ENERGY TRANSITION AND LONG-TERM OPERATION OF THE SPANISH NUCLEAR POWER PLANT FLEET

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All the analyses indicate that the Spanish electricity system needs the nuclear power plants to continue their operation in order to comply with the environmental objectives and guarantee base load supply 24 hours a day, every day of the year, at a reasonable cost. Consequently, it is necessary to create an environment in which the extension of the operating lifetime of our nuclear power fleet is possible. In order to successfully address the energy transition in Spain, the phasing out of the nuclear fleet must be scheduled adopting a long-term view, by means of an orderly plan aimed at minimising the consequences for the electricity system and society.

INTRODUCTION: OVERVIEW OF THE GLOBAL SITUATION

As regards the issue of whether or not the production of electricity using nuclear means has a future, the answer is clearly positive at a global level. As of the end of May, there were 450 operational reactors in 31 countries – many with authorisations for their continued long-term operation – and 59 more under construction in 16 countries, some with a long nuclear tradition and others that are newcomers to the sector, as well as a number of projects at different stages of planning and development.

In recent years, the production of electricity by nuclear means has represented almost 11% of that consumed across the world. In November 2017 the International Energy Agency (IEA) published a new edition of its forecast report World Energy Outlook 2017, in which three possible scenarios are contemplated: new policies, current policies and a new scenario – sustainable development – which "provides a road map for the energy sector bringing together three different but closely linked energy policy objectives: assurance of universal access to affordable, reliable and modern energy sources by 2030; substantial reduction of atmospheric pollution causing sickness and deaths; and implementation of effective actions to combat climate change", according to which world nuclear power would grow from the current 390 GWe plus to 586 GWe in 2030 and 720 GWe in 2040.

Most of the nuclear growth will take place in China, where there has been a rapid increase over the last decade, from 53 TWh in 2005 (2% of the country's total production) to 213 TWh in 2016 (3.5%). In the United States the installed power would drop from the current 121 GWe to 109 GWe in 2030 and to 105 GWe in 2040, the production decreasing to 851 TWh and 820 TWh respectively in these two years. Likewise, in Europe installed power would drop from 144 GWe in 2016 to 112 GWe in 2030 and to 101 GWe in 2040, and production from 952 TWh to 789 TWh and 744 TWh respectively.

Other geographical areas such as Turkey and certain African countries, especially countries in the Persian Gulf such as Saudi Arabia and the United Arab Emirates, are making important efforts to develop nuclear programmes allowing them to incorporate nuclear technology in their energy mix in a short space of time.

There is a particularly important issue that underlies decision-making in all areas of society: the containment of greenhouse gas generation. With a view to achieving the international objectives set out in this area, it is necessary to establish the technical, economic, human and training and knowledge-related mechanisms required, if possible agreed to by the social, political and business players, in order to map out specific policies for the decarbonisation of the economy.

In this respect, the IEA report points out that if the international community

wishes to achieve the objectives mapped out in the Paris Agreement, nuclear energy – providing a solid, predictable and manageable basis – will have to produce at least 15% of the electricity consumed at world level by 2040. This increase will be supported by the new reactors that will come into operation and by extending the service lifetime of those currently in operation.

THE SPANISH NUCLEAR INDUSTRY

The Spanish nuclear fleet comprises seven reactors on five sites (Figure 1). In addition, the country has a further two nuclear installations: the nuclear fuel manufacturing facility belonging to Enusa Industrias Avanzadas in Juzbado, in the province of Salamanca, and the very low, low and intermediate level radioactive waste disposal centre belonging to Empresa Nacional de Residuos Radiactivos (Enresa) located at El Cabril in the province of Córdoba.

But the Spanish nuclear industry is not made up exclusively of these nuclear facilities. Spain has capabilities covering the entire fuel cycle, including companies supplying nuclear systems, engineering firms, machine tool manufacturers, construction and assembly companies and personnel training and specialist services companies. The Spanish nuclear industry is versatile in its technological capabilities and the work it has performed at our facilities has provided support for construction, operation, maintenance and refuelling over the last 50 years. Furthermore, its presence in nuclear projects in more than 40 countries and for more than 30 years underlines the experience it has acquired and allows it to enjoy international prestige. This has also allowed it to diversify its areas of business and to participate in high-tech sectors such as aeronautics, aerospace and high-speed rail.

THE SPANISH NUCLEAR FLEET AND ITS CONTRIBUTION TO THE ELECTRICITY SYSTEM

Spain has wide experience of the use of nuclear energy as a source of electricity generation, the Spanish nuclear power plants having accumulated more than 250 years of safe and reliable operation.

