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# CANDIDE – Coordination Action on Nuclear Data for Industrial Development in Europe

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**Abstract.** A Co-ordinated Action has been launched with the ambition to establish a durable network on nuclear data efforts that are important in the context of minimising the high-level waste stream of nuclear energy. This implies optimal incineration of all actinides that nowadays constitute spent nuclear fuel, in critical and sub-critical reactors. As a consequence, the scope of the CA encompasses transmutation in fast critical reactors as well as sub-critical systems (ADS). The purpose is to identify the needs for improved nuclear data, assess the present status of knowledge, and to estimate what accuracy can be reached with state-of-the-art techniques.

## 1 Introduction

The EC-supported Coordination Action (CA) CANDIDE, Coordination Action on Nuclear Data for Industry Development in Europe, addresses the following two objectives:

- Establishment of better links between academia, research centres and industry end users of nuclear data. This is reflected in the project name.
- Assessment of nuclear data needs for advanced nuclear reactors. The emphasis is on the radioactive waste issue, i.e., either waste transmutation in critical or sub-critical devices or minimizing the production of nuclear waste in future nuclear reactors, as envisaged in some fast critical systems.

For a long time activities concerning all aspects of nuclear data for commercial nuclear power reactors, i.e., nuclear data production, theory, evaluation, validation and industrial use, have been part of a well-organized international community, monitored by large international organizations, like OECD. Recently, a new nuclear data community has been formed around the production of nuclear data for accelerator-driven systems, while the other ingredients of traditional nuclear data work (e.g., evaluation and validation) have to a large degree been missing up to now. The present project aims at establishing links for this new community to the existing structure of coordinated nuclear data activities in general, and to provide links to industry in particular.

Another recent development in Europe has been the enlargement of the EU, which opens new possibilities in the realm of nuclear data. Integration – both of different research communities and between new and previous member states – is an important objective of the CANDIDE project. Moreover, improved training and integration are essential parts of the CA, exemplified by the development of a European course on nuclear data to be part of the project.

In the public literature, the concept of transmutation is quite often used in a restricted sense, synonymous to accelerator-driven systems for incineration of spent nuclear fuel. CANDIDE has been designed with the intention to consider transmutation in a broader, more general sense, i.e., incineration of spent nuclear fuel by changing the nature of the elements through nuclear reactions. As a consequence, the scope of the proposed CA will encompass transmutation in fast critical reactors as well as sub-critical systems (ADS). The purpose of CANDIDE is not to produce new experimental data or evaluations, but to review the current modes of nuclear data production, assess the present status of our knowledge, estimate what accuracy can be reached with state-of-the-art numerical simulation techniques, identify the needs for improved

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nuclear data, and suggest appropriate actions to be taken to meet those needs. A large fraction of the existing data were obtained far back in time, and it might be beneficial to identify cases where new experiments on already measured reactions could exploit technology improvements. Key input is expected from industrial partners, since they are closely involved in application of nuclear data libraries and their performance.

The final result of the CA will be a report describing the state-of-the-art and giving recommendations to EC outlining how nuclear data research should be organized in FP7 and beyond. Moreover, the organisation of workshops and a training course will lead to broader European involvement in the subject.

## 2 Nuclear data for transmutation of spent nuclear fuel

In the public debate of today, the concept of *transmutation* has often become synonymous with accelerator-driven systems (ADS) for incineration of nuclear waste. This is not surprising, because ADS represents a very innovative option, while the use of critical reactors represent a more conventional alternative. In CANDIDE, however, we will consider transmutation in a very broad sense, not restricted to a particular system or scenario. Presently, nuclear waste transmutation options are investigated as part of reactor and fuel cycle studies for existing reactor types (PWR, BWR, CANDU), i.e., GEN-III, for evolutionary designs of existing reactors, GEN-III+ (EPR, AP600, etc.), for GEN-IV reactors (SFR, GFR, LFR, MSR, SCWR, VHTR) or for dedicated transmuters (such as ADS). All these activities generate a significant amount of nuclear data needs either for the feasibility phase of these studies or for the performance phase.

