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The Nuclear Renaissance and AREVA's Reactor Designs for the 21st Century: EPR and SWR-1000

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ABSTRACT

Hydro and nuclear energy are the most environmentally benign way of producing electricity on a large scale. Nuclear generated electricity releases 38 times fewer greenhouse gases than coal, 27 times fewer than oil and 15 times fewer than natural gas [9]. On a global scale nuclear power annually saves about 10% of the global CO_2 emission. European nuclear power plants save amount of CO_2 emissions corresponding with the annual emission of CO_2 from all European passenger cars [16]. Also, that is approximately twice the total estimated quantity to be avoided in Europe under the Kyoto Protocol during the period 2008–2012.

In respect to main drivers – such as concerns of the global warming effect, population growth, and future energy supply shortfall, low operating costs, reduced dependence on imported gas – it is clear that 30 new nuclear reactors currently being constructed in 11 countries and another 35 and more planed during next 10 years confirm the nuclear renaissance.

Participation in the construction of 100 reactors out of 443 worldwide operated in January 2006 and supplying fuel to 148 of them AREVA helps meet the 21st century's greatest challenges: making energy available to all, protecting the planet, and acting responsibly towards future generations. With EPR and SWR-1000, AREVA NP has developed advanced design concepts of Generation III+ nuclear reactors which fully meet the most stringent requirements in terms of nuclear safety, operational reliability and economic performance.

1 INTRODUCTION — FACING THE CHALLENGES

The world will need greatly an increased energy supply in the next period, and in particular cleanly–generated electricity. Its demand is increasing much more rapidly than overall energy use and is likely to double within next 20 years.

Estimates show that the global population is rising toward 9 to 10 billion people by 2050, with general energy consumption expected to double or triple. About 70% of this growth in energy consumption is attributed to demand in developing countries. Electricity consumption is estimated to grow much faster — by a factor of 5 to 7 until 2050 [15].

Global energy trends and developments paint a fairly clear picture, clearly showing:

- Steep growth of population and energy demands,
- Severe competition in getting access to limited and unevenly distributed fossil resources,
- Increasing instability in oil/gas–exporting countries,
- Increasing ecological concern and environmental limitations,
- Increasing disparity in energy consumption between rich and poor countries.

At present, nuclear power provides over 16% of the world's electricity, almost 24% of electricity in OECD (Organisation for Economic Cooperation and Development) countries, and 34% in the EU (European Union). Since the mid 1980s, the share of nuclear in world electricity production has remained almost constant at around 16% with output from nuclear reactors actually increasing to match the growth in global electricity consumption. Using hydrocarbon fuel to meet the growth of energy consumption is rather questionable, for reasons varying from limited oil resources to concerns about the greenhouse effect. In that light, projections indicate that the share of nuclear in the global energy market could reach 35% by the year 2050 [15].

Furthermore it is also a fact that nuclear technology is not only an element of the energy market. It goes far beyond the generation of electricity, penetrating social, political, and economic spheres of industrial societies in many forms, which include:

- Nuclear medicine in health care,
- Nuclear techniques in food management and agriculture,
- Nuclear applications for quality control in industry,
- Nuclear applications in science, research, and industry (lasers, accelerators, isotope production),
- Nuclear power for potable water supply.

In energy/electricity market nuclear power plants (NPP) have proven to be good assets for the energy business. They are reliable, have low operating costs and the fuel is abundantly available from geopolitically stable sources. There is no doubt that the nuclear renaissance is under way, but fulfilling nuclear energy’s promise comes with many challenges [6]:

- Many new plants are coming on–line with little time for the staff to gain experience;
- The market is focused on short–term results, but the nuclear industry must manage a long construction period (*frozen investment*) — therein lies a potential conflict;
- Different current performance of worldwide existing plants — the gap between the best performers and the worst performers is still too large in all 4 regions;
- Competition and the attendant cost–cutting, staff reductions, and production pressure — high levels of safety and a competitive environment have to coexist;
- Commercial competition has the potential to erode nuclear cooperation — instead to use increased competition as a catalyst the sharing among nuclear organizations could be increased.

Facing all these challenges is the challenge itself for the nuclear renaissance.

Today nuclear energy — improved and advanced — is back on the policy agendas of many countries. This signals a revival in support for nuclear power that was diminished by the accidents at Three Mile Island and Chernobyl and also by NPP construction cost overruns in the 1970s and 1980s [2]. But, no matter how much nuclear industry has improved over the years, it must be kept in mind that an accident is always possible. To think and to act as if it were not only increases the probability of an accident’s occurring. If another accident does occur, it will undo all the good work of recent years, and it will halt and postpone the nuclear renaissance for another 15 or 20 years [6]. It takes a long time to build credibility, but a single moment for it to vanish. In nuclear industry, there is no margin for error, no positive bank account of goodwill.

As Hans Blix, the former director general of the IAEA (International Atomic Energy Agency) said, “Only the prolonged, relatively problem–free operation of NPPs will dispel misgivings about the use of nuclear power” [6].

In addition to the present market situation, the structure of energy markets is also looking to change within this century. There is an emerging new market — hydrogen production — that projections show will help to fuel an increase in the use of nuclear power by the end of 21st century. By then, in long–term future, total nuclear power generation could reach 12000 to 15000 GWe (gigawatt electric) compared to today’s level of about 370 GWe [15].

2 THE NUCLEAR RENAISSANCE

Since the beginning of this century there has been much talk about an imminent nuclear revival or renaissance implying that the nuclear industry has been dormant or in decline for some time. Increasing energy demand, concerns over climate change and dependence on supplies of fossil fuels are coinciding to make the case for nuclear build stronger. At present, the revitalisation of nuclear energy is a reality, with projections for new build similar to or exceeding those of the early years of nuclear power.

2.1 Key Drivers

The first generation of NPPs were justified by the need to alleviate urban smog caused by coal–fired power plants. Nuclear was also seen as an economic source of base–load electricity which reduced dependence on foreign imports of fossil fuels. Today's drivers for nuclear build have evolved some new factors.

2.1.1 Increasing Population and Energy Demand

Global population growth in combination with industrial development will lead to a doubling of electricity consumption by 2030. Besides this incremental growth, there will be a need to renew a lot of generating stock in the USA and the EU over the same period. An increasing shortage of fresh water calls for energy–intensive desalination plants, and in the longer term hydrogen production for transport purposes will need large amounts of electricity and/or high temperature heat.

Energy will remain one of the major issues of the 21st century, especially in Europe — given its high dependency on energy imports.

Currently, installed generating capacity of Europe totals about 803 GW [16], whereof some 49% is fossil fuel fired (gas/oil, hard coal and lignite), 23% is hydro, and 17% is nuclear. The total generation structure in Europe in 2007 is presented in **Figure 1** [16].

In 2004 approximately 54% of electricity production in Europe was generated by fossil fuel combustion and some 27% by nuclear power [5].

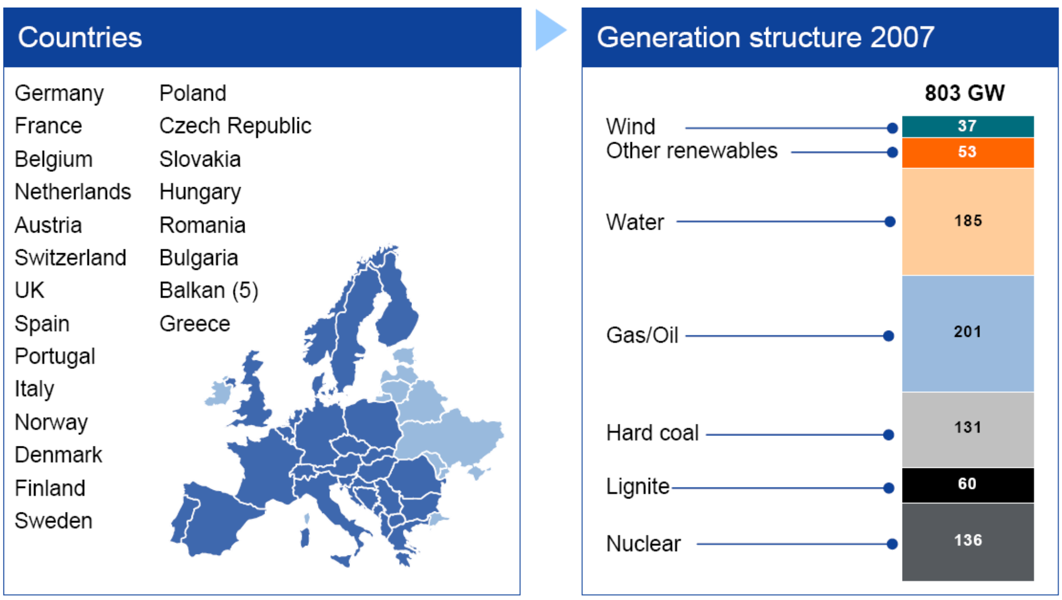


Figure 1 Total Generation Capacity Structure in Europe

2.1.2 Nuclear Safety and Security

The safety record of nuclear industry over the last 20 years is unrivalled and has helped restore public faith in nuclear power. Over this period, operating experience has tripled, from about 4000 reactor–years to more than 12500 reactor–years.

