Enrique González-Romero

NUCLEAR DATA ACTIVITIES IN FP7

Enrique González-Romero[1], Amd Junghans[2], Willy Mondelaers[3]
on behalf of the ANDES, ERINDA, EUFRAT and CHANDA collaborations

[1]CIEMAT, Spain
[2]HZDR, Germany
[3]IRMM (JRC-EC), Belgium

Summary

Nuclear research within the Seventh Framework Programme (FP7 and FP7+2) of Euratom has devoted a significant fraction of its efforts to the development of advanced nuclear fuel cycles and reactor concepts, mainly fast reactors, aiming to improve the long-term sustainability through the reduction of final wastes, optimal use of natural resources and improvement of safety in present and future nuclear installations. The new designs need more accurate basic nuclear data for isotopes, like minor actinides (MAs), potentially playing an important role in the operation, fuel concept, safety or final wastes of those reactors and fuel cycles. Four projects, supported by Euratom within the FP7 and FP7+2, have drawn together most of the European nuclear data community to respond efficiently and in a coordinated way to this need. This paper summarises the objectives and main achievements of these four projects: ANDES, ERINDA, EUFRAT and CHANDA.

ANDES has developed new experimental methods, and performed new measurements, validations and evaluations of cross-sections and other nuclear data. The paper summarises the objectives and results at the end of the nearly completed ANDES project. ERINDA has offered the nuclear data research infrastructures of 13 partners, from all over Europe, to experimental teams making new nuclear data measurements, in particular for ANDES. ERINDA has also provided an efficient framework to support the facilities and the experimental groups, helping to select high-quality experiments and to direct them to the most suitable infrastructure. EUFRAT facilitated the access of outside users to the nuclear data facilities of the Joint Research Centre – Institute for Reference Materials and Measurements (JRC-IRMM), and promoted a coherent use of the measurement infrastructure in order to meet Nuclear Energy Agency (NEA) high-priority neutron data requests. EUFRAT focused measurements on the international neutron data needs for innovative nuclear systems. CHANDA, which started in December 2013, will combine the efforts of 35 institutions and the types of activities of ANDES, ERINDA and EUFRAT with coordination and facilitation of the access of experimental teams to existing European experimental facilities to develop the capabilities that should allow solving the main nuclear data challenges and to prepare a sustainable framework to maintain those capabilities.

1. Introduction

Nuclear research within the FP7 and FP7+2 of Euratom has devoted a significant fraction of its efforts to the development of advanced nuclear fuel cycles and reactor concepts, mainly fast reactors, aiming to improve the long-term sustainability through the reduction of final wastes, optimal use of natural resources and improvement of safety in the present and future nuclear installations. The new designs need more accurate basic nuclear data for isotopes, like MAs, potentially playing an important role in the operation, fuel concept, safety or final wastes of those reactors and fuel cycles. Four projects, ANDES, ERINDA, EUFRAT and CHANDA, supported by Euratom within the FP7 and FP7+2, have brought together most of the European nuclear data community to respond efficiently and in a coordinated way to this need. This paper summarises the objectives and main achievements of ANDES, ERINDA, EUFRAT and the preparations for CHANDA.

Accurate and detailed simulation is a fundamental tool for the design of new nuclear reactors and fuel cycle facilities and for the optimisation of existing nuclear installations and of the fuel cycle as a whole. Simulations are being used regularly to:

- identify the limits for safe operation of nuclear reactors and fuel cycle facilities;
- optimise their performance;
- interpret sensors data as diagnostic or description tools;
- evaluate the limits of validity of experimental demonstrations.

They are also used for other applications.

Simulation codes and computing systems are presently able to describe with great detail the models of the individual phenomenology of the process taking place in the nuclear system, producing only moderate or small biases in the predictions. However, the uncertainties on the basic nuclear data induce uncertainties on the predictions of those codes. Clear needs to reduce these uncertainties had been identified in relation with the simulation of advanced fuel cycles and advanced reactors for improved nuclear sustainability, including waste transmutation. New needs already identified include new isotopes, new priorities for different energy ranges and new phenomena. The Fukushima accident has more recently focused, even more, nuclear research and development (R&D) on safety, and in particular on improving the prediction capabilities for nuclear installations in accidental and beyond-design conditions. This objective is raising extraordinary challenges to safety simulation systems, including also the basic nuclear data to be used. In addition, it will also be mandatory to be able to make a robust and complete determination of the global uncertainties of these simulations, and this will require a much better evaluation of the uncertainties of the basic nuclear data.

