

# Is nuclear power a realistic alternative to the use of fossil fuels for the production of electricity?

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# **Is nuclear power a realistic alternative to the use of fossil fuels for the production of electricity?**

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## **Abstract:**

It is an undisputed reality that the energy production and their sustained growth constitute indispensable elements to ensure the economic and social progress of any country. For this reason, the use of all type of energy available in the country, including nuclear energy, should be included in its energy mix in order to ensure its future economic and social development. However, there are certain factors that need to be considered by the competent authorities of a country during the selection of the most economic energy sources for the generation of electricity. For instance the use of fossil fuels is a major and growing contributor to the emission of carbon dioxide to the atmosphere, while nuclear energy and renewables are almost carbon dioxide free.

Considering the different available energy sources that the world can use now to satisfy the foresee increase in energy demand in the coming years, there should be no doubt that, at least for the next decades, there are only a few realistic options available to reduce further the CO<sub>2</sub> emissions as result of the electricity generation. These options are, among others, the following: Increase efficiency in electricity generation and use; expand use of all available renewable energy sources such as wind, solar, biomass and geothermal, among others; massive introduction of new advanced technology like the capture carbon dioxide emissions technology at fossil-fueled (especially coal) electric generating plants, with the purpose to permanently sequester the carbon produced by these plants; increase use of new types of nuclear power reactors that are inherent safe and proliferation risk-free; and increase energy saving.

## Introduction

It is an undisputed reality that the energy production and their sustained growth constitute indispensable elements to ensure the economic and social progress of any country. For this reason, the use of all type of energy available in the country should be included in its energy mix in order to ensure its future economic and social development.

However, there are certain factors that need to be considered by the competent authorities of a country during the selection of the most economic energy sources for the generation of electricity. For instance the use of fossil fuels is a major and growing contributor to the emission of carbon dioxide to the atmosphere. This is a greenhouse gas that contributes significantly to global warming and to produce a significant change in the climate all over the world. These changes are affecting almost all countries in all regions ones in one way and another in others.

Considering the different available energy sources that the world can use now to satisfy the foresee increase in energy demand in the coming years, there should be no doubt that, at least for the next decades, there are only a few realistic options available to reduce further the CO<sub>2</sub> emissions as result of the electricity generation. These options are, among others, the following:

1. Increase efficiency in electricity generation and use;
2. Expand use of all available renewable energy sources such as wind, solar, biomass and geothermal, among others;
3. Massive introduction of new advanced technology like the capture carbon dioxide emissions technology at fossil-fueled (especially coal) electric generating plants, with the purpose to permanently sequester the carbon produced by these plants;
4. Increase use of new types of nuclear power reactors that are inherent safe and proliferation risk-free,
5. Increase energy saving.

The amount of total energy produced and used per capita is increasing in several countries, particularly in emerging economies countries such as China, India, among others. Due to the increase in the demand of energy the world total energy requirements increased from 6 181 GW/yr to 15 311 GW/yr during the period 1970 - 2006.

According to estimates made by the World Energy Council, the International Institute for Applied Systems, among other international organizations, the demand of electricity probably would be triple from now until 2050. The following are, among others, the main reasons for this significantly:

- a) Increase in the world population;
- b) Increase in the percentage of the world population living in big cities, which increase the demand of electricity;
- c) Improve the quality of life of the world population bringing as consequence an increase in the demand of electricity;
- d) Increase in the demand of electricity in the most advanced developing countries such as India, China among others, due to fast economic and social development.

According to IAEA information, in 1990 the world average annual capacity factor for nuclear power plants was 67.7%. In 2005 this figure increases up to 81.4%, which is the equivalent to the construction of some 74 new nuclear power units of 1 GWe. However, it is important to single out that the increase in the capacity factor of the nuclear power reactors in operation and the number of nuclear power reactors under construction are not enough to satisfy the foreseen increase in the demand of electricity in the coming years in almost all regions. The problem that the world is now facing is how to satisfy the foreseen increase in the demand of energy using the all available energy sources in the most efficient manner and without increasing the emission of CO<sub>2</sub> to the atmosphere and climate changes. Without any doubt one of the available types of energy that has proved in the past that can be effectively used for the generation of electricity is nuclear energy. Can be confirmed that nuclear energy could be safely used for electricity generation in the future despite of the problems that the nuclear industry faced in the past and is now facing in several countries? The answer to this question is yes, nuclear energy can play again an important role in the energy balance of several countries in almost all regions as it did in the 1960s, 1970s and 1980s. "Over the last three years, several international assessments of the possible future of nuclear power in the world have been adjusted to more optimistic prospects for the horizon of 2030. The OECD International Energy Agency's World Energy Outlook 2007 presents a "reference scenario, an alternative policy scenario and a 450 stabilization case that include respectively 415 GW, 525 GW and 833 GW of nuclear power. Electricity generation from nuclear plants under the high scenario would more than double from current levels to reach 6 560 TWh in 2030. Under the reference scenario the share of nuclear power in the world commercial primary energy supply would drop from 6% to 5% in 2030". However, it is important to stress that "nuclear power will only become more important if the governments of countries where nuclear power is acceptable play a stronger role in facilitating private investment, especially in liberalized markets and "if concerns about plant safety, nuclear waste disposal and the risk of proliferation can be solved to the satisfaction of the public". [15, p 7]

According to the document titled "Nuclear power plants in the world, edition 2008" prepared by the Atomic Energy Commission (CEA) of France, there are 439 nuclear power reactors in operation in 31 countries (or 30 if Taiwan is included as part of China), this means around 16% of the total United Nations Member States, with a net capacity of 372 182 MWe<sup>[1]</sup> and 33 nuclear power reactors under construction in 14 countries with a net capacity of 27 193 MWe<sup>[2]</sup>. During the period 1950-2007, 119 nuclear power reactors were shut down in 18 countries totalizing 35 150 MWe (net). The countries with the highest number of nuclear power reactors shut down are United States of America (USA) with 28, following by the United Kingdom (UK) with 26, Germany with 19 and France 11. From the 31 countries now operating nuclear power plants six of them, USA, France, Japan, Germany, Russia and the Republic of Korea, produce three quarters of the world nuclear electricity. However, the role of nuclear power in the overall energy sector remains very limited even in these six countries. In France, for example the country with the highest participation of nuclear energy in its energy balance in the world generated, in 2007, around 77% of its electricity with nuclear power plants, but the use of this type of energy only provides 17.5% of its final energy demand. Like most of the other countries, France remains highly dependent on fossil fuels that cover over 70% of its final energy consumption. Oil holds the lion share with 45%. None of the other five largest nuclear countries cover more than 7% of their final energy demand by nuclear power. In the specific case of the USA and Russia, the nuclear energy industry participation of both countries is less than 4%.

During 2007, three nuclear power plants were connected to the grid in India, China and Romania adding 1 852 MWe to the electric grid in these countries. Seven nuclear power reactors started their construction in 2007 totalizing 5 195 MWe. Countries involved in the construction of these 7 nuclear power reactors were China, the Republic of Korea, Russia and France. Nine new orders for the construction of nuclear power reactors were approved in China, the Republic of Korea, Japan and Russia totalizing 11 660 MWe.

During 2008 no new nuclear power reactor was connected to the grid, while three old nuclear power reactors were closed. These reactors are Hamaoka Units 1 and 2 in Japan and Bohunice Unit 3 in Slovakia. This last one was closed as condition for the entrance of Slovakia to the EU. In that year the construction of 10 new nuclear power reactors begun: 6 in China, 2 in the Republic of Korea and 2 in Russia, increasing the number of nuclear power reactors under construction from 33 in 2007 to 43 in 2008. In 2009 one new nuclear power reactor was added to the list totalizing 44 reactors under construction. In addition to what has been said in Slovakia the works for the conclusion of Mochovce Units 2 and 3 began after years of inactivity. In India two small nuclear power reactors (PHWR) should have entered in service in 2008, but they could not make it due to lack of nuclear fuels.

According to the International Energy Outlook for 2009 (IEO 2009), "electricity generation from nuclear power is projected to increase from about 2.7 trillion kWh in 2006 to 3.8 trillion kWh in 2030, as concerns about rising fossil fuel prices, energy security, and greenhouse gas emissions support the development of new nuclear generation capacity. Higher fossil fuel prices allow nuclear power to become economically competitive with generation from coal, natural gas, and liquids despite the relatively high capital and maintenance costs associated with nuclear power plants. Moreover, higher capacity utilization rates have been reported for many existing nuclear facilities, and it is anticipated that most of the older nuclear power plants in the OECD countries and non-OECD Eurasia will be granted extensions to their operating lives". [8, p 4]

## The energy situation in North America

The IAEA has foreseen that the participation of nuclear energy in the world's energy balance will drop from 16% to 8-10% in 2030, if no decision is adopted by the EU, Canada and the USA to build more nuclear power plants for electricity generation in the coming years. North America is one of the regions of the world with more nuclear power plants currently in operation. Until April 2009 there were 126 nuclear power plants in operation in the USA and in Canada. In the case of the USA, there were 104 nuclear power plants in operation in 2008.

| Country                  | Number of nuclear units connected to the grid April 2009 | Nuclear electricity generation (net million kWh) 2007 | Nuclear percentage of total electricity supply (%) 2007 |
|--------------------------|----------------------------------------------------------|-------------------------------------------------------|---------------------------------------------------------|
| United States of America | 104                                                      | 806.6                                                 | 19.4                                                    |
| Canada                   | 22                                                       | 88.2                                                  | 18                                                      |
| Total                    | 126                                                      | 894.8                                                 | -                                                       |

Source: WNA 2009.

Table 1: The production of electricity using nuclear energy in North America.

The construction of new nuclear power plants in North America, particularly in the USA, was stop after the Three Mile Island and Chernobyl nuclear accidents occurred in Pennsylvania, USA in 1979 and in Ukraine, in the former Soviet Union in 1986 respectively. The energy crisis the world is now facing, the real possibility of the extinction of the world oil reserves in the coming decades, the significantly increase in oil price in 2007 and 2008 and the negative impact in the environment due to the release to the atmosphere of a significant amount of CO<sub>2</sub> as a result of an increase in the consumption of fossil fuel in the USA and Canada, but particularly in the USA, among other relevant factors, are changing the negative perception of the public opinion in these two countries regarding the future use of nuclear energy for electricity generation.

According to public information disclose during the last presidential campaign, the USA should plan the construction of around 45 nuclear power reactors for 2030 and around 55 more after that year in order to satisfy the foreseen increase in the energy demand in the coming decades. Why the construction of new nuclear power reactors is so important for North America, but particularly for the USA? The reason is the following: North America had an aging base of nuclear and fossil fuel power plants for electricity generation. In the specific case of nuclear power plants the last unit to enter commercial operation in the USA was TVA's Watts Bar Unit 1 in June 1996, this means more than 13 years ago. The last successful order for a US commercial nuclear power plant was presented in 1973, this means 36 years ago.

The USA is a pioneer of nuclear power development. Annual nuclear electricity generation in the USA has more than tripled since 1980 reaching 780 billion kWh in 2002. In 2006 the total energy generated was 4 260 billion kWh of electricity, half of it from coal-fired plant, 19% from nuclear (809.8 billion kWh), 19% from gas and 7% from hydro. In 2007, the 104<sup>1</sup> US nuclear power reactors generated 806.5 billion kWh and achieved an average 91.8% capacity factor, which is a very high capacity factor in the nuclear energy sector. The net load factor per type of nuclear power reactor in operation in the USA in 2007 was the following: BWR, 90.4% and PWR, 92.9%. With all 104 nuclear power reactors in operation in 2008, nuclear power now accounts for 20% of total electricity generation in the USA. US annual electricity demand is projected to increase from 4 000 billion kWh in 2008 to 5 000 billion kWh in 2030, this means an increase of 25% in 22 years.

“From 2006 to 2030, the USA is expected to add 12.7 GW of capacity at newly built nuclear power plants and 3.7 GW from up rates of existing plants—offset in part by the retirement of 4.4 GW of capacity at older nuclear power plants. The increase in US nuclear capacity is attributed to policies enacted to spur nuclear power growth, as well as concerns about greenhouse gas emissions, which limit additions of coal-fired plants in the projection”. [8, p 71] Coal will continue to be the main energy source in the USA in 2030.

In Canada, electricity generation from nuclear power it is expected to increase by 1.5% per year during the period 2006-2030. Until April 2009, two nuclear power reactors are under construction with a total net capacity of 1 500 MWe, 3 nuclear power reactors planned with a total net capacity of 3 300 MWe and 6 nuclear power reactors proposed with a total net capacity of 6 600 MWe. For most of this coming decade, the construction of new nuclear power plants in Canada are

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<sup>1</sup> In 2007, 103 licensed power reactors operated at 65 plant sites in 31 States (not including the Tennessee Valley Authority's [TVA's] Browns Ferry 1, which has not operated since 1985; TVA spent about \$1.8 billion to restart the operation of this reactor in 2008.

uncertainvbased on the most recent electricity market outlooks. Accoding with the Canadian authorities the return to service of the remaining laid-up nuclear units and the completion of gas-fired power units already under construction should satisfy the foresee energy demand in the comming yeras. While market prospects for he construction of new nuclear power reactor sales in the near- to medium-term are not too promising, the refurbishment of existing units holds more promise and would avoid, at least in the medium-term, the replacement of nuclear generating capacity with fossil-fuelled plants incerasing the CO<sub>2</sub> emission to the atmosphere. However, AECL is currently working on the development of the 700 MW Advanced CANDU Reactor (ACR), and is aiming at reducing the capital cost to build this type of reactor by up to 40%. The economics of the new CANDU reactor has been ranked highly by international experts relative to other advanced nuclear power reactors and has the potential to be cost competitive with others now under development. Can not be excluded that in the comming years, the ACR technology could provide an economic incentive to replace existing nuclear power reactors as they reach the end of their service lives, as well as for some new nuclear power plants in Canada and abroad.

Summing up can be stated that in North America (USA and Canada) it is expected that the participation of nuclear energy in the energy balance in 2030 will be somehow similar to the level of participation in 2006 not exceeding 20% of the total generation of electricity of the region. The participation of the different energy sources in the energy balance of North America is shown in the following figure.

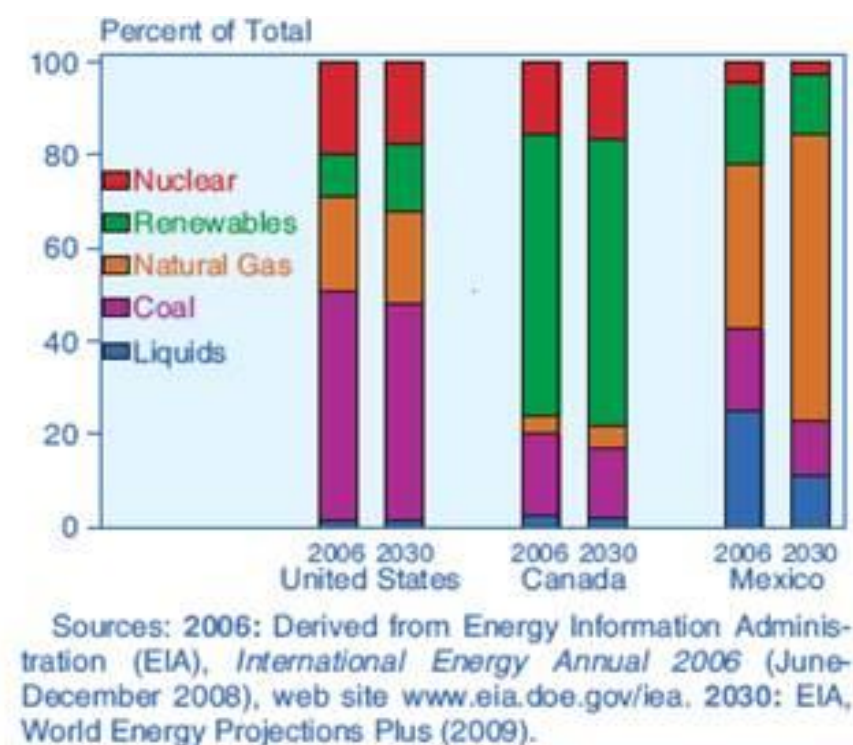


**Figure 1: Net electricity generation in OCDE North America (including Mexico) by fuel during the period 2006-2030.**

The current energy crisis that the world is now facing has pushed the government and the local energy industry in the USA and Canada to look again to the use of nuclear energy for electricity

generation. But the US local energy industry is adopting a conservative approach to see what measures and incentive the government is ready to adopt in order to encourage the participation of the energy industry in the construction of new nuclear power plants. Meanwhile, the power industry is waiting to see what the government would do next in order to avoid an energy crisis that could affect the whole North America region, particularly the USA.

