The evolution of nuclear energy. Opportunities for the industry

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At the turn of the XXI century, the world energy context underwent a significant change due mainly to the increases in the demand for energy in the developing countries, a rise in gas prices and increased government support of clean energies in response to environmental issues. These boundary conditions led rapidly to renewed interest in nuclear energy worldwide. The phrase "a Renaissance in nuclear energy" was included in almost all energy forecasts. Unexpectedly, however, just ten years later the panorama changed once again: unconventional gas appeared as a new energy source, the world financial crisis hampered investment, and the demand for energy fell. This panorama has lowered expectations with regard to the size of the nuclear energy renaissance to a less bouyant but more balanced scenario of nuclear energy deployment that we could now dub as the "evolution of nuclear energy".

This article describes how fission nuclear energy has continuously been evolving to adjust itself to these changing scenarios and, in particular, how it is being adapted itself to today's vision of the role of the nuclear energy in the long term. The analysis in this paper focuses on those programs that could bring opportunities for Spanish nuclear industry participation.

Starting with the development programs affecting existing reactors already in operation, the analysis moves on to the new builds of Light Water Reactors (LWR) Generation III+, to then address, in two sections, Research Reactors and finally, the opportunities presented by Generation IV technologies. The development of fusion technology is not covered in this paper.

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EVOLUTION OF THE TECHNOLOGY IN NUCLEAR POWER PLANTS IN OPERATION

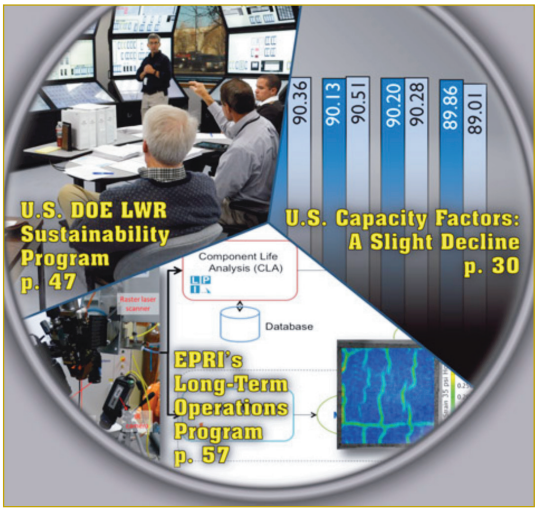
The evolution of the technology of the reactors in operation is driven by the objective of maximizing nuclear assets to adjust their costs to operate in more competitive scenarios. Two areas are the major contributors here: the extension of the operational cycle up to 60 or 80 years, and the power uprating and increase in availability of the reactors by increasing their energy output.

Initiated in the US, the strategy of renewing licenses for long-term operation up to 60 years was well developed and supported by the US Nuclear Regulatory Commission (NRC) and the nuclear industry as a whole. The Electric Power Research Institute Long-Term Operation Program (EPRI - LTOP) got underway in 2009 is now a large, collaborative research effort reaching across multiple countries and entities, among them, Spain.

Spanish industry has closely followed and developed capabilities in all the research activities associated with the long term operation defined by EPRI in preparation of their application to our nuclear reactors. Primary system degradation, advanced welding processes, reactor surveillance, concrete aging management, cable aging management, diagnostics and integrated life-cycle management are some of the areas of research in this program. In this context, it is relevant the coordination effort made by UNESA providing access to the most relevant EPRI documentation for the applicability analysis to the Spanish NPPs.

In addition to this investigation and research oriented at a 60-year operation horizon, the DOE has recently launched the Light Water Reactor Sustainability Program to develop the scientific basis for extending nuclear power plant operation life beyond 60 years.

The LWRS Program is divided into four research pathways: Materials Ageing and Degradation, Advanced Instrumentation, Information, and Control Systems Technologies, Risk-Informed Safety Margin Characterization and Advanced Light Water Reactor Nuclear Fuels. Descriptions of each of these pathways follow, together with highlights of recent results. This program will offer opportunities for the Spanish nuclear industry to participate in the near future.



Areas of Evolution in Operating Reactors

The second line for maximizing nuclear assets is related to the increase of capacity factors and power uprating. In this respect, the effort of the Spanish nuclear industry has been relevant, with very positive results. The 2012 operating results of the Spanish NPPs as a whole, with a load factor of 88.82%, an availability factor of 89.84%, an operation factor of 90.60%, non-programmed unavailability of 1.33%, and an increase of 6.4% in nuclear energy generation over 2011 all evidence the top-level performance of the Spanish installations in terms of generation.