It is important to note that to prepare and maintain reliable nuclear databases, all the steps of the nuclear cycle have to be correctly covered and improved, including:

- measurement,
- evaluation,
- validation,
- dissemination.

In each step, the recommended value as well as the data uncertainties and covariances must be provided.

Within the four Euratom programmes mentioned, ERINDA and EUFRAT are mainly coordinating and facilitating the access of experimental teams to existing experimental facilities for nuclear data measurements and validation. On the other hand, ANDES has developed new experimental methods, and performed new measurements, validations and evaluations of cross-sections and other nuclear data. CHANDA will combine both types of activities.

2. ERINDA

European Research Infrastructures for Nuclear Data Applications (ERINDA) has provided a convenient platform to integrate all scientific efforts needed for high-quality nuclear data measurements in support of waste transmutation studies and design studies for Generation IV (Gen IV) systems. The objectives of ERINDA also included the following:

- to provide access for nuclear data measurements at the consortium's facilities;
- experiments should account for nuclear data requests of highest priority and scientific value;
- simulation methods to predict the running conditions of innovative reactor systems and the transmutation of nuclear waste;
- generation of complete, accurate and consistent nuclear data libraries and measured nuclear reaction cross-sections.

To reach these objectives, ERINDA coordinated the European efforts in order to exploit up-to-date neutron beam technology and novel research on advanced concepts for nuclear fission reactors and the transmutation of radioactive waste. This coordination resulted in providing transnational access to all relevant nuclear data facilities in Europe, with a total pool of 2 500 hours of beam time for experiments over a 36-month period from 1 December 2010 to 30 November 2013. Special attention was placed on the selection of supported experiments, to take into consideration their contribution to the competence building of young scientists.

ERINDA offered the nuclear data research infrastructures of 13 partners (HZDR, IRMM, CERN, CENBG, IPNO, UU-TSL, PTB, NPI, IKI, IFIN-HH, NPL, FRANZ and CEA) from all over Europe to experimental teams making new nuclear data measurements. The facilities of ERINDA also included different sources and methods for nuclear data measurement, in particular:

1. *Time of flight facilities for fast neutrons*:
   - nELBE (HZDR, Dresden); n_TOF (CERN, Geneva); GELINA (IRMM, Geel);
2. *Charged-particle accelerators*:
   - production of quasi-monoenergetic neutrons electrostatic accelerators in Bordeaux, Orsay, Bucharest and Dresden,
   - neutron reference fields at PTB Braunschweig and NPL Teddington,
   - cyclotrons in Rez, Jyväskylä, Oslo and Uppsala with neutron energy range up to 180 MeV,
   - pulsed proton linear accelerator in Frankfurt;
3. *Research reactors*:
   - Budapest and Rez cold neutron beam, PGAA.

ERINDA has also provided an efficient framework to support the facilities and the experimental groups, helping to select high-quality experiments and to direct them to the most suitable infrastructure, including in particular scientific support of experiments in the form of 10 scientific visits (up to 8 weeks each) at the participating institutes. ERINDA has additionally contributed to the communication and dissemination of results, organising four scientific workshops in Dresden, Prague, Jyväskylä and Geneva.

Finally, the main results achieved in the ERINDA project are:
Nuclear data measurements for:

- optimisation of existing power plants' design and operation of advanced reactor systems, nuclear waste management strategies and transmutation,
- advancing nuclear safety and security,
- development of new experimental techniques;

- *Performance indicators*:
  - **25** Experiments, **2 876** beam-time hours, **109 p**articipants, **21** young researchers and **18** scientific visits to ERINDA institutes (average duration 40 days);
  - *Scientific workshops*: Dresden, Prague, Jyväskylä and Geneva;
  - *Publications in refereed journals:* 33 papers by September 2013.