## The energy situation in the European Union (EU)

Due to different reasons today's the debate about the use of nuclear energy for electricity generation started again in the European region. The first of the reason is the high price of oil reached during 2007 and 2008, and the tendency to an increment of the gas price. The second reason is the need to reduce the CO<sub>2</sub> emissions to the atmosphere due to the commitments of the EU States to the Kyoto Protocol. The third reason is the dependency of the EU to the import of fossil fuel from politically unstable regions like the Middle East. During the consideration of the role that nuclear energy should have in the energy balance in the EU in the coming years, three main realities should be taken into account. These realities are the following:

1. Expectations of the use of nuclear energy for electricity generation are rising again in several EU States. The answer to questions like 'is nuclear power economic' cannot be made using a single universal answer. As with just about everything else in life, the answer is 'it depends' — sometimes yes, sometimes no.
2. Economics comparison. Whether the use of nuclear energy for electricity generation is more economics or not than the use of other energy sources will depend on how cheap it is compared to alternative energy sources.

"Certainly, the nuclear industry can influence this issue by bringing down costs, but there are factors outside the industry's control, such as the price of natural gas or of carbon credits that will also determine, for any particular investor, whether nuclear is a cost-effective option". [11, p 45]

Currently, in the European region (including Russia and Ukraine) generates around 31% of its electricity from 197 nuclear power plants in operation in 17 countries.

| Country        | Number or reactors in operation (Until April 2009) | Net capacity MWe (2007) | Number of reactors under construction (Until April 2009) | Net capacity MWe (2007) |
|----------------|----------------------------------------------------|-------------------------|----------------------------------------------------------|-------------------------|
| Belgium        | 7                                                  | 5 824                   | -                                                        | -                       |
| Bulgaria       | 2                                                  | 1 906                   | 2                                                        | 1 906                   |
| Czech Republic | 6                                                  | 3 619                   | -                                                        | -                       |
| Finland        | 4                                                  | 2 676                   | 1                                                        | 1 600                   |
| France         | 59                                                 | 63 260                  | 1                                                        | 1 600                   |
| Germany        | 17                                                 | 20 470                  | -                                                        | -                       |
| Hungary        | 4                                                  | 1 829                   | -                                                        | -                       |

|                                          |            |                |           |               |
|------------------------------------------|------------|----------------|-----------|---------------|
| <b>Lithuania</b>                         | <b>1</b>   | <b>1 185</b>   | <b>-</b>  | <b>-</b>      |
| <b>Netherlands</b>                       | <b>1</b>   | <b>482</b>     | <b>-</b>  | <b>-</b>      |
| <b>Romania</b>                           | <b>2</b>   | <b>1 300</b>   | <b>-</b>  | <b>-</b>      |
| <b>Russian Federation</b>                | <b>31</b>  | <b>21 743</b>  | <b>8</b>  | <b>5 980</b>  |
| <b>Slovakian Republic <sup>(1)</sup></b> | <b>5</b>   | <b>2 034</b>   | <b>-</b>  | <b>-</b>      |
| <b>Slovenia</b>                          | <b>1</b>   | <b>666</b>     | <b>-</b>  | <b>-</b>      |
| <b>Spain</b>                             | <b>8</b>   | <b>7 450</b>   | <b>-</b>  | <b>-</b>      |
| <b>Sweden</b>                            | <b>10</b>  | <b>9 014</b>   | <b>-</b>  | <b>-</b>      |
| <b>Switzerland</b>                       | <b>5</b>   | <b>3 220</b>   | <b>-</b>  | <b>-</b>      |
| <b>Ukraine</b>                           | <b>15</b>  | <b>13 107</b>  | <b>2</b>  | <b>1900</b>   |
| <b>United Kingdom</b>                    | <b>19</b>  | <b>10 222</b>  | <b>-</b>  | <b>-</b>      |
| <b>Total</b>                             | <b>197</b> | <b>170,007</b> | <b>14</b> | <b>12 986</b> |

**Note (1):** In 2007, the Slovakian government decided to continue the construction of Units 3 and 4 at Mochovce.  
**Source:** WNA and CEA 8th Edition, 2008.

**Table 2: Nuclear power reactors in operation and under construction in the European region.**

According to some expert's opinion, and based on the commitments adopted by the EU regarding the Kyoto Protocol, the above-mentioned proportion should be maintained or increased in order to meet the 2020 target, with an increase in the actual wattage generated by the use of nuclear energy to meet increasing power demand. "It is a fact that nuclear energy is already making a substantial contribution to an energy policy that is low carbon, cost-effective and that provides assured supply. At present, nuclear supplies almost one third of Europe's electricity, produces very low CO<sub>2</sub> emissions calculated over the entire fuel cycle (comparable to wind energy), and has a quasi 'indigenous' character, i.e., it can rely on a complete European nuclear fuel cycle. In addition, it contributes to the stabilization of electricity prices, owing to the favorable ratio of primary investment costs to fuel costs". [4, p 49]

Today a strong debate is happening among the oldest and most industrialized EU Member States, which do not want slower growth, and are beginning to view nuclear energy as a real alternative to the current energy crisis. The increase in the oil price occurred in 2007 and 2008 changed the minds of people in the European region who turned against nuclear power after the Chernobyl nuclear accident. Although less pronounced than in other parts of the world, energy and electricity consumption in the EU are expected to continue increasing over the foreseeable future, at least until 2030, and most likely beyond. At the same time, energy resources are becoming ever scarcer and more expensive, and excessive emissions of the greenhouse gas CO<sub>2</sub> to the atmosphere are driving the impending threat of climate change.

There is an urgent need for investment in the energy sector in many countries with the purpose to satisfy the growing demands of electricity in the coming years. "In Europe alone, to meet expected energy demand and to replace ageing infrastructure, investments of around one trillion Euros will be needed over the next 20 years". [1, p 3] At the same time, the European energy balance should include all available energy technology, including nuclear energy. For this reason, there should be no doubts that nuclear energy would contribute to alleviate energy supply dependency, local air pollution and global climate change. In 2004, the nuclear share of electricity production in the EU reached 31%, which represents a 'non-emission' to the atmosphere of nearly

900 million tones of CO<sub>2</sub> per year. This represents almost the quantity of carbon dioxide produced annually by the transport sector.

There are other reasons why nuclear energy should be included in the EU energy balance in the future. One of the reasons is the following: Unless the EU "make domestic energy more competitive in the next 20 to 30 years, around 70% of the EU energy requirements, compared with 50% today, will be met by imports products some from regions threatened by insecurity". [1, p 3] If the EU does not increase the nuclear share in the coming years, then it is expected that the EU energy dependence would increase up to 60%-70% or even more by 2030, the reliance on imports of gas is expected to increase from 57% to 84% and reliance on imports of oil is expected to increase from 82% to 93%. The EU is consuming more and more energy and importing more and more energy products in order to satisfy it increase energy needs. External dependence for energy is constantly increasing and this situation is considered by many politicians and experts very danger from the political and economical point of view. If no measures are taken, in the next 20 to 30 years, 70% or more of the EU energy requirements will be covered by energy imported from outside the European region.

In the other hand if the EU current energy policy does not change in the coming years, which is something very difficult not to happen, then the major reduction in the use of nuclear energy for electricity production will occur in the EU. There should be no doubt that this situation would have a negative impact in the energy sector of several countries. However, the recently announcement of the UK government to built up to 10 new nuclear power rectors in the coming years and the decisions adopted by France, Finland, Bulgaria, Romania and the Czech Republic, among others, to built new nuclear power reactors in the future or to reintroduce the use of nuclear energy for electricity generation or the intention of some EU governments to change previous phase out policy adopted by them, will have a positive impact in the current situation of the energy sector within the EU, particularly regarding the use of nuclear energy for electricity generation.

## **The energy situation in Asia**

In Asia the situation regarding the use of nuclear energy for electricity generation is completely different from the situation in the EU and in North America. The major increase in nuclear energy capacities for electricity generation in the near future are foresee in China <sup>[3]</sup>, Japan, India and the Republic of Korea. It is expected that these four countries, plus the USA and Russia, will have around two-third of the world nuclear energy capacity in 2030, an increase of 16%-17% from the current level <sup>[4]</sup>.

Nuclear power is an industry still in crisis in the West, due to the panic produced by the nuclear accidents at Three Mile Island and Chernobyl, the concern of the public opinion about the management of the high radioactive nuclear waste and because of the multi-billion-dollar cost overruns that have plagued nuclear-energy projects throughout Europe and the USA. But if the nuclear-energy genie is dying in the West, it has being reborn in Asia. The booming, fuel-hungry nations across the region are ordering and building nuclear plants at a rate not seen in decades. Why this boom in the construction of new nuclear power reactors in Asia? Asian leaders say they have no choice but to use nuclear energy for the production of electricity due to the explosive rate at which the demand for energy is growing in several countries. According with the IAEA projections power demands in Asia will triple by 2015.

In Asia, they are 103 nuclear power reactors in operation in six countries, including Taiwan. China and India alone have 17 nuclear power reactors under construction and have plans to construct 128 new nuclear power reactors in order to elevate the proportion of nuclear energy in the generation of electricity in both countries. In the case of China <sup>[5]</sup> the new nuclear power plants planned and proposed is 103, for the time being the biggest nuclear power programme in the world. The situation regarding the number of nuclear power reactors in operation and under construction in Asia is shown in the following table.

| Country      | Power reactors in operation<br>(Until April 2009) | Power reactors under construction<br>(Until April 2009) | Power reactors planned or proposed<br>(Until April 2009) |
|--------------|---------------------------------------------------|---------------------------------------------------------|----------------------------------------------------------|
| Australia    | -                                                 | -                                                       | -                                                        |
| Bangladesh   | -                                                 | -                                                       | -                                                        |
| China*       | 11 (6)                                            | 11 (2)                                                  | 103                                                      |
| India        | 17                                                | 6                                                       | 25                                                       |
| Indonesia    | -                                                 | -                                                       | 6                                                        |
| Japan        | 53                                                | 2                                                       | 14                                                       |
| S. Korea     | 20                                                | 5                                                       | 5                                                        |
| N. Korea     | -                                                 | -                                                       | 1                                                        |
| Malaysia     | -                                                 | -                                                       | -                                                        |
| Pakistan     | 2                                                 | 1                                                       | 4                                                        |
| Philippines  | -                                                 | -                                                       | -                                                        |
| Thailand     | -                                                 | -                                                       | 6                                                        |
| Vietnam      | -                                                 | -                                                       | 10                                                       |
| <b>Total</b> | <b>103</b>                                        | <b>25</b>                                               | <b>174</b>                                               |

Note: \*Including 6 nuclear power reactors operating and 2 under construction in Taiwan.

Source: WNA and CEA, 8th 2008 Edition, 2008.

**Table 3: Nuclear power in Asia.**

There should be no doubt that 2006 and 2007 were years of increasing activities in the field of nuclear power in the Asian region. Asia is the only region in the world where electricity generating capacity and specifically nuclear power is growing significantly. Important plans for the expansion of current nuclear power programmes were announced by some countries in Asia, while others are considering plans for the introduction of nuclear power programmes for the first time in the future.

“In contrast with North America and most of Western Europe where growth in electricity generating capacity and particularly nuclear power leveled out for many years, a number of countries in the Asia region, particularly in the East and South Asia sub-region, are planning and building new nuclear power reactors to meet their increasing demands for electricity”. [3, p 1] The countries that have announced plans for significant expansion in the use of nuclear energy for electricity generation are the following: China, India, Japan, Pakistan and the Republic of Korea. Other countries such as Indonesia, Vietnam, Bangladesh and the Democratic People Republic of Korea have plans for the introduction of nuclear energy for electricity generation in the coming years.

Asia produced in 2007 a total net of 5 546 GWh of electricity out of which 523 GWh came from nuclear energy representing 9.4 % of the total electricity produced in the region by all energy sources. The Southeast Asian economies, themselves beneficiaries of an oil and gas export bonanza through the 1970s-1990s, also find themselves in an energy crunch as once ample reserves run down

and the search is on for new and cleaner energy supplies. For this reason, regional leaders at the 13th ASEAN Summit meeting held in Singapore in November 2007 issued a statement promoting the use of nuclear energy for electricity generation alongside renewable and alternative energy sources in the future.

According to the IAEA and CEA information, there are currently 103 nuclear power reactors operating in six countries of the region, including Taiwan, 25 units under construction in six countries and plans to build about another 174 units in the coming years. In addition, there are about 56 research reactors in 13 countries of the region. The only two major Pacific Rim countries without any research reactor in operation are Singapore and New Zealand.

Until 2010 the projected new generating capacity in Asia is around 38 GWe per year. For the period 2010 to 2020 the projected new generating capacity is 56 GWe. Much of the growth foresees will be in China, Japan, India and the Republic of Korea. The nuclear share in the region in 2020 is expected to be at least 39 GWe and perhaps more if environmental constraints adopted by the international community limit fossil fuel expansion. "The largest increase in installed nuclear generating capacity is expected in non-OECD Asia, where annual increases in nuclear capacity average 6.3% and account for 68% of the total projected increase in nuclear power capacity for the non-OECD region as a whole. Of the 58 GWe of additional installed nuclear generating capacity projected for non-OECD Asia between 2004 and 2030, 36 GWe is projected for China and 17 GWe for India". [7, p 4] In the other hand, "China, non-OECD Asia's largest economy, is expected to continue playing a major role on both the supply and demand sides of the global economy. IEO 2007 projects an average annual growth rate of approximately 6.5% for China's economy over the period 2004 to 2030. The country's economic growth is expected to be the highest in the world. India is another Asian country with a rapidly emerging economy. Average annual GDP growth in India over the 2004 to 2030 projection period is 5.7%. In the rest of non-OECD Asia, economic activity has remained robust, with exports increasing in response to a rebound in global demand for high-technology products and stronger import demand from China. Over the medium term, national economic growth rates in the region are expected to be roughly constant over the period 2004 to 2015, before tapering off gradually to an average of 4.3% per year from 2015 to 2030 as labor force growth rates decline and economies mature". [7, pp 11 and 12]

To satisfy the foresee increase in the energy demand, it is expected that nuclear power plants continuing to play an important role within the energy balance of several Asian countries. For new nuclear power plants constructions in the Asian region, however, the economic competitiveness of nuclear power plants will depends on the different energy alternatives available, on the overall electricity demand in a particular country and how fast it is growing, on the market structure and investment environment, on environmental constraints and on investment risks due to possible political and regulatory delays, among others. Thus, economic competitiveness is not the same in all countries and it depends on the countries and on specific situations. For example, in Japan and the Republic of Korea, the relatively high cost of using energy alternatives benefits nuclear power's competitiveness. In other countries such as India and China, "rapidly growing energy needs encourage the development of all energy options". [13, p 10]

There are different motivations which drove nuclear power developments in different periods in Asia. Three periods can be identified in which different motivations drove nuclear power programmes in the region. These are:

1. The US Atoms for Peace initiative in the 1950's.
2. The oil crisis of the 1970's.
3. The economic growth and need for energy in the 1990's.

There are several forces that have limited the use of nuclear energy for electricity generation in Asia. These are the following:

- a) Response to the Three Mile Island nuclear incident.
- b) The Indian nuclear explosion in 1974.
- c) Restraints on international nuclear cooperation by supplier States.
- d) The Chernobyl nuclear accident.

