Spanish Nuclear Safety Research under International Frameworks

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The Nuclear Safety research requires a wide international collaboration of several involved groups. In this sense this paper pretends to show several examples of the Nuclear Safety research under international frameworks that is being performed in different Universities and Research Institutions like CIEMAT, Universitat Politècnica de Catalunya (UPC), Universidad Politécnica de Madrid (UPM) and Universitat Politècnica de València (UPV).

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CIEMAT

The international nature of the investigation conducted by the Unit of Nuclear Safety Research (UNSR) of CIEMAT, responds to the belief that international cooperation is the only efficient way for addressing a so complex area. Namely, international involvement is seen by CIEMAT as an indispensable instrument to meet its generic objectives:

- To develop, validate and assimilate methodologies of risk assessment.
- To reduce existing uncertainties in postulated accidents.

However this heavy international component, UNSR activities build up a bridge between worldwide forefront research and its results application in a domestic environment. This is the major driver for CIEMAT's collaboration with the Spanish nuclear industry and institutions.

Three are the areas of investigation CIEMAT is presently addressing: severe accidents, nuclear fuel thermo-mechanics and safety of innovative nuclear systems.

RECENT UNSR RESULTS UNDER INTERNATIONAL PROJECTS

During the last 5 years CIEMAT has been participating in a good number of international projects. Besides, the just born projects in which UNSR is participating will be introduced.

Severe Accidents

The main projects shaping CIEMAT's research in the area of severe accidents have been: PHEBUS-FP, SARNET, OECD-SFP, OECD-BIP, OECD-CCVM and ARTIST. The first two were launched under the EURATOM framework program, whereas the next three have been framed under the OECD-NEA; the last one was an international project led by PSI.

The PHEBUS-FP (Clément & Zeyen, 2013) used a scaled down facility (1:5000 with respect to a 900 MW French PWR) to conduct a total of 5 experiments (4 of them with spent fuel). Outstanding insights have been gained into fuel degradation, fission products transport and iodine chemistry. CIEMAT has been contributing in the pre- and post-test analysis of containment phenomena with codes like CONTAIN 2.0, IODE 5.1, MELCOR 1.8.6 and ASTEC 2.0. Based on this work an extensive validation has been carried out and major observations, like the dominant contribution of sedimentation in aerosol deposition or the effective trapping of iodine by oxidized silver in the aqueous pond of containment, have been consistently estimated. It is worth mentioning the comparison set between the major findings concerning containment iodine behavior within the PHEBUS-FP tests and the NUREG-1465 (Herranz & Clément, 2010b). The experience gained within the project was the basis for an assessment of how significant iodine chemistry might be in NPP source term estimates (Herranz et al., 2009). Complementary to PHEBUS-FP experience, the International Source Term Project was launched to explain and deepen into some of the PHEBUS observations.

Since 2004 most severe accident investigation has been articulated through the SARNET project (Van-Dorsselaere et al., 2012). The major issues addressed within this network of excellence were: corium coolability, core-concrete interaction, steam explosions and hydrogen combustion in the containment and source term. Most of data obtained through experiments have been stored in a database called DATANET and the models developed and validated are being implemented in the next version of the ASTEC code (2.0 r3). CIEMAT has been involved in several activities with particular emphasis in those related to source term. Significant contributions have been already published as for aerosol evolution (Herranz et al., 2010a) and iodine chemistry (Dickinson et al., 2010). As a consequence of these SARNET analytical activities, CIEMAT has conducted an extensive validation of the ASTEC and the MELCOR codes (Kljenak et al., 2010; Girault et al., 2012).

The OECD-NEA projects have addressed different issues: SFP, fuel degradation under anticipated conditions during a complete LOCA (Loss Of Coolant Accident) in spent fuel pools; BIP, organic iodides generation and iodine-paints interactions; CCVM, validation matrix for containment codes. Within the OECD-SFP project, the UNSR built-up MELCOR models for BWR and PWR fuels for two fuel configurations, "hot neighbor" (i.e., no radial thermal radiation from the fuel cell) and "cold neighbor" (i.e., periphery fuel assemblies heated up by the central one). This work allowed identifying strengths and weaknesses of the code when addressing these scenarios (Herranz et al., 2013). Key elements of the modeling were the hydraulics of air going upward through the fuel assembly, the zirconium oxidation by air and the thermal radiation heat transfer. Under the OECD-BIP framework, a sound database has been obtained and CIEMAT has proposed an empirical approach accounting for the different kinetics observed of the organic iodides production (Herranz et al., 2010). The OECD-CCVM project allowed gathering relevant experimental work that might be the bases for validation of containment codes and/or modules of integral codes; specific contributions were made from CIEMAT as for the identification and definition of key in-containment phenomena and the description of relevant experimental data in areas such as aerosol removal in leakage paths and aerosol resuspension and reentrainment.

The ARTIST projects have investigated the potential retention of fission products within the secondary side of the steam generator during a meltdown SGTR sequence (Güntay et al., 2004). CIEMAT's activities have been experimental and analytical. Experimentally, CIEMAT has complemented the project database by measuring particle retention in the break stage of the steam generator. More than 30 tests have been conducted in the LASS (Laboratory for Analysis of Safety Systems) of CIEMAT, in which the effects of particle nature, breach type and size and gas mass flow rate have been explored. Consistently with other partners' findings, major insights have been gained: even in the worst scenario, some mass retention should be expected in the break stage; particle nature largely determines mass trapping; largely agglomerated particles may undergo fragmentation due to tangential fluid stresses and collisions against tubes; etc. These and many other results have been reported by Herranz et al. (2006), Sánchez et al. (2010) and Delgado et al. (2013). On the analytical side, the main achievement has been the development and validation of a semi-empirical model, called ARI3SG, capable of predicting in-break stage aerosol deposition (Herranz et al., 2007; Herranz et al., 2012; López et al., 2012).

In addition to the above projects, CIEMAT is participating in some other international projects recently launched under the frame of the 7th FWP of EURATOM. This is the case of PASSAM and CESAM. Even though research on severe accident management is one of the main pillars of both projects, PASSAM is mostly empirical while CESAM is entirely analytical. PASSAM main goal is to set up a data base on the performance of existing and innovative systems for source term mitigation. Fission products retention in aqueous ponds and in sand filters will be investigated under realistic challenging conditions still unexplored or poorly characterized, like water saturation or jet injection regime. Also, performance of innovative systems as pre-filter acoustic agglomerators, electrostatic precipitators, high pressure sprays and improved performance zeolites are to be tested under prevailing conditions in case of containment venting. The intention is to gather a sound database useful to enhance the potential performance of filtered containment venting systems. CIEMAT has focused their activities on aqueous ponds retention under jet injection regime and on the particle growth resulting from an acoustic agglomerator.

CESAM is entirely focused on development of the ASTEC code models and extension of its analytical capabilities to different reactor designs. CIEMAT is contributing through preparation of a generic input deck for a BWR plant, modeling the BWR fuel degradation tests conducted by Sandia simulating a complete LOCA accident in a spent fuel pool and assessing and improving models dealing with pool scrubbing, air oxidation of Zr alloys and thermal radiation in spent fuel pool configurations.

Finally, less than one year ago, CIEMAT joined the OECD-BSAF project (Benchmark Study of Accident at the Fukushima Daiichi Nuclear Power Station), through the bilateral project with CSN for severe accidents. The project aim is to reach a deep understanding of the scenarios, with particular emphasis on identifying the governing phenomena and the final status of the units 1-3. CIEMAT is building up MELCOR 2.1 models for each of the units. The results of each participant will be discussed and the conclusions are planned to be used for the units decommissioning.

Thermo-mechanics of nuclear fuel

CIEMAT has two major national collaboration agreements on nuclear fuel thermo-mechanics, one with CSN and the other with ENRESA. Some of their activities have a domestic scope, but there are others of an international nature related to projects like OECD-HALDEN, OECD-CABRI and OECD-SCIP (focused on fuel behavior under steady and transient conditions); additionally, a close follow-up is being conducted of the ESCP (focused on fuel extended storage) program. Access to the data resulting from these frameworks comes from the CSN involvement in the international projects.

Data from HALDEN experiments have been used for many years to improve and validate codes like FRAPCON-3. Since 2012 CIEMAT has launched an activity to assess the FRAPTRAN-1.4 predictability of the fuel thermo-mechanics under LOCA conditions. Through the analyses of the LOCA experiments, major code drawbacks and needs will be identified and, potential improvements to be made in the short and medium term will be defined.