Up to now, there has been a very large research volume spent on data on neutron-induced nuclear reactions up to 20 MeV. This was carried out from around 1950 until today, and was motivated by the needs in the development of civil nuclear power, as well as weapons applications and fusion technology. During the last decade, nuclear data at higher energies have been in the limelight due to the discussions about ADS.

The approaches in these two disciplines differ significantly. This is neither a surprise nor a bad choice, because the underlying physics differs significantly, resulting in different research strategies. Below 20 MeV, a single cross section can be of paramount importance to the entire application. An example is the neutron capture resonance at 6.7 eV in $^{238}$U that provides the Doppler effect so important for the stability of critical reactors. Moreover, some cross sections are fundamentally inaccessible to theory, in particular in the resonance region. As a result, at low energies more or less complete data coverage for major elements is required. Above 20 MeV, the situation is fundamentally different. The cross sections are slowly varying in energy, and the behaviour of the system is always dictated by the sum of a large number of reactions, none of which strongly dominates the performance. Therefore, getting a grip on the overall picture has been a more natural ambition in an initial stage, rather than providing precision data on a single reaction.

Thanks to the nuclear data campaigns for ADS in FP5 and FP6, we have now reached a stage where such an overall picture, although fairly rough in many respects, is appearing. As a consequence, the uncertainty in modelling of various ADS concepts due to nuclear data uncertainties have decreased significantly during the last few years. There is, however, still plenty of room for improvement of ADS-relevant nuclear data, only part of which will be fulfilled by IP-EUROTRANS [1].

Up to now, nuclear data at the energies of critical reactors (less than 10 MeV) and accelerator-driven systems (up to 1 GeV) have not been systematically treated on an equal basis. The importance of this aspect was recently highlighted at the International Workshop on Nuclear Data Needs for Generation IV Nuclear Energy Systems [2], after which a WPEC subgroup was established to investigate the nuclear data needs for advanced reactor systems [3]. We find it important for the further development of nuclear data activities for transmutation, and even for the entire research on transmutation, that the nuclear data from these very different regimes can be compared and used in a consistent manner. This is a major underlying theme of CANDIDE.

In general, the safe, economical, and reliable operation of a nuclear reactor depends on the use of nuclear data to predict several important characteristics of plant operation. In the case of transmutation in general, the major benefit of accurate nuclear data relates specifically to avoiding unnecessary conservatism in design and operation such as shielding requirements, power coefficients for a core loaded with minor actinides, and the related power requirements of the proton accelerator for ADS systems.

Another important difference between a dedicated transmutation system – critical or sub-critical – and a conventional critical power reactor is that for the latter, deficiencies in detailed nuclear data can partly be overcome through normalizing calculations to existing reactor measurements or experience from the operation of prototypes and test rigs. The desire to pursue new designs (Gen-IV as well as ADS concepts) without performing extensive reactor experiments dictates using nuclear data that will support reactor calculations that give dependable results even without experimental re-normalization.

On a (very) broad level, the nuclear data requirements for transmutation of waste fall into two classes: (1) resonance and fast neutron reactions for materials that are specific to transmutation: unconventional structural materials, coolants and (in the case of ADS) targets, and minor actinides, whose abundance in the core is much larger than in a conventional reactor, (2) energy regimes that extend beyond the fast neutron region (up to hundreds of MeV) for the above materials and conventional materials. The first class applies to any transmutation method, i.e., including critical reactors, whereas the second class exclusively applies to ADS. In this project, we will consider both classes. Although the motivation for the present project arises from waste minimization using novel reactor types, conventional power reactors can still benefit from the outcome of the CA. Indeed, nuclear data needs that apply to a critical power system, in general also apply to transmutation systems, critical as well as sub-critical. For example, the important interplay between $^{238}$U fission, capture and inelastic scattering, is crucial for a precise determination of criticality. Minimizing the uncertainties in these data is also important for transmutation systems. One interest of the CA is to identify needs that are common to various applications.

## 3 Training and networking

CANDIDE is not limited to involvement of existing activities, but will also promote growth for the future. Therefore, an important part of the project is the development of a dedicated training course on nuclear data for young professionals, the European course on EXperiment, Theory and Evaluation of Nuclear Data (EXTEND) to be held in Budapest. The target group of this course are young professionals, primarily recently employed staff in industry and at research centres, as well as Ph.D. students in the field.