Nuclear security has also gained priority in recent years. Both national and international nuclear security activities have expanded greatly in scope and volume. The international community is making progress — while much remains to be done globally — nuclear installations have strengthened security forces, additional protective barriers, and have taken other measures to meet current concerns about security risks and vulnerabilities. The key solutions for the future large–scale nuclear power industry will also include technological support of non–proliferation regimes and final waste disposal.

2.1.3 Carbon Emissions and Their Consequences

The important issue driving the nuclear renaissance is certainly the degree to which global attention remains focused on limiting greenhouse gas (GHG) emissions and reducing the risk of climate change. The degree to which fossil fuels or low carbon energy sources are tapped to supply growing energy demand, will have a major environmental impact.

World CO_2 emissions corresponding to world population by area is illustrated in **Figure 2** and **Figure 3**. Strong non–proportionality between CO_2 emissions and population for areas is obvious — in 2004 OECD countries with 18% of world population contributed 58% of the world's CO_2 emissions.

In 1997, the EU signed the Kyoto Protocol, which sought to achieve an overall reduction of 8% in GHG emissions during the period 2008–2012, compared to the emission levels of 1990. However, in 2002 the 15–member EU had managed to reduce its combined emissions by only 2.9% and the current trend suggests that emissions will increase. Climate change is a long–term challenge for the international community — the objectives mapped out in the Kyoto Protocol are simply the first stage. Thus, the EU recently established a 50% emission reduction target for the year 2030 and an 80% reduction target for the year 2050.

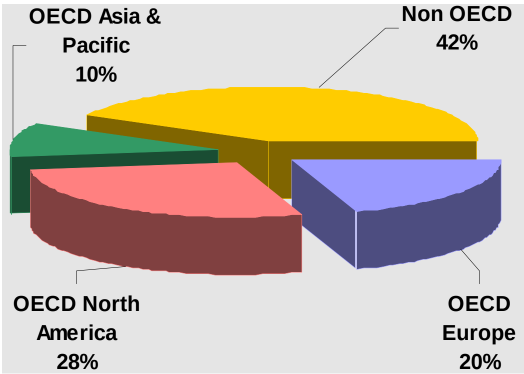


Figure 2 World CO_2 Emissions by Areas in 2004

The fact that nuclear power generation does not produce CO_2 is increasingly relevant to its role in the European energy mix. The European Commission (EC) now also recognises that Europe cannot make any significant impact on CO_2 emissions without relying on nuclear energy. In its latest publication "Energy Policy for Europe" published in January 2007, the EC also stressed that nuclear power production must be considered as an option to reduce CO_2 emissions and to meet the targets of the Kyoto Protocol.

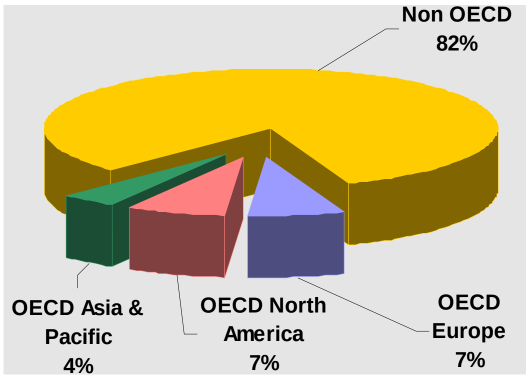


Figure 3 World Population by Areas in 2004

2.1.4 Security of Energy Supply

The currently emphasis on security of energy supply is important for the nuclear renaissance as well. The EU Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy" (from March 2006) estimated that 'business–as–usual' growth would increase energy imports from a current 50% share in total energy supply to about 70% in 2030 [5]. A similar concern drove nuclear power investment, during the oil crisis of the 1970s. Large uranium resources in a country or region are not a necessary pre–condition for nuclear energy security, given the diverse global roster of stable uranium producers, and the small storage space required for a long–term nuclear fuel supply.

2.1.5 Economics and Insurance against Future Price Exposure

Increasing fossil fuel prices have greatly improved the economics of nuclear power for electricity at the current time. Several studies show that nuclear energy is the most cost–effective of the available base–load technologies [2]. In addition, as carbon emission reductions are encouraged through various forms of government incentives and trading schemes, the economic benefits of nuclear power will increase further.

A longer–term advantage of uranium over fossil fuels is the low impact that increased fuel prices have on the final electricity production costs, since a large proportion of those costs is in the capital cost of the plant. This insensitivity to fuel price fluctuations offers a way to stabilize power prices in deregulated markets.

2.2 Worldwide Development

By 2050, the world population is expected to reach about 9 billion people and energy consumption should double at least. Since all energy sources are likely to be needed, one major interest is to explore and develop optimal energy mixes that satisfy requirements for energy security, generation cost, resource savings and mastery of environmental impact, under different future circumstances. Several prospective studies of International Energy Agency (IEA) show that — even with optimistic assumptions about the potential contribution of fossil and renewable energies — nuclear energy will be needed where it can be developed safely and competitively (**Figure 4**) [11].

With 30 reactors being built around the world today, another 35 or more planned to come online during the next 10 years, and over two hundred being planned, the global nuclear industry is clearly going forward strongly (**Figure 5**). Countries with established programmes are seeking to replace old reactors as well as expand capacity, and an additional 25 countries are either considering or have already decided to make nuclear energy part of their power generation capacity [4].

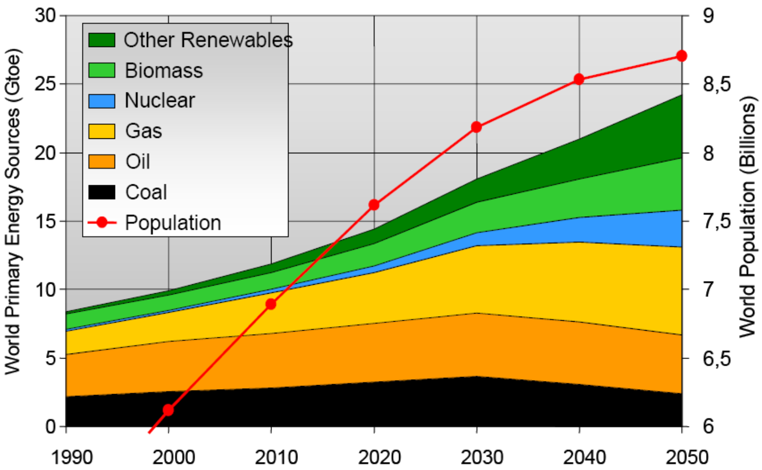


Figure 4 IEA Scenario of Energy Growth for a Sustainable Future

The Ontario government in Canada has decided to refurbish and restart four reactors, adding 25 years to operating lifetime, as a step in its plan to expand its nuclear fleet. Alberta is now considering using nuclear power to extract oil from its northern deposits of oil sands. In the USA, the Nuclear Regulatory Commission (NRC) has received notice of application for joint construction and operating licences for 19 new units, and it is clear that there will be substantial new nuclear capacity by 2020. Argentina and Brazil both have commercial nuclear reactors generating electricity, and additional reactors are planned or under construction [2].

Japan and South Korea have plans or placed orders for 11 and 8 new NPPs, respectively.

