ENUSA and Westinghouse have signed on December 16th, 2014 an Agreement for Manufacturing of Nuclear Fuel and Associated Services for the EDF Nuclear Power Plants in France. This signature follows the award to Westinghouse by EDF of a long-term contract to provide several thousand tons of nuclear fuel continuing the current contract expiring at the end of 2014.

The supply of nuclear fuel and services to EDF takes place under the European Fuel Group (EFG) Agreement, based on which both ENUSA and Westinghouse cooperate on an exclusive basis in the marketing, design, engineering, manufacture, sale and servicing of PWR fuel for the European market.

The first version of the EFG Agreement was signed back in 1991 and since then it has been renovated a number of times between ENUSA and Westinghouse.

The nuclear fuel for EDF is manufactured under the terms of the EFG Agreement at the Westinghouse facilities in Västerås, Sweden; Springfields, U.K. and at the ENUSA plant in Juzbado, Salamanca-Spain.

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The relationship with EDF goes back to 1991, when the first contract was signed between EDF and ENUSA/EFG for the delivery of 1300 fuel design for the period 1992-1996.

After extensive effort 4 LTA’s and 4 ADA’s with Zirlo were delivered by ENUSA to Belleville 1 Nuclear Power Plant in the 1993-1994 period.

At the end of 1996, EDF and ENUSA/EFG agreed to modify the contractual validity period to 1994-1999.

In 1997 the first reload delivery to Cattenom 1 Nuclear Power Plant takes place. At that time the RFA fuel design replaced the original Vantage 5 fuel design.

EDF and ENUSA/EFG agreed again in 2001 to modify the contractual validity period to 1994-2004.

Back in 2002 a new contract was signed between EDF and Westinghouse/EFG for the delivery of fuel for the period 2003-2007. This contract was followed by others covering the period 2008-2014. During this period of time several ENUSA-Westinghouse Agreements have been put in place to support the nuclear fuel manufacturing from Juzbado.

In 2003, 4 APA-1300 FAs with Optimized Zirlo cladding were delivered by ENUSA to the Paluel 1 Nuclear Power Plant.

From 1993 to end of 2014 a total of 2172 fuel assemblies, equivalent to approximately 1070 tU have been manufactured and delivered to EDF.

Following the new Agreement with Westinghouse, ENUSA will manufacture a volume of approximately 600 tons of RFA 900 and RFA 1300 equivalent to 100 tons a year during the
2015-2020 time frame. ENUSA will also continue to provide engineering support to EDF both in the Operations and the Technology and Equipment Development areas.

In the frame of the new contract a redistribution in the EDF plant type supplied by EFG will take place starting in 2015-2016, where the number of 900 MWe reactors versus the number of 1300 MWe reactors will become more balanced implying an important challenge from the logistic point of view.

A significant scope engineering related activities which will require ENUSA support are envisioned for the time frame of the new agreement including, among others, the promotion of products/solutions that respond in the expected way to the customer PCI strategy, the increase in the core management scope by providing added value through improved modeling and benchmarking to startup data and also through a better implication and control on EDF’s licensing file for the EFG fuel in the PCI, DNB and LOCA areas.

From a product perspective there is a number of changes already under EDF’s evaluation that are expected to be introduced in the frame of the new contract like the robust P-grid, oxide coated cladding or double bulging all of them tailored to improve even more the fuel behavior in accordance with the customer expectations.

ENUSA will continue to support EDF in the fuel surveillance campaigns through the corresponding engineering evaluations as it is currently done.

Finally to remark that the signature of this Agreement with Westinghouse takes place after a long period of intense negotiations supported by the higher and higher credit that Westinghouse gives to the value added by ENUSA developed throughout the years since the EFG joint venture was created, and leveraged by the recognition that the EFG customers in general, and EDF in particular, provide to ENUSA.