Summer schools in nuclear engineering (e.g., the Eugene Wigner School on Reactor Physics [4] within the ENEN [5] association or the Frederic Joliot-Otto Hahn summer school [6]) are regularly organized, and there are relatively frequent summer schools on fundamental nuclear physics. Up to now, however, there have been few initiatives to bridge these two communities. EXTEND has been designed to fill this gap.

Besides the development of EXTEND, other activities on training and mobility of young industry professionals and researches, as well as European integration are also foreseen. The most visible example is the planned extension of NEMEA workshops [7], organized by IRMM, which are included in the CA. The previous NEMEA workshops have been targeting nuclear data research in Eastern Europe, but will now be enlarged to be open to all Europe. Our intention is to make these workshops meeting places for all European scientists in the field, including the nuclear industry, which has previously not been the case. The outcomes of two previous such workshops have been beneficial for the present proposal, in so far that they have promoted valuable links between old and new member states in general, and scientists from these in particular.

## 4 Project strategy

As has been described above, we have identified possibilities to enlarge the nuclear data activities in Europe by integrating the new research communities (ADS research, new member and candidate states) into the already existing structures for nuclear data work, and CANDIDE will address these issues by organizing open workshops intended for bridging gaps between these communities. Moreover, the project itself has been designed to make industry a more visible player in the research-related activities via the top-down approach of CANDIDE. Last but not least, the development of a new course for young professionals is in line with these goals, but it is also intended to foster closer links between nuclear physics and reactor physics.

The project involves a wide range of industry partners. Three reactor construction or manufacturing organizations are represented. AREVA (France) is a leading manufacturer of nuclear reactors in Western Europe, having received widespread attention recently with the two EPRs under construction in Finland and France. The BNFL group (UK) has a wide range of reactors on its repertoire, gas-cooled reactors in the UK as well as light-water reactors (LWR) manufactured by Westinghouse. The Skoda corporation in the Czech Republic is constructing heavy structural parts to nuclear reactors, like reactor vessels, and are represented in the present CA via their technical support organization, NRI Řež.

Two power utilities, TVO (Finland) and EdF (France), participate in the project, representing light water reactor technology. Fuel manufacturing is represented by Nexia/BNFL and AREVA, while reprocessing is represented by Nexia/BNFL. Design of future ADS-related facilities is represented by SCK·CEN (Belgium) and CIEMAT (Spain).

The validation (CEA Cadarache, NRG Petten) and evaluation (CEA Cadarache, CEA Bruyères-le-Châtel, NRG Petten) teams of the proposed CA represent leading European competence in the field. ITN (Portugal) contributes expertise in nuclear data related to spallation targets. The current-day computer power enables sophisticated nuclear reaction modelling and validation against integral experiments with both deterministic and Monte Carlo software.

On the experimental side, IRMM Geel is the dedicated EU lab for reactor-relevant nuclear data (0–20 MeV), while TSL Uppsala is the primary European facility for neutrons above 20 MeV (up to 200 MeV), which will cover important input for ADS neutronics.

With these partners, we cover the entire chain from industry to experiments, with a top-down approach. The industry partners define the needs from the end-users perspective, and their participation guarantees that the work is application-oriented. The role of the non-industry partners is to assess the possibilities to provide data of sufficient quality to meet the application needs. As a consequence, the issue of which data is required or need to be improved is primarily an industry concern, while the question of how to reach those goals is mostly dealt with by the non-industry partners. Efficient dissemination is guaranteed by the involvement of the IAEA and OECD/NEA Data Banks.

Improved training, as well as integration of new member states, are important issues for the CA. Improvement of training on nuclear data is undertaken in close collaboration with European Nuclear Education Network (ENEN) [5], and it brings educational resources in old and new member states together. Additional integration is provided by the strong involvement of industry throughout Europe. Close contacts with the EFNUDAT [8] integrated infrastructure initiative have been established.

## 5 Project scientific content

As outlined above, the project concerns the integration of nuclear data efforts for all types of transmutation-relevant nuclear systems, i.e., critical thermal and fast reactors, as well as accelerator-driven systems. Up to now, various nuclear-data projects have concentrated on different sub-sets of the global issue. In the present CA, we attempt to unify important aspects of these activities, with the ambition to provide a consistent basis for comparisons of various waste transmutation options.