Additional information on the ERINDA project and the supported experiments can be found on the ERINDA webpage, available at http://www.erinda.org online.

3. EUFRAT

European Facility for Innovative Reactor and Transmutation Neutron Data (EUFRAT) facilitated the access of outside users to the facilities of the Nuclear Physics unit at JRC-IRMM, and promoted a coherent use of the measurement infrastructure to meet high-priority neutron data requests.

EUFRAT did focused measurements on the international neutron data needs for innovative nuclear systems, specifically to obtain new or more accurate neutron cross-section data for fission reactor technology, fission reactor and fuel cycle safety, high-burn–up fuels, nuclear waste transmutation and innovative reactor systems. The selection of experiments took into account the priorities of NEA high-priority neutron data requests, with a particular focus on measurements following the international neutron data needs for innovative nuclear systems, and support for measurements included in the ANDES project.

Figure 3.1: GELINA and Van de Graaff nuclear data facilities at JRC-IRMM

The main topics for the experiments finally supported by EUFRAT were:
Nuclear data for waste transmutation systems and innovative reactor design (80 %), including:

- waste transmutation and minimisation,
- accelerator-driven systems,
- improved reactor operation and fuel management,
- advanced innovative nuclear energy systems,
- nuclear reactor safety;

Development of experimental set-ups and techniques needed for these data measurements (13 %), including:

- characterisation and calibration of new facilities or set-ups,
- validation of innovative measurement methods,
- testing and/or calibration of new detector systems,
- characterisation of samples;

Advanced methods in nuclear technologies, safety and security (7 %).

In total, EUFRAT enabled the accomplishment of 33 experiments with very high scientific quality and including some measurements of high importance and/or high priority in the fields of interest. In addition, it should be noted that the requested beam time was twice what was available in the project, and that EUFRAT delivered 5 985 hours of beam time, corresponding to 33 % more than foreseen in the project. In total, 33 participating institutes made use of EUFRAT support, with 61 % first-time users and 21 % young students.

4. ANDES

The Euratom FP7 project Accurate Nuclear Data for Nuclear Energy Sustainability (ANDES) addressed nuclear data needs associated with the new reactors and new fuel cycles supported by the Sustainable Nuclear Energy Technology Platform (SNETP) in its Strategic Research Agenda (SRA) and in the European Sustainable Nuclear Industrial Initiative (ESNII) proposal taking into account the priority lists for nuclear data from the Organisation for Economic Co-operation and Development's NEA (OECD/NEA), and Euratom FP6 projects EUROTRANS-NUDATRA and CANDIDE. The ANDES collaboration included 20 research centres and universities and started its activities in May 2010.

ANDES combined a reduced group of selected differential measurements, the improvement in uncertainties and covariances within the evaluation process, and the validation of present and new data libraries using integral experiments to bring most critical nuclear data to the level of accuracies required by the new reactors and systems promoted by ESNII and the SNETP. In addition, a specific work package (WP) was dedicated to improving the prediction capabilities of high-energy transport codes for the design of an accelerator-driven sub-critical system (ADS), developing better models and performing a few selected measurements. All these activities were coordinated with the main actors for nuclear data dissemination, the OECD/NEA and International Atomic Energy Agency (IAEA).

For the measurements of low and medium energies for advanced reactor systems, a combination of the best world facilities has been used in ANDES, including: IRMM neutron sources, both the e- linear and the Van de Graaff accelerators, the n_TOF spallation facility at the European Organization for Nuclear Research (CERN), the Jÿvaskÿla cyclotron and the Ion Guide Isotope Separator On-Line (IGISOL) facility, the National Center for Scientific Research (CNRS) Orsay accelerators, and the GANIL accelerator complex. ANDES concentrated these measurements on:

- high-accuracy measurements of neutron inelastic scattering cross-sections of ^{238}U and isotopes of structural materials and inert fuel matrix;
- high-accuracy measurements of neutron total and capture cross-sections of ^{238}U and ^{241}Am;
- high-accuracy measurements of fission cross-sections of several Pu isotopes, and MAs, including the fission yields by surrogate neutrons and inverse kinematics;
- decay data measurements for reactor kinetics and decay heat of relevant fission fragments.