CIEMAT's experience on fuel transient behavior under RIA (Reactivity Insertion Accident) conditions has been gained within the CABRI project. Post-test analysis and preliminary analysis of the upcoming LWR-RIA tests has fostered technical exchange among partners. The best example is the RIA benchmark organized under the frame of the international project, which has been articulated in 9 RIA scenarios based on tests already conducted or to be conducted of the CABRI and the Japanese NSRR program. CIEMAT contributed to the benchmark by analyzing those scenarios with FRAPTRAN-1.4 and SCANAIR-7.1 (Sagrado et al., 2013). As a result of this work an extensive and deep comparison of thermal, mechanical and fission product transport models responses has been made.

SCIP has been supplying data for years on irradiated BWR and PWR mechanical behavior. Through them a better understanding of the potential cladding failures by pellet-cladding interaction and hydrogen-related phenomena has been gained. Additionally, a sound database on clad ramping has been set up and two benchmarks have been recently organized. In addition to technical contributions with FRAPCON-3 and FRAPTRAN codes, CIEMAT has been deeply involved in the coordination of both exercises. Some analyses have been conducted with FRAPCON-3.3 and some others with FRAPTRAN-1.4; this way the capability of these two codes to capture phenomena in the time range of ramps has been checked (ramp timing is right in between steady state and RIA, which are the natural domains of FRAPCON-3 and FRAPTRAN -1, respectively). Herranz et al. (2011) reported in detail results and major outcomes of the first exercise.

Safety of innovative nuclear systems

Since the early 90's, CIEMAT has been working on innovative aspects of safety systems of new reactor designs. The studies evolved from modeling of passive systems performance of Generation III reactors to accident analysis of Generation IV reactors. From 2005 to 2009, CIEMAT focused on High Temperature Reactors (HTRs) through 6th EURATOM projects, like RAPHAEL, and through bilateral contracts with PBMR (Fontanet et al., 2009). However, last years the interest has moved to safety of Sodium Fast Reactors (SFRs). In that environment, CIEMAT has been working on source term studies under the frame of the CP-ESFR project of the 7th EURATOM FWP. The project addressed key design aspects of an SFR, from the configuration (pool vs. loop) to the most suitable power cycle to be coupled (Rankine vs. Brayton), going through safety aspects. In this specific regard, a critical assessment of what was known and unknown and an identification of the major needs in terms of model development were the first task undertaken by Herranz et al. (2012b).

Presently, CIEMAT is heavily involved in developing and validating models considered fundamental for source term prediction. That is the case of sodium vapor nucleation under anticipated conditions of SFR containments in case of a BDBA (Beyond Design Basis Accident). This work together with the development of a semi-empirical law for SFR cladding creep and the assessment of a modified version of RELAP-5 against sodium thermal-hydraulic tests (conducted in collaboration with UPV), are the major tasks of CIEMAT within the JASMIN project of the 7th EURATOM FWP. The final aim of the project as a whole is to enable the ASTEC platform to also address SFR accident scenarios.

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GROUP OF THERMALHYDRAULIC STUDIES (GET) OF TECHNICAL UNIVERSITY OF CATALONIA (UPC)

The group of thermal-hydraulic studies (GET) of the Technical University of Catalonia (UPC) is currently participating in different international projects in the field of dynamic analysis of nuclear systems behaviour under accidental scenarios. Such initiatives could be classified in two groups: those developed in the framework of a common effort of different Spanish universities and those build up by the group itself with other sponsorship. In the former group one can find projects like CAMP (under the leadership of the NRC), OECD-ROSA project dealing with experiments performed at the LSTF facility (JAEA-Japan) and OECD-PKL2 project dealing with experiments performed at the PKL facility (Areva-Germany). In the latter group one can find three projects: BEMUSE, UAM and PREMIUM. Both groups of projects are strongly connected with a general strategy established and sponsored by the Spanish Nuclear Safety Council (CSN). Since the former group is well known by the Spanish nuclear community, the purpose of this text is to describe the participation of UPC-GET in the latter group of projects. UPC-GET members are the authors of the work done in these projects. The names of the researchers are the following: E. de Alfonso, C. Arenas, L. Batet, J. Freixa, E. Mas de les Valls, V. Martínez, M. Pérez, R. Pericas, C. Pretel and F. Reventós.

BEMUSE is the first of these projects and it has been already completed. BEMUSE stands for **B**est **E**stimate **M**ethods for **U**ncertainty and **S**ensitivity **E**valuation. It has been a programme promoted by the working Group on Accident Management and Analysis (GAMA) and endorsed by the Committee on the Safety of Nuclear Installations (CSNI). BEMUSE represents an important step towards a reliable application of high-quality best-estimate and uncertainty and sensitivity evaluation methods. The application of these methods to a Large-Break Loss of Coolant Accident (LB-LOCA) constitutes the main activity of the programme, structured into two main stages:

- Step 1: Best-estimate and uncertainty and sensitivity evaluations of the LOFT L2-5 test. This step includes Phases II and III (A. De Crécy et al. 2008). LOFT is the only integral test facility with a nuclear core where thermal-hydraulic safety experiments have been performed.
- Step 2: Best-estimate and uncertainty and sensitivity evaluations of a nuclear power plant. This steps includes Phases IV (M.Pérez et al. 2010) and V (M.Pérez et al. 2011).

A presentation of the uncertainty methodologies to be used by the participants (Phase I) was included in the first step. The final phase (Phase VI) consisted of the synthesis conclusions and recommendations.

UPC-GET participated in all the phases of the activity being also the coordinator of phases IV and V (devoted to the exercise related to the nuclear power plant). The team took advantage of the project and managed to come to a common understanding with all the participants on the general aspects involved in the different steps of the calculating exercises. In parallel with its participation in BEMUSE, UPC managed to develop the so-called UPC-CSN methodology of Best Estimate Plus Uncertainty (BEPU) evaluation, which is a statistical method based on Wilks' theory with some specific features related to the validation of the basic plant nodalization and also to the reduction of the number of input uncertain parameters. Figure 1 shows UPC's prediction of peak cladding temperature (PCT) for large break LOCA comparative exercise along with its upper and lower bands.

UAM is the second project. UAM stands for **U**ncertainty in **A**nalysis **M**odelling. The objective of this project is to conduct an OECD benchmark for uncertainty analysis in best-estimate coupled code calculations for design, operation, and safety analysis of LWRs. The proposed technical approach is to establish a benchmark for uncertainty analysis in best-estimate modelling and coupled multi-physics and multi-scale LWR analysis, using as bases a series of well defined problems with complete sets of input specifications and reference experimental data. The full chain of uncertainty propagation from basic data, engineering uncertainties, across different scales (multi-scale), and physics phenomena (multi-physics) are tested on a number of benchmark exercises for which experimental data are available and for which the power plant details have been released.

Several steps or exercises, each of which can contribute to the total uncertainty of the final coupled system calculation, are prepared by coordinators. Participants have to identify relevant aspects of each step and propagate the uncertainties in an integral system simulation for which high quality plant experimental data exist.

The main scope covers uncertainty analysis in best estimate modelling for design and operation of LWRs, including methods that are used for safety evaluations.

UPC-GET is participating in selected phases of this project (C. Arenas et al. 2013). The team is gaining experience in the selected steps of the calculating exercises, bearing in mind its own specific goal of establishing a neutron-kinetics-thermal-hydraulic coupled model for a Spanish Nuclear Power Plant having the capability of being used for Best Estimate Plus Uncertainty (BEPU) evaluation in the licensing context.

The third project is **PREMIUM**, Post BEMUSE REflood Models Input Uncertainty Methods, a project endor-

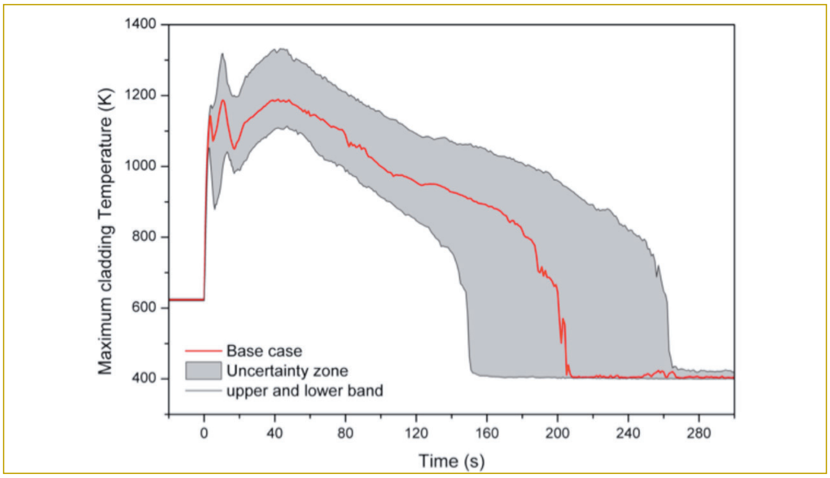

Figure 1. Base case and uncertainty upper and lower bands results obtained at the UPC for a large break LOCA in the BEMUSE project.

sed by the OECD/NEA/CSNI/WGAMA group. The objective of PREMIUM is to progress on the issue of the quantification of the uncertainty of the physical models in system thermal-hydraulic codes, by considering a particular case: the physical models involved in the prediction of core reflooding. The final goals of the project are: the assessment of advanced methods and tools used for event/accident analysis and the review of current analytical tools as well as risk assessment approaches regarding their applicability to safety assessments of new designs, and their further development and validation.