A general approach to nuclear data for waste management would imply a very large project. To keep the task limited to a reasonable size, but still with the potential to provide results of relevance to the assessment of various transmutation strategies, the work has to be concentrated to a few issues that are of key importance to both fast critical reactors and ADS.

Up to now, the nuclear data research at classical reactor energies, up to 20 MeV, and the ADS-motivated research above 20 MeV have been conducted with very different approaches. This has made sense, because the pre-conditions have been very different. With the recent development in nuclear data for ADS, resulting from FP5 and FP6 projects, we believe it is now possible to conduct research on what is common to critical reactors and ADS. A major unifying aspect is the role of neutrons. In both concepts, the major incineration is due to neutron-induced fission. Moreover, other neutron-induced reactions, like capture and scattering, play significant roles in all these techniques. Another common aspect is that the core will contain large amounts of minor actinides, although the composition differs among various systems. Furthermore, the design studies around GEN-IV type systems encompass not only the core but also the full fuel cycle. One important GEN-IV criterion is the reduction of radioactive waste that is competing against other criteria such as sustainability (full use of Uranium or Thorium ores), economics, safety and reliability, proliferation resistance and physical protection.

As a natural consequence of this, a study that could cover only the transmutation aspect of a core would not be complete. We therefore envisage the project to cover all nuclear data that have some relation to the reactors and their associated fuel cycles, whether they are dedicated specifically to transmutation (just like ADS) or if transmutation is only one of their key features.

In the present CA, we intend to assess the data situation for all neutron energies, from thermal and up to the highest available (200 MeV), both experimentally and theoretically. In the first instance, the focus of the CA should be on cores of fast reactors and ADS. Nuclear data are of great relevance also for irradiation effects on materials, radiation protection and a number of other issues. A possible list of data to be studied is given below:

- General purpose files that include (1) cross sections induced by neutrons, protons and gammas, (2) secondary particle energy distributions, and (3) fission spectra and energy release.
- Gamma production induced by different reaction types.
- Fuel cycle data (fission yields, spallation yields, decay heat).
- Activation files.

Participants from nuclear industry should give guidance on the proper parameters to be investigated and optimised. These needs should be translated into data evaluation and measurement requests, to be carried out in FP7 and beyond. Part of the effort in this CA consists of a critical assessment of major and minor actinide data in the latest nuclear data libraries and an assessment of the corresponding uncertainties. This should in a natural way lead to well-focused measurement requests.

As has been emphasized, the industrial needs will drive the assessment within the CA. It is worthwhile to point at the close connection of the present collaboration with the OECD-NEA High Priority Request List for nuclear data, where such well-defined requests are collected and reviewed to mobilise the community for their resolution. CANDIDE will serve to identify and propagate the EU interests in this domain and to provide the focus for future EU research on nuclear data. Also in the area of follow up on the formulated requests, CANDIDE is well connected to running EC projects, especially the JEFF project, as mentioned previously.

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## References

1. EUROTRANS – European Research Programme for the Transmutation of High-Level Nuclear Waste in an Accelerator-Driven System. http://nuklear-server.ka.fzk.de/eurotrans/.
2. *Proceedings of the International Workshop on Nuclear Data Needs for Generation IV Nuclear Energy Systems, Antwerpen, Belgium, 5–7 April 2005*, edited by P. Rullhusen, http://www.jrc.cec.eu.int/gen4-workshop/main.html.
3. M. Salvatores et al. (these proceedings).
4. The Eugene Wigner School on Reactor Physics. http://www.reak.bme.hu.
5. The European Nuclear Education Network. http://www.sckcen.be/ENEN.
6. The Frédéric Joliot & Otto Hahn Summer School on Nuclear Reactors. http://www-cadarache.cea.fr/fr/cadarache/ecoles/fjohss2007.htm.
7. The most recent event in this series was NEMEA-3, *3rd Workshop on Neutron Measurements, Evaluations and Applications, Oct. 25–28, 2006, Borovets, Bulgaria*, http://www.irmm.jrc.be/html/events/events/nemea-3.htm.
8. G. Barreau on behalf of the EFNUDAT consortium (these proceedings), www.efnudat.eu.