INNOVATIVE FISSION REACTORS FOR THIS CENTURY

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1. Introduction.

It is well known that global trends indicate a rebirth of nuclear energy due to several items: the climate change and the use of energies that emits CO_2, the cost and dependence of gas and oil, the new innovative reactors which are competitive, safer, sustainable and can support the Kyoto Protocol.

Now the new power plants that have being constructed are classified in the Generation III. Several units of this technology are in operation in Japan and other countries of the Pacific. Europe is now constructing the first unit in Finland (Olkilouto) with european technology: the European Pressurized Reactor (EPR). France has announced the beginning of the construction of an EPR in Flamanville next year.

In 2000, several countries with advanced nuclear technology established the Generation IV International Forum (GIF) to develop and demonstrate nuclear energy systems that offer advantages in the following areas: sustainability, economics, safety and reliability and proliferation resistance and physical protection. These new systems will be deployed commercially after 2030. Six innovative concepts are under research, and the aim is not only produce electricity, but also hydrogen using the operational conditions of several concepts.

Developed countries with NPPs in operation have strategies for the future of the nuclear energy. For the short term is to extend the operation of the NPPs until 60 years, or alternatively construction of new units of Generation III, to substitute those closed for decommissioning, keeping the percentage of contribution to the electricity generated. Between the period 2030-50, the solution is to operate the new innovative systems of the Generation IV, which uses the passive concept, and in the second part of the 21st Century both innovative fission reactors and fusion reactors. For 2025, it seems that many countries of EU will have to construct NPPs until 40 GWe: France, UK, Germany, North Europe, Russia, Spain, Rumania and Turkey, between others.

2. Present state of the Nuclear Energy in the world

The nuclear energy is one of the disciplines that spans engineering systems from the microscopic world (atoms) to the macroscopic one (energy production). It contributes to welfare via power, human health and security.

With the nuclear technology the energy is supplied in a sustainable and safely way, and has less environmental impact than other energies, contributing to the keep the Kyoto Protocol behaviours.

The energy produced is competitive at lower cost than other energies, and the nuclear industry has been continuously developing new innovative systems to be ready for electricity generation or other industrial applications.

At present, the total number of Nuclear Power Plants (NPP) is 440 with 370 GWe. The Light Water Reactors represents the 80% of the total NPP, with 352 units. All these NPPs in operation generate the 16% of the total electricity in the world, being about 33% in the European Union (EU). France with 80%, Belgium with 54%, Finland and Germany with 30% each, and Sweden with 45% are the countries in EU with more nuclear power capacity.

The contribution of the nuclear energy to the CO_2 emission avoidance is really relevant, having zero emission in comparison with other energies. If all nuclear power capacity in EU would be closed, CO_2 emission would rise every year more than 50% of the usual emission. Similarly the replacing of all the nuclear capacity in EU by coal to produce electricity will increase the CO_2 in 935 million tonnes, in 700 million of tonnes if replacing by oil, and in 460 million of tonnes if replacing by gas.

So, as conclusion the nuclear energy is now giving a positive answer related with the global warming, and contributing to keep the Kyoto Protocol levels.

Nuclear energy is also economically competitive with both gas or coal fired power plants, being the nuclear fuel safely provided, and its prize represents only the 10% of the total cost of the energy.

Concerning waste management, the volume of radioactivity waste from NPPs is small and they need long term stewardship. The disposal of all radioactive wastes is technically and economically feasible and several examples can illustrate the advances in the waste management so far: CLAB in Sweden, Habog in Holland, and using casks to storage fuel elements, as in Surry (United States). Additionally, EU, Japan and United States are dedicating resources to the research and development of the Separation and Transmutation Radioactive Wastes in the last ten years. This technology can reduce both the volume and also the radioactivity of the radioactive wastes, and then the control of High Level Waste will be easy.

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For 2025, it seems that many countries of EU will have to construct NPPs until 40 GWe: France, UK, Germany, North Europe, Russia, Spain, Rumania,

Turkey, between others. Last year the International Energy Agency has recommended the construction of NPPs to maintain a sustainable energy generation.

