The future of nuclear power in France, the EU and the world for the next quarter-century

C. Pierre Zaleski
Center for Geopolitics of Energy and Raw Materials
University of Paris - Dauphine
February 2005

Paper prepared for the Nonproliferation Policy Education Center
Follow-up to oral presentation at the workshop " Is Nuclear Proliferation Inevitable?" (October 2004)

The future of nuclear power in France, the EU and the world for the next quarter-century

The organizers of this workshop asked me to present my views about the future of nuclear energy. Speaking about the future is always a perilous exercise. The probability of being wrong is much higher than of being right. Just two examples: In the 1970s, the assumptions about electricity demand growth adopted by U.S. utilities and the nuclear industry were so wrong that they led to the cancellation of more than half the nuclear power plant orders that had been placed. In France as well, a too-high projection of electricity demand growth led to the construction of too many nuclear plants and thus the utilization of many of them in non-economically-optimal conditions (not in baseload operation). This was despite a large effort to export electricity, which has led to exporting some 15% of electricity produced in France. Today, in addition to the classic issues of electricity demand growth and of competitiveness of nuclear power versus alternatives, we have to face the uncertainties of rapid evolution in two areas: prices of fossil fuels, and the way CO_2 emissions will be handled. These uncertainties may have a very large impact on the future of nuclear energy.

Considering these factors, I will not try to present a precise picture, but rather will indicate my perception of possibilities and trends.

Before giving the presentation of trends country by country and region by region, let me discuss two items which have a major influence on the future prospects of nuclear energy: its competitiveness with alternative sources for electricity production; and the attitude of public authorities towards nuclear energy.

Competitiveness of nuclear with alternatives

As stated in the 2003 MIT report, *The Future of Nuclear Power* (Ref. 1), and as we have indicated at the same time in the paper, *Nuclear Energy Facing Deregulation in Electricity Markets* (Ref. 2), it seems sufficient to compare nuclear energy to CCGT (combined cycle gas turbine) power plants and pulverized coal power plants, as they are the main alternatives. It is clear, as we explained in Ref. 2, that there is a strong geographic influence on this competitiveness, for two main reasons: geographical dependence on coal and gas prices, and different expectations for the cost of a nuclear kilowatt-hour, or even more precisely, the cost of a nuclear kilowatt electric installed.

The difference in the cost of coal and gas can be rationalized mostly on the basis of location of consumption region vis-a-vis the coal and gas production regions. The difference in expectations of the cost of a nuclear kWh may have as a main driver--at least in large industrial countries--the differences in past experience with nuclear projects in a given country.*

****

Let us have a look at the **past experience** of two major nuclear programs, in the United States and in France. In the U.S., the development of the nuclear program, which took place mostly between the end of the 1960s and the beginning of the 1980s (the last nuclear plant order that was not cancelled was in 1973), was economically catastrophic, as shown during a French-U.S. seminar comparing implementation of the two countries' nuclear programs in 1985 (see Ref. 3). In particular, the length of construction went from 63-66 months at the beginning (1967), to 142-158 months estimated in 1980. The total cost of an installed kilowatt electric, according to the energy economics data base of the U.S. Department of Energy, increased by an average 15% per year above inflation, leading to a value of $1,500 per kW (in 1988 dollars) for a plant which started in construction in 1978, and $3,192 per kW (in 1992 dollars) for a plant which started in construction in 1998 (Ref. 3a).

* Clearly, there are many other parameters which may differ from country to country, and which may influence the relative cost of nuclear and fossil, and especially gas, kilowatt-hours--for example, financial parameters like tax structure, amortization scheme, length of loan, or other types of parameters like cost of labor. But what seems also quite important is the "cost of money," or effective interest rate, which is related to the perception an investor has of the risk connected with a given technology. Therefore, at least for "domestic" investors, the past experience with a technology in the country is likely very important.

Of course, there exists a large variation in cost from plant to plant, and even between different regions in the U.S., but the results given for four U.S. regions (Ref. 3b) confirm the general trend above.

It is particularly interesting to compare the U.S. program with the French nuclear program--based at least initially on Westinghouse (U.S.) technology--which is the second largest in the world (103 GWe in the U.S., 63 GWe in France) and which represents more than half of the nuclear capacity of western Europe. In addition, France today has the most powerful nuclear industry in the world (incorporating the former Siemens nuclear business in Germany).