The Spanish nuclear fleet has a gross installed power of 7,398.7 MW, representing somewhat more than 7% of the country's total installed generating capacity. Every year the fleet produces almost 20% of the electricity consumed in the country, some 55,000 GWh, with overall indicators pointing quantitatively to the effectiveness of the most significant technical aspects of operation, above the average for the world's nuclear fleet. Particularly noteworthy is the load factor, situated historically above 85%, this meaning that our nuclear power plants operate on average almost 8,000 hours a year, providing the necessary regulation for the technically stable and continuous operation of our electricity system and indicating its degree of reliability, efficiency and availability.

Figure 1. Location of the Spanish nuclear power plants.

This solid basis for production guarantees electricity supply 24 hours a day, every day of the year, balancing the generating mix. The availability and diversified geographical origin of the fuel required for electricity generation at the nuclear power plants should also be taken into account. The international approach adopted by the Ministry of Energy considers uranium supply to be a national issue, among other reasons because of the legal requirement that it be stored at the plants at least two months prior to the beginning of the refuelling outage. The purchasing, supply and provisioning of the fuel may be organised with sufficient notice since the scheduling of the refuelling outages is known perfectly, even years beforehand.

Furthermore, the Spanish legislation requires the plant owner companies to keep a reserve stock of uranium, this implying the availability of the uranium required to manufacture the fuel that would be used for two refuelling processes for a 1,000 MWe type reactor like the ones that make up our nuclear fleet. Alongside this reserve, the plant-owning electricity utilities maintain a voluntary stock that would allow for an additional year of operation of the entire Spanish nuclear fleet. Also to be taken into account is the low relative cost of nuclear fuel compared to the total cost of operating the plants.

Additionally, electricity generation by nuclear means amounts to almost 40% of the emission-free power produced in the country, avoiding the emission to the atmosphere of between 30 and 40 million tons of CO_2 every year. This represents a key factor as regards compliance with the objectives deriving from the struggle against climate change and the obligations to comply with the Energy-Climate objectives established by the European Union for the timeframe of the years 2030 and 2050, determined to a very substantial extent by the terms adopted in the COP21 Paris Agreement.

All of our installations operate safely, as is shown by the Nuclear Safety Council's Integrated Nuclear Power Plant Supervision System (SISC). Throughout 2017, all the operations indicators have remained in the green band, i.e. with a very low level of safety significance. Our plants are not only supervised at all times by the regulatory authority, which is the greatest guarantee of compliance with the national and international standards established, but are also continuously subjected to benchmarking and improvement exercises with respect to the best practices implemented at all the world's nuclear power plants.

THE ROLE OF NUCLEAR POWER IN THE ENERGY TRANSITION

The nuclear fleet is a strategic asset in the Spanish electricity system and is destined to play an essential role in the transition to a carbon-neutral system, maintaining at all times conditions of safety. In the short term it is not possible to phase out nuclear energy without risk for the stability and efficiency of the system and without increasing CO_2 emissions.

This is stressed in the report "Analysis and proposals for decarbonisation",

Vandellós II NPP.

delivered to the Ministry of Energy in early April 2018 by the Commission of Experts on Energy Transition. The degree of agreement reached by this Commission should be emphasised, since the report was approved with the favourable vote of the vast majority of its members. Represented on the Commission were all the parliamentary groups of the Spanish Congress plus social agents such as the trades unions and business associations. The report sets out a general framework of scenarios covering the evolution of the energy sector, making different energy policy proposals for the country for the years 2030 and 2050.

For 2030, the report considers that in the basic scenario the nuclear power plants are assumed to remain in the generating mix. It maintains that the early shutdown of the nuclear fleet would imply an increase in annual generating costs of between 2 and 3.2 billion euros and that CO_2 emissions would increase by some 15 million tons per year, making it impossible to comply with the limits set out in energy sectors subject to emission rights trading. Furthermore, in the event of total shutdown of the nuclear fleet, there would be a need for a 7,100 MW increase – with respect to the basic scenario – of additional synchronous base load power in order to guarantee the index of coverage in extreme situations.

This power could be supplied only with additional investments and more CO_2 emissions. The consequences would be even more serious if the objectives established by the European Union for 2030 in relation to the participation of renewable energy sources were to increase with respect to the basic scenario.

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The total annual electricity production in Spain amounts to some 260 TWh. Of these, some 55 TWh are produced by the nuclear power plants, some 65 TWh by renewable energy sources, some 30 TWh by major hydroelectric installations and the remaining 110 TWh by CO_2-emitting sources such as coal, gas and fuel-oil.