This level of excellence in the operation of reactors reflects the commitment of the utilities and is indicative of the skills of the Spanish nuclear industry supporting plant operation. This expertise as "operators" is attractive on the international market where new contracting schemes that combine vendors and operators in joint ventures, for example, the BOT contract model, are being implemented.

EVOLUTION OF TECHNOLOGIES IN THE NEW CONSTRUCTION OF NUCLEAR REACTORS

Construction of the new generation of LWRs known as Gen III+ has begun. 36 new reactors in 15 countries are now being built. Russia, China, Korea, India, Europe and United States have programs under which Generation III+ reactors, of various technologies, mainly PWR and BWR, are under construction. In response to the increased nuclear energy deployment foreseen at the end of the XX century, vendors began developing evolutionary reactors. Thanks to this effort, the ESBWR GE-Hitachi; ABWR GE-Hitachi; AP-1000 Westinghouse Electric Company; EPR AREVA; APR-1400 Korea Electric Power Corporation; APWR Mitsubishi Heavy Industries; AES-2006 VVER, Rosatom are examples of the available Gen III+ reactors that will most likely be in operation in the next decade, bringing to the nuclear industry additional expertise in licensing new processes, project organization and construction models, passive system behavior, advanced engineering and CAD design tools, etc.

The participation of the Spanish nuclear industry in most of the above developments has been and continues to be relevant. Starting with the Spanish Advanced Reactor Programme launched 20 years ago, Spanish industry is being involved in most of these new built programs, either in design activities, in procurement or in EPC contracts for packages.

The participation of Empresarios Agrupados in the Design Certification of the GEH ESBWR performing design activities, licensing reports such as the Design Control Document and Responses to NRC Additional Information Requests; in the technology evaluation of the different reactor technologies for specific site applications; and in the development of engineering design packages supporting EPC contractors for New Build proposals are relevant examples of this participation.

EVOLUTION IN THE RESEARCH REACTORS TECHNOLOGY

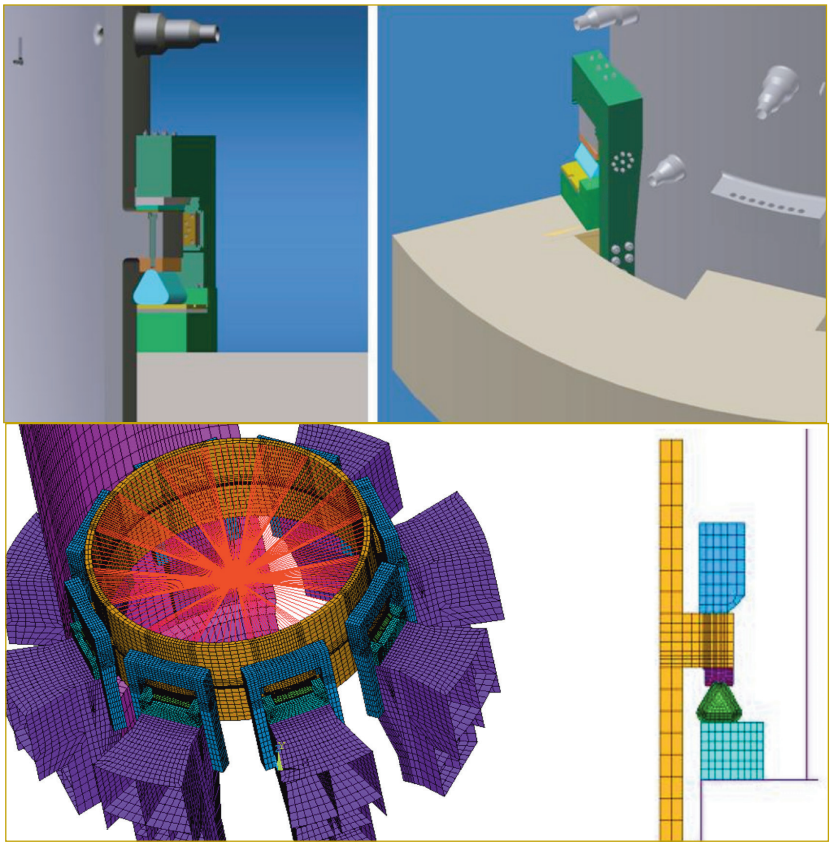
Apart from the use of the nuclear energy for electricity production, there are several areas of development supporting the commercial reactors and other applications of nuclear energy. These areas refer to the basic research supporting the technological development of Gen III+ and Gen IV.

