Nuclear data for sustainable nuclear energy

Final report of a Coordinated Action on Nuclear Data needs for Industrial Development (CANDIDE)

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Executive summary

The successful development of advanced nuclear systems for sustainable energy production depends on high-level modelling capabilities for reliable and cost-effective design and safety studies, and for the interpretation of key benchmark experiments. High-quality nuclear data, in particular complete and accurate information about the nuclear reactions taking place in advanced reactors and the associated fuel cycles, are crucially important for such modelling capabilities. The lack of complete and accurate nuclear data for technical design and development can lead to inefficiencies, lack of reliability, and design problems, all of which translate into margins and excess conservatism, which can be very costly. Indeed, a primary benefit of improved nuclear data lies in the perspective of cost reductions in developing and operating nuclear reactors; as with precise nuclear data, future nuclear systems can be designed to reach high efficiencies whilst maintaining adequate safety standards in a cost-effective manner.

In the CANDIDE project, nuclear data needs for sustainable nuclear energy production and waste management have been studied and categorized. Meeting those needs will require that the quality of nuclear data files be considerably improved. Maybe the most important conclusion is that the know-how and (experimental and theoretical) instruments necessary to make such a significant step forward are still actually available in Europe, and in certain cases world-leading: they "only" need to be mobilized, enlarged and organized in the appropriate way. However, at the same time, the current situation appears quite fragile globally, which motivates a number of initiatives and immediate actions.

The CANDIDE project has produced a roadmap for sustainable nuclear data development. Thereby, a distinction is made between ***horizontal issues***, which concern general nuclear data development required for any system, and ***vertical issues***, which concern more specific issues per nuclear system. The most important conclusions and recommendations for horizontal nuclear data development are:

- **A long term commitment to modern nuclear data evaluation should be provided in Europe**. This concerns nuclear data evaluation that implements the latest advances in nuclear physics into high-quality nuclear data libraries (JEFF) for applied use. This should include a complete assessment of the uncertainties and uncertainty correlations in nuclear data (covariance matrices). If accomplished, this will allow the better determination of safety and economical margins of both existing and future nuclear systems. Without this, advances in experimental and theoretical nuclear physics will remain disconnected from the industrial application of nuclear technology. A European long-term nuclear data evaluation program should be maintained, to ensure that Europe's position remains competitive with the USA and Japan, where such measures have already been taken. Specific high-priority recommendations include:
    - Production of complete nuclear data libraries, including **a comprehensive set of reliable covariance matrices**, using both theoretical and experimental nuclear data information.
    - Development of systematic quality-assured data evaluation methods, which guarantee consistent nuclear data libraries in which new

experimental and theoretical information becomes directly and correctly available.

The production of covariance matrices in JEFF is an extremely important task, which calls for a dedicated high-priority specially-funded action on the part of nuclear and reactor physics experts in close collaboration. This is an area where targeted support from the EC could help bridge the current gap.

- **Provide and support the facilities that are capable to produce the required nuclear measurements and stimulate high-level measurements on key reactions of interest to advanced reactor development**, especially those measurements that demand higher accuracy than available from nuclear modeling, and critical data that serve as standards for large classes of other measurements. Specific high-priority recommendations include:
  - The stimulation of selected differential measurements that answer generally accepted high-precision nuclear data needs, such as those emerging from the recent NEA SG-26 working group on nuclear data needs for advanced reactors and ADS, as categorized in the High-Priority Request List for nuclear data.
  - Insistence on, or even force, a "culture change" in experimental nuclear physics, to deliver systematically to the international data bases a complete documentation of performed experiments and all available covariance information, both of which are required to guarantee no quality loss when transferring basic nuclear reaction information to technology by means of data evaluation.
  - The stimulation of integral measurements to test nuclear data in well defined reactor-type spectra and to decrease the nuclear data uncertainties in cases where differential measurements do not suffice.
- **Provide the capability for advanced nuclear model development** to address the priority needs that cannot be met due to the lack of experimental facilities or because model calculations can provide certain important data in a more cost effective way. Specific high-priority recommendations include:
  - Bring the predictive power of nuclear models for actinides to the same level as that for non-fissile nuclides. For this, consistent nuclear fission models and parameters for all important major and minor actinides need to be developed and made generally available. This will give flexibility to produce covariance data for actinides as well.
  - Development of consistent statistical methods to produce reliable covariance information from both theory and experiment.
- **Ensure flexible implementation of improved nuclear data libraries in nuclear technology and design**. Those companies or institutions that can assure and reduce the cycle time for innovations and quality improvements in nuclear data have a distinct advantage in either research or the industrial markets. This requires a much more modern approach to reactor software development, in particular regarding the handling of nuclear data. Obviously, the nuclear data community will benefit from rapid and flexible application of their results in actual reactor calculations, and the associated feedback will allow further improvements to be made. Specific high-priority recommendations include:
  - Assist reactor code developers in developing easy upgradeable nuclear data library interfaces, for both static and dynamic system analyses.