To improve and assess the absolute accuracy of the results from computer simulations, the ANDES collaboration decided to improve the existing tools for nuclear data evaluation with estimation of the data uncertainties and correlations. A similar effort has been made to prepare simulation programmes to use covariance information. To demonstrate the performance of these tools, the covariance matrices of one major and one minor actinide were evaluated.

Integral experiments provide very relevant information for the evaluation and validation of nuclear data. For these purposes, ANDES selected data coming from the following facilities: MUSE, GUINEVERE, PROFIL, ZPPR10A, and SNEAK-7A and -7B, and the collection of international criticality benchmarks. Each of these experiments provides specific complementary information.

To provide directly useful data for the ESNII ADS demonstration facility, the main objective for ANDES in the high-energy range was model validation and optimisation in the 150–600 MeV energy domain.

In parallel with these technical activities, ANDES has contributed to improving the knowledge and training of young professionals in nuclear science and technology by promoting PhD work within ANDES and organising a dedicated training school. Finally, to accelerate dissemination of the new measured or evaluated nuclear data, ANDES set up a close cooperation with NEA and IAEA, the two agencies coordinating the distribution of nuclear data.

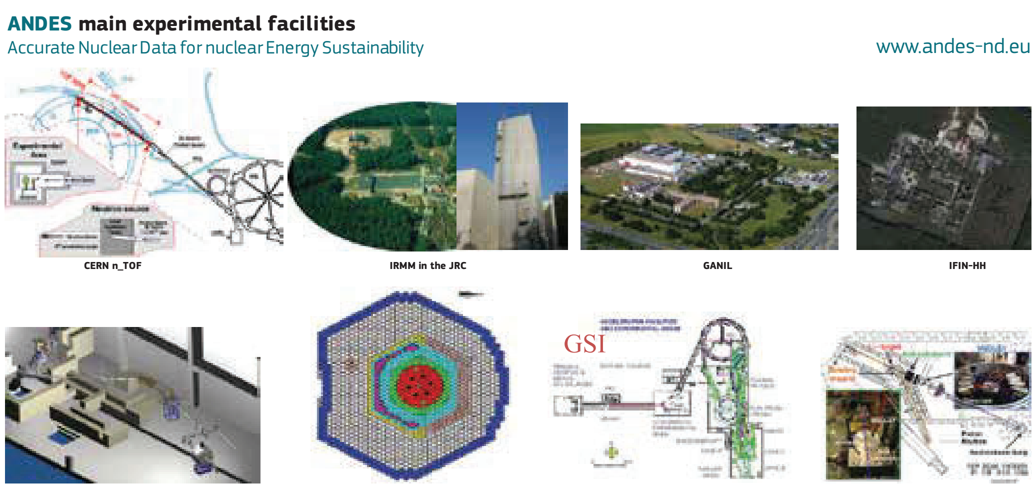

Figure 4.1: Main ANDES experimental facilities

At the time of the FISA 2013 meeting, ANDES was close to reaching its end, having already made very important progress in experiments measuring with high accuracy very relevant cross-sections of critical isotopes, the analysis of which is now in progress or completed and many had been presented at international conferences. More than 20 contributions based on or directly related to the ANDES project were presented at the recent International Conference on Nuclear Data for Science and Technology (ND2013). Large improvements have also been realised in the programmes developed for covariance and uncertainties management through the whole nuclear data cycle from measurement to analysis, evaluation and utilisation in standard codes for reactor and fuel cycle calculations. These tools are also being applied to analyse available integral experiments and the collaboration within ANDES is helping to get a fast convergence on the methods and tools used by different teams, particularly those using Monte Carlo (MC) simulations. Finally, new results on high-energy measurements and interpretation of the recent international benchmarks have allowed identifying some weak points in the high-energy models that are being corrected for their next releases.