PREMIUM is structured in 5 phases to deal with the quantification of the uncertainties for the influential physical models in the reflooding. The participants will:

- Determine the uncertain parameters of their code associated with these physical models (Phase 1 and 2).
- Quantify the uncertainties of these parameters using FEBA/SEFLEX experimental result or own reflood experiment (Phases 3)
- Confirm the found uncertainties by uncertainty propagation in the case of the 2-D reflood PERICLES experiment. This part will be performed as a blind analysis. (Phases 4 and 5)

UPC-GET intends to participate in all the phases of the activity being also the coordinator of Phase 1. The team will try to take advantage of the project to develop a methodology to quantify the uncertainties for different physical models. Figure 2 shows UPC's prediction of Quench Front in FEBA experiment compared with the associated experimental data.

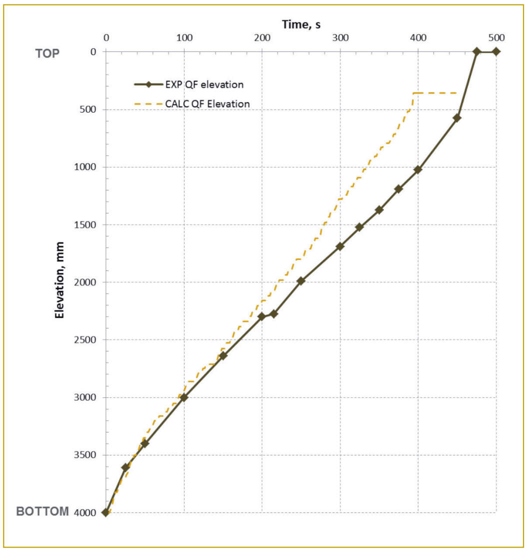

Figure 2. Prediction of the quench front propagation in the FEBA experiment of the UPC group (PREMIUM project).

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UNIVERSIDAD POLITÉCNICA DE MADRID (UPM)

The UPM participates in several international projects related with Nuclear Safety which can be split in two groups:

- those which have been funded by EURATOM, involving four projects in nuclear safety (NURESAFE, SARGEN-IV, ESFR, ESNII+) and in three projects about education in nuclear safety (ENEN-III, TRASNUSAFE, NUSHARE), and
- those corresponding to other international projects which have been funded in Spain by CSN and UNESA: CAMP, NEA/OECD PKL, NEA/OECD ROSA, NEA/OECD ROSA-2, NEA/OECD SM2A, IDPSA network.

The following description is mainly focused on the first group because there are other projects like CAMP, NEA/OECD PKL or NEA/OECD ROSA which are well-known or are described with more detail by other groups inside this paper.

NURESAFE

The NURESAFE project addresses safety of light water reactors which will represent the major part of fleets in the world along the whole 21st century. The first objective of NURESAFE is to deliver to European stakeholders a reliable software capacity usable for safety analysis needs and to develop a high level of expertise in the proper use of the most recent simulation tools. Nuclear reactor simulation tools are of course already widely used for this purpose but more accurate and predictive software including uncertainty assessment must allow quantifying the margins toward feared phenomena occurring during an accident and they must be able to model innovative and more complex design features.

This software capacity will be based on the NURESIM simulation platform created during FP6 NURESIM project and developed during FP7 NURISP project which achieved its goal by making available an integrated set of software at the state of the art. The objectives under the work-program are to develop practical applications usable for safety analysis or operation and design and to expand the use of the NURESIM platform. Therefore, the NURESAFE project concentrates its activities on some safety relevant "situation targets". The main outcome of NURESAFE will be the delivery of multiphysics and fully integrated applications.

The platform will achieve the coupling neutronics, thermal-hydraulics, and fuel performance codes, at various physical and time scales. In particular it should incorporate new models addressing recent findings from safety research as well as demands from the current plant operation, as new fuel designs, higher resolution in energy, time and space. Full time dependent solutions of stochastic and deterministic 3D neutron transport should be developed to model heterogeneous core configurations.

In the NURESIM Platform is included the participation of twenty two European organizations ASCOMP, CEA, CHALMERS, EDF, HZDR, KIT/FZK, GRS, IMPERIAL COLLEGE, INRNE, IRSN, JSI, KFKI, KTH, LUT, NRI, PSI, TUDELFT, UCL, KIT/UNIKA, UPISA, UPM, VTT. The UPM is involved in the multiphysics and multiscale simulation capacity as a main objective in the nuclear reactor modelling nowadays, joint with the high performance computing power, in order to take advantage of the advanced hardware features as parallel computation. The multiphysics simulation capability may be composed of individual physics capabilities and common support services separately, and a software tool capable of integrating the separate pieces.

CP-ESFR: COLLABORATIVE PROJECT ON EUROPEAN SODIUM FAST REACTOR

Besides the Generation IV International Forum (GIF), which focuses on the medium-long term (> 2040), the international nuclear community are defining a new framework to fit with the short - medium term. Among them, the European Technology Platform on Sustainable Nuclear Energy (SNE-TP) and its European Strategic Research Agenda (SRA) propose a vision for the short, medium and long-term where the sodium technology as a reactor coolant plays a key role.

The roadmap for a European Innovative Sodium cooled Fast Reactor defines its specific R&D strategic objectives for a fourth generation European Sodium cooled Fast Reactor (ESFR). The roadmap addresses the needs for research and development, as well as for technology demonstration. The project ESFR follows this action identifying, organizing and implementing a significant part of the needed R&D effort.

The UPM contribution has been a Doctoral dissertation for development and verification of the European NURESIM platform for pin-by-pin and nodal coupled NK-TH simulation codes with application for the ESFR core physics and safety analysis. The analysis of the impact of the minor actinides concentrations on the transients results. The UPM has collaborated also in the analysis of the simulation results obtained with different TH codes for representative design basis accidents.

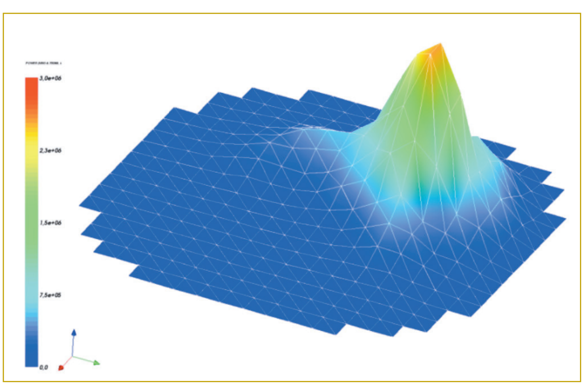

Figure 3. Boron dilution transient power peak calculation (MW) in 3D with COBAYA3/FLICA coupled codes by UPM in the NURESIM Platform.

SARGEN-IV PROJECT

The ESNII was launched in November 2010 to anticipate the development a fleet of fast reactors with closed cycle. Three fast neutron technologies have been selected:

- the Sodium cooled Fast Reactor with the ASTRID prototype.
- the Lead cooled Fast Reactor with the ALFRED demonstrator which will be preceded by a pilot plan MYRRHA.
- the Gas cooled Fast Reactor with the ALLEGRO demonstrator.

With the objective of future assessment of these advanced reactor concepts, the SARGEN_IV Project is intended to gather safety experts from recognized European Technical Safety Organizations from Designers and Vendors as well as from Research Institutes and Universities to:

- develop and provide a tentative commonly agreed methodology for the safety assessment,
- identify open issues in the safety area, mainly addressing and focusing on assessment relevant ones,
- detect and underline new fields for R&D in the safety area
- provide a roadmap and preliminary deployment plan for safety-related R&D, including cost estimation.

With the aim of preparing the future assessment of these advanced reactor concepts, the SARGEN_IV Project is intended to gather safety experts from 22 partners from 12 Member States in order to:

- identify the critical safety features of the selected Generation IV concepts, relying on the outcomes from existing projects from the 7th Framework Programme (FP7),
- develop and provide a tentative commonly agreed methodology for the safety assessment, relying on the outcomes of the investigations carried out within international organizations (such as IAEA, WENRA, AEN), on national practices presently in use and on practices proposed within other European Framework Programs projects,
- identify open issues in the safety area, mainly addressing and focusing on assessment relevant ones, detect and underline new fields for R&D in the safety area (addressing methodological, theoretical and experimental issues, as well) in order to provide a roadmap and preliminary deployment plan for the fast reactor safety-related R&D.