This should be pursued into the area of full core coupled neutronic and thermo-hydraulic reactor calculations.
  - Develop systematic approaches to integral validation and sensitivity studies, to ensure that improved nuclear data (e.g. better covariance matrices) can directly be tested on relevant integral measurements such as those from the ICSBEP, IRPHE, and SINBAD collections, or on advanced reactor and ADS sensitivity cases as initiated by SG26.

Contemporary analyses of current reactors, GEN-IV reactors and ADS have also given rise to various specific issues. The most important conclusions and recommendations for vertical nuclear data development are:

- **High burnup systems.** Increased burnup scenarios will put a larger emphasis on the quality of fission product evaluations. In order to better assess the neutron absorption rate of the fission products, their cross section, fission yields and radioactive decay properties need to be known. Therefore, decay data and fission yield data need to be critically examined and future evaluations be accompanied by both uncertainty and covariance data. These data are also important for fast reactor inventory analyses.
- **Fast neutron actinide cross-sections for both critical and sub-critical reactors.** There are strongly motivated requests for improvement in the nuclear data for U-238 (capture and inelastic) and the Pu-238 to 242 isotopes (capture and fission). More precise measurements, fission model development, and a careful data library evaluation including covariance treatment are called for.
- **Fast neutron cross sections for structural materials and coolants.** Modern nuclear data evaluations and precision measurements of inelastic scattering cross sections are required for important (system dependent) structural materials, coolants and inert fuel elements (Na, Mg, Si, Fe, Mo, Zr, Pb, Bi). In particular, an accurate determination of the sodium void coefficient of an SFR requires improvements in the inelastic scattering cross sections for Na-23 and a complete covariance treatment.
- **Cross-sections for transmutation and target design in accelerator-driven systems.** Transmutation with sub-critical reactors, loaded with minor actinides, coupled with an accelerator are characterized by some specific nuclear data concerns:
  - Specific capture and fission measurements in the 1 eV to 1 MeV range for Am and Cm isotopes.
  - Well-chosen integral measurements for neutrons at intermediate energies.
  - Assessment of uncertainties of high-energy data (>20 MeV).

In conclusion, **a substantial long-term investment in an integrated European nuclear data development program is called for, complemented by some dedicated actions targeting specific issues**. It can be expected that, as nuclear analysis and design methods improve, reactor designers will become more demanding, which will result in more stringent requests on nuclear data evaluations, measurements, and validation. In order to be responsive, it will be necessary that we retain a critical mass of scientists trained in a variety of nuclear data related fields with sufficient funding to maintain, develop and pass on their skills to the next generation. There are indications that over the last few years we have lost much of our expertise in the area of evaluation and data testing. There is also concern that what we have left will deteriorate rapidly. This deterioration will result from experienced people retiring or taking better career opportunities outside of their current research fields, and inadequate funding available to train replacements. It is noted that significant enhancements in the nuclear data field can be generated through doctoral level student projects and postdoctoral research. Students can additionally be a source of well-educated staff for the nuclear power industry and regulatory bodies, provided these positions are seen as good long-term career options.