In particular, the new measurements already performed within the ANDES project include new data of high accuracy for the cross-sections of inelastic scattering and capture in ^{238}U, capture in ^{241}Am, and inelastic scattering in sodium and fission in $^{240,242}Pu(n,f)$, $^{243}Am(n,f)$ and $^{245}Cm(n,f)$. The experiments for ^{238}U and ^{241}Am capture were performed in two different facilities to further reduce the systematic uncertainties and achieve even better accuracy.

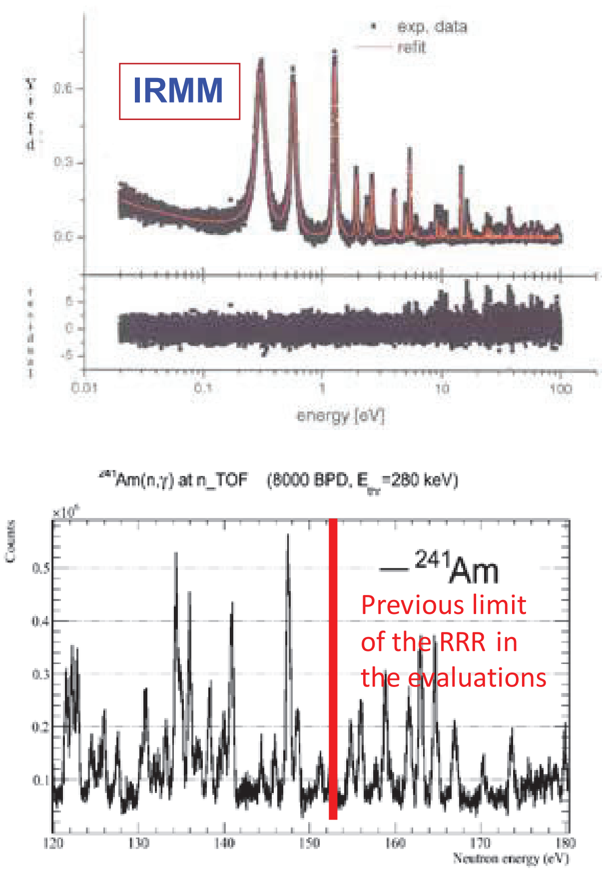

Figure 4.2: ^{241}Am capture measurements in ANDES at IRMM and n_TOF/CERN

Significant progress has also been achieved in the development of tools for covariance preparation and utilisation in reactor and fuel cycle calculations. One of the most relevant results has been the upgrade of the ACAB code, which is now able to use nearly all available sources of data, uncertainties or covariance information for the simulation and analysis of fuel cycle calculations. Also, the impressive progress on the GENEUS full Bayesian evaluation tool has strongly enhanced the robustness and mathematical correctness and self-consistency of the nuclear data evaluation, including covariance determinations. The code has also been extended to be able to handle most relevant isotopes (including actinides and structural materials) and most relevant reactions (including fission).

Significant effort was being devoted within ANDES to precisely define, implement and validate a methodology that allows evaluation of uncertainties and sensitivities and extracting feedback for the nuclear data from integral experiments using MC simulations. This methodology is complementing the more standard tools based on deterministic codes. The first demonstrations of the different ANDES teams, for example using the ISCBEP databank benchmarks and the total MC methods, are already showing the large potential value of the MC methodology as well as the associated huge requirements of computing power and storage space. A large number of simulations were performed with different tools by several institutions, both for the validation of the new tools using simple criticality benchmarks and for the evaluation of selected integral experiments.

For the high-energy range, the modelling activities achieved important progress through analysing the results from the international benchmark and using this information to identify components of the models to be improved. In fact, some of these improvements are already being implemented and tested and will be incorporated in future versions of the standard MC neutronic simulation codes. The high-energy experiments have also progressed, with an early completion of the measurement of neutron-induced light ion cross-sections at 175 MeV on Fe, Bi and U. The MEGAPIE analysis being performed is helping to validate the high-energy models in a direct integral way.