IDPSA NETWORK

UPM, together with CSN and Indizen Technologies, participates in IDPSA network which stands for Integrated Deterministic/Probabilistic Safety Analysis. IDPSA is considered as a complementary to PSA and DSA approaches intended to help in: Resolving time dependent interactions between physical phenomena, equipment failures, control logic, operator actions in analysis of complex scenarios; Identification and characterization of a-priori unknown vulnerable scenarios, or "sleeping threats"; Consistent treatment of different sources of uncertainties; Reduction of reliance on expert judgment and assumptions about interdependencies; Potential reduction of the cost of safety analysis due to larger involvement of computers in what they can do better: multi-parameter, combinatorial exploration of the plant scenarios space.

IDPSA network provides a platform for: regular exchange of information and experience between IDPSA research and developers, and Potential users: PSA/DSA practitioners in Utilities, Vendors and Regulators.

ESNII+

The European Sustainable Industrial Initiative ESNII+ project (2013-2017) aims to define strategic orientations for the Horizon 2020 period, with a vision to 2050. To achieve the objectives of ESNII, the project will coordinate and support the preparatory phase of legal, administrative, financial and governance structuration, and ensure the review of the different advanced reactor solutions.

The UPM is contributing in two different tasks within the project. The first task is the assessment of core safety parameters for high fidelity transient safety analysis of the ASTRID sodium-cooled fast reactor. The second task is related with the evaluation of the sensitivity coefficients with respect to nuclear data, and the uncertainties on the reactivity coefficients using TSUNAMI-3D/SCALE6.1 module of the ALFRED lead cooled reactor.

EDUCATION AND TRAINING IN NUCLEAR SAFETY EUROPEAN PROJECTS: ENEN-III, NUSHARE, TRASNUSAFE

The ENEN-III project (2009-2012) covered the structuring, organization, coordination and implementation of training schemes in cooperation with local, national and international training organizations, to provide training to professionals active in nuclear organizations or their contractors and subcontractors. The training schemes provide a portfolio of courses, training sessions, seminars and workshops for continuous learning, for upgrading knowledge and developing skills in Nuclear Engineering.

The UPM has collaborated in the development of the training scheme for non-nuclear engineers and personnel of nuclear facilities, contractors and subcontractors. Two UPM alumni were also trained in the scheme for design challenges of GEN III plants.

TRASNUSAFE (2010-2014), a Project supported by the European Commission, aims at designing, developing and validating two training schemes on nuclear safety culture for professionals operating at a high level of managerial responsibilities in nuclear installations. One of the training schemes is related to the nuclear industry, while the other is related to the other installations making use of ionizing radiation based technology, mainly the medical sector. Both training schemes will have a common basis reflecting the challenging approach to risk management, followed by sector-specific specialized modules. The final product will consist in a package of five training modules for managers of both industrial and medical sectors, ready for use after validation through pilot sessions.

The objective of NUSHARE (2013-2016) is to develop and implement training and informing activities with the aim to share and grow, across EU Member States, the safety culture in nuclear installations. Security aspects (in particular, proliferation resistance and physical protection) will also be treated.

SENUBIO. GROUP OF TECHNICAL UNIVERSITY OF VALENCIA

The research group SENUBIO (Nuclear Safety and Ionizing Radiations Bio-engineering) forms part of the Environmental, Radiophysics and Industrial Safety Institute of the Universitat Politècnica de València (UPV). This group has strong relations with several universities and institutions abroad the world. We mention, Università di Pisa, particularly with the Professor D'Auria in the area of coupled codes, University of Dresden, particularly with the Professor Henning in the area of Boiling Water Reactor (BWR) instabilities, Technische Universität München, particularly with the Professor Macián in the area of uncertainties, Karlsruhe Institute of Technology, particularly with the Professor Sánchez in the area of coupled codes, Università de Milano, particularly with the Professor Zio in the area of Reliability analysis, University of Chalmers, particularly with the professors Demàziere and Pazsit in the area of neutron noise analysis, with the institute INSTN of the CEA of France, particularly with the professor Eric Royer in the area of coupled codes, with the Paul Scherer Institute and the nuclear plant KKL of Switzerland in the area of BWR instabilities, and with University KTH in the area of uncertainties. Regarding universities and institutions of America, the research group has relations with the Federal Universities of Rio de Janeiro and Minas Gerais in the area of coupled codes, with Pennsylvania State University, particularly with the Professors Ivanov and Avramova in the areas of coupled codes and uncertainties, with the University of Urbana-Campaign, particularly with the professors Kozlowsky and Udinn in the area of BWR instabilities, with the University of North Carolina at Rayleigh, particularly with the professor Azmy in the area of transport equations, and with the Tennessee University and Oak Ridge National Laboratory in the area of BWR instabilities.

Furthermore, we must mention that the research group has relations with the companies, AREVA, SIEMENS, WESTHINGHOUSE, EDF, STUDVISK and the Spanish companies IBERDROLA, TECNATOM… The research areas are neutronic and thermal-hydraulic coupled codes, BWR instabilities, neutron noise fluctuations and signal analysis.

Furthermore, SENUBIO Research group has participated in the USNRC CAMP program (Code Applications and Maintenance Program), which represents the international framework for verification and validation of NRC Thermal Hydraulic codes.

In this frame, SENUBIO has actively worked in the international projects OECD/NEA ROSA and OECD/NEA ROSA II, simulating different accidental scenarios using the thermal hydraulic code TRACE. ROSA (Rig of Safety Analysis) comprises a series of experiments performed in the Large Scale Test Facility (LSTF) of the Japan Atomic Energy Agency (JAEA). The OECD/NEA ROSA project has investigated issues in thermal-hydraulics analyses relevant to water reactor safety, focusing on the verification of models and simulation methods for complex phenomena that can occur during reactor transients.

The SENUBIO group has focused efforts in the simulation of the following experiments:

- Test 6.1: pressure vessel upper head Small Break Loss-Of-Coolant Accident (SBLOCA) under the assumption of total failure of HPI System.
- Test 6.2: pressure vessel lower plenum SBLOCA under the assumption of total failure of HPI system.
- Test 3.1: cold leg SBLOCA under the assumption of total failure of HPI system.
- Test 3.2: high-power natural circulation due to failure of scram during a Loss-Of-Feed Water (LOFW) transient under the assumption of total failure of HPI system, but an actuation of Auxiliary Feed Water (AFW).
- Test 5: condensation-induced water hammer tests.

Regarding to OECD/NEA ROSA II project, we have used the TRACE code to simulate the following experiments:

- Test 2: 17% cold leg intermediate LOCA.
- Test 3: 1.5% hot leg SBLOCA with an assumption of total failure of HPI system, under two different pressure conditions as a counterpart to PKL-2 Project test. Major test objectives were to clarify responses of core exit thermocouples (CETs) vs. fuel rod surface temperature at both of high-and low-pressure conditions corresponding to the pressure range of LSTF and PKL facilities.
- Test 5: thermal-hydraulic responses after a PWR Steam Generator Tube Rupture (SGTR) induced by Main Steam Line Break (MSLB).

Main results and conclusions of these works are summarized in different NUREG-IA reports (4 corresponding to ROSA project and 3 corresponding to ROSA II project).

Organizers of ROSA projects, OECD/NEA and the operating agent (JAEA) have encouraged the participation of all involved groups by means of different meetings (at least two per year) and a final Workshop "Joint PKL2-ROSA2 workshop on analytical activities related to PKL/OECD and ROSA/OECD projects" held in Paris (2012). Discussions and information exchange have been fruitful and allowed us to improve our knowledge of thermal hydraulic phenomena involved in important transients in Nuclear Safety. ■

On-Site Field Services

M. Rodríguez Aycart, E. Bobo, L. Pascual, A. Merino, I. Martínez Gozalo, J. T. Ruiz, M. Soto & S. Vilanova

The Spanish nuclear industry has extensive experience in the development of services for nuclear power plants.

The moratorium on new projects in the decade of the 1980s led these nuclear industry companies to find and enter new markets.

The quality of their services, along with the long experience gained in the support of the Spanish plants, has enabled a significant number of companies to win relevant contracts in competition with leading corporations around the world.

European countries are an important market. The first experiments to support the operation in Central and Eastern Europe are being extended with work in neighboring countries. Meanwhile, Latin America is a nearby market for reasons of language and historical proximity, which is also present in the industry. It emphasizes the participation of Spanish companies in projects in countries of the Asia-Pacific region.

This article describes the experiences of four Spanish-owned companies and of the services division of Westinghouse in Spain.

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ENUSA

THE ENUSA STRATEGY FOR THE ACCESS TO INTERNATIONAL NUCLEAR FUEL MARKETS

Why "going abroad"

The reasons behind the progressive globalization of the ENUSA operations can be found in the behaviour of its reference markets. As it became clear in the '80s that the Spanish market was not going to grow in the years ahead, the company decided to break into the European markets. As a result ENUSA is now exporting products and services to France, Belgium and Sweden.