Looking ahead, there are six countervailing political movements that might impact nuclear power's future in Asia. First is the concern for global warming which might promote the use of nuclear energy for electricity generation. Second is the growing public distrust of nuclear safety which reduces support for the use of this type of energy for electricity generation. Third is the disposal of high nuclear waste and the lack of a final disposal location for the disposal of this type of waste in the region. Fourth is the high capital cost involved in the construction of a nuclear power plant, despite of the reduction in the construction time achieved by Japan. Fifth the increase use of nuclear energy for electricity production in Asia will depend of the availability of new generation of nuclear power reactors. Sixth is the so-called proliferation risk that is involved in the use of nuclear energy for electricity generation, particularly if the country decided to develop its nuclear fuel cycle.

## **The energy situation in Latin America**

In the case of Latin America higher world market prices for fossil fuels, the reduction of the current world fossil fuels reserves and the climate changes affecting all countries in the region, have put the use of nuclear energy for electricity generation again on the agenda of many Latin American countries such as Chile, Ecuador Peru, Uruguay and Venezuela without nuclear power programmes and had revived interest in Argentina, Brazil and Mexico, the only three Latin American countries operating nuclear power reactors in the region, in the expansion of their nuclear power programmes. It is important to note that in general the use of nuclear energy for electricity generation in Latin American region is very low. In 2007 only 3.1% of the electricity generated in the region comes from nuclear energy sources. The total production of electricity using nuclear energy in the Latin American region in 2007 reached the amount of 28 350 GWe. However, if expansion plans approved by Argentina, Brazil and Mexico are implemented, and the intention of Chile, Ecuador, Peru Uruguay and Venezuela of constructing new nuclear power reactors are materialized in the near future, then that proportion could be more than double in a decade.

Until April 2009 there were 6 nuclear power reactors operating in three countries of the region, two in Argentina, two in Brazil and two in Mexico. There are plans for the conclusion of the construction of one nuclear power reactor in Argentina (Atucha 2) with a net capacity of 692 MWe and for the construction of 2 new nuclear power reactors with a net capacity of 1 480 MWe. In the case of Brazil there are plans for the conclusion of the construction of one nuclear power reactor (Angra 2) and for the construction of 5 new nuclear power reactors with a total net capacity of 5 245

MWe. Mexico has plans for the construction of two nuclear power reactors with a total net capacity of 2 000 MWe.

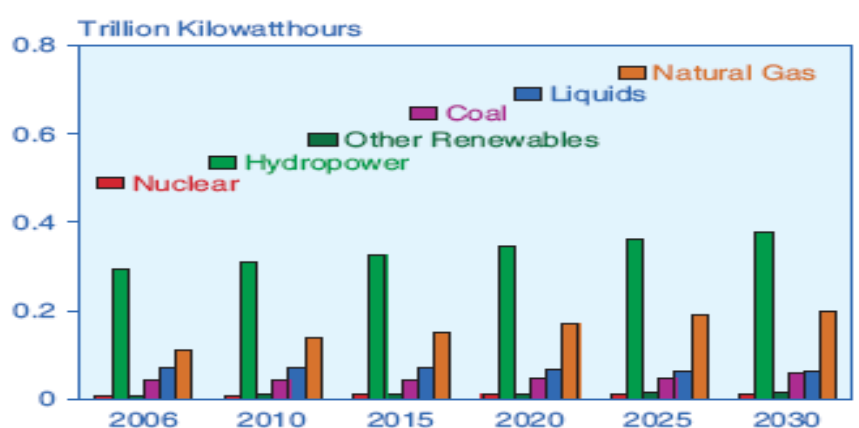
The total production of electricity using nuclear energy in the Latin American region in 2007 reached the amount of 28 350 GWe. However, if expansion plans approved by Argentina, Brazil and Mexico are implemented, and the intention of Chile, Ecuador, Peru, Venezuela and Uruguay of constructing new nuclear power plants are materialized in the near future, then that proportion could be more than double in a decade.

| Country   | Number of reactors (Until April 2009) | Net Capacity (MWe) (2007) | Energy Production 2007 Million of (kWh) | Nuclear share (%) (2007) | Net Load Factor 2007 (%) (2007) (Until April 2009) | Number of Reactors Under Construction (Until April 2009) | Number of Reactors Planned and Proposed (Until April 2009) |
|-----------|---------------------------------------|---------------------------|-----------------------------------------|--------------------------|----------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------|
| Argentina | 2                                     | 935                       | 6.7                                     | 6.2                      | 82.1                                               | 1                                                        | 2                                                          |
| Brazil    | 2                                     | 1 795                     | 11.7                                    | 2.8                      | 74.1                                               | 1                                                        | 5                                                          |
| Mexico    | 2                                     | 1 360                     | 9.95                                    | 4.6                      | 83.5                                               | -                                                        | 2                                                          |
| Total     | 6                                     | 4 090                     | 28.35                                   | -                        | -                                                  | 2                                                        | 9                                                          |

Source: WNA and CEA 8th Edition, 2008.

Table 4: The information on the nuclear power programme in Latin America.

The potential use of nuclear energy for electricity production in some countries in the Latin American region is an option that cannot be excluded from any future energy balance study to be carried out by them [6]. The purpose of these studies is to find the most adequate energy mix balance in order to satisfy the future increase in electricity demand in some Latin American countries the most efficiency manner. Renewable energy sources available in the region are not enough to satisfy the foresee increase in the energy demand. The net electricity generation projections in South and Central America by fuel until 2030 are shown in the following figure.



Sources: 2006: Derived from Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site [www.eia.doe.gov/iea](http://www.eia.doe.gov/iea). Projections: EIA, *World Energy Projections Plus* (2009).

Figure 2: Net electricity generation in South and Central America by fuel during the period 2006-2030.

From the above figure can be confirmed that the projections of the use of nuclear energy for electricity generation until 2030 will continue to be very small, despite of the expansion plans in the use of this type of energy adopted or under consideration in some Latin American countries. Hydropower will continue to be the dominant energy sources for the production of electricity.

## **The energy situation in Africa and the Middle East**

Elsewhere in Africa, electricity production is unacceptably low. Of the 53 African countries, only a limited number have large energy potential. "Hydropower potential is the most evenly spread, but the highest concentration is on the Congo River. Oil and gas are mostly concentrated in Algeria, Nigeria, and Libya; coal is mostly found in southern Africa; and geothermal potential exists in eastern Africa. Together with South Africa, the Maghreb countries (Morocco, Algeria, Tunisia, Libya, and Mauritania) account for more than 80% of Africa's electricity generating capacity. As a result, in the absence of adequate trans-African resource-sharing arrangements and infrastructure, many African countries suffer from scarce energy resources and must pay high prices to import energy. [10, p 1]

Until 2008, there are only two nuclear power reactors in operation in one African country: South Africa. These are Koeberg-1 and Koeberg- 2. Koeberg-1 started operation in 1984 and Koeberg-2 in 1985. Both nuclear power reactors have a net capacity of are 900 MWe and are PWR type of reactors. Based on this information it can be stated that nuclear power is today only a very small part of Africa's energy supply, but its contribution could grow in the future if plans to use nuclear energy for the generation of electricity are approved and implemented by Algeria, Egypt, Morocco, Namibia and Nigeria. The governments of these countries are seriously considering the use of nuclear energy for the production of electricity in the future. In the near term for the use of nuclear energy for the production of electricity in Africa, would be necessary to bridge the gap between the economies of scale that favor large nuclear power plants and the smaller electrical grids and capital capabilities of many African countries. To understand the possibilities in the use of nuclear energy for electricity generation in Africa the following question need to be answered: Which are the real possibilities to use nuclear energy for the production of electricity in the African region in the near future? These possibilities are associated with the solution, among others, of the following important matters:

1. The use of small and medium-size nuclear power reactor designs that should be available in the market in the short term.
2. The integration of electricity grids among neighboring countries.
3. The lack of technological development of many African countries
4. The safety of the operation of the nuclear power plants.
5. The management of the spent nuclear fuel.
6. The political instability in some African countries, the interstates conflicts and ethnic strife <sup>[7]</sup>.
7. The lack of resources to finance the construction of a nuclear power plant.
8. The lack of well-trained professionals and technicians in the use of nuclear energy for the generation of electricity.

The attitudes of African decision makers, experts and public about nuclear power range from negative/cautious to positive/enthusiastic. Supporters perceive nuclear power as a "silver bullet" that would allow the continent to demonstrate both technical progress and competence. The search for cleaner energy sources such as nuclear is also motivated by widespread concern that Africa is more vulnerable than other regions to climate change. Some of the serious consequences of climate change in Africa could include desertification, food shortages, epidemics, insufficient water supply, coastal erosion, and increased refugees. It is important to note that from the 436 nuclear power reactors operating around the world in 2009 just two are located in Africa; this means only 0.46% of the total. Of the 44 nuclear power reactors under construction around the world in 2009 none of them is located in Africa. However, from a handful of promising new nuclear power reactor designs now reaching the prototype stage in the world, an important one is the South Africa's Pebble Bed Modular Reactor (PBMR). This type of nuclear reactor could represent an acceptable solution regarding the type of reactor to be used not only in South Africa, but in other African countries as well. The net electricity generation projection in Africa by fuel until 2030 is shown in the following figure.

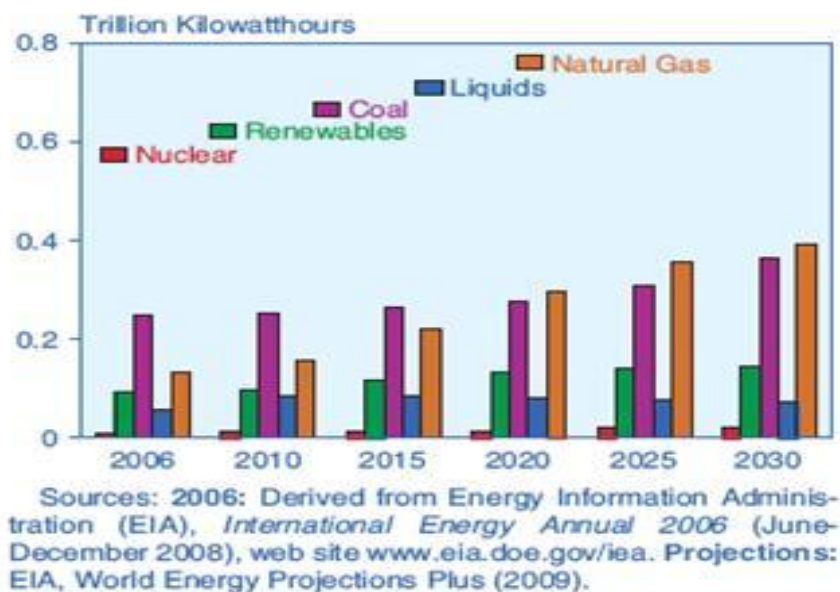


**Figure 3: Net electricity generation projection in Africa by fuel until 2030.**

As can be easily seen from the above figure, coal and natural gas are the two main sources of energy for the generation of electricity in Africa. Renewables are the third source of energy in the region. This situation is expected to be maintained until 2030.

Based on the above projection, the main questions to be answered are the following: Which is the future role to be played by nuclear energy for the generation of electricity in Africa, and what possible technological and policy adjustments need to be introduced to the current trends in nuclear power development in order to respond to the needs of African countries? Might the PBMR or some other innovative new nuclear power reactor designs be able to represent a technological opportunity for Africa, i.e. an opportunity to move directly to the next generation of nuclear power reactor technology without repeating all the intermediate steps travelled by industrialized countries with long-established nuclear power programmes? It is well known that economies of scale argue

for larger and larger nuclear power plants. At the same time the greater the number of nuclear power reactors to be in operation the lower is the per kilowatt-hour cost of the infrastructure built. However, economies of scale are only valuable where the capital and electricity demand exist to take full advantage of them and this is something that in many countries of Africa does not exist. Then, what are the options available? For these countries, there are at least two routes by which a nuclear power plant might become part of a least-cost energy strategy. These routes are the following: First is the use of small or medium-size reactors (SMRs) for the generation of electricity and the second is the integration of electricity grids among neighboring countries, this means the regionalization of electricity grids.

There should be no doubt that the use of nuclear energy for the production of electricity in Africa will be a reality at least in some of the most advanced African countries in the middle-long term if small and medium size reactors will be available in the market and the regionalization of the electric grid can be materialized.

Until April 2009 there were no nuclear power reactors operating in the Middle East and natural gas and oil are the dominant sources of energy for the production of electricity in the region. As can be easily seen from the below figure the projection of the participation of nuclear energy in the generation of electricity in the Middle East will continue to be very marginal in 2030, despite of the intention of some countries of the region to use nuclear energy for the production of electricity. However, it is important to stress that the great instability that exist in the region is an important obstacles for the introduction of a nuclear power programme in any Middle East country in the near future. The world energy projection for the Middle East place natural gas as the dominant energy source in the energy balance of the region for 2010, 2020 and 2030.

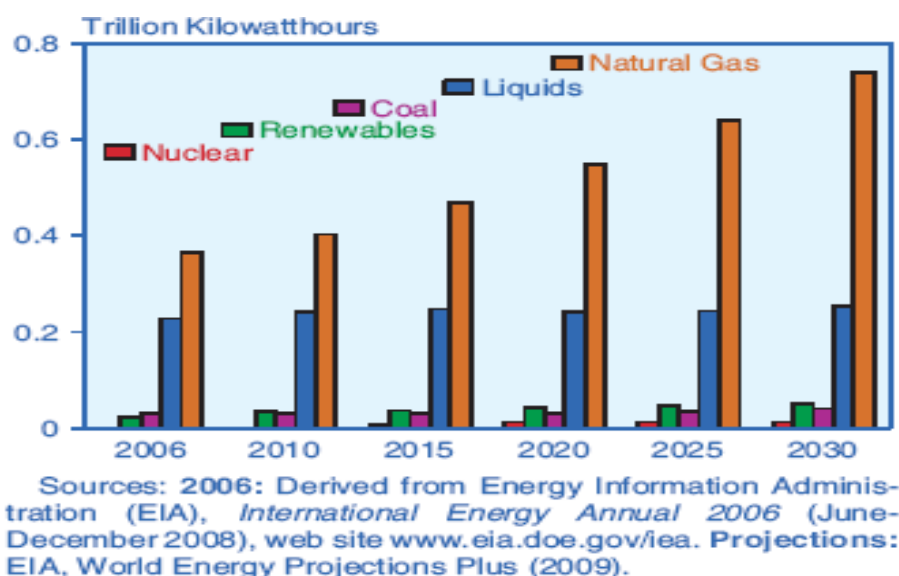


Figure 4: Net electricity generation in the Middle East by fuel during the period 2006-2030.

Summing up can be stated the following: The situation regarding the number of nuclear power plants in operation and under construction by region in 2009 is the following: In Asia the number of nuclear power plants in operation is 103 in five countries (if Taiwan is included within China) with a

net capacity of 76 718 MWe and there are 25 nuclear power reactors under construction in 5 countries, with a net capacity of 21 921 MWe. The European region there are 197 operating nuclear power reactors in 18 countries with a net capacity of 170 007 MWe and 14 nuclear power reactors under construction in 5 countries with a net capacity of 12 986 MWe.