In order to be able to comply with its international climate-related commitments, Spain must reduce its emissions of greenhouse gases by 40% by 2030, this implying a reduction of almost 60% in the electricity system. This requires the replacement of almost 60 TWh of electricity produced using fossil fuels with energy produced by other sources that do not emit CO_2.

If this replacement were accomplished using renewable energy sources, it would mean having to double the current renewable generating capacity of the system, some 30,000 MW. If at the same time the nuclear fleet were phased out, it would mean losing the 55 TWh/year that it generates, which would also have to be replaced with renewable energy sources since these are not CO_2 emitters. This would imply the installation of some 30,000 MW additional to those already required to meet environmental commitments. This would mean a total 60,000 MW from renewable energy sources (three times the power currently installed), which would have to be put into operation by 2030. Furthermore, it would also be necessary to install an enormous large-scale storage capacity, for which technology development is still lacking. These two measures would require particularly significant investments, a very rapid development of technology and a deployment of networks and back-up power that would be difficult to achieve fully in that timeframe, or the provision of additional base load power, with the corresponding increase in CO_2 emissions.

These reasons point to the continued long-term operation of the nuclear power plants as being the most appropriate alternative from the economic and environmental points of view to achieve the objectives of energy sustainability and for the transition to a low carbon economy, since the

operation of the nuclear fleet would allow renewable energy sources and storage to reach economic and technological maturity.

VIABILITY OF THE NUCLEAR FLEET

It should be remembered that in Spain the legislation does not establish any limit as regards the operating lifetime of the nuclear power plants. The Nuclear Safety Council, as the State body solely responsible for nuclear safety and radiological protection, determines the technical conditions required for the safe operation of the aforementioned facilities.

Furthermore, the international environmental agreements are neutral from the technological point of view, as a result of which there is no restriction or limitation on the different countries using whatever technology they consider to be suitable in their generating systems. This is the reason for there currently being 59 nuclear power plants under construction in the world and for 125 of the 450 operating reactors having been granted authorisation for continued long-term operation by the different regulatory authorities (Figure 2).

Spain cannot be oblivious to the continued operation of the nuclear power plants, this meaning that it is essential to ensure their economic-financial viability during the period of energy transition, as is the case in other countries in which processes of this same type are under way.

The economic-financial viability of the nuclear power plants implies the guarantee of sufficient revenues to compensate for the operating costs and necessary investments, to operate these installations safely.

Sufficient revenues may be achieved by different mechanisms implying adaptation of the operation of the electricity market. These mechanisms should recognise the key role nuclear power in the technical system operation (security of supply and stability of the grid) and its contribution to compliance with environmental commitments. Among these would be payments for capacity, payments for frequency-voltage regulation, zero CO_2 emission credits, stablishing regulated prices and a reasonable revision of the beared taxation.

It should not be forgotten that in recent years the overall fleet has set aside around 1 billion euros per year for taxes, charges and rates, almost 40% of electricity production billing.

LONG-TERM OPERATION AND PLANS FOR THE ORDERLY SHUTDOWN OF THE NUCLEAR POWER PLANTS

The continued operation of our nuclear fleet should also take into account a long-term plan for orderly shutdown minimising the consequences for the electricity system and for society, the aim being to contain the costs of the back end of the nuclear fuel cycle and of dismantling and decommissioning.

The dates of entry into commercial operation of the seven operating reactors were concentrated in a five-year period: 1983 to 1988 (Figure 3). A scenario in which they all closed after the same number of years of operation (for example 40 or 50 years) would also concentrate their dates of shutdown in a five-year period, giving rise to an accumulation of dismantling-related activities.

The dismantling of the plants requires the removal of the irradiated fuel generated during their operation, as a result of which it is not possible to undertake this activity without first having a plan contemplating its safe disposal. The General Radioactive Waste Plan establishes the suitability of an irradiated fuel management strategy based on a Centralised Temporary Storage (CTS) facility. This strategy was urged by unanimous resolution by the Congressional Commission for Industry in December 2004, the latter including representatives of all the parliamentary groups.

An efficient and realistic management approach taking all the above into account implies the earliest possible availability of the CTS facility and a stepwise planning of the removal from operation of the plants. This planning is justified in order to avoid the increased costs associated with bottlenecks and inefficiencies deriving from certain limitations:

- The existing technical-administrative capabilities impose time limitations on the simultaneous or overlapping evaluation of accumulated shutdown proceedings by the Nuclear Safety Council and the responsible Ministry, evaluations that are necessary for granting of the corresponding authorisations.
- The technical capabilities available impose limitations on the simultaneous disassembly of major items of equipment, a task necessary for dismantling.
- The technical restrictions existing for the removal, loading, transport and storage of the irradiated fuel from each plant to the CTS facility also impose a timeframe requiring the process to be addressed stepwise.