For further information, please contact miguel.montes@enusa.es
Redesign of Gd oxide fuel rod manufacturing area (Gd-area).
Upgrading of safety equipments corresponding to the ventilation and air cleaning system (VACS) in Gd-area

The BWR fuel design has used Gadolina fuel rods as burnable absorber for more than 40 years now.
ENUSA started to make fuel for the Spanish Nuclear power plants, PWR, and BWR, in 1985. For the BWR reactors, ENUSA did not have the capability of making Gadolina fuel rods, and therefore BWR fuel rods including UO₂ and Gd₂O₃ pellets were manufactured abroad. These gadolinia fuel rods were supplied by GNF (General Electric Nuclear Fuel), given that the Juzbado-factory in Salamanca had not integrated this product into the original design.

In addition, PWR fuel design began to include gadolinia fuel rods in 1994. The first Spanish PWR fuel reload with such type of rods was Asco nuclear plant. At that moment, the Gd fuel rods were also procured from abroad.

Considering the increase use of this burnable absorber, ENUSA decided to address the implementation of a manufacturing line (Gd-area) for the production of such type of fuel rods in its factory in themed 90’s. This first Gd-line was designed and built with a yearly production capacity of around twenty five tons for both BWR and PWR products.

The physical separation of the Gd-rods and U-rods manufacturing process was established in origin as a main condition to integrate the new production line at the facility, due to an initial interpretation of requirements for safeguarding and protection from contamination. Then the Gd-area should be spatially separate from other activities, with their specific ventilation and air cleaning system.

At the same time, a particular space for generated wastes (the characteristic of Gd-area and those of UO₂-area but potentially contacted with Gd₂O₃) was necessary to fulfill the condition of complete separation of the area. Thereafter, solid waste of radioactive material from both U and Gd lines and other radioactive waste generated in laboratories are processed together in that Gd-area.

The evolution of production volumes leads over time the need for a redesign and expansion of the Gd-area to develop the productive space. A new distribution of installed equipment is needed, and the replacement
of technically obsolete equipment. The operating conditions and regulatory requirements are different now for the manufacture of this type of product with Gd$_2$O$_3$ content and their radioactive waste managing. In addition, technological upgrading of safety systems in the coverage of the area is recommended.

Particularly, ventilation systems and air cleaning require an adjustment of items to the new configuration of areas of waste management and deployment production equipment.

The system installed in the Gd-area was designed three decades ago. Thus, it requires a renovation of critical elements of operation and control to avoid frequent and costly obsolescence and reduce maintenance interventions, to maintain the facility in a good functional status, to achieve adequate levels of reliability and improve operating performance. An assessment by an external engineering company has identified several aspects to increase the efficiency of the system whose implementation will involve a substantial advance.

The amendments set out in a new distribution-implementation, improvements established by a study of the mentioned engineering company and renewal of the system because of its obsolescence are bases of the new design for ventilation and air cleaning in the Gd-area. This new specific design and same type of system modifications will be applied as a testing and foundation to develop similar tasks in the other manufacturing areas.

**New lay-out for gadolinium rods manufacturing area**

Thus, the new design of Gd-area is based, in short, on needs of expansion and technological renovation to meet requirements and demands of present and future. The criteria taken into account for all purposes and in a more detailed way are:

- surface extension for the installation of new equipment,
- new furnaces for oxidation and dis-gassing,
- new sintering furnace,
- extension of the waste treatment areas for contaminated parts processing and reconditioning of drums,
- adapting and updating of safety systems and auxiliary facilities,
- new store drums containing UO$_2$ with Gd,
- technological upgrading of the ventilation system and air cleaning,
- new ventilation and air cleaning system for chemical laboratory,
- new design for earthquake prevention criteria in the same way as in the project of 1993.
- re-defined fire protection areas, associated with areas of ventilation and air cleaning,
- complete new welding and sealing rods production, similar to the analogous lines in UO$_2$ area.
New lay-out for radioactive waste processing area

The treatment facility for radioactive waste in Gd-area has not satisfied the needs generated these last years and have accumulated not rated or treat contaminated materials due to insufficient space and equipment.