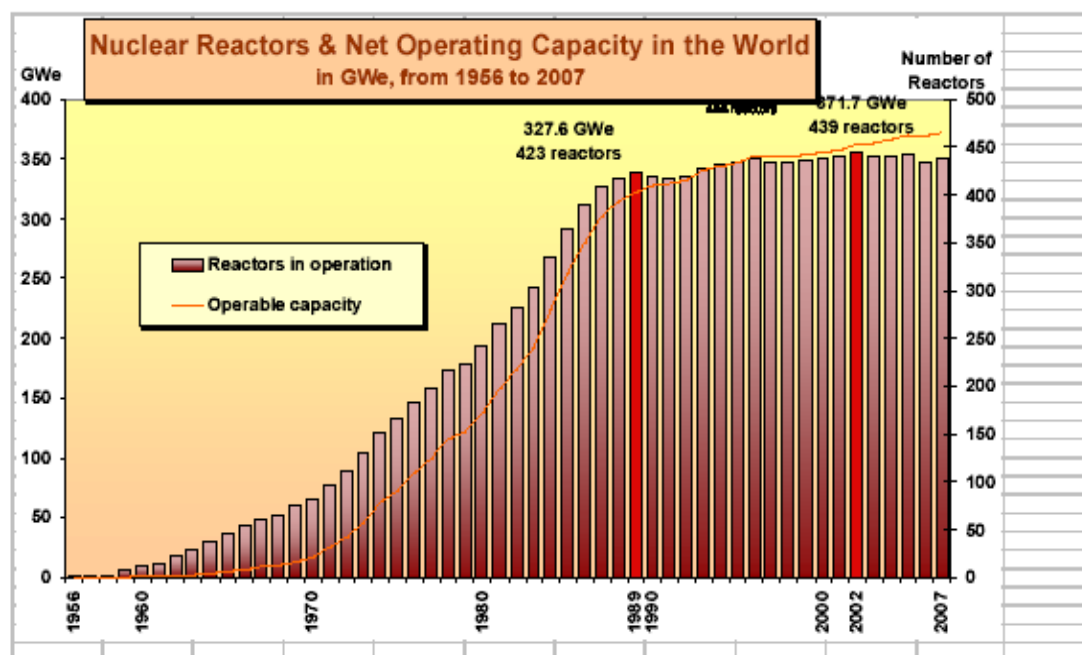
In the following table the evolution of nuclear power plants capacities connected to the grid during the period 1970 to 2007 is shown.

| Year  | Number of countries | Units | MWe     |
|-------|---------------------|-------|---------|
| 1970  | 14                  | 81    | 16 202  |
| 1980  | 24                  | 243   | 136 164 |
| 1990  | 30                  | 419   | 325 854 |
| 2000  | 31                  | 436   | 351 550 |
| 2007  | 31                  | 439   | 372 182 |
| 20091 | 31                  | 436   | 372 203 |

Note: The data for 2009 is until April.

Source: CEA 8th edition, 2008 and IAEA data information.

Table 5: Evolution of nuclear power plants capacities connected to the grid during the period 1970 to 2007.

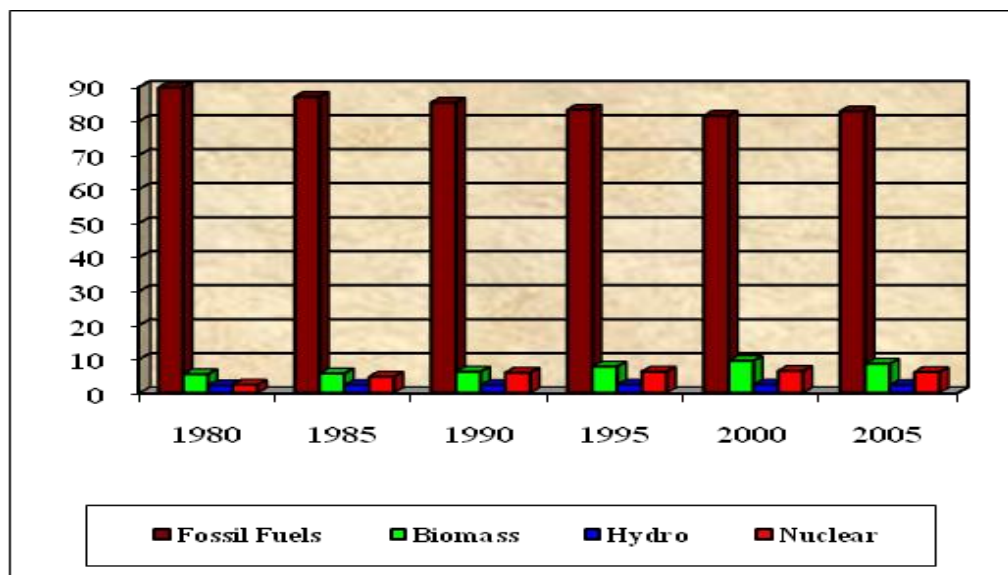


Source: IAEA SIPRIS, 2007.

Figure 5: Nuclear power reactors in operation and net operating capacity in the world from 1956 to 2007.

As can be clearly see in the above table the major increase in the construction of nuclear power plants occurred in the 1970s, 1980s and 1990s. The increase in the number of nuclear power plants constructed from 1970s to 1980s jump from 81 to 243, this means an increase of 200%. From 1980s to 1990s the number of nuclear power plants constructed increased from 243 to 419, this means an increase of 72%. However, in the last 17 years the number of nuclear power plants constructed was only 20, this means a modest increase of 5%.

The world energy used by fuel type during the period 1980-2005 is shown in Figure 6. In this figure it is easy to see that fossil fuels are the dominant type of energy in the last 25 years. During this period a small progress in the use of the other types of available energy was achieved [8]. However, there is a great difference between the use of fossil fuels and renewable energies for the production of electricity during the abovementioned period. The contribution of nuclear energy for the electricity generation is third after biomass.



Source: IAEA data, 2007.

Figure 6: World energy used by fuel type 1980-2005.

The following table includes information on the level of participation of the different types of energy in the generation of electricity by region.

| Region        | Thermal  |       | Hydro    |       | Nuclear  |       | Renewables |      | Total    |     |
|---------------|----------|-------|----------|-------|----------|-------|------------|------|----------|-----|
|               | Use (EJ) | %     | Use (EJ) | %     | Use (EJ) | %     | Use (EJ)   | %    | Use (EJ) | %   |
| North America | 22.21    | 65.71 | 2.43     | 14.53 | 9.61     | 18.99 | 0.73       | 0.77 | 34.98    | 100 |
| Europe        | 32.92    | 67.02 | 2.84     | 5.82  | 12.71    | 26.03 | 0.55       | 1.13 | 49.02    | 100 |
| Asia          | 52.84    | 84.70 | 2.94     | 4.72  | 5.90     | 9.46  | 0.70       | 1.12 | 62.38    | 100 |
| Latin America | 4.42     | 38.28 | 2.46     | 58.31 | 0.33     | 2.61  | 0.32       | 0.81 | 7.54     | 100 |
| Africa        | 4.89     | 80.01 | 0.35     | 17.74 | 0.11     | 1.84  | 0.04       | 0.41 | 5.4      | 100 |
| World total   | 117.28   | 73.66 | 11.02    | 6.92  | 28.66    | 18    | 2.24       | 1.42 | 159.22   | 100 |

Note: One EJ =  $2.78 \times 10^5$  GW/h or 31.7 GW/a.

Source: IAEA.

Table 6: Level of participation of the different types of energies in the generation of electricity by region in 2006.

From the Table 6 can be concluded that the contribution of nuclear energy to total electricity generation varies considerably among region. In Europe, nuclear generated electricity accounts for 26.03% of the total electricity produced. In North America it is approximately 19%, whereas in

Africa and Latin America it is 1.84% and 2.61% respectively. In Asia, nuclear energy accounts for 9.46% of electricity generation. It is not difficult to conclude that the use of nuclear energy for electricity generation is concentrated in technologically advanced countries.

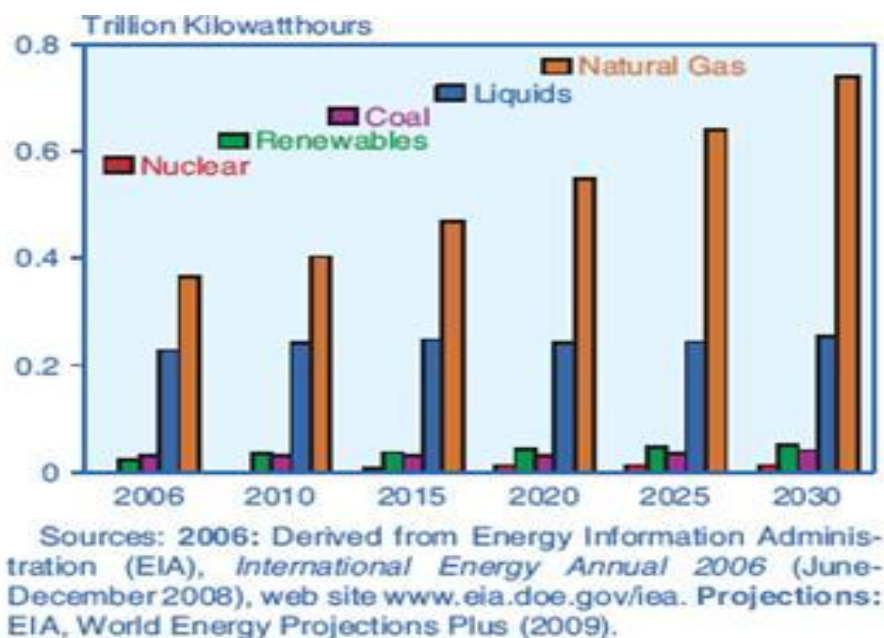
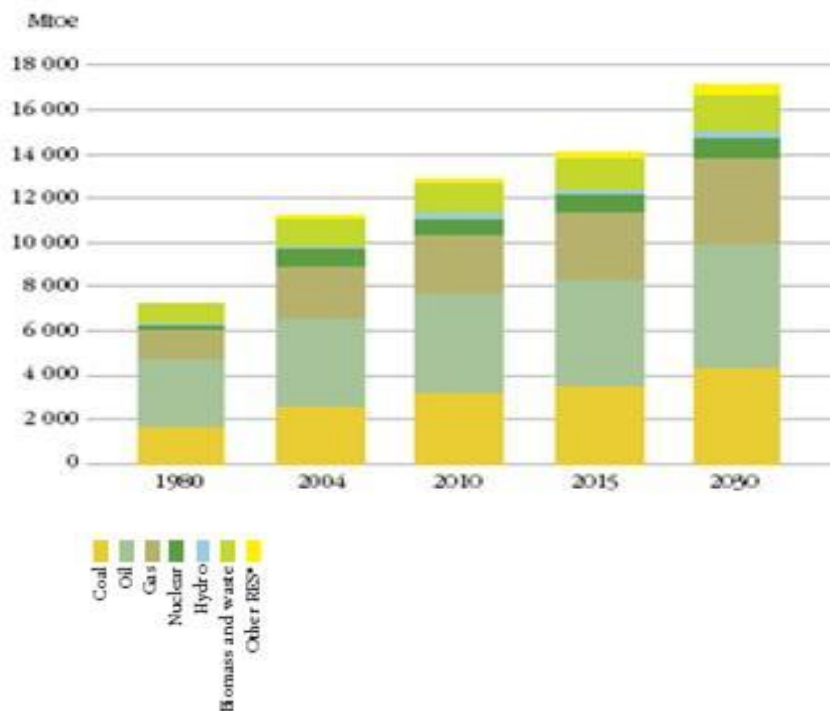


Figure 7: Net electricity generation in the Middle East by fuel during the period 2006-2030.

Based on the information included in the above paragraphs it is easy to conclude the following:

1. Europe remained the largest nuclear energy user for electricity generation among all regions since 1980.
2. North America was the second largest user of nuclear energy for electricity production since 1980.
3. With the largest regional population and fast growing economies, Asia became the third largest nuclear energy user for electricity production since 1980.
4. Latin America registered almost the same growth in its nuclear energy use for electricity generation since 1980. Its share remained more or less unchanged between 2.61% to 3.1%.
5. Africa is the region with the smallest nuclear share since 1980.

In the following figures the world primary energy demand evolution during the period 1980-2030 and the world net electricity generation from nuclear power by region during the period 2006-2030 are included,



Source: World Energy Outlook 2006.

Figure 8: Foreseen EU-27 energy import dependence up to 2030.

From the above figure can be stated that the EU will continuing to depend on the import of oil and gas to ensure its economic and social development until 2030.

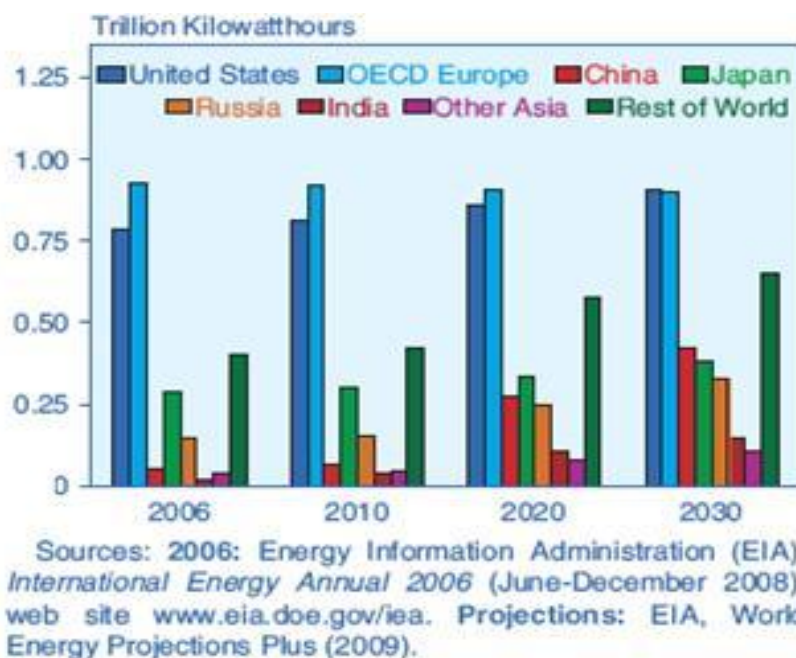


Figure 9: World net electricity generation from nuclear power by region during the period 2006-2030.

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## Limiting factors

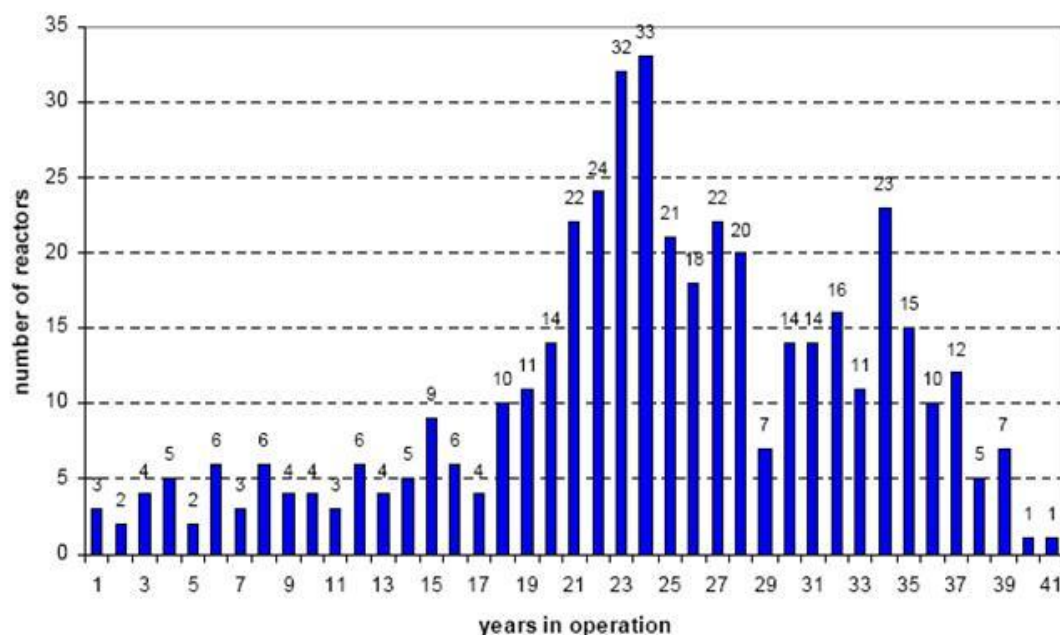
If nuclear energy will be an important component of the energy balance in the non-OECD Asia region in the coming years, then why the use of this type of energy cannot play the same role in other regions as well. The reason is the following: There are a number of limiting factors that are making difficult that the nuclear energy increase significantly its role in the energy balance in other regions now and in the future. These limiting factors are, among others, the following [\[9\]](#):

1. "Management of the radioactive waste, particularly high level nuclear waste.
2. Proliferation security.
3. Operational safety of the nuclear power plants.
4. Economic competitiveness.
5. Public acceptance". [12, pp 57 and 58]

### ***Management of the radioactive waste***

Management of the radioactive waste, particularly high-level nuclear waste, is an unresolved problem for many people in different countries all over the world. However, the technology for the safe management of nuclear waste is now available and can be used by any countries with an important nuclear power programme. The USA and Sweden have achieved some progress regarding the final disposal of high radioactive nuclear waste and the technology used by these countries could represents a real and objective solution to this problem for other countries as well.