3. Nuclear Energy with innovative reactors.

By 2050, the world population is expected to reach close to 9 billion people. Without a doubt, global energy consumption will grow strongly and is forecast to double to some 20 Gtoe per year while in the same period electricity demand is forecast to triple. Faced with such strong demand, nations are now forced to seek new technically and economically efficient and environmentally sound ways to meet the expected growth.

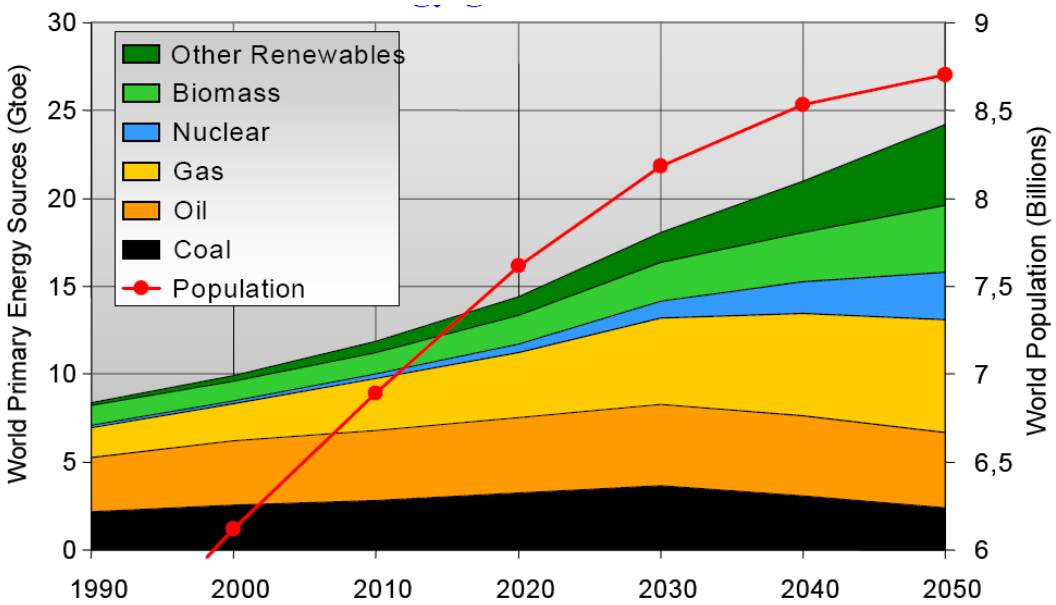

Figure 1. IEA report Energy to 2050- Scenario for a sustainable future.

In terms of its future energy choices, Europe is today at a crossroads: more than 80% of installed capacity (currently more than 1,000 GW) will be more than 30 years old by 2020. That means a large number of power plants will be retired over the period between 2010 and 2030. This is a major challenge but also a unique opportunity, since the choices made today will be shaping Europe's energy future for decades to come. There is little doubt that economic and environmental factors will be the deciding forces in defining what kind of role nuclear power will play in the global energy sector in coming years.

The Advanced Reactors have safer systems than those developed in the Generation II, which demonstrates that are sustainable for the present and nuclear industry has also developed new concepts for the future which also will be sustainable.

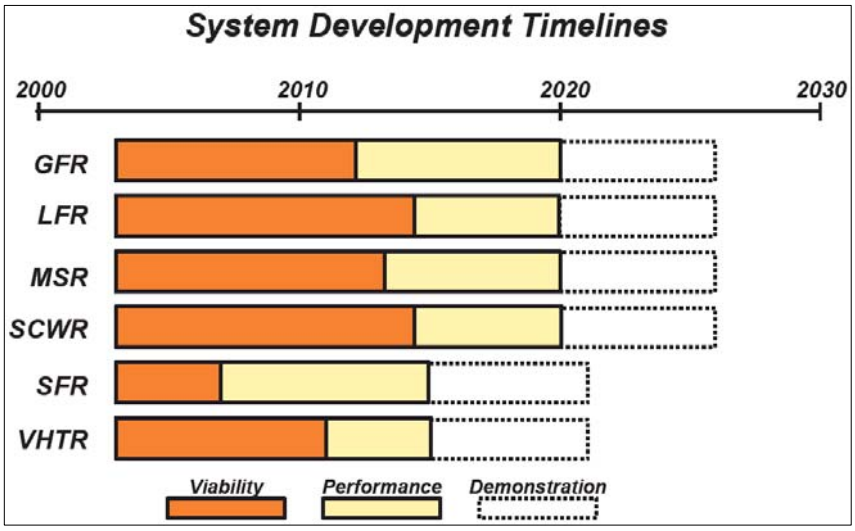

Figure 2. Generation IV Systems. Timelines for viability, performance and demonstration.