Now, given the reduction trend of the European PWR and BWR fuel markets (see Figure 1) ENUSA is looking abroad again to expand its business.

From the maximum in years 2009-2010 the market is expected to reduce its size in approximately 20% due to the early shutdown of 23 reactors within the period 2007-2023 and only two new connections to the grid. The major part is obviously due to the German phaseout although other countries will see some of its reactors shutdown too.

Another factor which contributes to the internationalization strategy is the high level of competition in the European fuel market. Currently there are five nuclear fuel factories in operation in Europe under the control of three different fuel vendors. Total installed capacity largely exceeds the current fuel needs.

The new markets being less mature than the European, offer clear advantages such as a significant demand for new technology and growing market size. In addition, these markets offer positive projections of nuclear development for the next decades. Overall, the new capacity up to 2030 in the most optimistic scenario is expected to exceed 350 GWe (Figure 2).

Segmentation

It is possible to make different segmentations attending to criteria such as geographical expansion areas, products and customers. A short review of each of these is presented below.

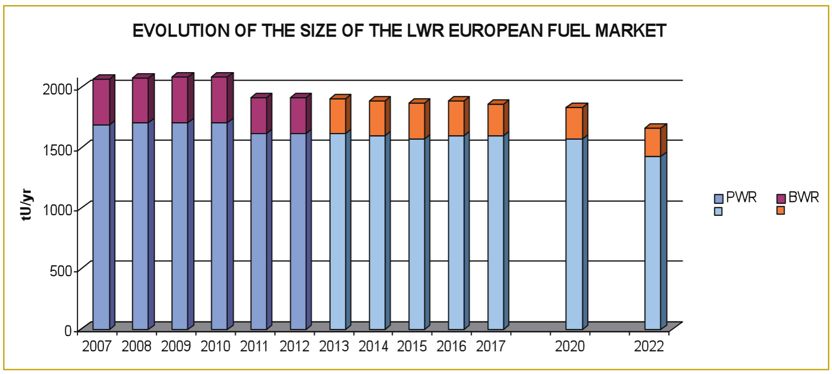


Figure 1: Evolution of the PWR and BWR European nuclear fuel market. (Source: ENUSA).

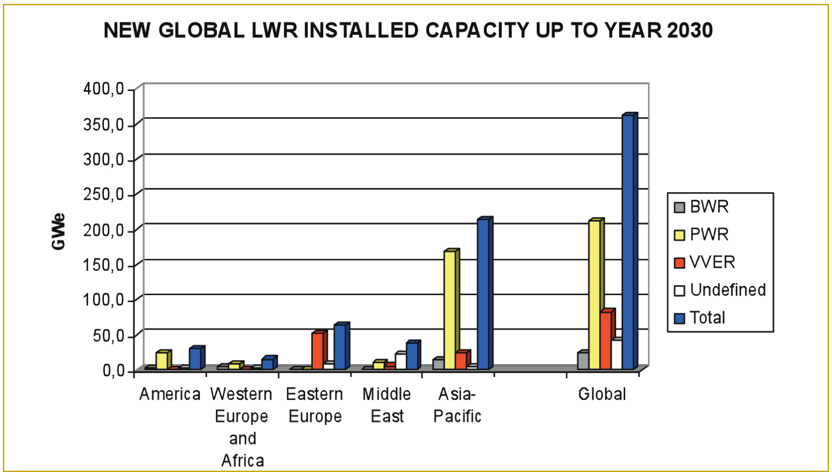


Figure 2: New global capacity in an optimistic scenario. (Source: ENUSA).

Geographic segmentation

Figure 2 shows how the new capacity is distributed worldwide. Weakness of the European market can be clearly identified when compared to the trends in regions such as Asia-Pacific. The expected added capacity in this region alone may exceed 200 GWe up to year 2030.

Other regions are newcomers to nuclear energy. Middle East countries are shifting from a traditional oil-based electricity generation to cleaner, carbon dioxide-free production systems based on nuclear and renewable electricity.

It is also relevant to focus on the South American market. Both Argentina and Brazil are building new reactors and there is a long-term investment plan for new nuclear capacity. These countries are developing their own industry which eventually will cover the entire fuel cycle. However some of its historic partners, in particular the German companies, are no longer in the nuclear business, what represents an opportunity for ENUSA.

Product segmentation

In the last years ENUSA has evolved from a pure fuel manufacturer to a more integrated fuel services vendor. Fuel services now include spent fuel, on site services have grown to add additional inspection capabilities and a new equipment design and manufacturing business is being created.

Nuclear fuel is the reference product of ENUSA and its credentials in the international markets. However the fuel market is a regional market where the fuel is produced close to the point of consumption. This limits the potential expansion of pure fuel vendors although it also explains the ENUSA success in the European market, well communicated and geographically small compared to other regions.

Commercialization of fuel inspection equipment offers many advantages. First, there is a limited competition in this field and second, normally it is not subject to political or technological barriers as the nuclear materials. ENUSA is working very actively in developing its technology together with its partner TECNATOM. As a result of these efforts new fuel inspection equipment has been sold to China and Brazil and there is a significant potential for new sales in other markets.

Finally a third pillar is constituted by the spent fuel services. The Spanish Interim Centralized Storage Facility ("ATC") project and the maturity of the Spanish nuclear sector has brought this topic to a first line of sight. ENUSA has decided to cooperate with ENRESA, ENSA and other Spanish companies to develop its own capabilities in this field, mainly linked to the dry storage of nuclear fuel.

Customer segmentation

The addition of new products and services to the ENUSA portfolio progressively broadens the perspective of potential customers. Traditionally the main customer has always been the utility/operator of a nuclear power plant and being the nuclear fuel a key supply for the power plant, the relation operator-fuel vendor will maintain its strategic nature either in the traditional or new markets.

In the new international markets however one can now find vertically integrated conglomerates such as the Chinese CGN and CNNC, which not only operate their own reactors but produce uranium concentrates, provide enrichment and conversion services, manufacture fuel assemblies, etc. These companies may search for virtually any kind of product in the market.

Finally, the accumulated experience at ENUSA in the design and operation of advanced inspection equipment paves the way to a direct relationship with the fuel manufacturers. Together with its partners, ENUSA can provide technological solutions for fuel manufacturing plants by adapting the technology developed at Juzbado plant to the specific requirements of other fuel vendors.

Association: best approach for mid-sized companies

The size, distance and complexity of the international markets make it advisable to search for the appropriate partners either in the country of origin or in the foreign market.

ENUSA has already adopted both practices. As a founding member of the Spanish Nuclear Group for Cooperation (SNGC) it is one of the four Spanish companies which have associated to join forces to enter into foreign markets. The SNGC provide marketing and coordination services to its members and performs a high level scrutiny of the most promising business opportunities.

The other approach ENUSA is following is the association with local companies in the export market. This is being done with the assistance of a sales agent who knows the specifics of the country and has direct contact with the local company. Once the company has been identified the usual approach is to sign a Memorandum of Understanding (MoU) to serve as a contractual umbrella for the relationship.

So far ENUSA has entered into a number of MoU with different Asian and South American companies (see Figure 3) and representation agreements in Brazil, Argentina and China.

Conclusions

Internationalization implies a cultural change in the organization. A significant effort on development of technology, quality improvement and efficiency must be undertaken throughout the company. ENUSA is working on these areas by implementing a more efficient organ-

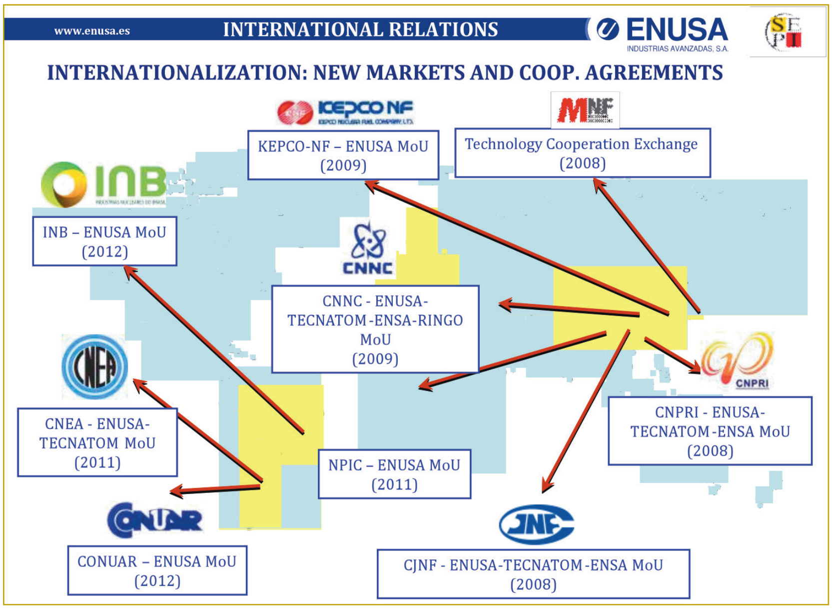


Figure 3: ENUSA international cooperation agreements.

ization, boosting its continuous improvement program and reinforcing its investment on R&D, which currently ranges between 6% and 10% of the total annual sales.