Another problem that several countries have to deal with in the coming years, particularly in the case of North America and Europe, is the increase ageing power-generation capacity, particularly in the field of electricity generation using nuclear energy. To overcome this problem both regions have an urgent need for major investment in the energy power sector in order to meet the expected energy demand and at the same time the replacement of ageing energy infrastructures. According to the EC, "around 800-900 GWe capacity will be required by 2030 to replace the existing capacity and to address increasing needs. It is reasonable to assume that out of these potential new 800-900 GWe, at least 100 GWe will be produced by Generation-III nuclear power reactors. This corresponds to the construction of 60 to 70 big nuclear power reactors and represents an investment of €150 billion over 20 years (for an average overnight construction cost of €1,500 per kWe). The new reactors should be designed to operate 60 years". [18, p 20]



Source: IAEA document GC (52)/INF/6, 2008.

Figure 10: Number of nuclear power plants in operation in the world by age as January 2008.

From the above figure can be single out that the number of nuclear power reactors currently in operation in the world with more than 20 years connected to the grid is 342, representing 78.4% of the total nuclear power reactors operating in the world until April 2009. For this reason the age of the nuclear power reactors now operating in the world is one of the urgent problems that need to be faced by those countries operating these reactors. The decision to be taken by the governments of these countries is: a) Extend the lifetime of the nuclear power reactors or b) Initiate the process of shut down and decommissioning of these reactors. Taking into account the current energy situation in the world it is expected that the majority of the States will decide to extend the lifetime of these reactors to satisfy the foresee increase in the demand of energy in the coming years.

It is foreseen that in the longer term a new generation of nuclear power reactors, the Generation-IV system will be commercial available once they have reached technical maturity and met sustainable development criteria, particularly those pertaining to waste management and preservation of energy resources. For this reason, commercial deployment of such systems is not expected to occur before 2040. It is important to single out that Generation IV reactors “would be much smaller in size (100 MW to 200 MW) and capital investment, represent a more flexible solution due to much shorter building times and a lower potential risk due to smaller radioactive inventories and passive safety features” [15, p 15]. Based on what has been said before, it is important to single out that the international community should be aware that each of the three generations of nuclear power reactors will coexist during the 21st century. All of these types of nuclear power reactors face specific technological challenges to be overcome on the path to sustainability, but all share the common goal of guaranteeing the highest level of safety.

***Proliferation risk***

Nuclear power entails potential proliferation risk, particularly for the possible misuse of nuclear technology, facilities or materials as a precursor to the production of a nuclear weapon. Due to this undisputed fact, it is extremely important to be aware that the future use of nuclear energy for electricity generation in several countries, will depend of the production of new type of nuclear power reactors that are proliferation risk-free. Nuclear power should be expanded in the world if the risk of proliferation from operation of the commercial nuclear fuel cycle associated with the introduction of a nuclear power programme is made acceptably small. How to achieve this goal? First the international community should strengthen the application of the IAEA safeguards system to all States, by putting into force for all of them the IAEA Additional Protocol. Second the international community should adopt a multilateral approach to the nuclear fuel cycle and must adopt all necessary measures to prevent the acquisition of weapons-usable material, either by diversion (in the case of plutonium) or by misuse of fuel cycle facilities (including related facilities, such as research reactors or hot cells) now operating in different countries. However, the adoption of a multilateral approach to the nuclear fuel cycle should be done in a way that respect the right of any States to develop their own nuclear fuel cycle in case of any political discrimination against the country in their access to the necessary services associated with the nuclear fuel cycle. In this case States must submit all facilities associated with its nuclear fuel cycle to full scope IAEA safeguards, including the Additional Protocol.

There are three issues of particular concern for the international community when the nuclear option is considered to satisfy the foreseen increase in the demand of electricity in the coming decades. These issues are the following:

- a) The existing stocks of fissionable materials in the hands of several countries that is directly usable for the production of nuclear weapons.
- b) The number of nuclear facilities with inadequate physical protection and controls. The lack of adequate physical protection in force in several countries could be used by terrorist groups to have access to certain amount of fissionable materials to use them for the production of a nuclear weapon.
- c) The transfer of sensitive nuclear technology, especially enrichment and reprocessing technology, to countries implementing a nuclear power programme that brings them closer to a nuclear weapons capability.

The proliferation risk due to the global growth in the use of nuclear energy for electricity production is an important element that needs to be reduced to the minimum, if the nuclear option is going to be supported by the international community in the coming years.

***Operational safety of the nuclear power plants***

Nuclear power has been subject of several nuclear accidents heightened by the 1979 Three Mile Island and the 1986 Chernobyl nuclear accidents occurred in the USA and Ukraine respectively, but also by accidents at fuel cycle facilities in the USA, Russia and Japan in the past. Some countries decided to phase out their nuclear power programme or to prohibit the use of nuclear energy for electricity generation, based on the consequences for the health and for the environment of some of these accidents, particularly the Chernobyl nuclear accident <sup>[10]</sup>. For this reason, the production of

new nuclear power reactors with stringent safety requirements is an indispensable condition to spread the use of nuclear energy for electricity generation in the coming years.

Nuclear energy produces very few emissions of gases to the atmosphere. If the whole production cycle is considered, this means from the construction of the nuclear power plant to their exploitation, the production of 1 kWh of nuclear origin electricity supposes less than 6 grams of CO<sub>2</sub> emission mainly associated to the construction of the nuclear power plant and the transport of fuel. On the other hand, a combined cycle gas power plant generates 430 g of CO<sub>2</sub> and a coal power plant between 800 to 1,050 g of CO<sub>2</sub>, according with the type of technology used. Based on this facts it can be stated that the use of nuclear energy for electricity generation is one of the cleanest type of energy available in the world.

### ***Economic competitiveness***

Nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. Fuel costs for nuclear power plants are a minor proportion of total generating costs, though capital costs are greater than those for coal and oil fired power plants. In assessing the cost competitiveness of the use of nuclear energy for the production of electricity, decommissioning and waste disposal costs should be taken into account. According with expert's calculations, decommissioning costs are about 10-20% of the initial capital cost of a nuclear power plant. This make the nuclear energy option more expensive than other sources of energy under specific conditions. However, if the social, health and environmental costs of fossil fuels are also taken into account, then the use of nuclear energy for electricity generation is outstanding. The increase cost due to delay in the construction of a nuclear power plant is another important element that need to be taken into account when the overall cost associated with the use of nuclear energy for electricity generation is analyzed.

"The future competitiveness of nuclear power will depend substantially on the additional costs, which may accrue to coal generating plants and the cost of gas for gas-fired plants. It is uncertain how the real costs of meeting targets for reducing sulphur dioxide and greenhouse gas emissions will be attributed to fossil fuel plants". [17, p 3]

### ***Public acceptance***

The public opinion is another important element that needs to be taken into consideration when planning the introduction of a nuclear power programme by any country. It is important to understand that the future of the use of nuclear energy for the production of electricity depends on the public's perception of the importance of their use with this purpose and the risks involved. The concern of the society arises because, although the probability of a nuclear accident is very low, the risks to have it can have important consequences on the environment and on the population particularly those that live in areas close to the plant but even to the population leaving far away to the plant site. This concern is not based on an objective perception but in an intuitive judgement, due to the initial history on how nuclear energy was used in the past for military purpose, due to serious nuclear accidents occurred in some facilities, and to the optimistic initial expectations associated with the use of nuclear energy for electricity generation that they have not been fulfilled.

Different studies carried out so far on the use of nuclear energy for electricity generation indicate that there is a lack of information in the public on this important subject, as well as about the price of the different energy options available for the production of electricity and or their

repercussion on the environment. The different nuclear actors, particularly the scientific community, technologists, operators, regulators and legislators have not been able to convince the public opinion on which of the energy options available for electricity generation are the most convenient for a particular country. For this reason, it is extremely important to make additional efforts to provide reliable and impartial information about the use of the different types energy sources available for electricity generation, including the nuclear energy option, to the public opinion: The aim is to help them to define their position regarding the different energy options for electricity generation available in the world and identify which of them are the most appropriate for the country.

The increase in the costs of the construction of a nuclear power plant, the unforeseen delays in the construction of these type of plants due to new safety and security requirements demanded to the operators after the nuclear accidents of the Three Miles Island and Chernobyl, environment impact, among other requirements, has stopped the construction of new nuclear power plants in the USA as well as in other countries, particularly in the European region. The repercussion of these accidents was a public opinion contrary to the use of nuclear energy for electricity generation in the USA and in Western Europe and, as consequence of this position, the rejection of the politicians to support any further development of the nuclear sector in these two regions. However, and despite of several other nuclear accidents of minor consequences occurred in other countries, the public opinion in several countries in Asia such as Japan, the Republic of Korea, and China as well as in Russia, where the energy demand has grown considerably, programmes for the construction of new nuclear power plants have continued to be carried out without major difficulties.

It is important to single out that in many countries people are ready to support the nuclear energy option, if and only if problems related with the final disposal of high radioactive nuclear waste and the safety of the nuclear power reactors are properly solved. In the particularly case of the USA, the country with the major number of nuclear power plants in operation in the world (104) the people is unlikely to support nuclear power expansion without substantial improvements in costs and technology.

The carbon-free character of nuclear power is one of the main elements used by those that support the use of nuclear energy for electricity generation, particularly in Europe. However, in the case of the USA the cost-free character of nuclear power does not appear to be one of the main elements that motivate the public opinion to prefer the nuclear option for electricity generation, compare with other energy sources available in the country. In some developed countries there is an impression that nuclear power is especially unpopular among available energy sources. For this reason, it is further assumed that unless and until this unpopularity can be overcome, nuclear power will not flourish, even in the event that the use of this type of energy for electricity generation has solid grounds to support it. Then the question to be answered is the following: Why public opinion in some countries is against the use of nuclear energy for electricity generation? “Some of the factors behind the loss of public confidence in some developed countries were caused directly by the industry itself. The construction times and costs of many plants were far higher than projected. The performance of many plants was disappointing. The accidents at Three Mile Island and Chernobyl also served to exacerbate growing mistrust of the nuclear industry and its often vocal supporters within governments. This mistrust had its origin, at least in part, in the arrogance and secretiveness of nuclear spokesmen in many countries. The suspicion that the industry and its supporters were able, for example, to put undue pressure on regulators further damaged their public credibility. Critics of the industry often had no apparent vested interest to do so, while the industry’s responses

increasingly came to be discounted – ‘they would say that, would not they?’ The passion which has surrounded the nuclear debate in recent years is to a considerable degree a legacy of these factors”. [6, p 2]

At the same time, perceptions of the availability of alternatives energy sources for electricity generation were changing. When global fossil fuel supplies were under apparent threat (notably in the 1950s and again in the 1970s until the beginning of the 1980s), "nuclear power programmes were introduced in many countries with relatively little objection, at least by today's standards. The discovery of vast reserves of gas, as well as oil, coupled with low prices and the development of the highly efficient Combined Cycle Gas Turbine by the mid-1980s, reduced the apparent need for nuclear power in many developed countries. However, this perception was not shared by some developing countries, notably India and China". [6, p 2] For this reason, both countries continuing with the development of important programmes for the construction of new nuclear power reactors.

Many developing countries have anti-nuclear movements, even if they may be small, and environmental pressure groups are increasingly establishing themselves in the developing world. “A number of specific explanations have been suggested for the apparent special unease felt about nuclear power in many countries. They include:

1. Links to the military, both real (the development of shared facilities) and perceptual.
2. Secrecy, coupled sometimes with an apparent unwillingness to give ‘straight answers’ (in part, perhaps, because of links to military nuclear operations in some countries, and in part because of commercial issues).
3. The historical arrogance of many in the industry, dismissing opposition, however well-founded or sincerely held, as ‘irrational’.
4. The apparent vested interest of many nuclear advocates, to be contrasted with the apparent altruism of opponents who, for example, are often not funded to take part in public inquiries.
5. The perceived potential for large and uncontrollable accidents and other environmental and health effects, notably those associated with radioactive waste.
6. The overselling of nuclear technology, especially in its early days, in particular with regard to its economics, leading to a degree of disillusionment and distrust.
7. A general disillusionment with science and technology, and with the ‘experts know best’ attitude of mind that was more prevalent in the years immediately after the Second World War.
8. The wider decline of ‘deference’ towards ‘authority’ (including, for example, politicians and regulatory bodies). [6, p 3]

Other explanations to the opposition to the introduction of a nuclear power programme or to an extended use of nuclear energy for other peaceful purposes are the following:

1. Radioactivity cannot be smell, felt or seen, this means has no color and is not cold or warm.
2. Radioactivity can only be detected using special equipment.

## The projection of the contribution of nuclear energy in the global energy balance

The world electricity generation by fuel during the period 2005-2030 is reflected in the following figure.

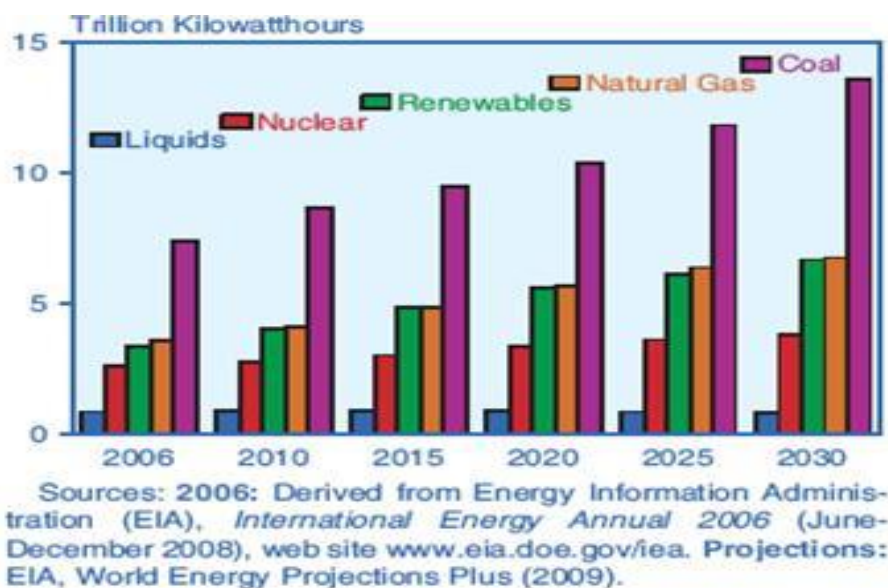


Figure 11: World electricity generation by fuel during the period 2005-2030.

In the following table the latest IAEA estimates of nuclear electricity generating capacity up to 2030 is included.

| Region                           | 2007  | 2010  |       | 2020  |       | 2030  |       |
|----------------------------------|-------|-------|-------|-------|-------|-------|-------|
|                                  |       | Low   | High  | Low   | High  | Low   | High  |
| North America                    | 113.2 | 113.5 | 114.5 | 121.4 | 127.8 | 131.3 | 174.6 |
| Latin America                    | 4.1   | 4.1   | 4.1   | 6.9   | 7.9   | 9.6   | 20.4  |
| Western Europe                   | 122.6 | 119.7 | 121.3 | 92.1  | 129.5 | 73.9  | 150.1 |
| Eastern Europe                   | 47.8  | 48.2  | 48.3  | 72.1  | 94.7  | 81.2  | 119.4 |
| Africa                           | 1.8   | 1.8   | 1.8   | 3.1   | 4.5   | 4.5   | 14.3  |
| Middle East and South Asia       | 4.2   | 7.6   | 10.1  | 12.5  | 24.3  | 15.9  | 41.5  |
| South East Asian and the Pacific | 0     | 0     | 0     | 0     | 0     | 1.2   | 7.4   |
| Far East                         | 78.5  | 81.3  | 83.1  | 129.2 | 151.8 | 155.7 | 219.9 |
| World Total                      | 372.2 | 376.3 | 383.1 | 437.4 | 541.6 | 473.2 | 747.5 |

Source: IAEA.

Table 7: The IAEA latest estimates of nuclear electricity generating capacity (GWe).