The French program (Ref. 3c), during the similar period as mentioned above for the U.S. program (the decade of the 1970s and early 1980s), built 34 900-MW-class reactors in three standardized series. In contrary to the U.S. situation, the length of construction decreased from 72-78 to 57-59 months at the end of that program. The evolution of costs in constant money, after adjustment for increasing difficulties linked to sites, was only 1.5% per year. This small increase may be explained by increasingly stringent safety requirements.

The actual cost for a power plant whose construction started in 1978 was a few percent below 4,000 French francs per kWe, and those started in construction in 1980 a few percent above 4,000 FF/kWe. The equivalence of this 4,000 FF in U.S. dollars is $800 per kWe at today's exchange rate (a rather low dollar value), or around $600/kWe at 1983 exchange rates.

The main reasons for the differences in cost between the U.S. and France were analyzed in Ref. 3. The two main reasons are:

- an extremely inefficient industrial organization in the U.S.--too many players, vendors, utilities, architect-engineers, resulting in no standardization--and very poor transmission of knowhow and of lessons learned. In France, there was a monopolistic organization with one utility acting as its own architect-engineer, one vendor of nuclear steam supply system, and except at a very early stage, one vendor of turbine-generators. This led to a high degree of standardization and good organization of work from one plant to the next, whether at the same site or on a different site, as well as a good transmission of knowhow and lessons learned.

This example seems to indicate that excess of competition might be counterproductive. The monopolistic situation is probably not optimal, but given the size of the market, a limited number of players is probably the best in the interest of society. For example, Boeing versus Airbus in the world aircraft market is likely more efficient than five U.S. aircraft manufacturers versus five European aircraft manufacturers.

- The second reason was the legal, regulatory and public opinion environment in the U.S.--an unstable regulatory environment, changing rules during plant construction; complex legal framework, varying from state to state and in general favoring opposition groups, delaying construction even if in the end the opponents' case was shown to be without merit; existence of well-organized and vocal antinuclear groups, who took advantage of the legal and regulatory situation mentioned above.

In France, even if basic safety requirements were as conservative as in the U.S. (see Refs. 2 and 3), rules remained stable during plant construction. This is similar to the situation which NRC is now trying to implement, called one-step licensing. The legal authority, if there is no clear violation of regulations, will generally not stop work until the legal process does not demonstrate that there is merit in the plaintiff's case. Opposition groups exist in France, but were much less efficient than their U.S. counterparts.

As a result of the high construction cost in the U.S., the cost of a nuclear kWh was not competitive, if the utilities were authorized to recover the whole investment, or alternatively led to high stranded costs.

On the other hand, the situation in France and in Europe in general--contrary to what is suggested in the MIT report--is quite different. Most European nuclear utilities using light water reactors, if not perturbed by political decisions, were able to recover fully their investments with proper interest rates, while producing kWh competitive with other available sources of electricity.

One exception is the situation in the United Kingdom, which has a large nuclear generating capacity but represents a special case. Indeed, most of the U.K. capacity is of the gas-cooled, graphite-moderated type, a technology developed in the U.K. to which the British decided to stick for many years. Relatively recently, they decided to try the light water reactor (LWR) technology and built one unit which started operation in the 1990s. The gas-cooled reactor technology appears less economic than LWRs. We may note that France also developed at an early stage a national gas-cooled reactor technology, but in the 1960s a debate between advocates of domestic and of imported technology turned out in favor of the LWR, which were perceived as more economic (Ref. 4). Today, all French gas-cooled reactors are shut down.

The financial difficulties encountered by British Energy in recent years are certainly connected with the technology used in most of its reactors. The Sizewell LWR, first of its kind in the U.K., is not a very significant example; indeed, the British decided that their nuclear industry must have the major role and the contract with Westinghouse provided essentially for the knowhow for the nuclear steam supply system. The British nuclear industry, not familiar with LWR technology, certainly learned a lot in the project, but the learning process seems to have been costly.