Internationalization also means growing business and this results in the need for additional human, technological and financial resources. This can only be achieved with a clear strategic determination and a strong institutional backing from the Administration. In the case of state-owned enterprises a third factor must be considered, which is the support of the SEPI holding, ENUSA's main shareholder, to internationalization initiatives. These conditions and the new reality of globalization present the best scenario for ENUSA to pursue its international development and reinforce its relevant place in the nuclear industry worldwide.

ENWESA

ENWESA IN THE INTERNATIONAL MARKET

ENWESA develops its international activity of nuclear services both in Europe (France, Finland, Sweden, Belgium, etc.) and America (Mexico and Brazil basically).

The international presence of ENWESA started right after its foundation in 1985, although it has been strengthened during the last years due to the important effort ENWESA has made in the French nuclear market.

In the middle of the last decade, ENWESA defined as strategic the French nuclear market for several reasons: its geographical proximity, its high potential and specially, the very good feedback received from the power plant managers to ENWESA's services portfolio. From that moment, ENWESA set out an ambitious plan that basically consisted in obtaining the required qualifications, training people specifically in French working methodology, and opening a well located branch office that brought ENWESA closer to the plants where services are performed.

At present, ENWESA has an important activity of maintenance services in French nuclear power plants property of EDF. These works of inspection and maintenance of equipment, valves and condensers are carried out both during the refueling outages and during the operation of the plants.

Part of the international activity of ENWESA is developed in collaboration with its shareholders EQUIPOS NUCLEARES and WESTINGHOUSE. Both companies have a significant international activity and ENWESA collaborates with them contributing with its capacity and providing highly qualified personnel in nuclear services.

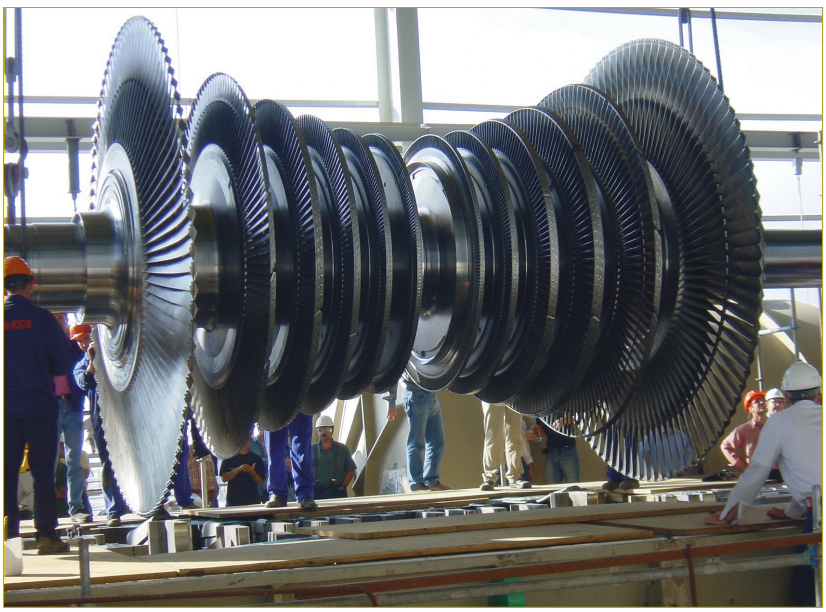
With EQUIPOS NUCLEARES, ENWESA participates the construction, mechanical erection and maintenance in nuclear plants of Finland and Sweden.

With WESTINGHOUSE, ENWESA participates in the inspection and maintenance of nuclear components in Slovenia, France, Belgium, etc.

Additionally, ENWESA cooperates with other important firms, like ENUSA, IBERDROLA INGENIERIA or AREVA, in activities related to nuclear fuel, reactor vessel, main coolant pumps, and so on.

Some of the main references of works performed by ENWESA out of Spain are:

- EDF: Maintenance of equipment and valves in Blayais, Tricastin,



Fessenheim, Golfech, Civaux NPPs (France).
- EDF: Condenser retubing in St. Alban I (France).
- ORTEC Group: Maintenance of valves in Cruas NPP (France).
- ENSA: Manufacturing and installation of AMS Neutron Shielding and installation of SG Pressure Equalization Ceiling in Olkiluoto 3 NPP (Finland).
- ENSA: Installation works and repairs in steam generators in Ringhals NPP (Sweden).
- ENSA: Collaboration in development phases for installation of vacuum vessel of ITER Project.
- WESTINGHOUSE: Maintenance works in cooling reactor pumps, reactor vessel opening and closure and equipment maintenance in Blayais and Gravelines NPPs (France), and Tihange and Döel NPPs (Belgium).
- ENUSA: Fuel inspection, and electro-erosion works in fuel top nozzles in Belgian nuclear plants.
- IBERDROLA INGENIERIA: Mechanical and QA supervision in erection works of condensers and MSRs in Bohunice NPP (Slovakia) and Laguna Verde NPP (Mexico).
- UDDCOMB ENGINEERING (AREVA Group): Orbital welding works in Oskarshamn NPP (Sweden).
- AREVA: Valves maintenance in Sizewell NPP (United Kingdom).
- AREVA: Several works related to cooling reactor pumps, steam generators, reactor vessel and fuel handling in Angra NPP (Brazil).

Besides, ENWESA participates as a founding member of Cluster of the Nuclear Industry in Cantabria (Spain), whose main objectives are reinforcing the nuclear industry in Cantabria, increasing the competitiveness and business opportunities of its founding companies, promoting the professional training and the creation of qualified employment. This Cluster is clearly internationally focused, with objectives like the participation in several phases of the "International Thermonuclear Experimental Reactor" (ITER) project, that is being developed in Cadarache (France).

It is worth to point out that holding an international activity in the nuclear market in the way ENWESA has done throughout these year involves an important factor of knowledge to our company and specially to our people, who pervade with different working methods, improving their professional qualification and enriching their technical background, which finally results in a better training to perform our services in the Spanish nuclear plants.

IBERDROLA INGENIERÍA Y CONSTRUCCIÓN

DEVELOPMENT OF LARGE INTERNATIONAL CONSTRUCTION AND SERVICE PROJECTS IN NUCLEAR PLANTS. RELEVANT EXPERIENCE OF IBERDROLA INGENIERIA Y CONSTRUCIÓN

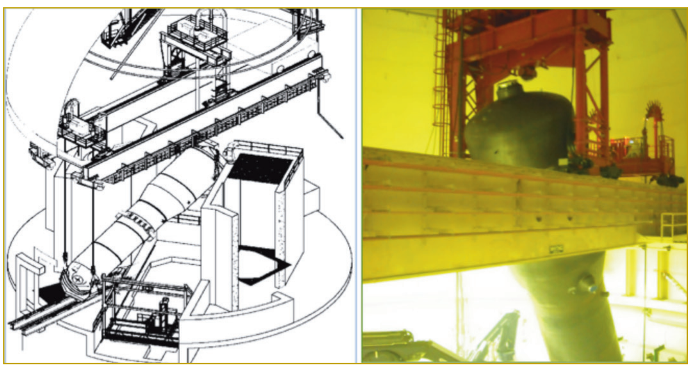
Summary

IBERDROLA INGENIERÍA Y CONSTRUCCIÓN (hereinafter IEC) has developed a significant number of large projects in several nuclear plants worldwide. Some of these plants are under operation, while others are under construction. Nowadays, IEC is actively participating in the design and construction of some safety and non safety class systems of Flamanville 3, for EDF, and has successfully closed the project for the refurbishment of Laguna Verde 1&2 turbine islands in Mexico, with a budget above 600 M USD. However, these projects cannot be understood without taking a look to the background of its international activities in the field of nuclear plants engineering and construction services.

The beginning: BRAZIL

International development of nuclear service and construction projects of IEC started in 1998 with the award of the outage service contract of Angra 1 in Brazil. This first international service contract, with duration of 5 years had limited scope involving management and services activities, although, it served as a scenario to show IEC capabilities to Brazilian customer, utility Electronuclear, supposing undoubtedly an important milestone for the award of the next contract in Angra I, for the replacement of the two steam generators by new ones.