In the 1950s, Research Reactors were a tool to demonstrate the viability of the use of nuclear energy for energy production. These research reactors, normally located at the universities and research centers, are now being dismantled due to a lack of use for the purpose for which they were built. Nevertheless, there are today strong drivers to deploy research reactors. These drivers are

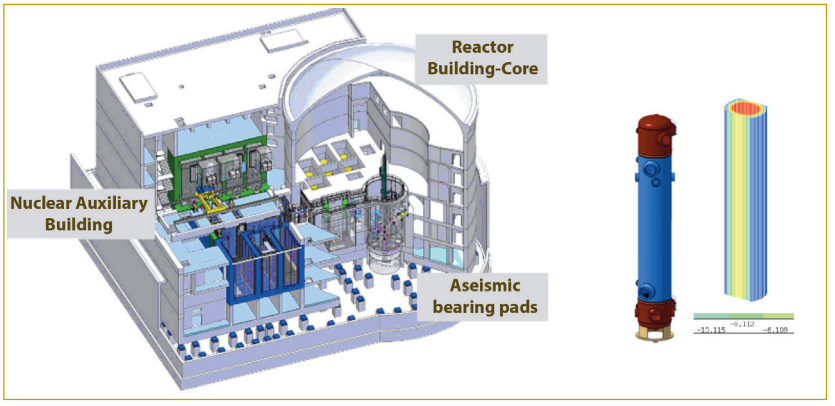
for supporting evolutionary and advanced reactors development Gen III+ and Gen IV, and to support nuclear energy applications different from electricity production, mainly for medical applications. The production of isotopes is one of the major applications.

One example of research reactor development in which the Spanish industry is involved is the Jules Horowitz Reactor (JHR), that will be built and operate in the framework of an international cooperation between several organizations.

With an investment of about 750 million Euros, JHR is expected to start operating in 2016. The reactor is a pool type reactor. The maximum thermal power is 100 MW. This power is dissipated via the primary and the secondary circuit to the external cold source during irradiation; the core, the primary



Gen III+ RPV Support Design performed by Empresarios Agrupados.



JHR - Plant layout and Main Heat exchanger. In-kind contribution by CIEMAT-ENSA-Empresarios Agrupados.

circuit and experimental rigs, are completely enclosed in the Reactor Building. The Reactor pool is connected to several storage pools and hot cells located in the NAB through a water block. Material investigation, isotope production, spent fuel behavior experiments, hot cell and laboratories development are major missions that the JHR will tackle for the international community.

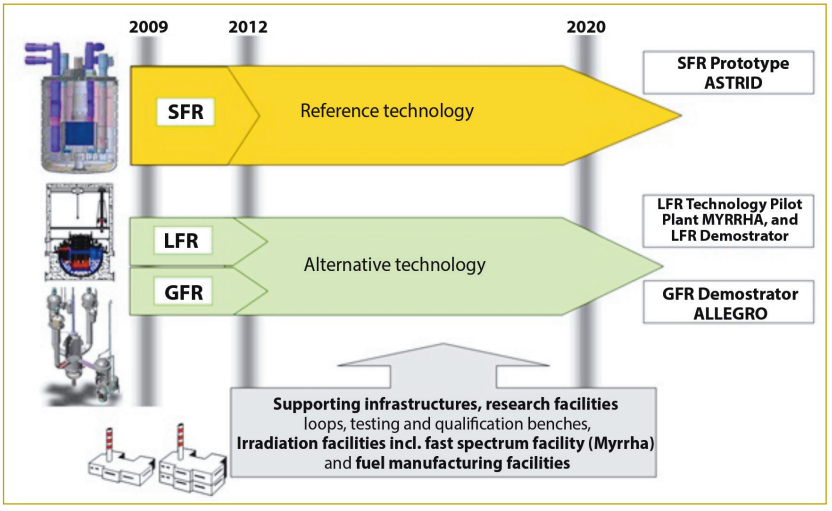
Spanish industry is providing inkind contribution to the JHR that will be compensated by rights to use the reactor for future research. This work is instrumented through a CEA-CIEMAT agreement. A relevant part of the scope of the in-kind contribution of Spanish industry covers the design and manufacturing of the three Primary Heat Exchangers. Empresarios Agrupados is responsible for the design, and ENSA is responsible for the manufacturing. Two other companies, Tecnatom and Socoin, are contributing with the experiment simulation platform. Similar opportunities could arise in the future.