****

Turning to the **present situation**, we can note that the MIT report rightly points out that under U.S. conditions, there is a need to demonstrate that the claims of the nuclear industry--regarding the schedules and costs of new plants--can be realized (four to five years' construction, and $1,100-$1,500/kWe overnight cost). Today, utilities and other potential investors, considering past experience, have a hard time believing the industry claims, and will likely not engage in construction of new plants without substantial help from the government for their projects. The industry itself seems also not ready to take large risks, for example turnkey contracts.

If the construction of a few plants demonstrates that new regulations for early site approval, standardized design approval and one-stop licensing really works, and if the industry can achieve the expected schedules and costs, at least the upper limit of $1,500/kWe, then investor confidence may be restored, and the financial conditions for nuclear plant construction may become similar to those for coal-fired power plants. This, combined with the current high volatility of gas prices, could ensure the competitiveness of nuclear in the U.S.

In Europe and other regions, the situation seems more favorable for nuclear. In Table I we compare the MIT study results (Ref. 1) with calculations done by Electricite de France in connection with the recent decision (September 2004) to build a 1,700-MW EPR unit at Flamanville (Ref. 5) .

Levelized cost of electricity (U.S. cents per kWh)

MIT (2002$)	EDF (2004$) (1 Euro= $1.3)	Type of fuel
4.2 - 6.7 (most optimistic) (base case)	4.1 - 5.0 (series of 10) (FOAK)	uranium
3.8 - 4.1 - 5.6	5.1 - 5.5	natural gas
4.2	4.7	coal

These data show that the cost of a new U.S. nuclear power plant in the MIT base case is much higher--about 60%-- than that of an EPR series unit--and even higher than that of a FOAK EPR--about 30%. However, the most optimistic case for the U.S. is quite close to the cost of a series EPR. The difference in gas and coal estimates may be explained by the different market situations between the U.S. and Europe, and perhaps also by a more conservative attitude concerning the evolution of gas prices in Europe, but the European gas cases are within the high limits of the MIT projections.

We may note that the organization for the Flamanville EPR is similar to the traditional French nuclear plant construction organization: EDF is owner and architect-engineer, and will place an order with Framatome ANP (the former Framatome plus Siemens nuclear) for a nuclear island, this company being the only vendor having a 1,700-MW NSSS design. EDF will also prepare the call for bids for the turbine-generator and balance of plant. EDF's cost projections for the EPR in Flamanville, which is scheduled to start up in 2012, must of course be confirmed.

It may be interesting to note that a Finnish study, from Lappenraanta University (Ref. 6), is even more optimistic than EDF for the competitiveness of EPR versus natural gas. TVO, a privately owned Finnish utility, ordered a 1,600-MWe EPR in December 2003 for a price "around 3-billion euros" (a rumored 3.08-billion) on a turnkey basis (startup expected in 2009). The price includes interest during construction, the first core, infrastructure and a training simulator. We may note that the vendor has subcontracted some architect-engineering work to a company where EDF is the main partner. In this case, the vendor, a consortium of Areva and Siemens (parents of Framatome ANP) assumes practically all the risk connected with the FOAK power plant (schedule, cost, performance). This shows the degree of confidence of the European industry (Areva and Siemens). In comparison, the unsuccessful General Electric bid to TVO seems to have been much less aggressive: more than $2,000 per kWe overnight cost, when a GE study for construction of an ABWR in the U.S.

indicated $1,200-$1,400 per kWe for a single unit and ABWR projects in Japan already achieved construction within 48 months.

We may add that recent construction in China of six nuclear power plants around the 700-1,000 MW range (two by French, two by Canadian, and two by Russian industry) is on or before schedule, and seems to be within budget.

****

As already stated above, we conclude that the competitiveness of nuclear versus coal and gas is strongly dependent on country. In the U.S., as the MIT report indicated, competitiveness of nuclear is not ensured, at least for the time being. In France, Finland and other countries, it is likely that competitiveness is ensured, even without any provision for a CO_2 penalty for fossil fuel-fired power, and also irrespective of whether electricity markets are deregulated or not.

Indeed, EDF is preparing for a deregulated French electricity market. TVO is a private utility operating in one of the first European markets to be deregulated, the Nordpool system. Even though TVO's shareholders are large power consumers, it must be pointed out that those shareholders are selling about 50% of their power on the Nordpool market.