5. CHANDA

The Fukushima accident has further focused nuclear R&D on safety, and in particular on improving the prediction capabilities for nuclear installations in accidental and beyond-design conditions, raising extraordinary challenges to safety simulation systems and the associated nuclear data. Solving Challenges in Nuclear Data for the Safety of European Nuclear Facilities (CHANDA) is a project that started in December 2013 that will combine the efforts of 35 institutions and the types of activities of ANDES, ERINDA and EUFRAT to develop the capabilities that should allow solving those challenges and to prepare a sustainable framework to maintain those capabilities.

The project is organised in 13 WPs integrating all the aspects of the nuclear data preparation and validation cycle, but also taking care of coordination with other international players in the field and preparing a structure for the nuclear data R&D coordination that can became sustainable for the development of long research programmes. The scheme of the CHANDA activities and its WPs is illustrated in Fig. 5.1.

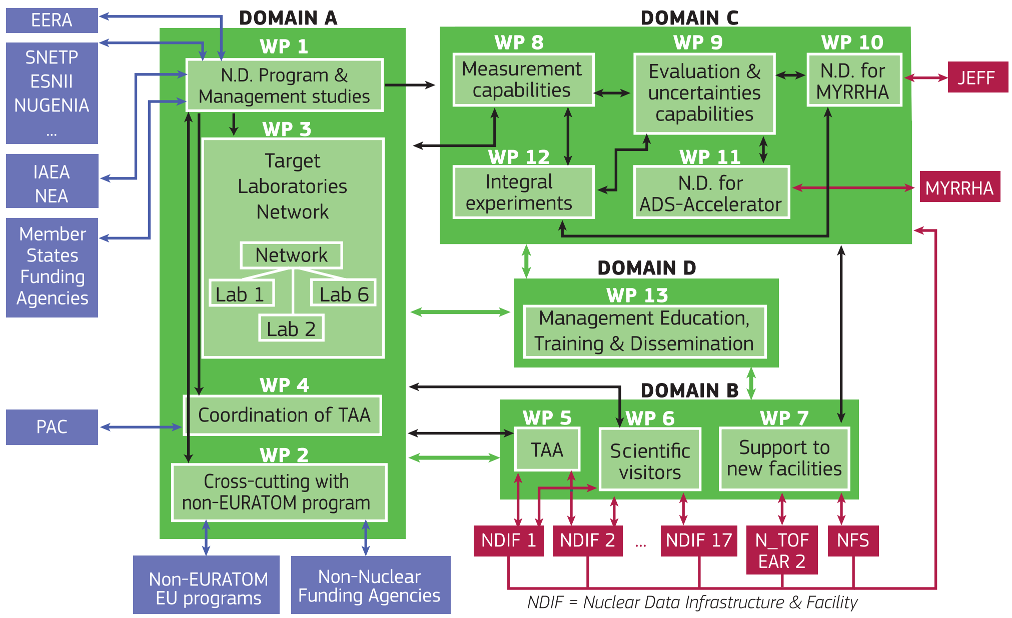

Figure 5.1: CHANDA: Activities and connections to other organisations

The CHANDA-proposed activities include:

- global coordination of nuclear data programme and capabilities;
- coordination of cross-cutting activities with programmes beyond Euratom in Horizon 2020;
- coordination of actions for the development of a network for nuclear target preparation and characterisation;
- calls for proposals of transnational access to the consortium facilities and their evaluation;
- support for experiments at consortium facilities, and scientific support of experiments;
- support for Neutrons For Science (NFS) and the short path n_TOF experimental area equipment;
- development and validation of new measurement capabilities and methodologies;
- development and validation of new nuclear data evaluation and application capabilities;
- development of nuclear data for MYRRHA reactor safety analyses;
- development of a methodology for uncertainty assessment and minimisation in ADS target and accelerator safety analyses;
- development and validation of new integral experiments;
- management, education and training.