The goal is to install a facility for material processing and decontamination in order to minimize environmental impact and facilitate the implementation of regulatory criteria. The planned actions in this area are:

- waste processing area separated from rooms for pellets grinding and rods loading,
- new quarantine drum store and shelves for ventilation system filters,
- new distribution and implementation of current treatment equipment and devices,
- classification of contaminated materials according to aspects of source, characteristics, degree of contamination and cleaning facilities,
- suction hood, buffer drum, compactor and cabins for handling and sorting at the area of (generated onsite) reconditioned drums,
- work-shop equipment for materials processing and decontamination.

Conceptual design of VACS modification

The design criteria for the new installation of this VACS system are consistent with their technological renovation and respond to discussed main needs:

- complete service for all processes equipment that will form part of the expanded area, taking into account both the current work-volumes such as those provided in the future,
- three separate ventilation zones, sintering, grinding and waste treatment, which will coincide with the fire protection sectors,
system modification in the chemical laboratory with same criteria as for manufacturing areas; and issues such as:
• use of automatic firewall valves for insulation of fire sectors in secondary filter cases and ducts,
• inclusion of smoke detectors in extractors and air conditioner.
Secondary filter housing design is replaced by other to meet flow tests according to ASME N510-1989 and DOP-site tests. These filters will incorporate elements necessary for monitoring their temporal evolution locally and at the control room. Emission control will be improved by installing new iso-kinetic sampling probe connected to an alpha monitor, continuously transmitting data to the control room via data acquisition modules (DAM). This system (VACS) have a logic operation interlocked with other safety systems (Fire Protection System, Radiological Protection System, Critical Alarm System) and manufacturing equipments.

Conclusions
The action described (Gd-line upgrading, improvement of radioactive waste processing and decontamination, VACS technological updating, spatial provision for future modifications or extensions of manufacturing area) will allow facing the future in response to the requirements and market demands.

The design modification of VACS in Gd-area is a task in 2015 with operational importance and executive coordination complexity. In addition, other actions will be necessary to disassemble, clean and decontaminate replaced equipment and ducts. This work and experience will provide the basis for the necessary changes in these systems to other areas of manufacturing and can be an advanced test in order to the obligatory future decommissioning of the installation in the long term. Testing and commissioning of VACS system will be supervised by the Regulatory Body (CSN) together with the documentary process associated with the changes.

For further information, please contact ppm@fab.enusa.es
Oxide Coating Cladding Equipment at Juzbado Manufacturing Plant

In the PWR market, the historic operating experience shows that a significant cause of failure for fuel assemblies manufactured at ENUSA or Westinghouse is debris fretting.

In order to improve fuel behavior against debris fretting, three features of “Defense-in Depth Protection” were developed and incorporated in the fuel:

1. Debris filter bottom nozzle (DFBN), designed to mitigate debris-induced fuel rod fretting failures,
2. the protective grid (P-Grid) traps any debris that passes though the DFBN against the elongated solid-fuel-rod-bottom end plug avoiding penetration of the clad, and
3. the oxide coating cladding over the bottom of each fuel rod to increase the surface hardness, thus increasing wear resistance over uncoated cladding.

Enusa included the DFBN and the P-grid in the fuel in 1991 and 1997, respectively and now is in the process to include the third defense-in-depth protection: the oxide coating cladding in order to provide additional debris and grid-to-rod fretting damage resistance margin and to improve fuel reliability.

The oxide coating was introduced in the mid-1990s in Westinghouse for US customers and the performance experience for the 17x17 RFA and RFA-2 fuel through the end of 2013 shows that there have been zero leakers in more than 7300 fuel assemblies with all three debris mitigation features, including oxide coating.

The oxide protective coating on fuel rods consist of a coating protective over the bottom end plug, the bottom end plug welding and a portion of the cladding (114 mm to 178 mm) with 2 to 6 microns of thickness.
Oxide coating is a process where the cladding oxide thermally grown in furnaces. The coating process is performed after the bottom end plug is welded and prior to fuel loading and consists of three major steps:

1. **Pre-Coating Station:** Prior to coating the tubes, the weld area is polished in a polishing station, cleaned with acetone, and finally the tubes are evacuated and backfilled with argon. Material removal during polishing and vacuum/argon backfill conditions are monitored and controlled to qualified levels.