Table 7 shows that the greatest expansion of nuclear generating capacity for the following 20 years is projected for the Far East. Significant expansion is also projected for Middle East and South Asia, the region that includes India. The region with the greatest uncertainty, i.e. the greatest difference between the low and high projections, is Western Europe, region that is now debating the future role to be played by nuclear energy in the energy balance mix in the whole region, particularly within the EU. Although approximately 20 new countries are included in the 2030 projections, the global increase in the high projection comes mainly from increases in the 30 countries already using nuclear energy for electricity production. The low projection also includes approximately five new countries that might have their first nuclear power plants in operation by 2030. It is important to note that the IAEA projections have changed over the past few years. In particular the high projection for the rate of increase in installed nuclear power plant capacity between 2020 and 2030 is higher from the projections done in 2004, reflecting an increase in optimism about the use of nuclear energy for electricity production in some regions. The low projection in 2004 showed a declining installed capacity as nuclear power plants in operation were taken out of service without replacement.

It is also important to note that the IAEA has identified several issues that could affect the future introduction or expansion of nuclear power programmes in a group of countries and hence the accuracy of the predictions of nuclear power used. According with the IAEA, these issues are the following:

1. "Nuclear power has generated stronger political passions than alternatives. Alternatives to nuclear power, natural gas, coal, hydropower, oil, renewables, have nothing comparable to the prohibitions and phase-out policies that several countries have adopted for nuclear power.
2. Because of the front-loaded cost structure of a nuclear power plant, high interest rates, or uncertainty about interest rates, will weaken the business case for nuclear power more than for alternatives.
3. Nuclear power's front-loaded cost structure also means that the cost of regulatory delays during construction is higher for nuclear power than for alternatives. In countries where licensing processes were relatively untested in recent years, investors face potentially more costly regulatory risks with nuclear power than with alternatives.
4. The strength, breadth and durability of commitments to reducing GHG emissions will also influence nuclear power's growth.
5. The nuclear industry is a global industry with good international cooperation and hence the implications of an accident anywhere will be felt in the industry worldwide.
6. Similarly, nuclear terrorism may have a more far reaching impact than comparable terrorism directed at other fuels.
7. While a nuclear power plant in itself is not a principal contributor to proliferation risk, proliferation worries can affect public and political acceptance of nuclear power.
8. Among energy sources, high level radioactive waste is unique to nuclear power. The nuclear power industry might feel a disproportionately broad impact if major problems are encountered in any of the repository programmes that are most advanced (Finland, France, Sweden and USA)". [9, p 27]

If the world is to meet even a fraction of the economics aspirations of the developing world, energy supplies must expand significantly. If the increase needs of the industrialized countries for its

economic development are considered as well, then the world energy supplies must expand even further.

The following table includes relevant information regarding the generation of electricity in 2007 and the number of nuclear power plants in operation and in construction in the world.

| Country           | Nuclear electricity generation 2007 |      | Reactors operable April 2009 | Net Capacity | Reactors under construction April 2009 | Net Capacity | Reactors planned April 2009 |         | Reactors proposed April 2009 | Net Capacity |
|-------------------|-------------------------------------|------|------------------------------|--------------|----------------------------------------|--------------|-----------------------------|---------|------------------------------|--------------|
|                   | billion kWh                         | %    | No.                          | MWe          | No.                                    | MWe          | No.                         | MWe     | No.                          | MWe          |
| Argentina         | 6.7                                 | 6.2  | 2                            | 935          | 1                                      | 692          | 1                           | 740     | 1                            | 740          |
| Armenia           | 2.35                                | 43.5 | 1                            | 376          | 0                                      | 0            | 0                           | 0       | 1                            | 1 000        |
| Bangladesh        | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 0                           | 0       | 2                            | 2 000        |
| Belarus           | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 2 000   | 2                            | 2 000        |
| Belgium           | 46                                  | 54   | 7                            | 5 728        | 0                                      | 0            | 0                           | 0       | 0                            | 0            |
| Brazil            | 11.7                                | 2.8  | 2                            | 1 901        | 0                                      | 0            | 1                           | 1 245   | 4                            | 4 000        |
| Bulgaria          | 13.7                                | 32   | 2                            | 1 906        | 0                                      | 0            | 2                           | 1 900   | 0                            | 0            |
| Canada            | 88.2                                | 14.7 | 18                           | 12 652       | 2                                      | 1 500        | 3                           | 3 300   | 6                            | 6 600        |
| China             | 59.3                                | 1.9  | 11                           | 8 587        | 11                                     | 11 000       | 26                          | 27 660  | 77                           | 63 400       |
| Czech Republic    | 24.6                                | 30.3 | 6                            | 3 472        | 0                                      | 0            | 0                           | 0       | 2                            | 3 400        |
| Egypt             | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 1                           | 1 000   | 1                            | 1 000        |
| Finland           | 22.5                                | 29   | 4                            | 2 696        | 1                                      | 1 600        | 0                           | 0       | 1                            | 1 000        |
| France            | 420.1                               | 77   | 59                           | 63 473       | 1                                      | 1 630        | 1                           | 1 630   | 1                            | 1 630        |
| Germany           | 133.2                               | 26   | 17                           | 20 339       | 0                                      | 0            | 0                           | 0       | 0                            | 0            |
| Hungary           | 13.9                                | 37   | 4                            | 1 826        | 0                                      | 0            | 0                           | 0       | 2                            | 2 000        |
| India             | 15.8                                | 2.5  | 17                           | 3 779        | 6                                      | 2 976        | 10                          | 9 760   | 15                           | 11 200       |
| Indonesia         | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 2 000   | 4                            | 4 000        |
| Iran              | 0                                   | 0    | 0                            | 0            | 1                                      | 915          | 2                           | 1 900   | 1                            | 300          |
| Israel            | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 0                           | 0       | 1                            | 1 200        |
| Italy             | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 0                           | 0       | 10                           | 17 000       |
| Japan             | 267                                 | 27.5 | 53                           | 46 236       | 2                                      | 2 285        | 13                          | 17 915  | 1                            | 1 300        |
| Kazakhstan        | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 600     | 2                            | 600          |
| Korea DPR (North) | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 1                           | 950     | 0                            | 0            |
| Korea RO (South)  | 136.6                               | 35.3 | 20                           | 17 716       | 5                                      | 5 350        | 3                           | 4 050   | 2                            | 2 700        |
| Lithuania         | 9.1                                 | 64.4 | 1                            | 1 185        | 0                                      | 0            | 0                           | 0       | 2                            | 3 400        |
| Mexico            | 9.95                                | 4.6  | 2                            | 1 310        | 0                                      | 0            | 0                           | 0       | 2                            | 2 000        |
| Netherlands       | 4.0                                 | 4.1  | 1                            | 485          | 0                                      | 0            | 0                           | 0       | 0                            | 0            |
| Pakistan          | 2.3                                 | 2.34 | 2                            | 400          | 1                                      | 300          | 2                           | 600     | 2                            | 2 000        |
| Poland            | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 0                           | 0       | 5                            | 10 000       |
| Romania           | 7.1                                 | 13   | 2                            | 1 310        | 0                                      | 0            | 2                           | 1 310   | 1                            | 655          |
| Russia            | 148                                 | 16   | 31                           | 21 743       | 8                                      | 5 980        | 11                          | 12 870  | 25                           | 22 280       |
| Slovakia          | 14.2                                | 54   | 4                            | 1 688        | 2                                      | 840          | 0                           | 0       | 1                            | 1 200        |
| Slovenia          | 5.4                                 | 42   | 1                            | 696          | 0                                      | 0            | 0                           | 0       | 1                            | 1 000        |
| South Africa      | 12.6                                | 5.5  | 2                            | 1 842        | 0                                      | 0            | 3                           | 3 565   | 4                            | 4 000        |
| Spain             | 52.7                                | 17.4 | 8                            | 7 448        | 0                                      | 0            | 0                           | 0       | 0                            | 0            |
| Sweden            | 64.3                                | 46   | 10                           | 9 014        | 0                                      | 0            | 0                           | 0       | 0                            | 0            |
| Switzerland       | 26.5                                | 43   | 5                            | 3 220        | 0                                      | 0            | 0                           | 0       | 3                            | 4 000        |
| Thailand          | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 2 000   | 4                            | 4 000        |
| Turkey            | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 2 400   | 1                            | 1 200        |
| Ukraine           | 87.2                                | 48   | 15                           | 13 168       | 0                                      | 0            | 2                           | 1 900   | 20                           | 27 000       |
| UAE               | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 3                           | 4 500   | 11                           | 15 500       |
| United Kingdom    | 57.5                                | 15   | 19                           | 11 035       | 0                                      | 0            | 0                           | 0       | 6                            | 9 600        |
| USA               | 806.6                               | 19.4 | 104                          | 101 119      | 1                                      | 1 180        | 11                          | 13 800  | 20                           | 26 000       |
| Vietnam           | 0                                   | 0    | 0                            | 0            | 0                                      | 0            | 2                           | 2 000   | 8                            | 8 000        |
| World             | 2 608                               | 15   | 436                          | 372 203      | 44                                     | 38 848       | 110                         | 121 595 | 243                          | 268 905      |

Sources: WNA April 2009.

Note: This table includes only those future reactors envisaged in specific plans and proposals and expected to be operating by 2030.

Table 8: World Nuclear Power Reactors 2008.

| Country      | PWR |        | BWR |       | GCR |       | PHWR |       | LWGR |       | FBR |       | Total |        |
|--------------|-----|--------|-----|-------|-----|-------|------|-------|------|-------|-----|-------|-------|--------|
|              | No. | MW(e)  | No. | MW(e) | No. | MW(e) | No.  | MW(e) | No.  | MW(e) | No. | MW(e) | No.   | MW(e)  |
| ARGENTINA    |     |        |     |       |     |       | 2    | 935   |      |       |     |       | 2     | 935    |
| ARMENIA      | 1   | 376    |     |       |     |       |      |       |      |       |     |       | 1     | 376    |
| BELGIUM      | 7   | 5824   |     |       |     |       |      |       |      |       |     |       | 7     | 5824   |
| BRAZIL       | 2   | 1795   |     |       |     |       |      |       |      |       |     |       | 2     | 1795   |
| BULGARIA     | 2   | 1906   |     |       |     |       |      |       |      |       |     |       | 2     | 1906   |
| CANADA       |     |        |     |       |     |       | 18   | 12610 |      |       |     |       | 18    | 12610  |
| CHINA        | 9   | 7272   |     |       |     |       | 2    | 1300  |      |       |     |       | 11    | 8572   |
| CZECH REP.   | 6   | 3619   |     |       |     |       |      |       |      |       |     |       | 6     | 3619   |
| FINLAND      | 2   | 976    | 2   | 1720  |     |       |      |       |      |       |     |       | 4     | 2696   |
| FRANCE       | 58  | 63130  |     |       |     |       |      |       |      |       | 1   | 130   | 59    | 63260  |
| GERMANY      | 11  | 13973  | 6   | 6457  |     |       |      |       |      |       |     |       | 17    | 20430  |
| HUNGARY      | 4   | 1829   |     |       |     |       |      |       |      |       |     |       | 4     | 1829   |
| INDIA        |     |        | 2   | 300   |     |       | 15   | 3482  |      |       |     |       | 17    | 3782   |
| JAPAN        | 23  | 18420  | 32  | 29167 |     |       |      |       |      |       |     |       | 55    | 47587  |
| KOREA REP.   | 16  | 14824  |     |       |     |       | 4    | 2627  |      |       |     |       | 20    | 17451  |
| LITHUANIA    |     |        |     |       |     |       |      |       | 1    | 1185  |     |       | 1     | 1185   |
| MEXICO       |     |        | 2   | 1360  |     |       |      |       |      |       |     |       | 2     | 1360   |
| NETHERLANDS  | 1   | 482    |     |       |     |       |      |       |      |       |     |       | 1     | 482    |
| PAKISTAN     | 1   | 300    |     |       |     |       | 1    | 125   |      |       |     |       | 2     | 425    |
| ROMANIA      |     |        |     |       |     |       | 2    | 1305  |      |       |     |       | 2     | 1305   |
| RUSSIA       | 15  | 10964  |     |       |     |       |      |       | 15   | 10219 | 1   | 560   | 31    | 21743  |
| SLOVAKIA     | 5   | 2034   |     |       |     |       |      |       |      |       |     |       | 5     | 2034   |
| SLOVENIA     | 1   | 666    |     |       |     |       |      |       |      |       |     |       | 1     | 666    |
| SOUTH AFRICA | 2   | 1800   |     |       |     |       |      |       |      |       |     |       | 2     | 1800   |
| SPAIN        | 6   | 5940   | 2   | 1510  |     |       |      |       |      |       |     |       | 8     | 7450   |
| SWEDEN       | 3   | 2819   | 7   | 6215  |     |       |      |       |      |       |     |       | 10    | 9034   |
| SWITZERLAND  | 3   | 1700   | 2   | 1520  |     |       |      |       |      |       |     |       | 5     | 3220   |
| UK           | 1   | 1188   |     |       | 18  | 9034  |      |       |      |       |     |       | 19    | 10222  |
| UKRAINE      | 15  | 13107  |     |       |     |       |      |       |      |       |     |       | 15    | 13107  |
| USA          | 69  | 66697  | 35  | 33885 |     |       |      |       |      |       |     |       | 104   | 100582 |
| TOTAL        | 265 | 243421 | 94  | 85275 | 18  | 9034  | 44   | 22384 | 16   | 11404 | 2   | 690   | 439   | 372208 |

The totals include 6 units, 4921 MW(e) in Taiwan, China.

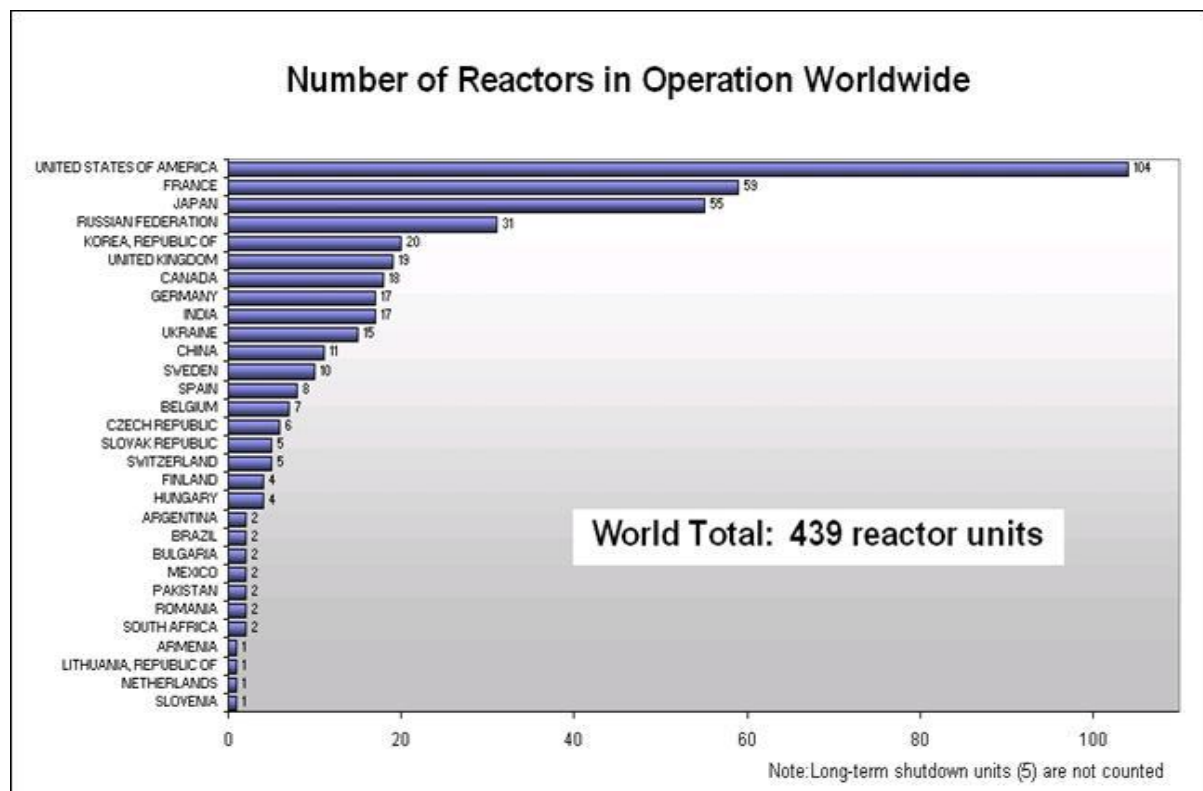
During 2007, 3 reactors, 1852 MW(e), were newly connected to the grid.