Attitude of public authorities

It is quite clear that nuclear energy needs a positive attitude on the part of public authorities (federal, but also regional) to be able to compete with other sources of electricity. Indeed, public authorities can initiate laws to forbid nuclear power, to impose moratoria on nuclear construction, or to mandate withdrawal from nuclear power. Even without going to such extremes, they may render nuclear power impracticable by taking a negative attitude on issues like disposal of radioactive waste--which cannot be resolved by the industry alone--or licensing and safety regulation--which may unnecessarily complicate and penalize the economics of nuclear power.

Therefore, public authorities should take positions by comparing the positive attributes of nuclear power--security of energy supply, absence of harmful emissions including CO_2--to some problems of the technology: radioactive waste disposal, the possibility, even if small, of severe accidents, vulnerability to terrorist attacks, influence on the proliferation of nuclear weapons. This comparison should be complemented by a similar analysis of alternative electricity sources. In the real world, the weighting of different attributes is not always calculated rationally, but often has an emotional dimension. Authorities are quite normally influenced by the attitude of the public. The public itself has some fears which often are exacerbated when there is no counterbalancing perception of the need for nuclear energy.

In addition, the public authorities may have a negative attitude towards nuclear energy even if the majority of the public is not opposed to the technology. It may be sufficient that a minority party strongly opposed to nuclear is needed to form a government coalition. The attitude of the public authorities may of course change in time, depending notably on the perception of the need for nuclear energy--linked to the satisfaction of supply security and/or limiting environmental pollution, notably greenhouse gases.

****

In the following section, we will give our views concerning the future of nuclear power in different countries or regions, of course taking into account our perception of the attitude of public authorities towards nuclear power as well as the possible evolution in that attitude.

The situation in France

It seems quite likely that demand stemming from the retirement of today's nuclear plants, as well as additional baseload needs, will be satisfied by new nuclear plants. This is because of the CO_2 issue, security of supply, and the good competitiveness of nuclear with natural gas and clean coal for baseload electricity production. The political consensus for this approach is broad, and even if one cannot be sure what the situation will be in 15 or 30 years, it seems to me that it is unlikely that this consensus will disappear. In addition, public acceptance, especially on the local level, is today quite broad. There was a clear competition between the existing nuclear power plant sites which were proposed to host the first EPR unit. The vast majority of the public and elected officials around these sites, especially in Flamanville which was chosen, was eager to host the new reactor.

<u>Let us now look at the needs for additional baseload capacity</u>. The limited prospects for large demand growth, linked to a renewed consciousness of the need for energy saving and efficient energy use stemming from the rise in oil prices, as well as an existing surplus of nuclear capacity, make it reasonable to expect that no new baseload power plants will be needed for 15, 20 or even 25 years. The non-baseload plant will likely be fueled by natural gas, except if there is a major and lasting increase in gas prices. Therefore, the construction of large nuclear capacity will be mostly linked in the next 25 years to potential <u>needs for replacement of existing nuclear power plants</u>. France has now 63 gigawatts (electric) of nuclear power capacity, which were built over a period of more than 25 years. Excluding the first PWR station, Fessenheim, the period was a little more than 20 years. The question is when the operating plants should be retired and when significant replacement capacity should be put in operation. If we exclude the two Fessenheim units, whose retirement will be compensated by a sharp decrease in electricity demand for uranium enrichment (because of a change in technology from gaseous diffusion to centrifuge), we

may consider, as EDF indicates, that this replacement should start in 20 years, assuming a plant lifetime of at least 40 years. We should, however, note that useful lifetime was initially supposed to be 20 years, then 25, then 30, and now EDF says 40 years. In the U.S., many plants of similar design but older, have obtained or are requesting licenses for 60 years. Therefore, it seems logical to ask whether 40 years for France's existing plants is the final number. The question may have to be considered plant by plant, but it seems certain that there will be strong economic pressure to extend plant lifetime over 40 years, and there is no clear evidence today that that will not be possible from the safety viewpoint. Therefore, it is not impossible that the 20 years expected by EDF before a large number of nuclear power plants are needed will become, for example, 25 or 30 years, and/or the duration of the replacements, instead of 20 years, may become 25 or 30.

The situation in the European Union and some neighboring countries.