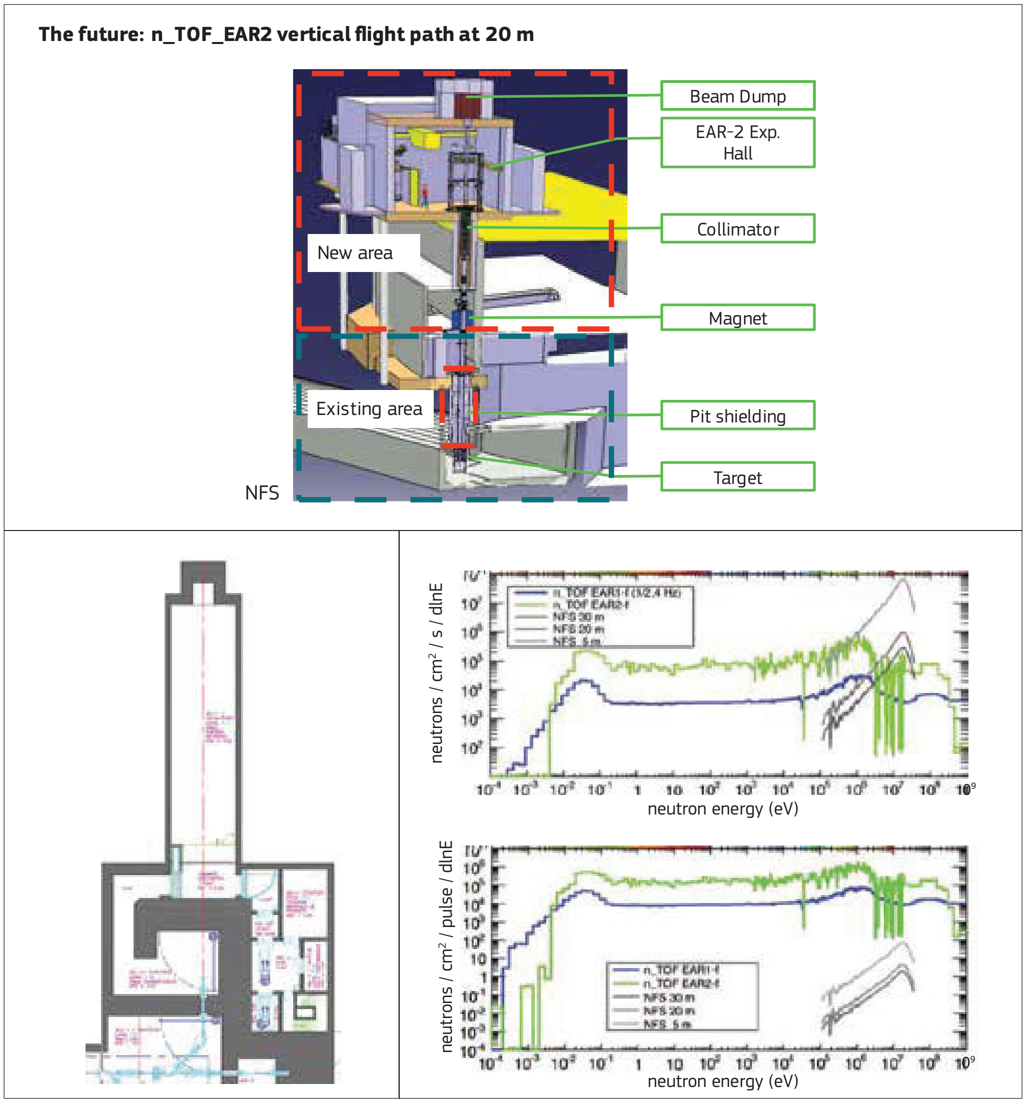

Figure 5.2: CHANDA: n_TOF_EAR2 and NFS new high-intensity facilities

A special highlight is worthy of the support for development of the NFS, and the short path n_TOF experimental area, that will provide the complementarity of one of the most intense neutron sources for average flux (NFS) with one of the most intense sources for instantaneous flux (n_TOF short path). The combination of these high-intensity sources, with improved sample preparation capabilities, improved detection systems, and improved evaluation and dissemination tools to be developed within CHANDA, will allow moving forward the limits of possible measurements and the size of the smaller samples that can be analysed to solve some of the remaining nuclear data challenges for the safe operation of present reactors and the development of more sustainable ones. The combination of these new facilities, with the best of existing nuclear data installations and new measurement and evaluation methods, should open the path to overcoming the new nuclear data challenges.