PWR: pressurized water reactor; BWR: boiling water reactor; GCR: gas cooled reactor; PHWR: pressurized heavy water reactor; LWGR: light water cooled, graphite moderated reactor; FBR: fast breeder reactor

**Note:** From this table, three nuclear power reactor were shut down in 2009. These nuclear power reactors are Hamaoka Units 1 and 2 in Japan and Bohunice Unit 3 in Slovakia.

**Source:** IAEA.

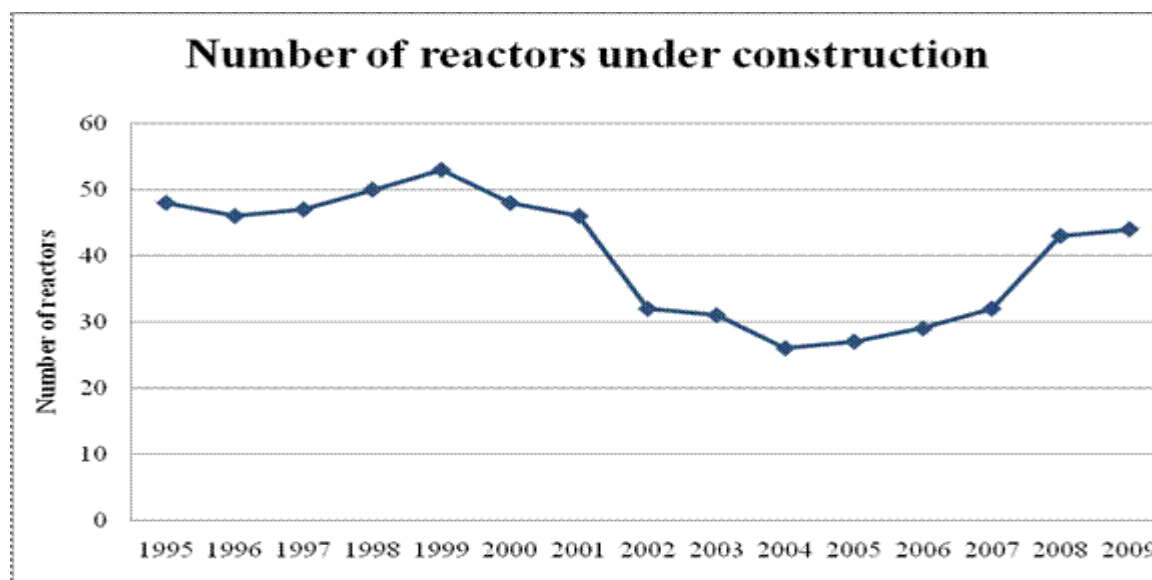
**Table 9: Type of reactor by country.**



**Note:** From this figure, three nuclear power reactors were shut down in 2009. These nuclear power reactors are Hamaoka Units 1 and 2 in Japan and Bohunice Unit 3 in Slovakia.

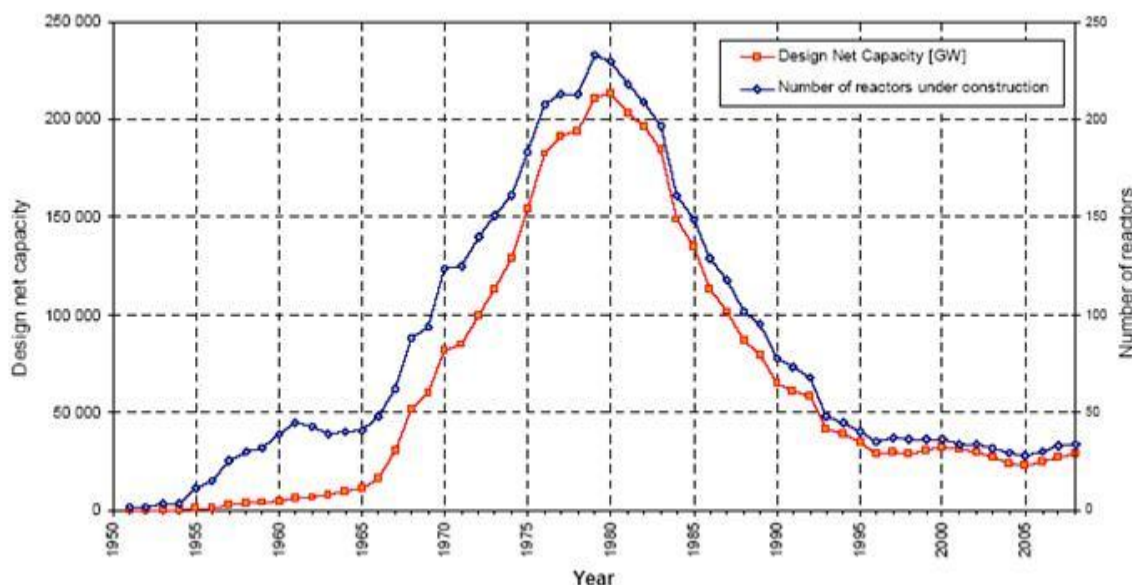
Source: IAEA, 2008.

Figure 12: Nuclear power reactors in operation worldwide.



Source: IAEA.

Figure 13: Number of reactors under construction during the period 1995-April 2009.



Source: IAEA.

**Figure 14: Number of nuclear power reactors and the total nuclear power reactor capacity under construction from 1951 to 2008.**

“During the period of peak construction there were major nuclear system supply companies in Canada, France, Germany, Japan, Russian Federation, Sweden, Switzerland, UK and USA. Today, nuclear system suppliers are in Canada, China, France, India, Japan, Republic of Korea, Russian Federation and USA. There are other potential suppliers who have designs in development such as Argentina and South Africa, but the designers of currently available nuclear steam supply systems have reduced to a small group who increasingly are working very closely together, for example through collaboration between Areva and Mitsubishi, GE and Hitachi, and Toshiba and Westinghouse”. [9, p 13]

As can be easily see from the Figure 11 the number of nuclear power reactors under construction dropped significantly during the period 1980- 1995. After 2005 there is a trend to increase very slowly the total number of nuclear power reactors under construction each year. It is expected that this trend will continue in the coming years.

### Types of nuclear power reactors

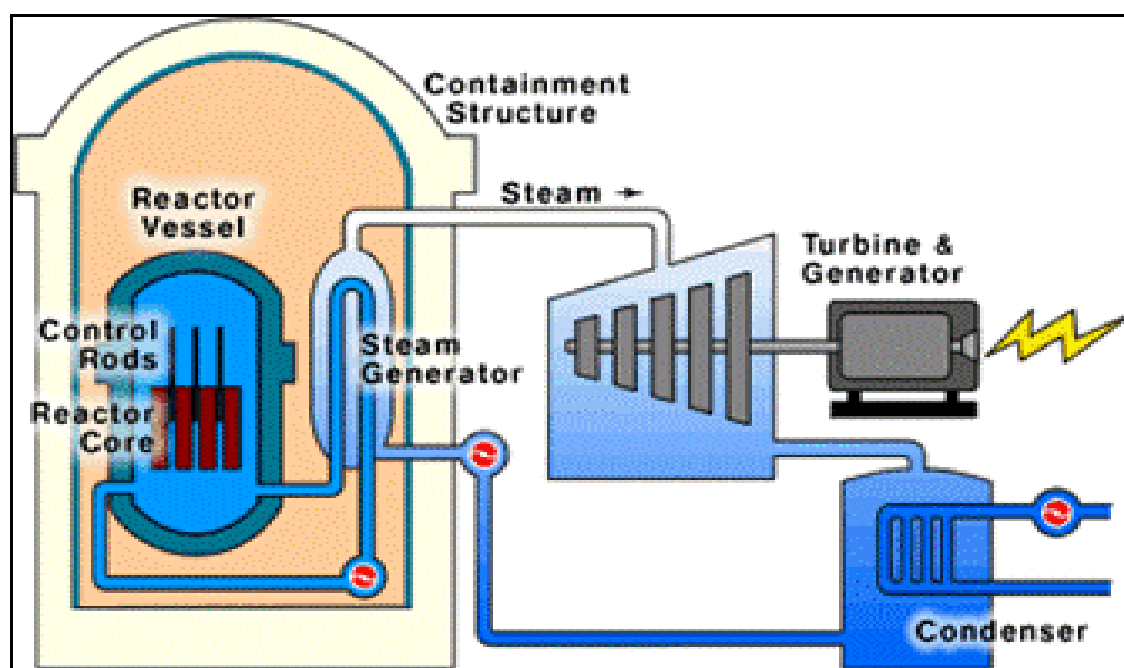
All nuclear reactors are devices designed to maintain a chain reaction producing a steady flow of neutrons generated by the fission of heavy nuclei inside the devices. The nuclear reactors are differentiated by their purpose and by their design features. Considering the purpose of the nuclear reactors they can be classified in two groups: a) Nuclear research reactors and b) Nuclear power reactors. Nuclear research reactors are devices that operate at universities and research institutions in many countries, including in countries where no nuclear power reactors are in operation. These types of reactors are used for multiple purposes, including the production of radiopharmaceuticals, medical diagnosis and therapy, testing materials and conducting basic research. Nuclear power reactors are those devices used for generating heat mainly for electricity production. However, this type of reactors is uses also for desalination of water. In the form of smaller units, they also power ships.

There are many different types of nuclear power reactors. What is common to all of them is that they produce thermal energy that can be used for its own sake or converted into mechanical energy and ultimately, in the vast majority of cases, into electrical energy. In this type of reactors, the fission of heavy atomic nuclei, the most common of which is uranium-235, produces heat that is transferred to a fluid which acts as a coolant. The heated fluid can be gas, water or a liquid metal. The heat stored by the fluid is then used either directly (in the case of gas) or indirectly (in the case of water and liquid metals) to generate steam. The heated gas or the steam is then fed into a turbine driving an alternator, which produce the electricity.

Nuclear power reactors can be classified according to the type of fuel they use to generate heat in: a) Uranium-fuelled nuclear power reactors and b) plutonium-fuelled nuclear power reactors.

### ***Uranium-fuelled nuclear power reactors***

The Uranium-fuelled nuclear power reactors could be classified in the following manner: a) Pressurized water reactors (PWR), and b) Boiling water reactors (BWR). The main components of the PWR are shown in the following figure.

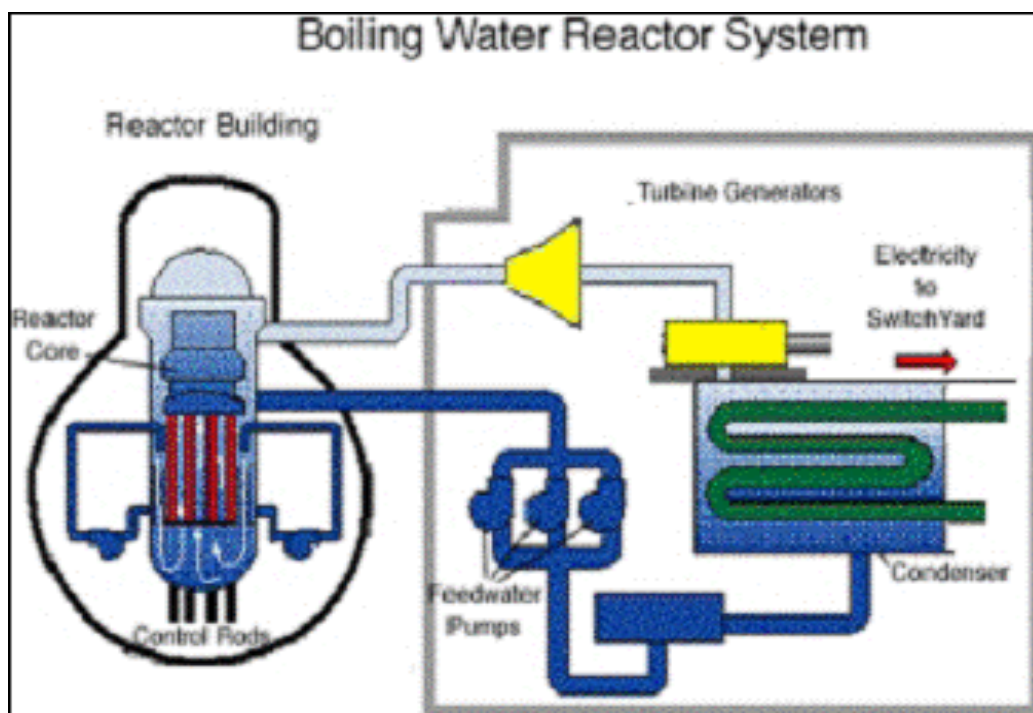


Source: International Nuclear Safety Center at Argonne National Laboratory.

**Figure 15: Main components of a PWR.**

The PWR is the most common nuclear power reactors operating in the world. There were 265 PWR nuclear power reactors in operation in 24 countries all over the world in 2007. The load factor of this type of reactor in that year was 83.4% (first place). In 2007 the net capacity installed of the PWR was 243 421 MWe. The USA and France are the countries with the highest number of PWR in operation in the world

In 2007 there were 94 BWR in operation in 9 countries all over the world. The net capacity installed of the BWR was 85 275 MWe. The load factor of this type of reactor in 2007 was 75.3% (fourth place). The USA and Japan are the two countries with the highest number of BWR in operation in the world. The main components of the BWR are shown in the following figure:



Source: International Nuclear Safety Center at Argonne National Laboratory.

**Figure 16: Principle of a nuclear power plant with boiling water reactor.**

Graphite-moderated, gas-cooled nuclear power reactors, formerly operated in France and still operated in the UK, are not built any more in spite of some advantages that this type of reactors have. RBMK-reactors (pressure-tube boiling-water reactors, LWGR)), which are cooled with light water and moderated with graphite, are now less commonly operated in some former Soviet Union bloc countries. In Russia there were 15 RBMK in operation in 2007 and one under construction. Following the Chernobyl accident the construction of this reactor type outside Russia ceased.

### ***Plutonium-fuelled Reactors***

Plutonium (Pu) is an artificial element produced in uranium-fuelled nuclear reactors as a by-product of the chain reaction. It is one hundred times more energetic than natural uranium; one gram of Pu can generate as much energy as one tone of oil. As it needs fast neutrons in order to fission, moderating materials must be avoided to sustain the chain reaction in the best conditions. The current Plutonium-fuelled reactors, also called "fast reactors", use liquid sodium which displays excellent thermal properties without adversely affecting the chain reaction. These types of reactors are in operation in France, Japan and the Commonwealth of Independent States (CIS).

### **The next generation of nuclear power reactor**

The majority of the nuclear power reactors today in operation in the world are from the so-called "second generation" (Generation II) of nuclear power reactors. Some countries are now constructing nuclear power reactors of the "third generation" (Generation III), which are more reliable and with a number of built-in safety features. It is important to note that "there is no clear definition of what constitutes a third generation design, apart from it being designed in the last 15 years, but the main common features quoted by the nuclear industry are:

- a) A standardized design for each type to expedite licensing, reduce capital cost and construction time.
- b) A simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets.
- c) Higher availability and longer operating life - typically 60 years.
- d) Reduced possibility of core melts accidents.
- e) Minimal effect on the environment.
- f) Higher burn-up to reduce fuel use and the amount of waste.
- g) Burnable absorbers (poisons) to extend fuel life.

These characteristics are clearly very imprecise and do not define very well what a third generation of nuclear power reactors is. It is important to single out that this type of nuclear power reactors are evolved from existing designs of PWR, BWR and CANDU reactors. Until there is much more experience with these technologies, any figures on the generation cost of power from these designs should be treated with the utmost caution". [16, p 9]

However, the future belongs to the so-called "fourth generation" of nuclear power reactors (Generation IV). This new generation of nuclear power reactors is a revolutionary type of reactors with innovative fuel cycle technologies. It is expected that they may be available for commercial application around 2030-2040. The Generation IV responds to the following main sustainability criteria and future market conditions, among others:

- a) Incorporate advanced nuclear safety.
- b) Are resistant to proliferation.
- c) Are highly economic and competitive.
- d) Produce minimal waste.