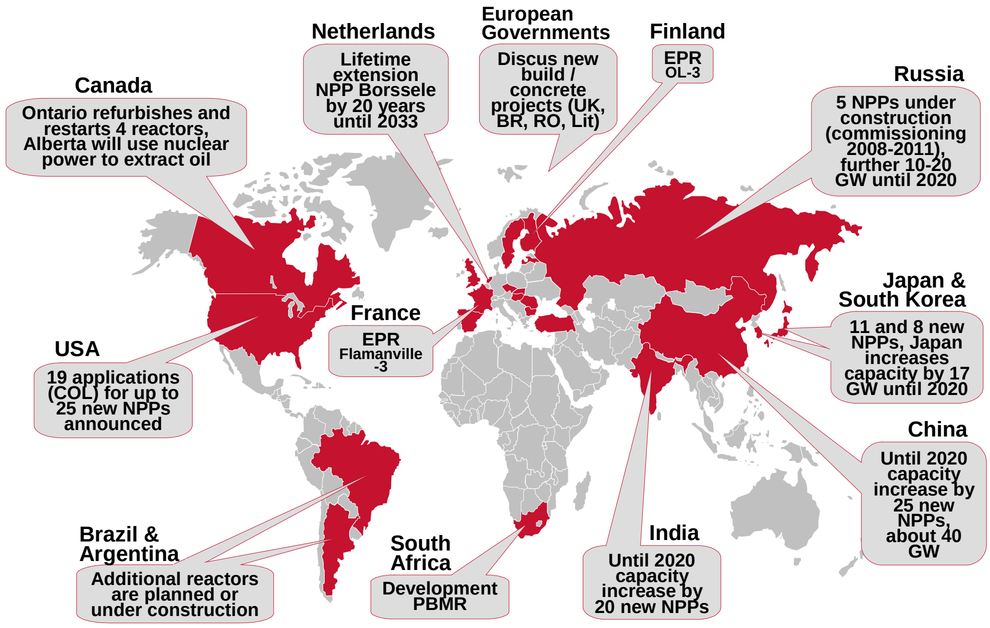


Figure 5 Nuclear Holds Key Position in the Recent International Development

China plans a 5–fold increase in nuclear capacity to 40 GW by 2020 [2], [19]. China has completed construction and commenced operation of 8 NPPs within the last 5 years [19], and 8 units are currently under or about to start construction and are planned to come online within 5 years [19]. At least 8 more reactors will start construction within the next 5 years and an additional 75 reactors are proposed in recent projections [2]. India's target is to add 20 to 30 new reactors (20 GWE [20]) by 2020 as part of its national energy policy. Under construction are 7 power reactors, of both indigenous and foreign design [2].

In South Africa a feasibility study is assessing plans for a third conventional nuclear power unit. There is also strong consideration of constructing a fleet of Pebble Bed Modular Reactors (PBMRs). Nigeria has sought the support of the IAEA to develop plans for two 1000 MWe reactors, and Egypt has revived its plans for a combined nuclear power and desalination plant through its ties with Russia.

2.3 European Market

Russia plans to build 40 GWe of new nuclear power by 2025, using domestically designed light water reactors (VVER). Construction of a large fast breeder unit has been prioritised, and development proceeds on others, aiming for significant exports. An initial floating power plant is under construction, with delivery in 2010. A target of nuclear providing 23% of electricity by 2020 was announced in September 2006 – commissioning two 1200 MWe plants per year from 2011 to 2014 and then three per year until 2020 [21].

Finland and France are both expanding their fleets of NPPs (**Figure 5**) with the 1600 MWe EPR from AREVA NP. Several countries in Eastern Europe are currently constructing (Romania) or have firm plans to build new NPPs (Bulgaria, Czech Republic, Romania, Slovakia, Slovenia and Turkey). Italy is considering a revival of its scrapped nuclear program, and has already invested in reactors in Slovakia and sought to do so in France [2]. A UK government energy paper in mid 2006 endorsed the replacement of the country's ageing fleet of nuclear reactors with new nuclear plants [22]. Sweden has abandoned its plans to prematurely decommission its nuclear power, and is now investing heavily in life extensions and up–rates. Hungary, Slovakia and Spain are all planning for life extensions on existing plants. A number of countries are considering developing nuclear programmes, among them Poland with Estonia and Latvia, who are looking into a joint project with established nuclear power producer Lithuania [2]. Communities in Finland and Sweden have accepted the local construction of permanent disposal sites for nuclear waste [2].

3 NUCLEAR POWER PLANTS IN OPERATION

In January 2006 there were 443 (437 in May 2007 [23]) NPPs operating worldwide (122 in North America, 6 in Latin America, 205 in Western and Eastern Europe, 17 in Middle East and South Asia, 91 in Far East and 2 in Africa) with total of 370 GWe installed capacity (**Figure 6**) — 27 additional NPPs were under construction [10].

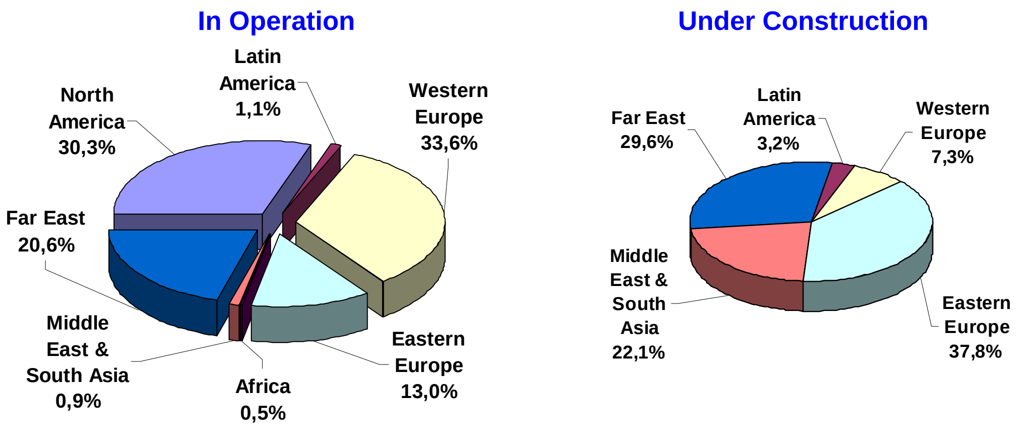


Figure 6 World Nuclear Generating Capacity by Regions (January 2006)

On 1st May 2004 and most recently on 1st January 2007, 12 new countries have joined the EU, bringing the number of EU Member States producing nuclear power to 15 out of the total 27 and the total number of reactors operating in the EU from 136 to 154 [5]. The share of nuclear power generation rose by 8.2% to more than 31% of total generation. In the pan–European group of 37 countries, the total number of operating nuclear reactors is 205 (**Figure 7**), generating some 27% of total electricity, compared with 54% by conventional thermal plants, 16% by hydroelectric plants and almost 3% by renewable energy sources (principally wind energy).