2. **Oxide Coating Station:** The Oxide Coating station consists of three induction heating coil coating where the tubes are loaded onto them in batches of 39 tubes about 25 minutes approximately. During the heating process, the insertion depth of the tube in the furnace is controlled to produce the cladding oxidation over the bottom end and end cap of the tube. The atmosphere surrounding the tube in the heater is air and argon on the inside of the tube. The air provides the correct ratio of oxygen to produce the oxide film under the time and temperature conditions, based on the zirconium alloy. Time, Argon hold time and temperature are monitored and controlled to qualified levels.

3. **Post-Coating Station:** After heating, the tube is allowed to dwell in still air for a short period after which the argon is evacuated from the tube and replaced with pure helium. The helium vacuum/backfill conditions are monitored and controlled to qualified levels.

In addition, auxiliary equipment and modifications in the current installation are required in order to integrate the coating equipment with the tubing manufacturing line.

The oxide coating implementation at Juzbado Plant is a challenge since the integration of the oxide furnace and the auxiliary equipment required have to be performed with the minimum impact in the production line. The overall equipment need to be placed over the fuel rod inspection area on a platform that has been designed to support all the coating and auxiliary equipment.

The project started in at the end of 2013 and it is scheduled to be completed at the end of 2015. The first application of fuel rods with coating feature is for Tihange 3 Cycle 25th and the fuel tubes will be manufactured at the beginning of 2016.

*For further information, please contact JMJ@enusa.es*
ENUSA fuel reliability improvement strategy overview

ENUSA is committed to providing our customers with fuel designs that meet their needs for efficiency, power, energy, performance and reliability. ENUSA's current fuel designs, covering BWR and PWR technologies, incorporate highest performance with proven reliability features developed in the past 40 years of nuclear power operation. As of January 2015, ENUSA has manufactured more than 20000 fuel assemblies (around half BWR and half PWR), with operating conditions reflecting varying reactor power densities, cycle lengths, operating strategies and water chemistry environments.

The Fuel Reliability Program

For ENUSA, any unexpected behavior of the fuel in one customer site, including leaking fuel and its latter inspections, outage time extension, fuel handling limitations, or extra efforts in fuel cycles management can impact our customers confidence and may induce them to a potential increase in radiation exposure and contamination events. For this, ENUSA has been focused on the performance and reliability of our manufactured fuel for the past decades. Nonetheless, in 2012 the indicator of leak free plants raised a flag that drove us to initiate a program aimed at improving our fuel reliability. In addition, all the nuclear industry operators and researchers (i.e. INPO, EPRI) increased their involvement since the 2000 decade, by establishing zero failure programs in which ENUSA has been actively involved.

This Fuel Reliability Program implemented by ENUSA follows a process that anticipates and prevents fuel reliability issues and is based on the existing ENUSA basic pillars tools for improvement, such as the Continuous Improvement Program, the Corrective Actions Process and the Human Performance Principles. The process works to ensure that feedback on fuel reliability and performance from mostly all available sources (Internal and External Operating Experience, Root Cause Analysis on Failed Fuel, Healthy Fuel Exams, Manufacturing changes, etc) is collected, screened and prioritized by a group of experts comprised from areas, such as Manufacturing Quality, Operational Engineering, Fuel Performance and Reliability, Fuel Services, Spent Fuel and Continuous Improvement. Also, given the nature of ENUSA as a manufacturer, the Manufacturing Quality engineer in this group of experts, presents a detailed evaluation of the trends of manufacturing non-conformance where a Critical Fuel Reliability Attribute (attributes that if altered, the affected fuel reliability can be compromised) is affected.