We may distinguish three groups of countries:

A. Countries clearly interested in building additional (or replacement) nuclear plants in the near future and within the next 25 years. These are: France, Finland, Bulgaria, Hungary, Lithuania, Slovakia, Switzerland, Romania, the Czech Republic, Ukraine, and likely the U.K. The size of the program and the precise schedule will likely depend on the evolution in demand and its anticipation, but also on the competition with alternatives--therefore, on the price of natural gas and the way the CO_2 problem is resolved.

The case of the United Kingdom is specific. The U.K. has a large nuclear program (12 GW), but has some problems: consensus on nuclear waste management; poor economic performance of present reactor technologies (AGR and Magnox); a very expensive LWR prototype at Sizewell; and privileged access to natural gas. In spite of these problems, it is likely that some nuclear plants will be built in the U.K. within the next 25 years, given the large involvement of the U.K. in the world nuclear industry.

B. Countries with major political opposition to nuclear: Germany (21 GW), Sweden (9 GW), Belgium (6 GW), which have laws imposing a phase-out of nuclear power; Spain (8 GW), whose new government indicated in mid-2004 its intention to phase out nuclear; Italy (0 GW), which in 1978 forbade construction of nuclear plants except those considered "inherently safe." The first four countries may, however, face the problem of reconciling the issue of CO_2 emissions and the need to curb electricity prices with the retirement of their nuclear plants. Energy conservation and energy efficiency, plus renewables, will likely not suffice to resolve this problem. Therefore, we cannot exclude that those countries will have to change their policies when the time comes to implement the nuclear phase-out. Some, like Germany, may consider the solution of replacing nuclear and simultaneously coal-fired plants with gas-fired plants to maintain CO_2 emissions at the same level, but this may pose the problem of security of supply and of the cost of electricity. The possibility of capture and sequestration of CO_2 from coal burning can be considered, but it likely will make coal largely uncompetitive compared to nuclear.

All these considerations in fact led the Swedish government to eliminate the initial target date for the nuclear phase-out to be finished (2010).

We may note that many political parties in these countries have already indicated that their position, if they regain power, would be to reconsider the nuclear phase-out. In January 2005, the prime minister of Italy, Silvio Berlusconi, called for a reconsideration of nuclear power in his country, saying Italian industry was penalized by high electricity prices from fossil fuel plants. In addition, utilities from Belgium, Germany, Italy and Spain have indicated their interest in the new French EPR unit, and the Italian parliament in 2004 passed a measure allowing utility Enel, in which the state has a majority stake, to participate in foreign nuclear power plant projects.

In conclusion, it is difficult to predict how and when these countries' policies will evolve, but at least we cannot exclude that some or even all of them will change their phase-out policies and build new nuclear plants within 25 years.

<u>C. Countries with slim chances of building new nuclear plants within 25 years.</u>

These include Austria, Denmark, Ireland, Luxemburg, Portugal, Norway, Greece and probably Poland. However, in Poland a discussion is resuming about nuclear energy under the pressure of the Kyoto Protocol, and the government's draft energy strategy proposes new nuclear capacity beyond the year 2020. In any case, there will not be major additions of nuclear capacity in these countries during the next 25 years.

The rest of the world

A. The U.S., which has the largest nuclear power capacity in the world (91 GW) and was at the origin of the technology, suffered major economic disappointment when building its current nuclear capacity: two to three times higher cost and much longer lead-times than had been predicted (see above). However, recently the spectacular improvement in performance of existing reactors has led, along with the issue of climate change, to renewed interest in nuclear power. For example, Vice President Cheney has put forth the scenario of 50 additional gigawatts of nuclear power by 2020. How and when this interest will materialize will depend on many factors, especially whether the government will, by providing financial and/or fiscal advantages for the first 6-8 reactor units, help the industry to demonstrate that new conditions permit construction of nuclear plants in four to five years and at similar costs to those in other countries.

B. China and India, which may have a major impact on the development of nuclear power within 25 years. China is likely to build 30 GW during the next 25 years and possibly more, depending essentially on how the CO_2 issue is tackled: will industrialized countries allow nuclear to be eligible for Joint Implementation or Clean Development Mechanism under the Kyoto Protocol, and will they apply these measures to China? India will likely build some 20 GW of nuclear within the next 25 years. The prime minister has announced that a total of 20 GW will be in operation in 2020. The success of this program will depend partly on how the CO_2 issue is tackled, but here the proliferation policies of industrialized countries may play a role; indeed, the lack of international cooperation with India has penalized the economics, but also perhaps the safety, of its civilian nuclear power program, without influencing military nuclear developments. If the nuclear weapons states decide to take a more realistic attitude toward India, this may improve the chances of its success and the size of India's civilian nuclear program.