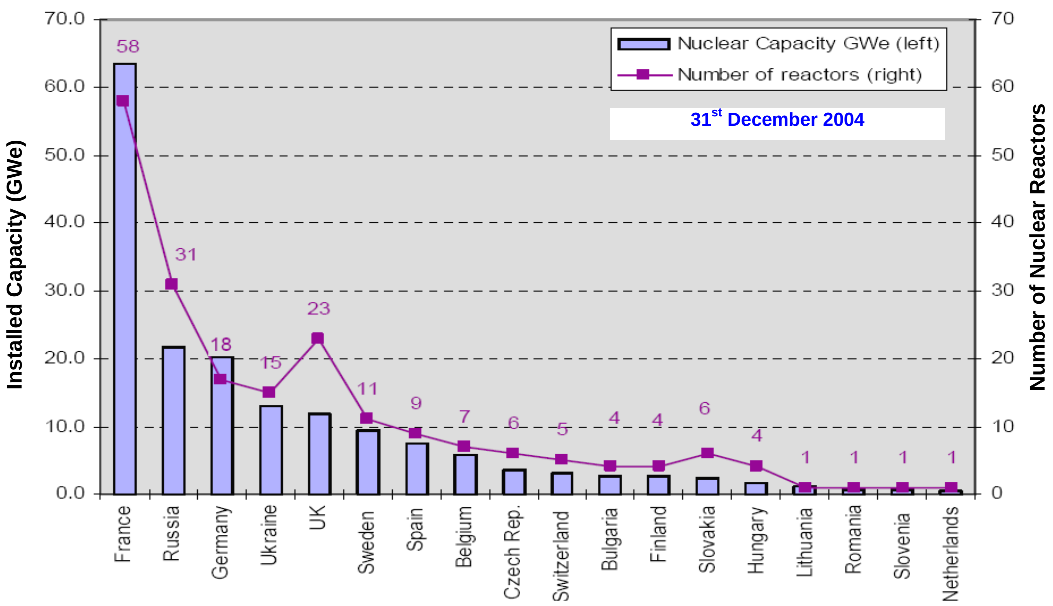
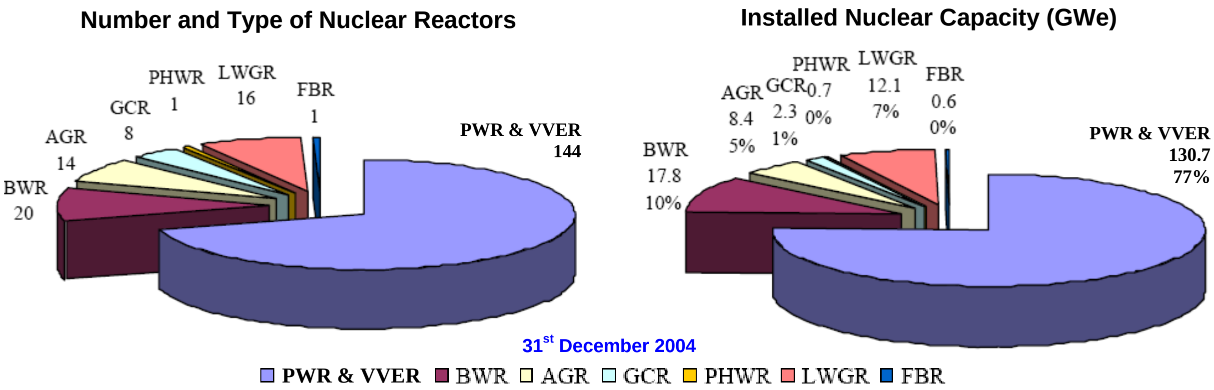


Figure 7 Total Installed Net Nuclear Capacity versus Number of Nuclear Units by Country in All of Europe

Nuclear generation in Europe is concentrated in a few countries (**Figure 7**). The five major producers (France, Germany, Russia, the UK and Sweden) in 2004 produced 73% of all nuclear power produced in Europe. In terms of nuclear capacity, France alone, with a strong nuclear tradition, accounted for 35% of total European nuclear power generation. Across the pan–European nuclear fleet dominant reactor design is the Pressurized Water Reactor (PWR and VVER – Russian version of PWR) type of reactor with about 77% participation (**Figure 8**) [5].



PWR	– Pressurised Water Reactor	GCR	– Gas Cooled Reactor
VVER	– Vodno-Vodyanoi Energetichesky Reactor	AGR	– Advanced gas-cooled Graphite Reactor
BWR	– Boiling Water Reactor	LWGR	– Light Water-cooled Graphite-moderated Reactor
PHWR	– Pressurised Heavy Water Reactor	FBR	– Fast Breeder Reactor

Figure 8 Nuclear Fleet Capacity in All of Europe

4 THE AGE FACTOR

Almost half (218) of nuclear reactors operating today started up in the decade 1980–1989 — an average of one every 17 days [3]. These included 47 in USA, 42 in France and 18 in Japan. The average power was 923.5 MWe. So it is not hard to imagine a similar number being commissioned in a decade after 2015. However with China and India getting up to speed with nuclear energy and a world energy demand double the 1980 level in 2015, a realistic estimate of what is possible might be the equivalent of one 1000 MWe unit worldwide every 5 days [3].

Some 30% of generating capacity in Europe is now more than thirty years old. The breakdown of installed capacity by plant age (**Figure 10**) reflects the technological history of Europe's electricity industry [5]. The oldest installations are hydroelectric. Following these in age are coal–fired plants, most of which date from the 1960s to 1990, and are now between 16 and 40 years old. In the 1970s, nuclear power started up, reaching a peak between 1980 and 1990, followed by a period during which development was halted. From the 1990s onwards, natural gas and renewables became more important. Renewable resources (mainly wind energy) have become especially popular over the last decade. **Figure 10** also shows the effects of the oil market shock of the early 1970s and the impact of the Chernobyl accident of 1986.

Coal and nuclear power plants account for more than 70% of all power plants that will be at least 30 years old in 2020 — today almost 70% of nuclear capacity in Europe is in the second half of the lifecycle (**Figure 9**) [16]. Renovation of more than 50% of the current electricity installations must be addressed from as early as 2010. The question of replacing capacity will first affect coal combustion and later nuclear energy.

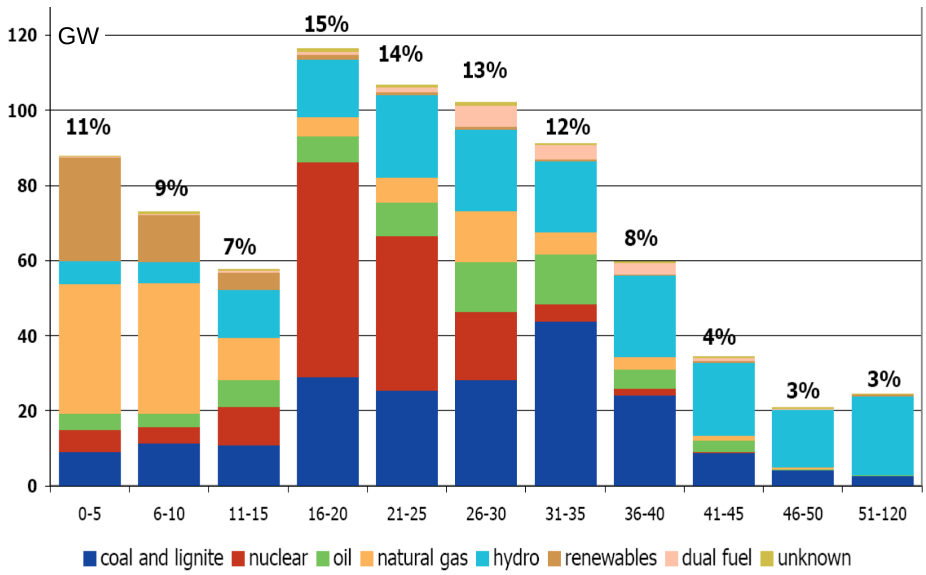


Figure 10 Breakdown of European Power Generation Capacity by Age (as of 31 December, 2004)

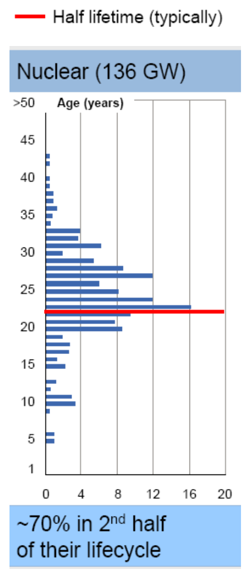


Figure 9 Ageing NPPs in Europe (in 2007)

5 PREDICTED CAPACITY SHORTAGE AND EXPECTED NEW BUILDS

By the beginning of 2006 the worldwide installed capacity in operating NPPs was about 370 GW with a further 22 GW under construction [9]. At the same time an additional 50 GW of nuclear capacity was planned [17]. Shutdown of some power plants will reduce the present capacity to about 230 GW but the extension of the lifetime and power up–rates of existing NPPs will provide an additional 170 GW [17]. In 2025, according to AREVA predictions, 487 GW of installed nuclear capacity will be necessary. The resulting worldwide supply shortfall will reach about 177 GW [17].

About 47% of the total world capacity is installed in Europe. According to some forecasts [8], [9], [13], by 2030 the electricity demand in Western Europe will increase by 760 TWh (terawatt–hour) per year. This additional annual consumption is equivalent to about 1.7 times the total annual oil production of Kuwait [8]. If the present 30–32% nuclear share of electricity production in Europe is maintained, 300 new nuclear TWh will be needed — this is equivalent to 40000 new nuclear MWe installed [8], [13]. Those 40000 new nuclear MWe installed would primarily be generated by new advanced Generation III and/or III+ (Gen–III/III+) reactors [17].

Some predictions performed in 2006 by UCTE (Union for the Coordination of Transmission of Electricity) and CERA (Cambridge Energy Research Associates) indicate severe capacity shortage by 2020 (**Figure 11**) and bottleneck even as soon as 2009 (**Figure 12**), respectively [16].