The replacement of the steam generators contract was awarded in 2006. This large EPC contract involved an international consortium headed by IEC, involving Westinghouse, and Brazilian construction company Odebtretch. The successful integration of the partners drove to achieve foreseen outage schedule 2008. The scope involved Reactor Coolant System analysis, pipe cut and welding, auxiliary work and the opening of a large hollow in the containment, by using wire rob cutting of the prestressed concrete wall and band sawing for the steel liner to extract old steam generators and introduce the new ones. In addition, a high accuracy rigging work was developed for the exchange work with the required precision and safety, while minimizing the interferences with large safety class structures located in the vicinity, as for example large safety systems water storage tanks.

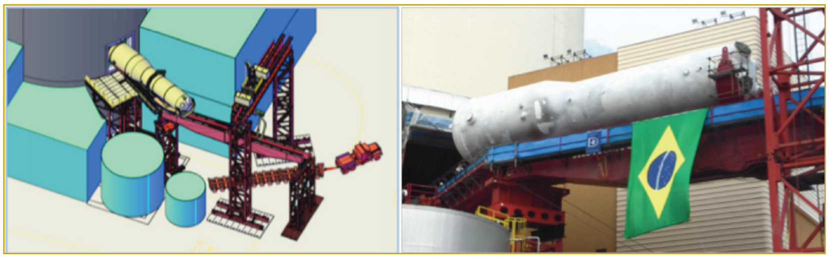


Design and Execution of Rigging Maneuver for extraction of old steam generator, Angra 1.

SLOVAKIA, a continuation and a sample of technology and cultural adaptation

In parallel to the expansion of the company in the Americas, several projects were awarded in Europe by Slovak company Slovenska Elektrarne.

First project was awarded in 2006, consisting in the design, supply and on site supervision of the assembly of 2 condensers to Bohunice nuclear stations V1 and V2. The novelty of this project was customer requirement to on site assembly of condenser bundles, while these are commonly supplied already assembled for its instal-



Extraction Part 2. Design versus reality.

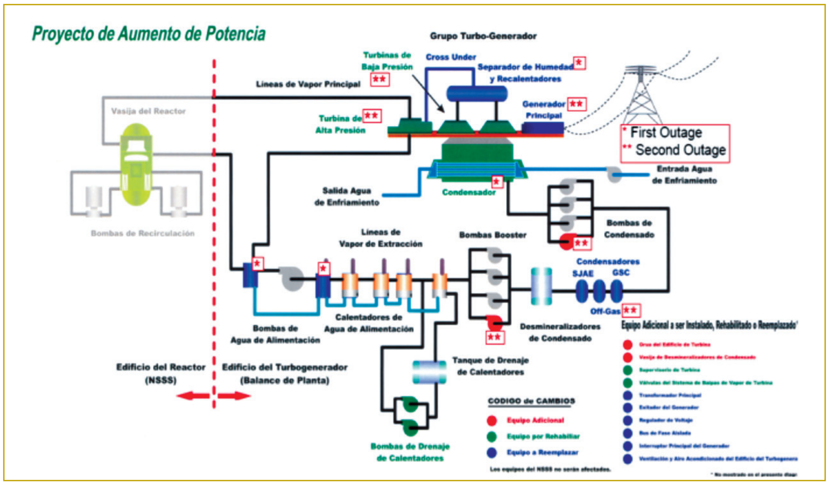
Rigging for new MSR Bohunice.

lation by customer. Condenser was designed to achieve outstanding efficiency to ensure adequate plant performance at demanding conditions of 9% expected power uprate of the plant. Design project involved was also focused in ensuring the required accuracy for the alignment and assembly in Bohunice workshop to comply with assembly and installation schedules. Of the outmost importance was the IEC supply chain for the components of the condenser, with specific mention to the local supplies, and the superb work developed by supervision personnel, which played a relevant work to ensure the constructability of the bundles.

Detail of Open Top Installation of TG31 condenser bundles. Notice accurate constructability design.

Required thermal performance was complied in excess by the new bundles in front of a third party.

A new project was awarded to replace old Soviet design vertical Moisture Steam Reheaters by new ones of high efficiency design. Two important challenges should be underlined for this project. First one is that new equipment should be integrated in a previous design, coming from the former days of Soviet Union. Secondly, all installation works, not only supervision, was under the responsibility of IEC, which involved the utilization of local Supply Chain at its maximum extent. Contract was awarded to IEC in 2008, being a remarkable success in both aspects. To remark (1) the outstanding compliance of outages schedule, being of the outmost importance the constructability analysis, which minimized interferences and maximize usage of existing turbine cranes, and (2) the exceed of contractual performance guarantees.



Scheme of Modifications developed in Laguna Verde Units 1 and 2. (not included off gas and turbine ventilation system upgrade).

Laguna Verde Unit 2 Condenser Installation sequence using Modularization scheme of construction (from top left to the right upto lowest right picture).

MEXICO, LAGUNA VERDE, largest nuclear project developed by an Spanish company outside Spain

Laguna Verde is a GE BWR-5 station located in the Gulf of Mexico, near Veracruz.

In February 2007 the contract for the complete refurbishment of Laguna Verde Unit 1 &2 turbine island was awarded to IEC, with a budget

Picture 7. Installation of several Flamanville Safety Class HX (Open Top and Non Open Top).

Picture 8. Circulation Water Channel Construction. Flamanville 3.

above 600 M USD, after a long and demanding bidding process. The goals of the project were modernization and increase of capacity to adapt turbine island to the new expected conditions at new reactor power level of 120%, and to upgrade turbine island for new life extended conditions of 60 years.

Complete information may be found in reference [1].

The project was developed in a scheme based in two outages per unit, between 2008 and 2010, and involved the complete supply, refurbishment and upgrade for both units of turbine generator and auxiliary systems, condensers, feedwater heaters, condensate pumps, booster pumps, new turbine crane, main trafos, new isolated bus and main switch gear, turbine island ventilation system, with new variable frequency fans to adapt to the demanding environmental conditions, offgas system, etc.

FLAMANVILLE 3: the future

Electricite de France (EDF) in 2006 began construction of a new EPR nuclear reactor in Flamanville central. IEC has been involved for five years in five EPC projects in the construction of the EPR in both the nuclear island and conventional island in the pumping station. Scope of projects involved the design, supply and onsite installation of safety class 2 and 3 heat exchangers, and safety and non safety class equipment for the water intake and water treatment.

These projects represent a challenge from the technical point of view because of the high requirements applicable to the project by the return of EDF operator's experience and compliance with the new regulations arising from the realization of ultimate nuclear plant in France. Additionally, the state of the supply chain after several years without building new plants, and the requirement in some of the projects using European standards, customer not accepting American legislation, assumed an additional challenge.

Additional information about these projects may be found in reference [2)].

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[1]. Spanish Society Magazine, November 2011. Monograph. Alejandro Merino, Jose Luis García- Serrano, Leticia Ruiz, Juan Jose González, Miguel Ángel Gabaldón, Ignacio Prieto.

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LAINSA

LMQ. AN EFFICIENT METHOD IN ORDER TO RECOVER THE PERFORMANCE OF THE MSRS. A SATISFACTORY EXPERIENCE

Inspections on moisture separator reheaters in the French Nuclear Power Plant has shown evidence of significant clogging due to deposits of magnetite inside tube bundle whose presence could damage equipment and harm productivity. We have developed a procedure that consists of a mechanical pre-cleaning of all tubes of the MSR in order to unblock them, followed by chemical cleaning where magnetite is dissolved and flushed out of the tube bundle.

The undesirable phenomenon of erosion-corrosion produced in the steam pipes, puts in circulation significant amounts of iron, which are accumulated, in the form of magnetite, valves and above all within the pipes of the MSRs and other heat exchangers and on the outside of the tubes bundle of the Steam generator (secondary side).

MSRs Inspections made in French Nuclear Power Plants, induced by

Interior of MSR pipe with magnetite deposits.

MSR tube bundles in workshop for the LMQ process homologation.

a decline of the equipment performance determined that MSRs of Fessenheim and Bugey Nuclear Power Plants are subject to the build-up of magnetite deposits, resulting from steam eroding the tube system. As deposits build up on the inner surfaces of the tubes, they impede flow, and increase the pressure drop between inlet and outlet of the MSR. In some cases, the pressure drop amount has been found to be near the maximum design criterion. This effect could result in equipment damage and loss of plant productivity.

We present the alternative of changing the MSR or proceed with a regular cleaning. An economic analysis and time savings induce the second process carrying out.

With this project we developed a method to remove magnetite and oxide deposits from the inner tubes of the MSR in order to recover a passage diameter and an exchange surface equivalent to the original and to prevent loss of plant productivity. This removal should be done in a safe way for the base metal of the bundle tube, without producing the chemical pitting of the tubes, which would encourage new cycles of erosion-corrosion.