Consequently, the shutdown sequence would be determined by the availability of the CTS facility. Before the shutdown of the first reactor, it would be necessary to have com-

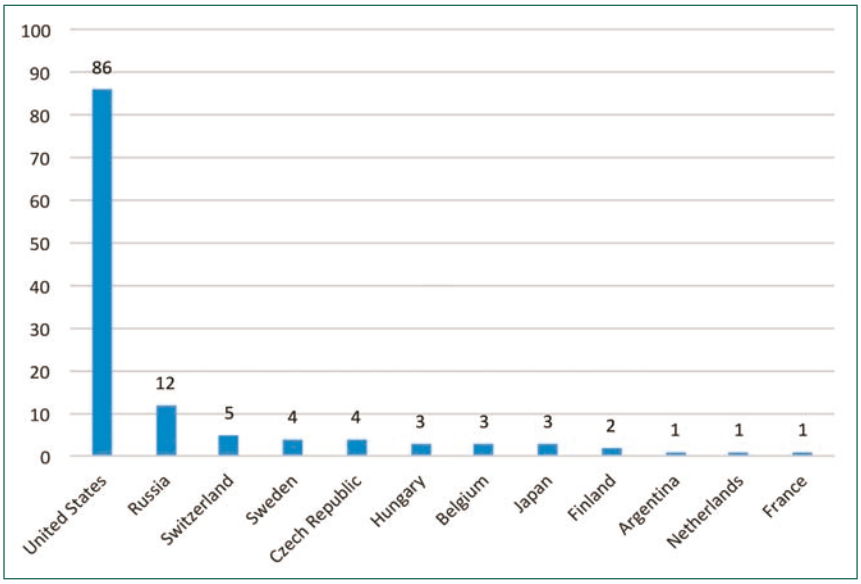

Figure 2. World nuclear power plants with operating licenses for long term operation. Data June 2018.
Source: In-house data with PRIS-OIEA, NEA, NRC, Rosatom, ENSI, HAEA, FANC, NRA/Jaif, STUK, SJUB, NASA, EPZ and ASN data.

NUCLEAR POWER PLANT	ENTRY INTO COMMERCIAL OPERATION
Almaraz I	Septiembre 1983
Almaraz II	July 1984
Ascó I	December 1984
Cofrentes	March 1985
Ascó II	March 1986
Vandellós II	March 1988
Trillo	August 1988

Figure 3. Dates of entry in operation of the Spanish nuclear power plants. Source: In-house data.

pleted the transfer to this facility of the fuel from the José Cabrera and Santa María de Garoña plants, as well as a large part of the fuel from this first reactor. The rest of the plants would be shut down at a rate of one every two or three years, which would allow for the orderly phasing out of the nuclear fleet over a period of 13 to 20 years. This approach would lead to a different operating term for each of the seven reactors, such that the average for the plants overall would amount to around 52 years.

CONCLUSIONS

All the analyses indicate that the Spanish electricity system needs the nuclear power plants to continue their operation in order to comply with the environmental objectives and guarantee base load supply 24 hours a day, every day of the year, at a reasonable cost. Consequently, it is necessary to create an environment in which the extension of the operating lifetime of our nuclear power plants is possible.

In order to successfully address the energy transition in Spain, the phasing out of the nuclear fleet must be scheduled adopting a long-term view, by means of an orderly plan aimed at minimising the consequences for the electricity system and society and containing the costs of the back end of the nuclear fuel cycle and the dismantling of the facilities. In this respect, there is a need to promote medium and long-term energy planning providing stability in the operation of our nuclear power plants and modifications to the regulations allowing the companies that operate what are strategic assets for the electricity system to obtain a reasonable profit.

It should also be pointed out that the Spanish nuclear industry has a high level of technology and know-how and experience, that it has acquired over more than five decades, as a result of which any decision taken regarding the nuclear fleet must be accompanied by an analysis of the impact in this respect, in order to safeguard high qualification employment and capabilities making it possible to operate and maintain our nuclear facilities and participate in international projects in more than forty countries.

Electricity production by nuclear means must maintain its participation in the electricity system as a power source free from CO_2 and an element containing costs in electricity billing, representing also an essential support in guaranteed supply for all the consumers and in the energy transition that must be undertaken in our country, through the continued long-term operation of our fleet of nuclear power plants.■