Generation IV International Forum (GIF) was stablished to develop and demonstrate innovative nuclear energy systems in the following areas: sustainability, economics, safety and reliability and proliferation resistance and physical protection. These new systems will be operated commercially by 2030 (figure 2). Concepts under research will produce electricity, and also hydrogen using the operational conditions of several concepts.

While several developing countries have long expressed an interest in nuclear power, it has not yet figured significantly in the energy plans of many less-advanced nations, due to several considerations. Most notably, many developing countries lack the sophisticated technical infrastructures and grid sizes to absorb and deploy currently available large-sized nuclear reactors in their electricity systems. Yet, at the same time the needs and demands for electricity in some developing countries are expected to grow substantially and the question arises as to whether nuclear power can help meet these needs. In this regard, some attention is being devoted to evaluating the merits of smaller, modular, simpler, and more passively safe reactor systems that might be better suited for introduction in less advanced countries.

It is assumed that selected R&D programs on assessment methodology and strengthening extrinsic barriers will continue in the intermediate and long-term periods to seek out further improvements, but the emphasis in the intermediate term will shift strongly to obtaining tangible results from intrinsic barrier R&D. For the intermediate term , the R&D program is mainly focused to:

a) Light water reactors (LWR) and their fuel cycles, mainly in extended fuel burnup; enrichment process developments; spent fuel repository R&D; thorium-uranium oxide fueled LWRs, which could result in reducing the quantity and attractiveness of weapons-usable material in spent fuel;

b) High temperature gas-cooled reactors, in which general development of both pebble bed and fixed prismatic core variants of these systems should be pursued, including especially development of fueling approaches that do not rely on weapons-usable material in fresh fuel, from which it would be very difficult to divert material, and resulting in production of small quantities of highly unattractive material in the spent fuel;

c) Fast Spectrum Reactors**;**

d) Small modular reactor systems, and

e) Transmutation technology.

To provide tangible results that can improve proliferation resistance in the longer term, that is, from about 16 years out, projects/programs should focus on the evaluation, and, as appropriate, development of selected advanced systems and concepts. These efforts should consider and assess advanced light water reactors, liquid metal reactors, liquid-fuel reactors, and gas cooled reactors. Various reactor concepts should be investigated that do not require refueling for 10 to 15 years. Advanced closed fuel cycle options also should be investigated when they offer potential opportunities for improving proliferation resistance and international security. This should include the examination of systems that would avoid the presence of separated plutonium. R&D that addresses all the facilities of an integrated system might better minimize proliferation risks and national security concerns.

Future success of nuclear power in the electricity market will be defined by the following key conditions:

- Stability, consistency and predictability of market rules to ensure investor friendly environment
- Independence and transparency of safety regulations
- Agreement on a common technically feasible, economically efficient and publicly acceptable framework for waste disposal
- A simple and rapid process for granting construction and operational licences
- Standardisation and scale effects for reactor manufacturers
- Support for nuclear R&D, and in particular for Generation IV technologies. This to secure a sustainable generation of electricity in a possible context of rising uranium prices and electricity by-products such as hydrogen, synthetic hydrocarbon fuels and high temperature process heat for other industrial applications.
- Active involvement of all stakeholders in the consultation and implementation processes
- Equitable distribution of risks and rewards between all involved.

An alternative to the fission reactors for the future is the nuclear fusion. There are two types of fusion devices or confinement technologies: magnetic and inertial. The first one uses intense electromagnetic fields and the second one uses intense laser beams. ITER is one of the big projects in the world, and it is the essential next step in the development of magnetic fusion. The main objective is demonstrate the scientific and technological feasibility of fusion power. In this project, an international collaboration exits between: China, EU, India, Japan, Korea, Rusia and USA. The construction will start in 2007 in Cadarache (France). It is scheduled to obtain the first experimental results in 2016 and the estimated cost is 5,000 M€.

4.Conclusions

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