World Nuclear Association Annual Symposium
3-5 September 2003 - London

Potential of Light Water Reactors for Future Nuclear Power Plants

Ralf Güldner

Introduction

You may wonder why I want to speak about the potential of light water reactors in a session on "Innovative reactors and their role in the long-term development of nuclear power". It is easy to say: in my analysis, LWRs and Generation IV reactors will largely be complementary. To define the long-term role of innovative reactors one has to take the potential of today's reactor types into account, and vice versa.

Rising energy demand

At world level, the need for energy is rising, and will continue to do so at least for the next several decades. Ever increasing use of fossil fuels, the primary source of energy today, cannot be a long lasting solution, for reasons known to every one of us in terms of finite resources, geostrategic considerations and concerns regarding climate change. Increasing the share of renewable energies is being strongly promoted, but for the foreseeable future their economically sound contribution will be limited, partly due to limited resources (hydro, biomass) and partly due to intermittent supply (wind, solar).

In its reference scenario up to the year 2050 presented in 1998, the World Energy Council shows that, if world primary energy demand doubles over the next 50 years, all energy sources will have to increase their contribution dramatically (*Figure 1*). Even expanding the consumption of fossil fuels far beyond the level compatible with climate protection and making optimistic assumptions relative to the expansion of the use of regenerative energies, the scenario results in a necessary nuclear power plant capacity that is more than four times the installed nuclear capacity of today. Studies of other leading institutions with time horizons up to 2030 show a less pronounced growth in nuclear capacity. But the growing number of such studies by itself underlines the renewed public interest in long-term energy perspectives. *Figure 2* shows a selection of such projections for the installed nuclear capacity.

The 2003 edition of the "World Energy Outlook", published every year by the US Department of Energy, has revised upwards the expected nuclear capacities, compared to the 2002 edition. In its study "World energy, technology and climate policy outlook", known as the WETO study, the European Commission, despite split opinions on nuclear energy among EU Member States, predicts nuclear growth even in the EU.

In *Figure 2*, the dotted lines show the decrease of the presently installed nuclear capacity assuming plant lifetimes of 40 and 60 years respectively for all existing units. The demand for new plants is the gap between the dotted line you select and the projected nuclear capacity you consider credible.

Although the different scenarios shown offer a wide spectrum of possible developments, these institutions largely agree that sustainable development requires that nuclear energy, on a worldwide scale, not only maintains but rather increases its contribution to an affordable, environment-friendly and socially acceptable energy supply.

This translates into a double challenge:

- maintaining and expanding the nuclear share in its traditional field of deployment, that is to say, in base-load power generation; and
- exploring and penetrating new fields for the deployment of nuclear energy, outside of electric power generation.

At an age of 50 years, nuclear technology is still young and evolving, offering a large additional potential that is under study in the framework of "Generation IV International Forum" (GIF) and INPRO. But as far as base-load electric power generation in large units is concerned, water-cooled reactors, and in particular light water reactors, have established themselves as proven technology and reliable workhorses. About 85% of all NPPs operating today and almost all units currently under construction worldwide are equipped with LWRs *(Figure 3)*. It is this technology that has made nuclear energy a success story, and it is also the technological asset for the next decades. The know-how accumulated within the nuclear industry, by NPP operators and vendors alike, and within the scientific community, expert organizations and licensing authorities is the most valuable capital for the future of nuclear energy.

Role of nuclear energy for base load power generation

Progressing electrification and ever more applications for electricity will result in the growth of electricity consumption being higher than the growth of primary energy demand. Increasing urbanisation, especially in developing countries, increases the need for more centralised electricity generation, contrary to all discussions on decentralised power generation.

Nuclear energy is a well-established source of primary energy for electricity generation in large units, especially in industrialised countries with large grids. It has demonstrated its competitiveness even under the conditions of deregulated electricity markets. For a long time to come, base-load electricity generation will remain a primary task for nuclear energy.