LMQ system of LAINSA

The method basically comprises a first step of mechanical pre-cleaning by running high pressure water, then introducing a rotary air operated tube cleaner through the tubes of the MSR to unblock the tubes without damaging them. The last step of mechanical pre-cleaning is a final rinse with high pressure water to eliminate all the residues resulting from mechanical cleaning and to facilitate the next step of chemical cleaning.

The second step refers to a chemical cleaning at low temperature (around 65°C) by using different combination of acids, preferably organic ones (citric acid, ascorbic acid, formic acid), and at low concentration, in order to dissolve the deposits from the inner side of the tubes.

The reaction of dissolution of magnetite by citric acid (C6H8O7 = AH_3) is based on the following equation:

$$Fe3O4 + 4AH_2^- \rightarrow 2Fe(III) - A + Fe(II) - A^- + 4H2O + A^{3-} \qquad [1]$$

AH_2^- and A^{3-} are chemical species resulting from citric acid (AH_3), but the following acid-base reactions:

$$AH_3 \rightarrow AH_2^- + H+ , \qquad pKa1 = 3.15$$
$$AH_2^- \rightarrow AH_2^- + H+ , \qquad pKa2 = 4.77$$
$$AH_2^- \rightarrow A_3^- + H+ , \qquad pKa3 = 6.40$$

The chemical cleaning operation also includes the steps of passivation by introducing a passivating agent to create a thin oxide layer on the metallic surfaces to prevent posterior corrosion. A final rinsing step at alkaline pH is then carried out to eliminate all the passivation residues and to leave the MSR in good operational condition.

Procedure description

Before starting mechanical pre-cleaning, the MSR is sealed off temporarily with pipe end and pneumatic plugs, in order to isolate the system.

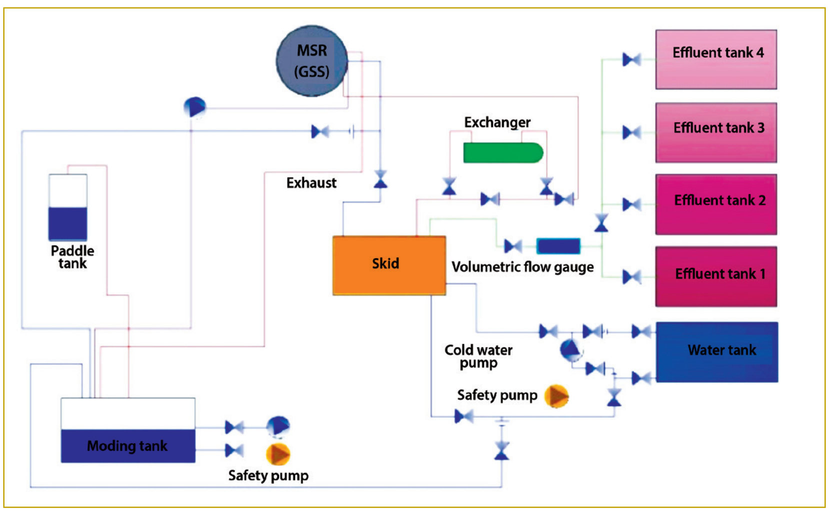
The first step of the process consists of checking for leaks by filling the system with water to a certain pressure.

The second step is mechanical pre-cleaning. Each tube is cleaned with a medium-pressure water jet (100-200 bars) from an electrical hydrodynamic unit (GHDE). This operation also enables creation of a map of clogged tubes.

The next step of the mechanical pre-cleaning process consists of using a rotary air-operated tube cleaner made of a flexible shaft, and a cleaning tool mounted to the tip of the flexible shaft. A final rinse with high-pressure water (400-600 bars) is carried out using the electrical hydrodynamic unit.

In the third step of the process, after a leak check (at 30°C), chemical cleaning with a recirculated aqueous cleaning solution (acid phase) is introduced into the system.

The cleaning solution used to dissolve the magnetite layers contains



Chemical cleaning schematic.

Sealing tool of the MSR water box.

citric acid, formic acid, a corrosion inhibitor and other chemicals. In order to improve the cleaning efficiency, the cleaning solution is heated to 65°C. This is done by an electrical heat exchanger connected in parallel with the chemical cleaning system.

During the chemical cleaning process, analytical controls are carried out periodically (at least each hour) to follow the following parameters:

- Temperature
- Acidity
- ph
- Ferric iron concentration
- Total iron concentration
- Inhibitor efficiency

Chemical parameter evolution gmph during the acid phase

The end of the acid phase is determined by the criterion of total iron concentration <14 g/L and by the stability of four measurements of total iron concentration.

The final step of chemical cleaning is passivation, which is also carried out with recirculation. The aim is to prevent corrosion of the tubes' metallic surfaces by creating a thin oxide layer which protects the surfaces.

During the passivation process, analytical controls are carried out periodically (at least each hour) to monitor the following parameters:

- pH
- Temperature
- Ferric iron concentration
- Total iron concentration
- REDOX potential

Three hours later, the solution is drained out of the MSR and the system is rinsed with alkaline solution.

Results

The results obtained during the various MSR cleaning (14) campaigns allowed the validation of the elimination of magnetite deposits. On sample coupons placed in the interior of the top of the MSR tube bundle, the loss of thickness caused by the cleaning process averaged about 10 µm. The load after cleaning (a measurement of delta P after restarting the unit) was comparable to new equipment.

Conclusions

EDF completed a follow-up of the fouling of the MSR by measuring the pressure delta (ΔP). We noticed that the plugging of the bundle begins to be significant from a threshold of ΔP of 2.5 bars; the maximum ΔP to avoid generation of plastic distortion, and thus MSR damage, is 3.4 bars. It can take four to six years to go from ΔP of 2.7 bars to 3.4 bars.

According to the maintenance strategy envisaged by EDF, when a MSR crosses the threshold of ΔP > 2.5 bar, a cleaning operation is scheduled for the most convenient shutdown less than six years away.

This process has been retained in EDF's MSR maintenance strategy.


MSR and chemical impulsion area.

LMQ Work Area.


Equipment supply area and wastes TK's.

WESTINGHOUSE

WESTINGHOUSE OPERATIONS SPAIN THE YOUNG EXPERIENCE

Westinghouse Operations Spain is increasing its capabilities around the world

Our operations in Spain are mainly located in Hospitalet del Infant (Tarragona) supported by a team located in Madrid. Our crews are able to help our customers around the world in some of the most important activities in the power plants.

Currently, our personnel has been giving technical advice and manpower in the fields of I&C, Cranes, Training, Reactor Vessel Head, Fuel activities, Steam Generators, Pumps and Motors. And this support is increasing every project thanks to our dedicated employees. We are proud to have in our facilities a mix of experience and vitality that allows us to achieve the goals of each project. We still have original plant start-up engineers in our crew as well as newly hired people able to provide a fresh perspective and new ideas in our group (and nuclear sector).

As a worldwide company our specialist are demanded to support nuclear needs in of qualified personnel. Below are some of the projects we have been involved with during the past years outside our local area.

We are supporting customers in South Africa, France and Great Britain performing the maintenance and outage support to fuel handling equipment. Our specialists are trained in help you in Instrumentation System as well as Mechanical systems to get the success of the outage. We are currently working on a refurbishment of an auxiliary bridge crane in a highly contaminated area of a decommissioning facility in Great Britain.

We are increasing each day our collaboration with a Slovenian facility to be one of its principal partners, this collaboration started with a RCP motor swap and other related activities. Currently, this collaboration is increasing with new projects, our cus-

Swapping a RCP motor at Krško NNP.

tomer wants to improve his facility trying to make it an example of nuclear safety culture, this is the reason we are designing a RTD bypass elimination for the reactor head, and in the creation of a isolated bunker for equipment similar to another which is currently build in a Swiss NPP.

We are always trying to meet or exceed our customer needs, especially when these needs are not expected. We know the importance to be in the plant as fast as possible and we try to be in the plant before 24 hours of any urgent issue as we did for the support complete hydraulic pump complete disassembly during a non programmed outage in Switzerland. This emergency support helps us to gain future contract of new parts and long duration material supply contract.

Some activities are rarely performed during the life of a power plant and require specialist to perform the work. It is our goal to have these specialists and train young people in these rare activities as we did in a Belgian facility modifying some fuel pins or the design of an OSPS for the RCPs in a Swedish NPP.

But not only in the non-routine jobs are needed specialist, during the normal maintenance activities of the outage is necessary that all work order for the correct function of the plant. This is the reason our French colleagues request our support in Reactor Head activities during the maintenance of the plant.

No country is too far for us, we have supported fuel activities in Brazil, and RCP frequently support activities in USA. Our goal is to help our customer with their activities and to grow and learn with them.

Westinghouse Operations Spain as part of Westinghouse group is working everyday for increasing the reliability of the Nuclear Power Plants and their auxiliary systems. Like our customers, we want to continue being a green and safe company to improve the quality of life around the world.