In 2006 for the EU–15 as a whole, CERA detected a declining reserve margin, even after accounting for new projects. If only those projects currently under construction are built, the electricity market would be short of around 26 GW in 2010 and the EU–15 reserve margin would fall from currently 22% to around 10% in 2010 (**Figure 12**).

Major drivers for these capacity bottlenecks in Europe may be summarised as [16]:

- Ageing power plants,
- Volatile gas prices (driven by oil prices),
- Supply constraints for power plant components, scarcity of licensed sites,
- Lengthy approval procedures for inter–connector extensions,
- Political risks threatening investment plans for power plants and networks.

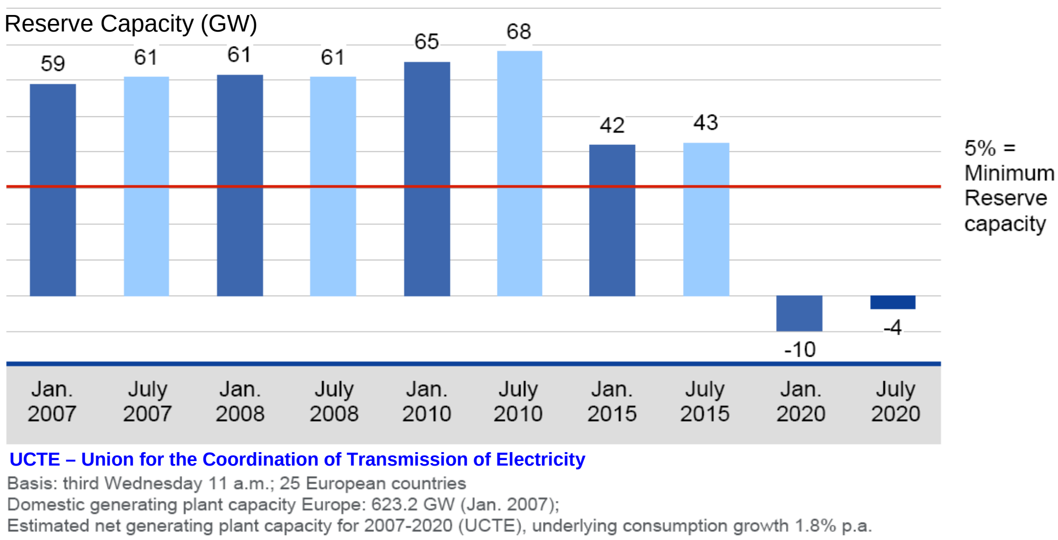


Figure 11 UCTE – Expected Severe Capacity Shortage by 2020

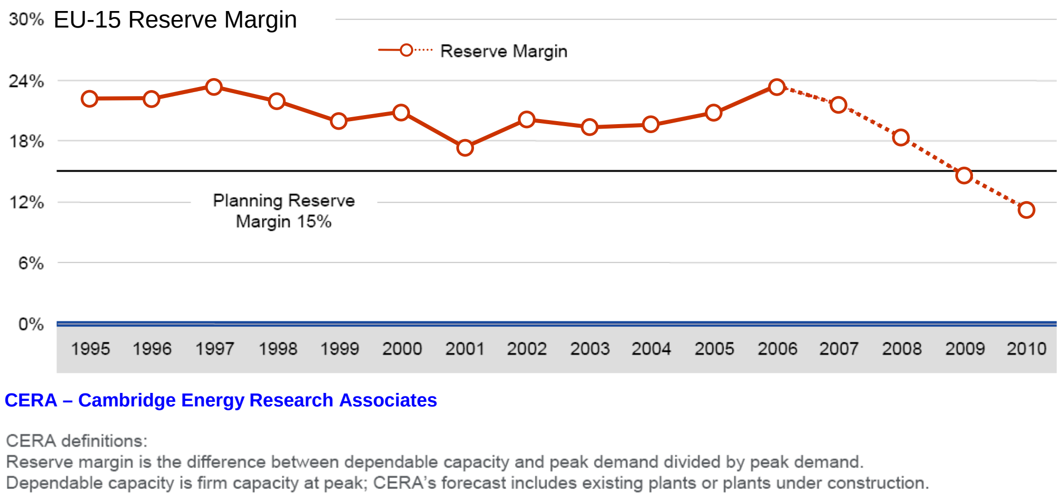


Figure 12 CERA – Expected Capacity Bottleneck in Europe as soon as 2009

Some localised drivers for expected future capacity shortage are [16]:

- Nuclear phase–out in Germany,
- Large Combustion Plant Directive (LCPD) in UK,
- Increased peak–load demand in France,
- Volatile hydro reservoir levels in Spain, Scandinavia, Austria, Switzerland,
- Decommissioning of old nuclear reactors in new EU Member States.

Starting now, Europe will be obliged to make some important decisions about its future generating capacity. These decisions will be influenced not only by economics, but also by environmental policy. Over the next 10–15 years, coal power plants may face some form of carbon tax in at least parts of Europe, while at the same time some NPPs will be shut down, possibly resulting in greater carbon emissions unless a good part of this capacity is replaced by new NPPs.

The need for capacity per country in Europe which reflects expected (and necessary) new build by 2012 for thermal plants and NPPs is illustrated in **Figure 13** [16].

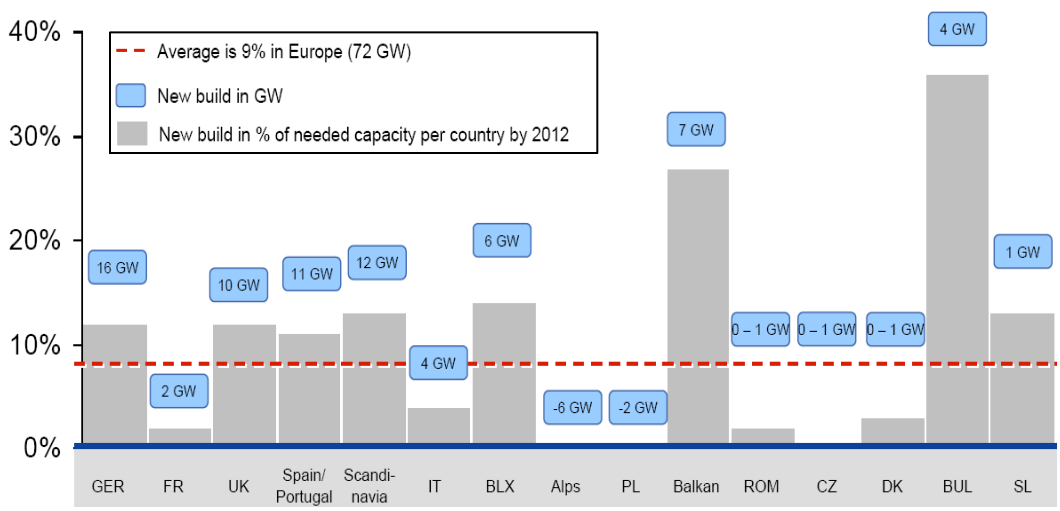


Figure 13 Expected New Build by 2012 for Thermal and Nuclear Power Plants

6 ADVANCED GEN–III+ REACTORS OF AREVA NP

6.1 AREVA — Energy as a Core Business

With manufacturing facilities in 41 countries and a sales network in more than 100 (**Figure 14**), AREVA offers worldwide customers reliable technological solutions for CO_2–free power generation and electricity transmission and distribution [1]. Its development strategy is based on a balanced presence in Europe, North and South America, and Asia (**Figure 14**). AREVA is the world leader in nuclear power and the only company to cover all industrial activities in this field — from uranium mining, processing and enrichment as well as fuel manufacturing, through reactor construction and services to reprocessing of spent fuel (**Figure 15**). AREVA has participated in the construction of over 100 reactors worldwide and supplies fuel to 148 of them. It is No. 1 worldwide in the entire nuclear cycle and No. 3 worldwide in electricity transmission and distribution [1].

AREVA's business help meet the 21st century's greatest challenges: making energy available to all, protecting the planet, and acting responsibly towards future generations.

Strategic objectives of AREVA are to capture 1/3 of the world market in the nuclear business, to be one of the most profitable leaders in electricity transmission and distribution, and to attain a significant position in the field of renewable energies [1].