In the majority of countries with nuclear power plants, the main focus is presently on maintaining or improving performance and output and, as far as technically, economically and politically possible, extending plant lifetime beyond 40 years. But beginning towards the end of this decade, the topic of new construction of NPPs will return to the agenda, both for replacing aging nuclear and fossil-fired plants and for satisfying growing power demand. In the absence of other proven reactor types or new types ready for deployment, the market belongs to water-cooled reactors and in particular light water reactors, i.e. PWRs of Western designs and the Russian VVER, and BWRs. In preparing for the forthcoming upswing in new plant construction, vendors have further advanced their second-generation designs or developed third-generation designs to better meet the economic needs of their customers and to attain public requirements for further safety improvements. In advance of the expected market for new NPPs in the US, many of the new designs have undergone the certification process with the US NRC or are preparing such a move *(Figure 4).*

The second-generation LWRs have accumulated more than 5000 reactor-years of successful operation and thus offer an unmatched basis of experience for the development of third-generation reactors. These reactors of generation III have been developed in close cooperation with customers taking into account up-to-date requirements defined by the utility industry, such as the European Utility Requirements, and state-of-the-art safety requirements. In several aspects, improvements achieved with generation III designs are in line with goals for generation IV reactors. Some of these advanced water-cooled reactors are now ready to compete in the market and are in bidding processes. *Figure 5* shows the overlapping life cycles of the different reactor generations.

There is no reason to assume that, with these generation III designs, water-cooled reactors have fully exhausted their technological potential. Further improvements can be expected in the future, both in plant design and in the fuel cycle. Standardization, improved man-machine interface and a high degree of automation are examples for further improvement. Given the time frame for the development of generation IV reactors, it is safe to say that water-cooled reactors will continue to dominate in the new orders for the power generation market at least for the next 20–30 years.

Expanding the use of nuclear energy into new fields of application

Limiting the use of fossil energies to a level compatible with sustainable development cannot be achieved by addressing the electricity supply sector alone. It is essential to substitute a growing part of fossil fuels consumed in the transport and heating sectors, too. There are three main fields where nuclear energy can serve this purpose:

- hydrogen generation (by electrolysis and thermo-chemical processes);
- desalination of sea water; and
- process heat and district heating.

A small number of NPPs are already today supplying some heat to sea water desalination plants and district heating grids and one Swiss plant provides process steam to a pulp factory. Nuclear energy could penetrate these segments far more with dedicated reactor plants in smaller units, provided that they can overcome by simplified designs the barriers set by economies of scale.

The most promising segment for introducing nuclear energy is the hydrogen market. There is a huge and fast-growing demand for hydrogen:

- as a chemical agent, for oil refineries and chemical plants, with a demand amounting today to the equivalent of 200 GW of thermal energy;
- as a fuel for fuel cells for both stationary and mobile applications, and possibly for heating; and
- possibly as a means for energy storage.

The long-term goal is hydrogen production by means of a thermo-chemical process with direct use of high-temperature heat from (V)HTRs starting not before 2020. Intermediate steps could be:

- electrolysis of water in off-peak periods using nuclear-generated electricity; and
- use of low-temperature nuclear heat to assist steam reforming of natural gas.

These intermediate steps could be taken with today's water-cooled reactors and their future advanced versions.

This means that during the next, say, two decades nuclear energy can penetrate these new markets with existing reactors in their standard sizes economically by combining heat and power production for achieving high load factors.

On the other hand, these new markets for nuclear energy offer opportunities for new reactor designs that have an advantage over current reactors, either by supplying process heat at temperatures beyond those achievable in water-cooled reactors or by being competitive in small unit sizes.

However, it should not be overlooked that any economic analysis of generation IV reactor designs needs to take into account the extent of the additional infrastructure necessary for its deployment, particularly in relation to the nuclear fuel cycle. This is to be set in relation to the market potential that can be opened up with each specific design.

Once a generation IV reactor has proven its economic viability in one of the new segments described above it is possible that, sooner or later, it will become competitive also in the "classical" electricity generation segment dominated until now by water-cooled reactors. Therefore, the possibility cannot be excluded that one or several new reactor types will conquer a part of the "classical" power generation market but penetration will probably be slow because it will mean an uphill fight against the well-established water-cooled reactors with their immense treasure of experience and their existing infrastructure.

Thus, in my analysis, generation IV reactors will for a considerable time not replace water-cooled reactors but rather be complementary to them.

Ensuring long-term supply of nuclear fuel

This is particularly true for high-converting and breeder reactors of which some types are under consideration in the framework of GIF. From the very beginning of the peaceful use of nuclear energy, there were concerns about whether uranium resources would be large enough to support a large-scale utilisation of nuclear energy for centuries. Therefore, a lot of effort and money was put into the development of fast breeder reactors which offer the potential to extract almost a hundred times more energy from a kilogram of uranium than LWRs by converting non-fissile U-238 into fissile plutonium in excess of their own consumption of fissile material. This excess fissile material can be used to fuel conventional LWRs or perhaps HTRs. As the installed nuclear generating capacity expanded far more slowly than originally anticipated, interest in fast breeders declined in the 1980s and 1990s.