Once the information is trended and analyzed, areas for improvement are identified, being the most relevant issues transformed into recommended projects.
classified in five major areas: design, materials, manufacturing, operational experience and spent fuel (characterization and storage). These projects are then presented for approval to ENUSA Fuel Reliability Steering Committee so that resources are made available to these projects. Once sanctioned, the projects are followed and controlled until closure.

This process has been described and included in ENUSA Operational Procedures, in the highest level of hierarchy of the ENUSA Quality Assurance program, so that ENUSA Nuclear Fuel Business Unit is globally involved, providing areas of improvement from across the organization, widening this way the sources of information.

Also, this process has been extended to the European Fuel Group frame, with a specific Fuel Reliability Improvement Steering Committee from both Westinghouse and ENUSA organizations, where strategic projects for ENUSA European customers are brought for discussion and approval.

The Results

ENUSA’s focus on fuel reliability has extended in the past years. The implementation of the Fuel Reliability Program has lead us, for instance, to standardize and promote excellence in our manufacturing facility in Juzbado, including the implementation of the Coating process, feature in the fuel that jointly with the Debris Filter Bottom Nozzle and Protective Grid, has a failure rate of 0%. Also, the development of the sipping inspection equipment has been considered critical given the importance of the classification of the spent fuel for our domestic customers. Most importantly, given that debris fretting is the most probable failure mechanism, actions to prevent debris fretting failures have necessarily become an area of industry focus, driving our manufacturing and sites to focus on improved foreign material exclusion practices. Figure 1 shows the evolution of the ENUSA fuelled leak free plant indicator since implementation of the Fuel Reliability Program in 2012, reaching and maintaining the levels up to the high ‘90%.

Summary

ENUSA, by implementing the Fuel Reliability Process, has adopted a robust strategy to promote fuel reliability and drive continuous improvement through design, manufacturing, materials, operational experience and spent fuel characterization and storage. ENUSA is committed to provide flawless fuel to our customers, bringing them the most valuable product. As a result of the implementation of the Fuel Reliability Process, the number of plants with leaker-free cores has increased to new levels, reaching 91% at the beginning of 2015.

For further information, please contact scb@enusa.es
Research on irradiated rods. Fuel rods shipment to a hot cell laboratory

Key research programs of ENUSA require of specific post-irradiation examination (PIE) in a hot cell facility in order to get reliable data to characterized properties and conditions of different products and materials. The shipment of the irradiated material from the nuclear power plant to the hot cell laboratory is a very complex process that involves important fuel handling operations, as well as administrative tasks concerning authorities from many countries. During last October 2014, ENUSA has successfully completed a transportation of 10 irradiated fuel rods from the Almaraz NPP in Spain to the Studsvik hot cell laboratory in Sweden.

Fuel rods were selected to attend a number of different research programs, some of them in collaboration with our Spanish PWR utilities, or with domestic or international partners such as CSN, Enresa, Westinghouse or Mitsubishi Nuclear Fuel.

The purpose of the programs includes a broad type of objectives such as the characterization of advance cladding alloys, the determination of significant fuel rod mechanical properties concerning spent fuel, or the validation of on-site PIE technics.

ENUSA has selected the suitable irradiated fuel transportation cask based on the previous shipments experience, the maximum allowable fuel rod burn-up, the licensing status, and the compatibility assessment performed jointly with the cask owner and Almaraz NPP operators and Studsvik operators. Based on these considerations, the R72 cask owned by the Belgium Company Transnubel has been selected and accepted by all the parties involved in this transportation.

It was the first time that the R72 cask was used in Almaraz NPP and in Studsvik
cell, therefore before the shipment the qualification of all the handling operations was performed during a detailed blank test at both sites.

ENUSA has created the corresponding intervention dossier for the irradiated fuel rod loading campaign at Almaraz NPP. This dossier includes a safety evaluation report for the R72 loading campaign at Almaraz NPP. As part of the safety evaluation, it was performed a seismic evaluation of the R72 handling.

ENUSA has performed the transfer of the 10 irradiated fuel rods from the storage basket to the transport basket. Later on, the transport basket has been loaded into the R72 cask that was located in vertical position at the cask loading pit. Then, and before the consignment, it was performed all the test and checks required by the cask certificate, such as drying test, leakage test and decontamination.