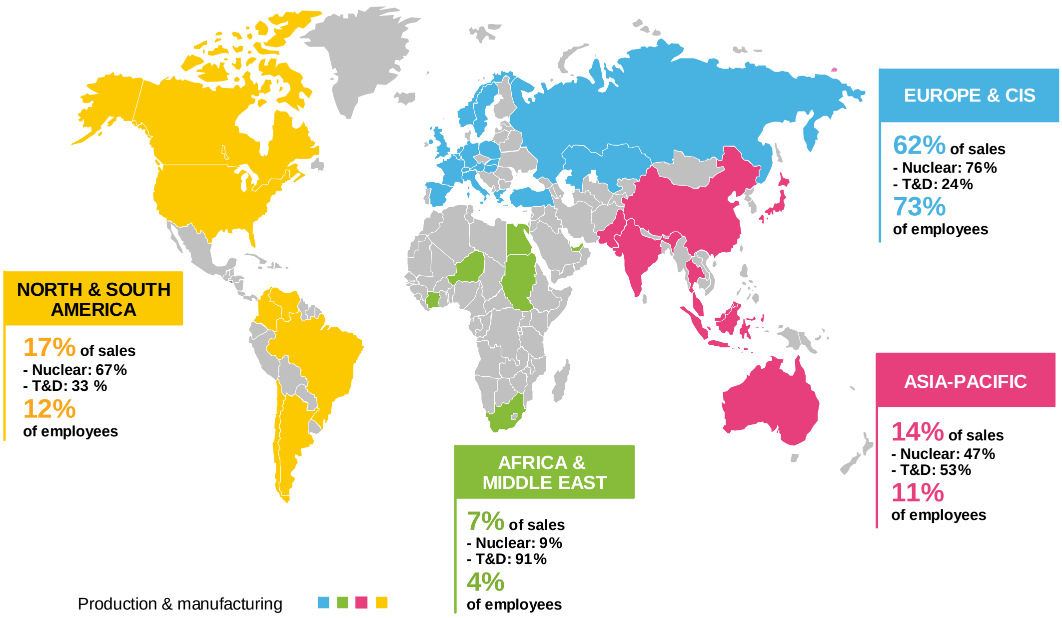


Figure 14 AREVA Around the Globe

6.2 Reactor Designs for the 21st Century

Since the beginning of the 1990s AREVA NP (Nuclear Power) has been intensively engaged in the design of new advanced Gen–III+ reactors [17], [18]:

(i) design of the PWR EPR (Evolutionary Power Reactor) in a joint venture of French and German vendors, utilities and regulators, and

(ii) design of the next generation BWR (Boiling Water Reactor) SWR-1000 in a joint venture of German, Finnish and other European utilities with Siemens/AREVA (compliance with German and Finnish regulations required as design basis).

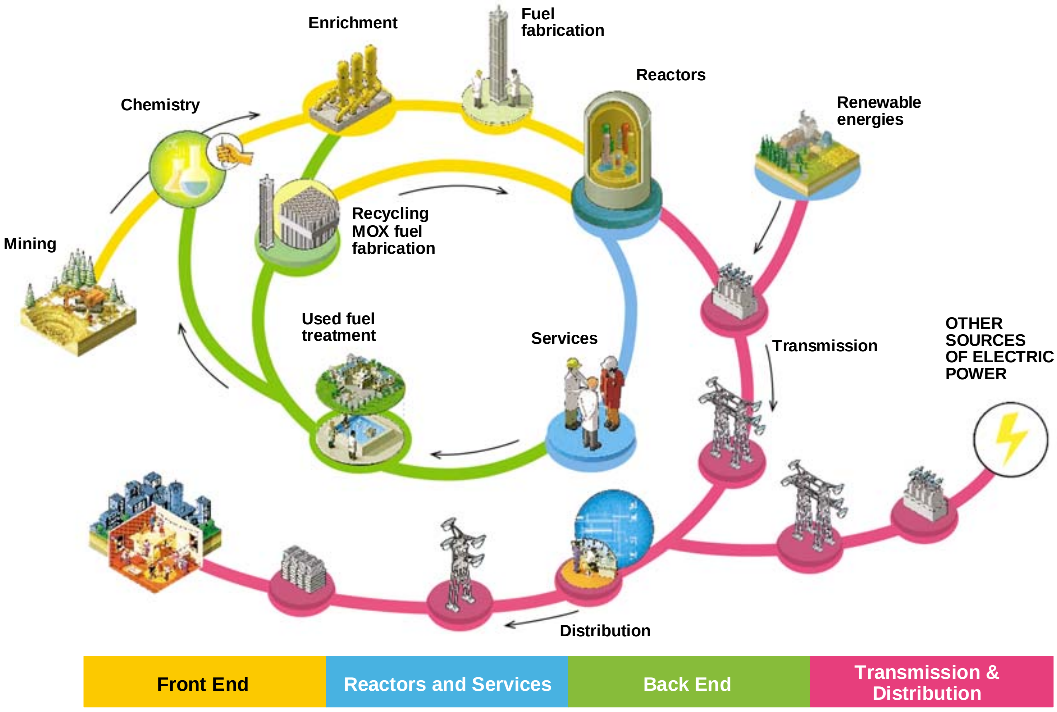


Figure 15 An Integrated Offer of AREVA NP Serving Energy Professionals

Key development goals for these Gen–III+ reactors of AREVA NP were to further increase safety and to further improve economic performance in order to strengthen nuclear energy's competitiveness with other energy sources. Both reactors meet the highest safety standards, including control of core melt accidents, and also offer exceptional resistance to external hazards, especially airplane crashes and earthquakes.

Both advanced reactors are summarised in **Table 1**, and some important characteristics are described below.

6.2.1 EPR

The EPR with a gross electrical output of 1600 MWe is developed on proven technology deployed in the two countries' most recently built NPPs — the French N4–series units and the German KONVOI–series plants — and constitutes an evolutionary concept based on these designs [14]. An evolutionary design was chosen in order to be able to make full use of all of the reactor construction and operating experience that has been gained not only in France and Germany — with their total of more than 2100 reactor operating years [14] — but also worldwide. Guiding principles in the design process included the requirements elaborated by European and US electric utilities for future NPPs, as well as joint recommendations of the French and German licensing authorities.

One of the EPR's main features is its simple design based on the 4 primary loops and 4 safety trains concept which applies to mechanical equipment as well as the electrical power supply and the associated I&C (Instrumentation & Control).

Major safety systems such as safety injection, emergency feed–water, component cooling and emergency power are arranged in a 4–train configuration (**Table 1**). These 4 independent trains of safety systems are housed in separate buildings and designed to preclude common failures.

The reactor core is surrounded by a neutron reflector that improves fuel utilization and protects the reactor pressure vessel (RPV) against irradiation–related aging phenomena.

Regarding safety, the EPR features innovations to prevent core meltdown and mitigate any potential consequence. Should a core meltdown occur, in spite of all the preventive measures taken, the extremely robust, leak–tight containment around the reactor would prevent radioactivity and its effects from spreading outside. In the event of core meltdown, molten core escaping from the RPV would be passively collected and retained in the reactor cavity below the pressure vessel. Melted corium would collect in this cavity, melt through a sacrificial plug and flow by gravity into a corium spreading area in the basement of the containment (core catcher) to be cooled (**Table 1**). The arrangement of the blockhouses inside the containment and hydrogen catalytic recombiners (passive devices) prevent the accumulation of hydrogen and the risk of deflagration.