If society opts for a strong expansion of nuclear energy and its long-term use, the question of how to ensure uranium supply becomes relevant again. However, we know from experience that breeders are more expensive to build than LWRs, so that there is no incentive for building more breeders than are necessary to ensure adequate supply of fissile material, thus forming a kind of symbiosis with water-cooled reactors in base-load electricity generation.

Fast breeders need a closed fuel cycle involving spent fuel reprocessing and MOX fuel production in order to truly benefit from breeding. They will be able to profit from the fact that both technologies are being applied on a commercial scale in Europe. Incidentally, this advantage does not exist for any fuel cycle involving thorium/U-233.

Winning public acceptance by switching to new reactor types?

Public-opinion polls in many countries have shown that the majority accepts or at least tolerates existing reactors. Normally, the level of acceptance is highest in the immediate vicinity of the plant. But when it comes to the question of building new NPPs, the acceptance level is considerably lower, with proponents often being a minority. Apart from the waste issue, concerns related to plant safety are identified as critical. Some people draw the conclusion that public acceptance can be won by switching to "super-safe" or "inherently safe" reactor models. Usually, they point to the HTR as a reactor in which a core-melt accident cannot happen. In a leading German newspaper this position was summarized in the words: "Nuclear certainly has a future, but not with today's reactors."

So we have to ask ourselves whether we can win the battle for new NPPs by switching to a new reactor line.

My answer is: “No”, for several reasons.

- First, no new reactor line is ready for near-term deployment, let alone with a multi-plant, multi-year track record for technical and economic performance that can convince investors to put billions of dollars into such plants. Near-term deployment is a must because the market is there, as demonstrated by ongoing plant construction in several Asian countries, by the Finland 5 project and by the US programmes for a plant construction revival. Moreover, an early upswing in new plant construction in Western Europe and the US will help preserve the capabilities of the nuclear industry.

- Secondly, advanced PWR and BWR models can meet the latest safety requirements, including the control of postulated core-melt accidents in such a manner that the consequences are limited to the plant perimeter so that no incisive emergency measures like evacuation of people living in the vicinity of the plant are necessary. Switching to a new reactor type for its presumed higher safety level would only undermine the public trust in the existing reactor models.

- Thirdly, the popularity bonus that futuristic concepts enjoy in the media and the public is usually gone at the moment when they leave the drawing-board. We experienced this in Germany when we tried to obtain a design certification for the modular pebble-bed HTR.

- And lastly, you know that the grass on the other side of the fence always looks greener. Or to quote an old saying in our industry: “The paper-moderated, ink-cooled reactor is the safest of all.” Once you launch a concrete project, all kinds of unexpected problems occur. This experience is not limited to any specific type of advanced reactors.

It is my conviction that the safety issue in public acceptance cannot be successfully addressed by technology alone. Zero-risk technology does not exist. The task ahead of us is to convince the public that the new plant to be decided upon is in the common interest of society and justifies the residual risk. It is not essential that we come up with new designs in which the safety concept is so simple that it can be explained to every child. What really counts is that the safety authorities are satisfied by the safety features on a design and that the safety authorities enjoy credibility with the public. This is the case, for example, in the Finland 5 project, where the positive decision by government and parliament was endorsed by a broad majority of the Finnish people.

Furthermore, a recent Eurostat opinion poll has shown that the biggest public concern relating to nuclear energy is the waste management issue, not reactor safety. In all the Member States of the EU, with the exception of Austria, a majority favours the use of nuclear energy on condition that the nuclear waste is stored in a safe manner. Finland has set a positive example by choosing the location for the final repository for high-level waste before deciding on the fifth plant.

My conclusion is: we should decide upon our involvement in new reactor lines according to their realistic market potential and should not let public relations aspects guide us in our technological choices. On the contrary, the nuclear industry should play a more active role in relation to the public, explaining the crucial contribution that nuclear energy is already making today towards sustainable development and what nuclear has to offer for the future. It is particularly important for public acceptance that nuclear energy is recognized as carbon-free and that, in national and EU politics, it gets the same treatment as other carbon-free sources of energy.