### ***Challenging technology goals***

The following areas are the main challenging technology goals for Generation IV nuclear energy systems now under development in several countries:

1. Sustainability.
2. Economics competitiveness.
3. Safety and reliability.
4. Proliferation resistance and physical protection.

### ***Sustainability***

One of the most important features of the new generation of nuclear power reactors is sustainability. "Sustainability is the ability to meet the needs of the present generation while enhancing the ability of future generations to meet society's needs indefinitely into the future. The benefits of meeting sustainability goals include:

- a) Extending the nuclear fuel supply into future centuries by recycling used fuel to recover its energy content, and by converting U-238 to new fuel.

- b) Having a positive impact on the environment through the displacement of polluting energy and transportation sources by nuclear electricity generation and nuclear-produced hydrogen.
- c) Allowing geologic waste repositories to accept the waste of many more plant-years of nuclear plant operation through substantial reduction in the amount of wastes and their decay heat.
- d) Greatly simplifying the scientific analysis and demonstration of safe repository performance for very long time periods (beyond 1,000 years), by a large reduction in the lifetime and toxicity of the residual radioactive wastes sent to repositories for final geologic disposal". [2, pp 1 and 2]

### ***Economic competitiveness***

Another important feature of the next generation of nuclear power reactors is economic competitiveness. The cost associated to the construction of nuclear power reactors is very high in comparison with the construction of a fossil-fuelled power plant and this factor impede that many countries consider the introduction or the expansion of a nuclear power programme.

"Economics goals broadly consider competitive costs and financial risks of nuclear energy systems. Looking ahead, the benefits of meeting economics goals include:

- a) Achieving economic life-cycle and energy production costs through a number of innovative advances in plant and fuel cycle efficiency, design simplifications and plant sizes.
- b) Reducing economic risk to nuclear projects through the development of plants built using innovative fabrication and construction techniques, and possibly modular designs.
- c) Allowing the distributed production of hydrogen, fresh water, district heating, and other energy products to be produced where they are needed". [2, p 2]

### ***Safety and reliability systems***

The third relevant feature associated with the new generation of nuclear power reactors is that the system should be safe and reliable in the generation of electricity. The security of supply is one of the major concerns of any country and for this reason the reliability of an energy system is one of the criteria to be used when the selection of a source of energy for electricity generation is going to be made.

"Maintaining and enhancing the safe and reliable operation is an essential priority in the development of next generation systems. Safety and reliability goals broadly consider safe and reliable operation, improved accident management and minimization of consequences, investment protection, and reduced need for off-site emergency response. Looking ahead, the benefit of meeting these goals includes:

- a) Increasing the use of inherent safety features, robust designs and transparent safety features that can be understood by non-experts.
- b) Enhancing public confidence in the safety of nuclear energy". [2, p 2]

### ***Proliferation resistance and physical protection***

It is important to ensure that the next generation of nuclear power reactors has a minimum proliferation risk and allow a high level of physical protection with the purpose to ensure the control and the secure of the nuclear material and facilities. Proliferation risk is one of the major concerns of

the international community and one of the reasons why the use of nuclear energy for electricity generation cause concern to many countries, particularly when the nuclear installations, including nuclear power plants are going to be built in countries located in unstable political regions. “Looking ahead, the benefits of meeting these goals include:

- a) Providing continued effective proliferation resistance of nuclear energy systems through improved design features and other measures.
- b) Increasing physical protection against terrorism by increasing the robustness of new facilities”. [2, p 2]

The following are the designs of Generation IV nuclear power reactors already selected on the basis of a set of criteria that have been established:

1. Sodium cooled Fast Reactor (SFR).
2. Very High Temperature Gas Reactor (VHTR).
3. Super Critical Water Cooled Reactor (SCWR).
4. Lead Cooled Fast Reactor (LFR).
5. Gas Cooled Fast Reactor (GFR).
6. Molten Salt Reactor (MSR).

The above Generation-IV nuclear power reactor designs are very different and also present different challenges that need to be solved in the ongoing research and development programmes in order to have all, or at least some of them, available in the market as soon as possible. It is expected that some of the Generation-IV designs could be available in the market not before 2030. Others designs may still need significant additional research and development work before they can be considered ready for the production electricity. It is expected that these reactors would only become available in the market well after the year 2040. The design of the Generation IV of nuclear power reactors and their main characteristics are shown in the following figures and described in the paragraphs below.

## The future

The use of nuclear energy for electricity production is under serious consideration not only in the USA and in the EU but in other countries as well. Thirty-one countries are already using nuclear energy for electricity generation and it is expected that almost all of them will continue to use this type of energy with this purpose in the future. Forty countries not currently using this type of energy are seriously considering the introduction of a nuclear energy programme in the coming years. This last group of countries includes the following:

- **In Europe:** Italy, Albania, Portugal, Norway, Poland, Belarus, Estonia, Latvia, Ireland and Turkey.
- **In the Middle East and North Africa:** Iran, Gulf States, Yemen, Israel, Syria, Jordan, Egypt, Tunisia, Libya, Algeria and Morocco.

- **In Central and Southern Africa:** Nigeria, Ghana and Namibia.
- **In South America:** Chile, Ecuador, Peru, Uruguay and Venezuela.
- **In Central and Southern Asia:** Azerbaijan, Georgia, Kazakhstan, Mongolia and Bangladesh.
- **In South Eastern Asia:** Indonesia, Vietnam, Thailand, Malaysia, Australia and New Zealand.

In all of the above countries, governments need to create the necessary environment to facilitate investment in nuclear power, including a regulatory regime, and the adoption of policies on nuclear waste management, decommissioning and non-proliferation. The public opinion is an important factor to be taken into account when considering the introduction of a nuclear power programme in all of these countries.

The institutional arrangements to be created vary from country to country. Usually governments in the industrialized world are heavily involved in planning the introduction of different types of energy in the balance mix, including nuclear energy and, in some cases, in the financing of the construction of nuclear power plants. In others the financing, construction, operation and decommissioning are the responsibility of the private industry. In developing countries, particularly for the introduction of a nuclear power programme, the role of governments are essential in all faces associated with the introduction of this type of programmes from planning till the operation of nuclear power plants.

In countries in which nuclear energy for electricity generation is introduced for the first time there is always a lack of nuclear engineers and other scientists, professional and technicians duly prepared and, for this reason, the way in which the construction of the nuclear power plants are carried out is often on a turnkey basis. In this case the supplier of the nuclear power reactors assume all technical and commercial risks in delivering a functioning plant on time and within the budget approved, or as an alternative, set up a consortium to build, own and operate the plant.

It is important to note that if a country is considering the use of nuclear energy for electricity generation, the following basic criteria should be used:

- a) "Nuclear power should be considered only when it is technically feasible and when it would be part of an economically viable long-term energy and electricity supply expansion strategy, considering all alternatives and relevant factors.
- b) A nuclear power programme should be launched only when it - and in particular, the first project - has a definite likelihood of being successful, i.e. it can be executed within the planned schedule and predicted financial limits and can be operated safely and reliably once in service.
- c) A nuclear power project should be finally committed only on the basis of comprehensive planning, and after steps have been taken to meet all necessary supporting infrastructure requirements, including assurance of financing". [14, p 7]

Other issues that must be considered in the framework of the introduction of a nuclear power programme are the following:

1. The economic competitiveness of the use of nuclear energy for the production of electricity in comparison with other energy sources available in the country.
2. The safety aspects related with the licensing of the nuclear power plant and the development of a safety culture.
3. The size of the electricity grids [\[11\]](#).
4. Proliferation considerations.
5. Environmental impact.
6. The cost involved in the construction of a nuclear power plant.
7. The need for trained personnel and how this training should be provided and by whom.
8. The technological capability to assimilate an advanced and demanding technology.
9. The safe management of the nuclear waste, particularly high nuclear waste.
10. The need to gain public acceptance.
11. The international and regional cooperation in the field of nuclear technology.

A nuclear power programme should be viewed within a medium to long-term electricity supply strategy and with potential economic benefits for the country. The programme should produce stability in power generation and electricity price and an important impact in the domestic industry.

The potential economic benefits of the introduction of a nuclear power programme, particularly in the developing world, "include a certain buffering against escalating fossil fuel prices, which therefore helps to maintain the long-term stability of electricity prices. An important consideration in many developing countries has been the influence of a national nuclear power programme in increasing the technological level of the country and enhancing the global competitiveness of the domestic industry. The participation of the domestic industry could help to speed up a nuclear power programme". [5, p 11]

One of the main elements that need to be considered to ensure the successful introduction of a nuclear energy programme in a country, particularly in a developing country, is the level of participation of the domestic or national industry. The participation of national industry in the development of a nuclear power programme could be materialized in one or more of the following manners:

1. "Local labor and some construction materials could be used for non-specialized purposes on-site, especially civil engineering works associated with the construction of the nuclear power plant.
2. Local contractors could take full or partial responsibility for the civil engineering work, including some design work assigned by the main constructor.
3. Locally manufactured components from existing national factories could be used for non-critical parts of the nuclear power plant.
4. Local manufacturers could extend their normal product line to incorporate nuclear designs and standards, possibly under licensing arrangements with foreign suppliers.
5. Factories could manufacture heavy and specialized specific nuclear components, possibly under licensing arrangements with foreign suppliers.

However, the economic viability of such undertakings would have to be assessed carefully in view of the future domestic market and the availability of such equipment internationally". [5, p 56]

Well-designed, constructed and operated nuclear power plants have proved to be a reliable, environmentally acceptable and safe source of electrical energy supply all over the world, including in Africa. Another important element for the successful introduction of a nuclear power programme is the existence of a well-prepared and trained force. In the last two decades, particularly after the Chernobyl nuclear accident, there was an increase lack of interest in several countries in the development and use of nuclear energy for electricity generation. This lack of interest, in addition to the retirement of the specialized work-force working in the nuclear sector in the last decades and its lack of perspectives, produced a significantly reduction in the number of well- trained professional and specialized force working now in the nuclear sector as well as on the new force that eventually will substituted them in the future. To overcome the lack of trained work-force available in different parts of the world, several countries had taken specific initiative to increase the number of professional and specialized work-force in the nuclear sector to ensure the development of this sector in the future.

Several initiatives have been promoted by companies that are building or they are about to build new nuclear power plants and supported by different government institutions and agencies, including the IAEA. The two biggest exponents of the French nuclear industry, EdF and Area that are building new nuclear power plants inside and outside France, hired a total of 15,500 new workers in 2008. However, not only nuclear companies in charge of the construction of new nuclear power plants are requiring specialized personnel. In the USA, for example, were 32 new nuclear reactors have been under construction, planned or proposed to be built in the coming years, the Nuclear Regulatory Commission should hire 600 new specialists in the next three years in order to assimilate the work increase foresee for this period. The UK and the Russian Federation recently decided to provide support for the establishment of university and institutes specifically dedicated to prepare professionals and technicians in nuclear sciences and technologies in order to satisfy the foresee demand of specialized work-force in their respective nuclear sectors.

The IAEA has been also promoting the preparation of new professionals and technicians in sciences and nuclear technologies in its Member States, in order to satisfy the foresee demand of specialized work-force in their respective nuclear sectors in the future.

## Conclusion

Due to economic and social development of several countries over the world occurred in last years it is expected that energy demand will increase in almost all countries in the near future. For this reason, it is inevitable an increment in the world consumption of different types of energy for electricity generation. The expected increase of electricity consumption should be part of a scheme, which should takes into consideration several factors particularly environmental effects that could produce this foresee increase in the demand of energy. Within this context the use of nuclear technology appears to be an excellent option for the electricity production for several countries in all regions.

The electricity demand is expected to grow at a rapid rate in the next few decades particularly in the Asian region. This is mainly due to the close relationship that exists between the growth in electricity demand and the economic and social development that several Asian countries are being facing in the last years, particularly in the cases of China, India, the Republic of Korea, among others.

The options available to meet an increase in electricity demand should take into account factors such as energy security, diversity in energy sources for electricity generation, technological development, energy reserves, level of investment and environmental protection, among others. Long-term stability of fuel prices is also another key factor as fossil fuel prices represent a high percentage of the cost of the electricity produced, whereas the cost of producing electricity using nuclear energy is less sensitive to variations of nuclear fuel prices. The future role of nuclear power has to be seen in the context of the above factors.

It is a fact that, if additional electricity-generating capacity is urgently needed, then the use of gas, oil or coal fired power plants will be considered by most countries in the first place, the case of the EU is an example of this situation, because it can be planned and built more quickly than nuclear power plants. However, expanding electricity generation using fossil fuel has its limits, should not be considered as a long-term solution from the environmental point of view, and increase the emission of CO<sub>2</sub> to the atmosphere producing a climate change.

Under these conditions, the use of nuclear energy for electricity generation is considered a valid option for several countries all over the world, if the special characteristics of the use of nuclear energy for the production of electricity are taken into account and the requirements it poses can be met, especially for the maintenance of a very high level of safety and the correct management of the nuclear waste. The decision to use nuclear energy for electricity generation will largely depend on the specific situation of the energy sector in the country, the foresee increase in the energy demand, the energy reserves of the different types of energy and the policies developed by its authorities and governments.

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## Notes

[1] In April 2009 there were 436 nuclear power reactors in operation in the world producing 372 208 MWe according with the IAEA latest information. In the number of countries with nuclear power reactors in operation Taiwan was included independently.

[2] In the list of countries with nuclear power reactors in operation and under construction, Taiwan is included as a separate country. According with the IAEA latest information, on April 2009 the number of nuclear power reactor under construction was 44 in 13 countries with a total capacity of 38,848 MWe.

[3] At the end of 2007, China and France signed an agreement for the construction of several nuclear power plants for US\$ 11.8 billion up to 2026. This is the major contract signed by the French company Areva up to now for the construction of nuclear power plants outside France and the most ambitious nuclear programme for generation of electricity under discussion and implementation in the world. It is important to stress that for China, the use of nuclear energy for electricity generation is a fundamental option to satisfy the growing demand of energy to sustain the high economic growth of this country. In April 2009 the number of nuclear power reactors planned or proposed in China is 103 according with the latest IAEA information. The capacity of these reactors is 91 060 MWe.

[4] The USA, France, Japan, Germany, Russia and the Republic of Korea are now producing three-quarters of the nuclear electricity generated in the world.

[5] China has in 2008 nine nuclear power plants in operation and four under construction. China hopes to incorporate 21 new nuclear power plants up to 2020 and at least other 20 or more nuclear power reactors later on. In total China has 103 new nuclear power reactors planned or proposed, with a new nuclear capacity of 91 060 MWe.

[6] These countries are: Argentina, Brazil, Chile, Ecuador, Peru, Uruguay and Venezuela.

[7] Examples of such risks are abundant. A group of armed men attacked Areva uranium prospecting camp in northern Niger, killing a security guard and wounding three other people. In Congo, a nuclear research reactor has an inadequate physical protection, possesses a totally outdated control room and an unguarded radioactive waste storage building. Through decades of war and political upheaval, the Congo has repeatedly been accused of illegally selling its natural uranium or not preventing smuggling schemes. In November 2007, armed gunmen gained access to a major nuclear research facility in South Africa and reached the emergency control room before guards control de situation.

[8] Renewables energy was not included in the above figure due to its limited participation (between 0.2 and 0.5 % only).

[9] According with the IAEA, other limiting factors are human resources, transport of uranium, fresh and spent fuel and waste, infrastructure building and the relationship between electricity grids and reactor technology.

[10] However, it is important to single out that there is any nuclear power reactor design that is totally risk -free for the following two reasons: a) Technical possibilities; b) Work-force problems. Safe operation of a nuclear power reactor requires effective regulation, a management committed to safety and a skilled work-force.

[11] It is important to take into account that normally no single nuclear power reactor should account for more than 10% of the installed capacity of the entire electricity network of the country.

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