6.2.2 SWR-1000

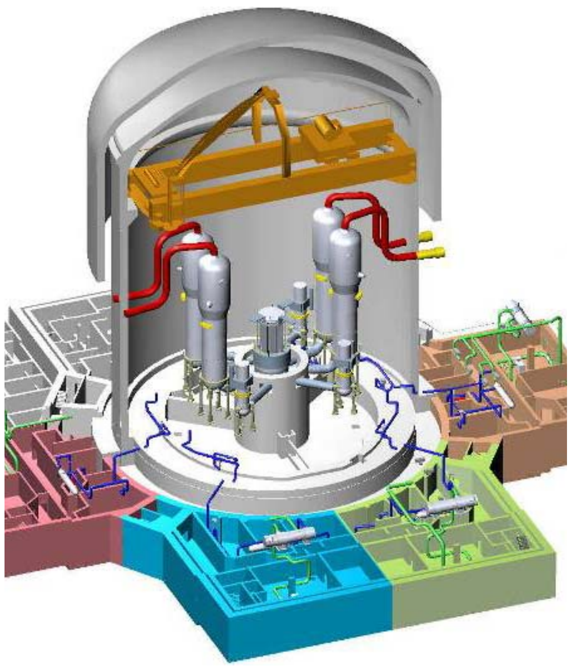
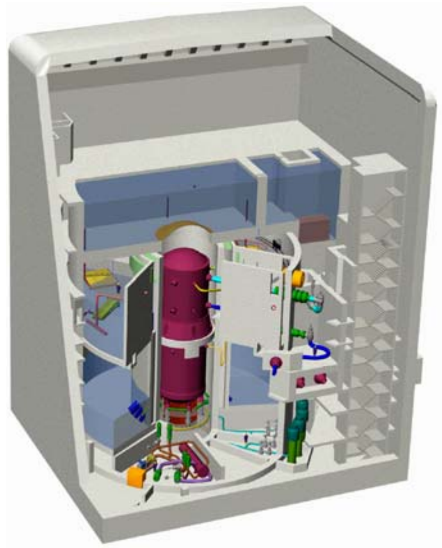
The SWR-1000 with a gross electrical output of approximately 1250 MWe is an innovative BWR design derived from an existing and proven BWR design — based on NPP Gundremmingen. New technological developments and accumulated operating experience have been integrated into the advanced design [18]. It is developed in close cooperation with German nuclear utilities and with support from various European partners. This reactor design is particularly suitable for countries whose power networks cannot facilitate large power plants. Very simple passive safety equipment, simplified systems for plant operation, and a very simple plant configuration in which systems engineering is optimized are deployed and dependence on electrical and I&C systems is reduced [18]. Such design simplifications include: a single–train feed–water heating system, no feed–water tank, 3 main steam lines, 2 feed–water lines, and replacement of redundant subsystems of the complex active residual heat removal system with simple passive systems.

The plant safety concept is based on a combination of passive safety systems and a reduced number of active safety systems (**Table 1**). All postulated accidents can be controlled using passive systems alone [18].

The containment houses the systems which interact directly with the RPV and also accommodates the new equipment provided for passive accident control. This comprises: safety relief valves with their additional passive pilot valves, emergency condensers for passive removal of heat from the RPV to the water of the core flooding pools, core cooling condensers (CCCs) for passive heat removal from the containment to the shielding/storage pools situated above, passive flooding lines, as well as passive pressure pulse transmitters (PPPTs) provided for safety function actuation (**Table 1**).

Since meltdown of the reactor core at high pressure is prevented by redundant and diverse depressurization devices, low pressure core melt is the only progression which can be postulated. The core melt is retained inside the RPV which integrity is fully provided by external cooling [18] (**Table 1**). For this purpose a passive flooding system (which is permanently isolated and is activated upon challenge) is provided for supplying water from the core flooding pools to the lower area of the drywell. The containment is designed to accommodate the pressure build–up due to hydrogen released from zirconium–water reaction of 100% the zirconium inventory present in the reactor core. The containment atmosphere is inerted with nitrogen to prevent pressure– and temperature–raising hydrogen–oxygen reactions (deflagration or detonation). Heat is passively removed from the containment by the CCCs to the storage/shielding pool outside the containment (**Table 1**). Makeup of this pool's water, several days after the accident, ensures heat removal for an unlimited time period without any release of radioactivity to the plant environs.

Table 1 Advanced Gen–III+ Reactors of AREVA NP

	EPR	SWR-1000
Generation III+ Reactors		
International Partnership	Full members: French Utility – *EDF* German Producer Federation – *VDEW* Finnish Producers – *Fortum & TVO* Spanish Nuclear Utilities – *DTN* Belgian Utilities – *Tractebel* Italian Nuclear Facilities – *SOGIN* Dutch Utilities – *NRG* UK Nuclear Producer – *British Energy / Nuclear Electric* Swedish Producers – *Vattenfall / FKA* Swiss Producer Federation – *UAK* Associate Member: Russian Nuclear Utility – *REA*	German Utilities and AREVA NP with contributions from: Finland: Teollisuuden Voima Oy (TVO), Technical Research Center of Finland (VTT) France: Electricité de France (EdF) Switzerland: Paul Scherrer Institut (PSI) Germany: Research Center Jülich (FZJ) Netherlands: Nuclear Research & Consultancy Group (NRG)

Key Technical Data

EPR		SWR-1000
4300	Thermal power, MWth	3370
1600	Net power output, MWe	1250
37	Net efficiency, %	37
PWR	Reactor type	BWR
HTP X5	Type of fuel assemblies	ATRIUM™ 12
241	Number of fuel assemblies	664
17×17 – 24	Number of fuel rods in assembly	12×12 – 16
89	Number of control rods	157
4.2	Height of active core, m	3
155	Operating pressure, bar	70
176	Design pressure, bar	88
12.71	RPV overall height, m	23.81
4.86	RPV inside diameter, m	7.12
4	Number of reactor coolant pumps	8
60	Plant design life, years	60

Table 1 Advanced Gen–III+ Reactors of AREVA NP (Continued)