Summary

Let me summarize.

- The nuclear industry is faced with the double challenge of maintaining and expanding the presence of nuclear energy in base-load electricity generation and the question of tackling the penetration of nuclear energy in other sectors of the energy market, in particular the hydrogen economy.

- For several more decades, water-cooled reactors, and particularly LWRs, will be the backbone for base-load electricity generation. Generation IV reactor types may enter this market in about 30 years from now, provided they become competitive with LWRs or are needed as a complement to LWRs to stretch out uranium resources.

- Generation IV reactors will find their market chance primarily in new segments of the energy market, such as the production of hydrogen, sea-water desalination and process heat before they can be expected to compete with standardized LWRs in electricity generation.

- Public acceptance for new NPP construction does not depend on the reactor type as long as the latest safety requirements are fulfilled. The critical public issue is waste management. An upswing in new plant construction in Western Europe and North America will depend on the real need for new plants and on public recognition that nuclear energy supports sustainable development.

Figure 1. World Primary Energy Demand

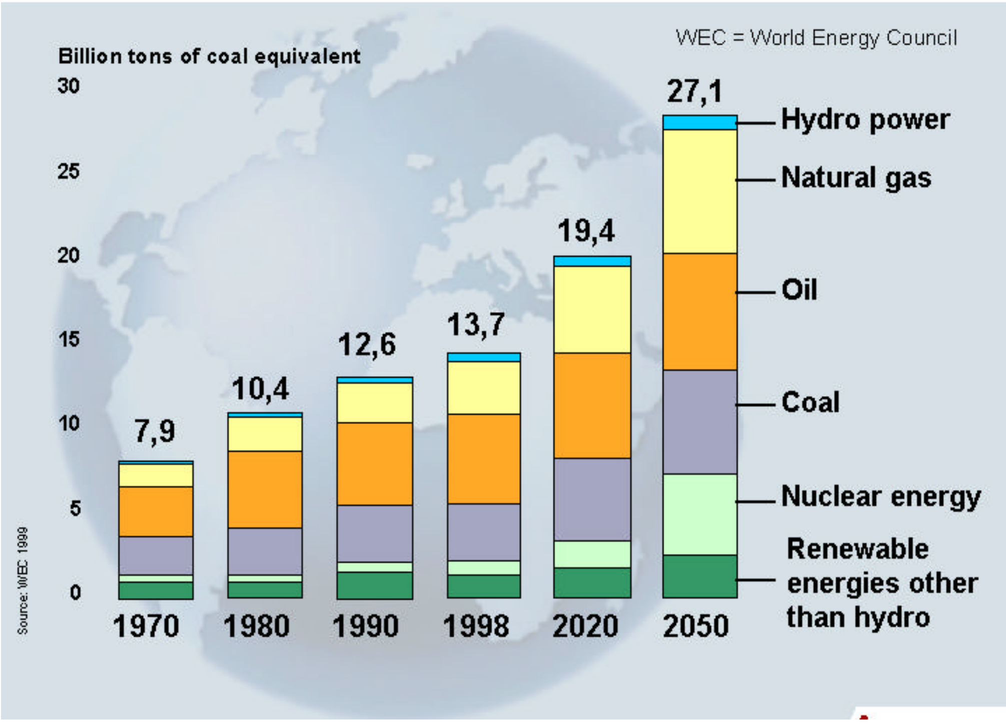

Figure 2. Forecasts for Worldwide Installed Capacity of NPPs

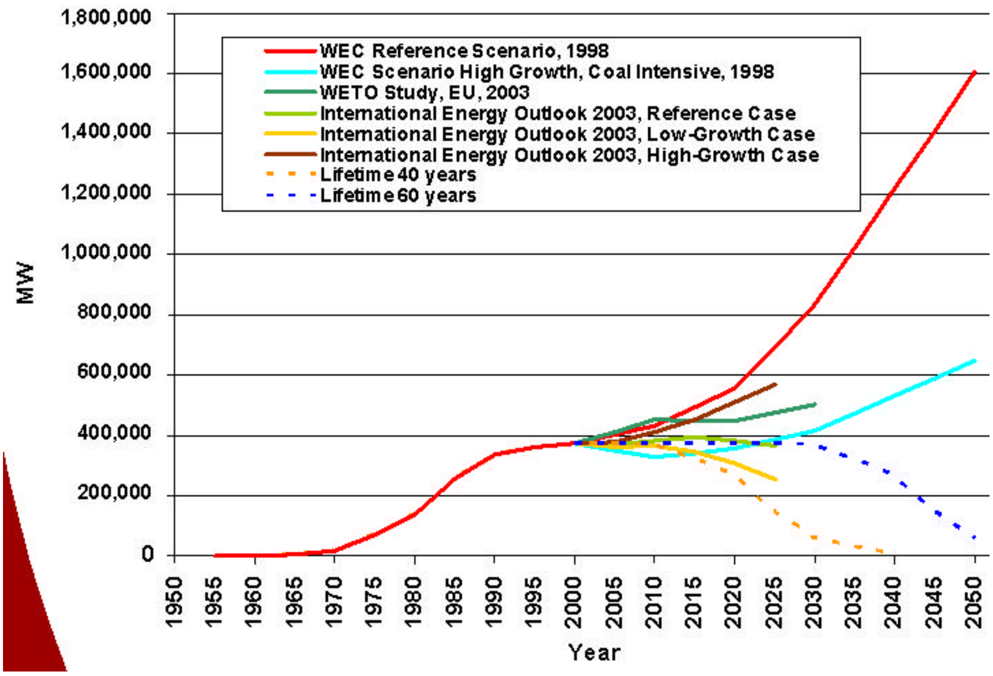

Figure 3. Installed NPP Capacity Worldwide by Reactor Types

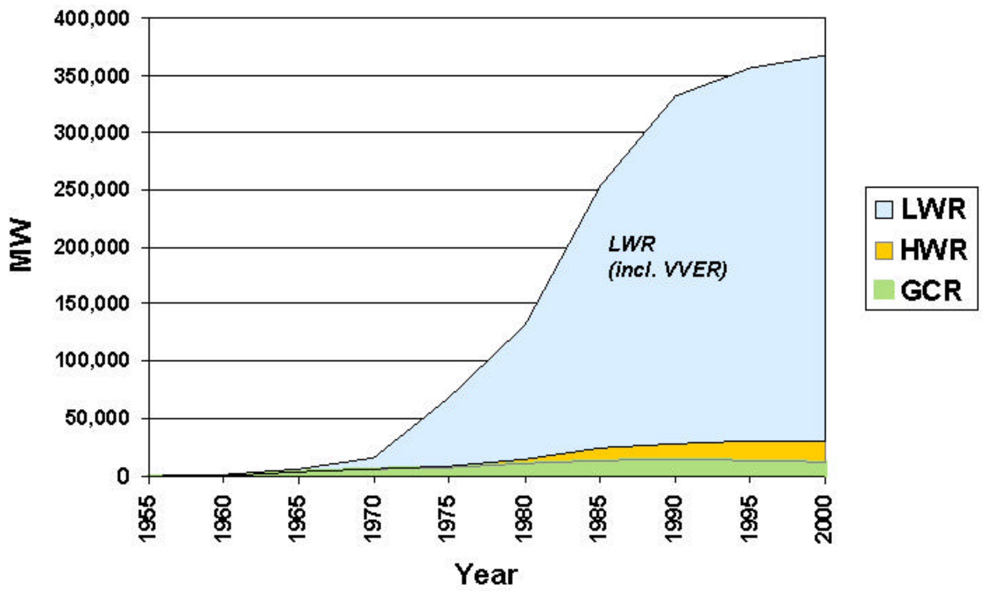

Figure 4. Certification in the US for New Water-cooled Reactors

Reactor Design	*Lead Vendor(s)*	*Design Category*	*Status at NRC*
System 80+	*Westinghouse BNFL*	*PWR*	*Certified*
ABWR	*GE, Toshiba, Hitachi*	*BWR*	*Certified*
AP600	*Westinghouse BNFL*	*PWR*	*Certified*
AP1000	*Westinghouse BNFL*	*PWR*	*Certification*
ESBWR	*GE*	*BWR*	*Pre-certification*
SWR-1000	*Framatome ANP*	*BWR*	*Pre-certification*
ACR-700	*AECL*	*PHWR*	*Pre-certification*
IRIS	*Westinghouse BNFL*	*PWR*	*Pre-certification*
EPR	*Framatome ANP*	*PWR*	*No application decision*
ACR-1000	*AECL*	*PHWR*	*No application decision*

Figure 5. Reactor Generations