The expedition convoy lasted five days to arrive to Studsvik and the following countries were crossed: Spain, France, Germany, Denmark and Sweden.

The cask R72 has been transported as a Type B(M)F package (UN3329), according with the ADR convention (European agreement concerning the international carriage of dangerous goods by road). The R72 original approval certificate was issued by the French Authority and it has been validated in all concerned countries.

The unloading operations at Studsvik were done in horizontal position by pushing the transport basket inside the hot cell.

The fuel rods will be subject of a quite extensive PIE to determine significant characteristics and properties of the irradiated material, including puncturing tests, fission gas release analysis, gamma scanning, profilometry, as well as different type of mechanical and metallurgical tests.

In summary, ENUSA has completed a successful irradiated fuel transport that will significantly contribute to the research projects on the new cladding materials and spent fuel characterization programs.

For further information, please contact lpf@enusa.es
ENUSA participates in the IAEA CRP on Long Term Interim Storage of Spent Fuel

In the frame of the research activities that Enusa performs to support its engineering operations in the field of spent fuel management, Enusa participates, together with CSN (Spanish Nuclear Regulator) and Enresa (spent fuel management company), in a Coordinated Research Project (CRP) organized by the International Atomic Energy Authority. The project is devoted to improve the knowledge and understanding of the phenomena involved in the behavior of spent fuel during very long term storage. The CRP includes experimental activities on the behavior of both the spent fuel and the storage system. In all, 21 different experimental projects from different countries are included in the CRP. The Spanish contribution to the project studies the effects of severe corrosion and hydriding of the cladding.

The second meeting of the CRP took place in Tokyo (Japan) last November, and an update on the status of the different projects was provided. The duration of the project is three years, and the third and final meeting is scheduled for spring 2016.

Expansion of cooperation with Yibin Fuel Plant

CNMC Jianzhong Nuclear Fuel (CJNF) and ENUSA have entered into a new agreement for which ENUSA, in cooperation with TECNATOM, will supply additional fuel inspection equipment to the Yibin Fuel Plant in Sichuan province (P.R. China) to complement the capabilities of the ultrasonic inspection equipment already delivered to the Yibin plant.

The system to be delivered along 2015, is intended for the detection of defects on the surface of fuel tubes by eddy current and it will make use of the know-how acquired by ENUSA at the Juzbado fuel factory and the extensive experience in eddy current non-destructive examinations of TECNATOM.

ENUSA paper published by ASTM International on Zirconium Technology

As one of the selected technical papers presented on the 17th International Symposium on Zirconium in the Nuclear Industry, celebrated in Hyderabad, India in February 2013, the paper “Oxidation and Hydrogen Uptake of ZIRLO Structural Components Irradiated to High Burn-Up” is published by the ASTM. This paper is authored by ENUSA, Vattenfall Nuclear AB, Associació Nuclear Ascó-Vandellòs II (ANAV) and Westinghouse Electric Corporation. It is the result of the joint research work that has been developed by these organizations along the years to get cutting-edge information on the oxidation and hydriding of fuel assembly structural components up to high fuel assembly burnup, 70 MWd/kgU.

Members of the Committee on Industry, Energy and Tourism of the Spanish Parliament visited Juzbado Factory

On January 14, members of the Committee on Industry, Energy and Tourism of the Spanish Parliament visited the nuclear fuel manufacturing plant that ENUSA has in the town of Juzbado (Salamanca).

The visit was conducted by Mr. José Luis González, CEO of the company, Mr. Javier Montes, Director of the Plant and Mrs. Carmen Vallejo, the Head of Institutional Relation.

In that visit, the Committee Members witnessed the process followed to manufacture the fuel for the nuclear power plants. They showed their satisfaction and expressed: “We have had the opportunity to know in live a market leader facility as Juzbado Nuclear fuel factory”.

Co-ordination: Institutional Relations relin@enusa.es