EVOLUTION OF THE NEXT GENERATION OF FISSION REACTORS

The GEN IV/GIF initiative, launched by USA in 2000, was the pillar for the consolidation of several initiatives of advanced technologies existing at that time around the world at the laboratory level. GIF has made it possible to join the effort and create an industrial forum capable of selecting the most promising technologies and defining deployment strategies. The main drivers of these Gen IV reactors are an increase in use of the fission resources (U, Pu, Th, etc.) and optimizing the management of nuclear waste. Europe's participation in GIF has allowed focusing the EU research program towards its contribution to the Generation IV reactors.

Sodium-cooled Fast Reactor (SFR), Very High Temperature Reactor (VHTR), Supercritical Water Cooled Reactor (SWCR), Gas-cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR) and Molten Salt Reactor (MSR) are the technologies being considered as Gen IV reactors. Over GIF's 13-year existence, the results of basic research and small-scale experiments have been shared among the members. Now, it is time to build the Demonstrators. The international community is proposing to contribute to this new phase, proposing the construction of several installations. In preparing the Horizon 2020 program, Europe is attempting to embark on the construction of prototypes. Three main initiatives, among others, are being considered in the EU Strategy Energy Technology Plan (SET-Plan): ASTRID (Advanced Sodium Technology Reactor), ALFRED (Advanced Lead Fast Reactor), MYRRHA (Multi-purpose Hybrid Research Reactor for High-tech Applications).

The most advanced initiatives are the MYRRHA project supported by the Belgium Government and open to collaboration, and ASTRID, supported by the French Government to be built in CEA (France). ASTRID is a 600 MWe reactor with fast spectrum. Preliminary studies started in 2010, and conceptual design studies are now under way. Construction will start in 2020, and the reactor is expected to be in operation in 2025. The reactor is the result of international collaboration between Russia, India, USA, Japan, Europe, Korea and China. The Spanish nuclear industry could participate through



EU SET-Plan Strategy.

MYRRHA: a consortium participated by Empresarios Agrupados, selected for FEED activities.

the EU Framework Program Horizon 2014-2020, now in preparation.

MYRRHA is a flexible research reactor of 100 MWth coupled to an accelerator. The linear accelerator will deliver a high density high-energy proton beam of 600 MeV to the LBE (Lead Bismuth) spallation target.

The installation will be built by the Belgium Nuclear Research centre (SCKCEN) in Mol with an estimated budget of 960 million euros. Construction on the facility is expected to begin in 2015, with commissioning by 2023. SCKCEN has recently decided to launch the related Front End Engineering Activities (FEED). For this purpose, a consortium in which Empresarios Agrupados is participating has been selected to perform this FEED phase. Civil design, the electrical distribution system, HVAC, fire protection, containment, and the Beryllium doping system are part of the activities assigned to Empresarios Agrupados in this project.

CONCLUSIONS

After 50 years of use, nuclear energy has proven its value as an energy source and its possible contribution in all long term scenarios is beyond question. Thanks to its continuously technology evolution, the nuclear energy is mature and innovate.

The nuclear industry has evolved in response to the changing scenarios, always with a long-term perspective. This article has focused on the recent developments in nuclear energy to be more competitive, to better use nuclear fission resources, and to optimize the management of nuclear waste.

The investment required for this development is shared between governments and industry. As this article states, the nuclear industry is supporting extensive modernization programs of the reactors currently in operation and of the advanced LWR of Gen III+, while the Research and the New Technologies of Gen IV are being supported more by Governmental organizations. As a result of these investments, the nuclear industry now has many opportunities to participate in these developments.

The Spanish nuclear industry has always responded to new challenges and is thus involved in almost all of the international nuclear programs described in this article. Its participation in the life extension programs, power uprating, research reactors, and advanced reactors described in this article are evidence of this involvement.

Nevertheless, the level of Spanish participation and investment in these nuclear programs is currently not on a par with our industry's capabilities and the excellence of the Spanish NPPs in operation. One of the primary goals of the Spanish institutions and nuclear industry should be to increase its involvement. Initiatives similar to the Advanced Reactor Programme launched 20 years ago upon joint government and industry effort should be convenient.