C. South Korea (16 GW) and Japan (45 GW) have large and steady nuclear power programs. These programs will likely go ahead, with perhaps some difficulty in Japan, where public opinion, the internal organization of safety, and communication continue to be issues. It is to be expected that the share of nuclear in total electricity production in those two countries will increase, notably because of tensions around oil and gas supply and the CO_2 problem.

D. In Russia and some former Soviet countries, we can expect construction of a few new nuclear plants, but totalling a modest capacity because of the availability of local resources (gas, coal, oil) and the scarcity of capital. Russia may, however, play an important role in the world nuclear fuel cycle - spent fuel storage, reprocessing, and perhaps final disposal - and its industry will certainly be a major competitor for the construction of new plants and supply of fresh nuclear fuel in other countries.

E. In some countries of South America, Africa, and Asian regions other than those mentioned above, with the increase in oil and gas prices, as well as the issue of CO_2, we can anticipate a renewed interest in nuclear energy. For example, Brazil, Argentina, South Africa, which already have nuclear power plants, may decide on the construction of additional plants. Other countries, like Egypt, Indonesia, Vietnam, Iran, are interested; some countries in northern Africa and the Middle East may also become more and more interested. The South African PBMR reactor concept (a "pebble bed" modular high-temperature helium-cooled reactor based on former German technology), if successfully developed, could interest countries with even much smaller electricity generating capacity.

****

In this short presentation, it is not possible to discuss the nuclear fuel cycle or the nuclear industry's capability to develop and implement new designs and to satisfy the likely demand for nuclear plants. But of course, those issues are also relevant for the question of the future of nuclear energy.

My final conclusion is that there is a large potential for the development of nuclear energy. There are some favorable arguments - the geopolitical risk connected with supply of oil and gas, as well as the increased perception of finite fossil fuel resources and of the detrimental effects of greenhouse gases - but there are still many uncertainties, especially regarding the magnitude and the schedule of nuclear capacity additions.

REFERENCES

1. John Deutch and Ernest Moniz, co-chairs; Eric Beckjord, executive director. The Future of Nuclear Power: an interdisciplinary MIT study. MIT Press, 2003.

2. C. Pierre Zaleski and Sophie Meritet. L'Energie Nucléaire face à la déréglementation des marchés d'électricité (Nuclear energy confronted with electricity market deregulation). *Revue de l'Energie* N°547, Paris, June 2003.

3. Proceedings of an Electric Power Research Institute-University of Paris Dauphine seminar, "Mise en Oeuvre des Programmes Nucléaires: une première comparaison internationale France-Etats-Unis" ("Implementation of nuclear programs: a first international comparison between France and the United States"). In *Revue de l'Energie* N°374, Paris, May-June 1985.

   a. John Crowley, United Engineers & Constructors. "The U.S. experience of construction of nuclear power plants and costs per installed kilowatt."

   b. Chaim Braun, EPRI. "Comparative Review of U.S. and French Power Plant Construction Projects."

   c. Georges Moynet, and Jean-Claude Sol, Electricité de France. "Les performances économiques du programme nucléaire français." ("Economic performance of the French nuclear power program|")

4. Gabrielle Hecht. The Radiance of France: Nuclear Power and National Identity after World War II. MIT Press, 1998.

5. Goulven Graillat, Electricité de France. Oral presentation during a seminar on the Finnish EPR project, University of Paris-Dauphine, January 2005.

6. Risto Tarjanne, Kari Luostarinen. Competitiveness comparison of the electricity production alternatives (price level March 2003). Lappeenranta University of Technology research report EN B-156 June 2003. ISBN 9517648952; ISSN 1459-2630.

6b. Risto Tarjanne, Kari Luostarinen. "Economics of Nuclear Power in Finland." Annual meeting of the American Nuclear Society, Hollywood, Fla., June 2002.