not operational periods, e.g. maintenance) and at shut-down, materials activation for disposal and even for material recycling. All information fundamental to get the licensing and ensure the safe operation of the plant. To mention that disposal and recycling are becoming more and more important in the frame of a safe and environmental friendly use of nuclear energy.

Nuclear design of fission and fusion systems needs thus neutron and photon transport calculations to provide the neutron/photon flux spectra that when convoluted with related nuclear data form the basis for the calculation of nuclear responses of interest (e.g. fuel burn-up, nuclear heating in the materials, dpa, doses and dose-rates, etc.).

Appropriate and qualified neutron transport computational tools and simulations are required to ensure the reliability of calculated nuclear responses. These, in turn, require *appropriate nuclear data* both for the neutron/gamma transport and nuclear responses calculation. High quality nuclear data are thus essential for the interpretation of key benchmark experiments needed for performance and safety evaluations of the nuclear systems. The results of benchmarks allows for establishing the quality of the used nuclear data and thus provide very useful information about the reliability of the nuclear analysis. This hold regardless we are considering fission or fusion systems, so the available benchmarks and mock-up experiments carried out independently for fusion and fission systems can be of great importance for testing and validating the calculation tools.

To this end, the *Shielding Integral Benchmark Archive and Database* (SINBAD) data base, developed since early 1990's jointly by the Organisation for Economic Co-operation and Development's Nuclear Energy Agency Data Bank (OECD/NEADB) and the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (ORNL) can play a role of paramount importance to link fission and fusion. SINBAD comprises over 100 benchmark compilations and evaluations of relevance to fission reactor shielding, pressure vessel dosimetry, fusion blanket neutronics as well as accelerator shielding. Evaluators using such a data base can test and validate code and nuclear data files in all the energy range of interest. This activity coupled to the sensitivity/uncertainty analysis of these experiments can produces important inputs to the nuclear data evaluators. Here synergy between fission and fusion is well consolidated.

In the present report a discussion about the status of fission and fusion nuclear data is first reported. In the specific, after shortly reviewing the status of nuclear data presently available both for fission and fusion we will consider the areas where the nuclear data for fission and fusion overlap and the possible actions to find and/or develop synergies are discussed. The figure here after summarizes the discussion about the possible synergies.



A list of possible topics where synergies could be looked for and implemented is also reported.

Re-analysis of past benchmarks (both fission and fusion) still points-out the need to improve Fe(n,n') reactions.

Several materials of interest to both fission and fusion can be also studied jointly e.g. Pb, W, Cu, Fe, Cr, etc. and in general all the elements/isotopes which are constituents of stainless steel or other structural materials, including the minor isotopes.

Activation and transmutation cross-section data must be provided for the isotopes of all stable elements that constitute the **structural materials** or may be present as impurities both for fission and fusion systems. Data up to 50-60 MeV needed.

For the sake of fusion systems (and ADS), also radio-nuclide targets require cross-section data, as *multi-step reactions* (also named charge-induced reactions) could be also important in the *high neutron fluxes* expected in these plants.

Last, but not least, the *decay data* of all possible nuclides must be available to enable activation calculations to be carried out so to foresee the doses in the plant both during operation, the maintenance phases and at shut-down.

The *information about materials activation* are essential also for the decommission phase since in a more advanced view of the global energy production process the problem of **materials disposal** and of their **potential recycling** has to be considered since the design phase.

Furthermore, the request from the regulatory authorities for doses as low as reasonable possible is also pushing toward the study and development of the so called **low activation materials** (LAM).

The inclusion of LAM in the nuclear analysis is part of modern approach to fission and fusion nuclear power plant design and "ad hoc" work is required to render available the nuclear data for such materials *including all the minor isotopes that constitute them.*