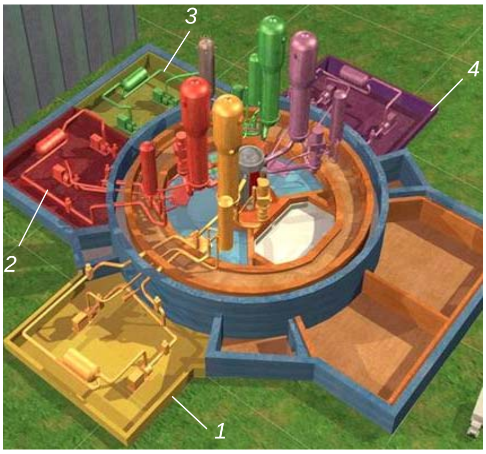
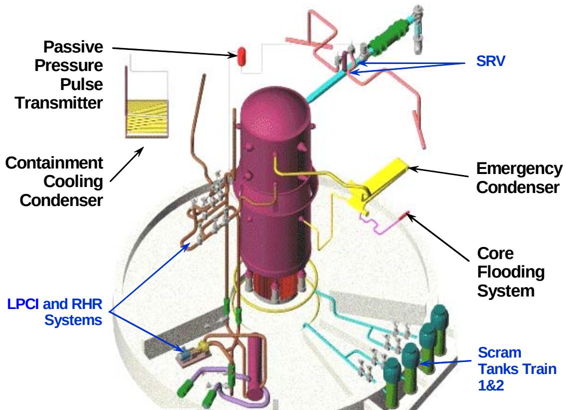
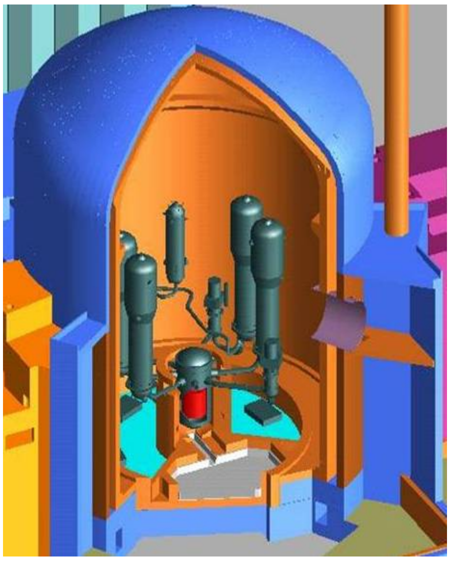
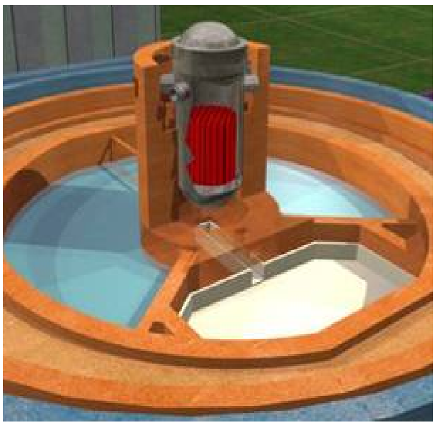
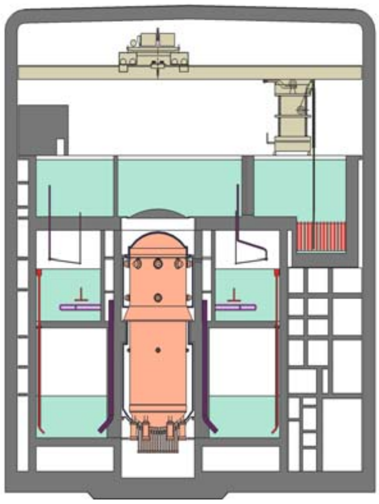
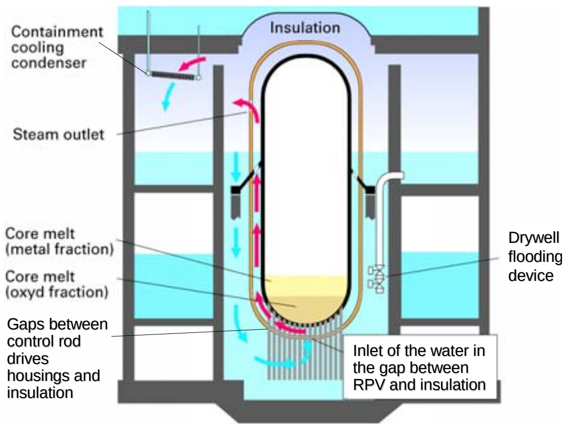
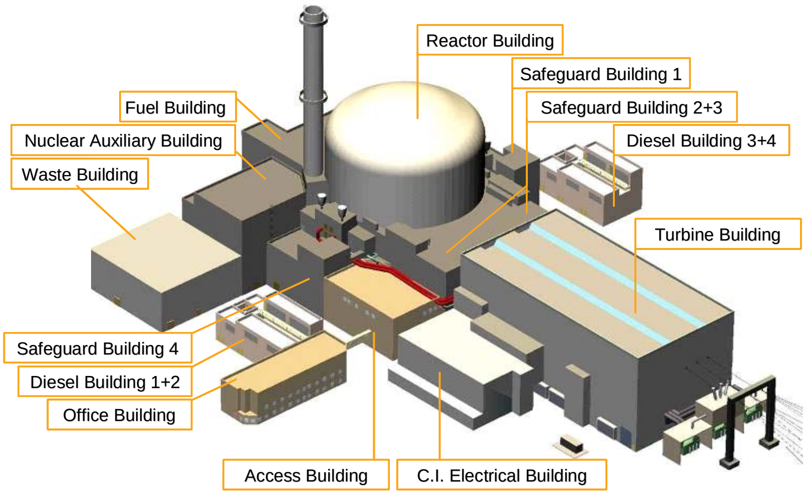
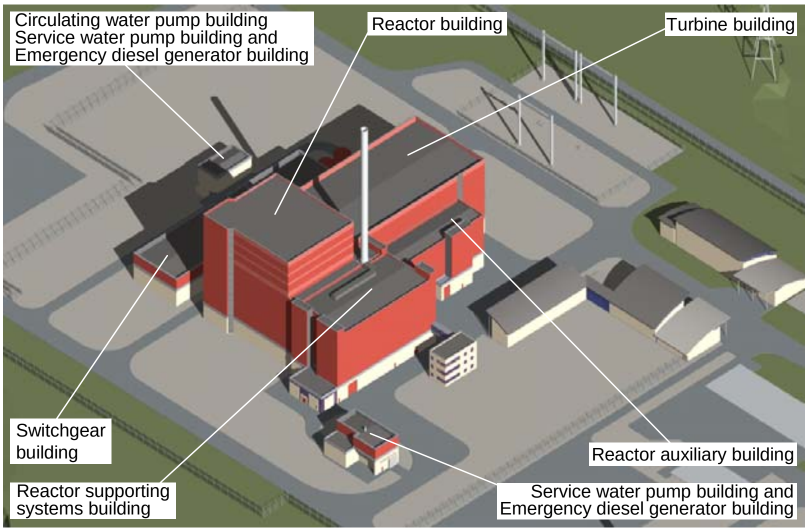
	EPR	SWR-1000
Safety Concept	**Four Train (N+2)** Each safety train is inde-pendent and located within a physically separate building 	 **Combining Active and Passive Safety**
Severe Accident Control	 **First reactor worldwide were control of a core meltdown can be guaranteed** 	**External cooling of RPV as a support for effective control of a core meltdown**  

Table 1 Advanced Gen–III+ Reactors of AREVA NP (Continued)

<table>
<tr><th></th><th>General Layout</th><th>Design Goals</th></tr>
<tr><td>EPR</td><td>
</td><td>Safety
➢ The EPR complies with the Rules and Regulations of the German as well as French licensing authorities
➢ Multiple redundant and diverse safety systems
➢ Reduction of the probability of severe accidents
➢ Use of digital instrumentation and control technology
➢ Improved interface between Humans and machines
➢ Management of serious accidents including a postulated core meltdown

Operation and Economics
➢ State-of-the-Art Design for 1600 MW_{el}
➢ Evolutionary development concept for systems and components on the basis of business and design experience minimize the risk for investors and on the operating company
➢ High fuel effectiveness/burn-up and high degree of efficiency
➢ High availability and short fuel reloading times
➢ Simplified maintenance due to easy accessibility and standardization
➢ Design lifespan of 60 years
➢ Shorter construction period</td></tr>
<tr><td>SWR-1000</td><td>
</td><td>Safety
➢ Introduction of safety systems with passive attributes
➢ High degree of diversity as well as redundancy of systems and components
➢ Reduction of core meltdown probability
➢ Management of postulated core meltdown without emergency measures
➢ longer period of time before manual intervention required (> 3 Days)

Operation and Economics
➢ Design of operational systems based on systems in operation on other plants to achieve high plant availability
➢ High availability and short outages.
➢ Low maintenance costs due to an easy maintenance design
➢ Flexible reload cycles (12 to 24 Months) and high Fuel effectiveness / burn-up (up to 65 GWd/t)
➢ Designed life span of 60 Years
➢ Shorter construction time of 48 months</td></tr>
</table>

7 CONCLUSION

The world's population in 2005 was estimated to be approximately 6.5 billion inhabitants — out of which almost 2 billion today have no access to electricity. In the next 25 years, the world population will rise to more than 8 billion. Estimates show that the global population is rising toward 9 to 10 billion people by 2050.

With non–renewable energy sources known today and by today's annual consumption (optimistic scenario) the present reserves in 2003 were estimated to be 43–62 years for oil, about 64 years for gas and 198–207 years for coal [7], [17].

In 1992 at the United Nations (UN) 'Conference on Environment and Development' in Rio de Janeiro three prerequisites were cited in the "Agenda 21" for *sustainable development*[1]: economic, development, ecological sustainability and social justice. Energy supply plays a key role for sustainable development.

General energy consumption is expected to at least double by 2030 and about to triple by 2050. Electricity consumption is estimated to grow much faster — by a factor of 5 to 7 by 2050.

Production of electricity by fossil energy power plants causes a huge amount of CO_2 emission to be thrown out into the atmosphere, increasing global warming risks and impacts.

In the IEA Reference Scenario [12] the global energy–related CO_2 emissions will increase by 55% between 2004 and 2030, or 1.7% per year. Power generation will contribute half of the increase in global emissions over the projection period. In this scenario developing countries will account for over 75% of the increase in global CO_2 emissions between 2004 and 2030. The share of developing countries in world emissions will rise from 39% in 2004 to over 50% by 2030 [12].

Nuclear power could make a major contribution to reducing dependence on imported gas and curbing CO_2 emissions by satisfying the expected future energy supply shortfall. These facts together with increased nuclear safety and security as well as security of energy supply are presently the most important driving forces for the nuclear renaissance.

Today there are some 437 nuclear power reactors in 30 countries [23], with a combined capacity of about 370 GWe. In 2006 these provided about 16% of the world's electricity.

About 30 new power reactors are currently being constructed in 11 countries (notably China, South Korea, Japan and Russia), and another 35 and more are planed during next 10 years.

The IAEA has recently increased its projection of world nuclear generating capacity [9]. It now anticipates at least 60 new plants in the next 15 years, making 430 GWe in place in 2020 — 130 GWe more than projected in 2000 and 16% more than actually operating in 2006. This change is based on specific plans and actions in a number of countries, including China, India, Russia, Finland and France, coupled with the changed outlook due to the Kyoto Protocol. This would give nuclear power a 17% share in electricity production in 2020 — the fastest growth is in Asia.

Participation in the construction of over 100 reactors worldwide and supplying fuel to 148 of them AREVA helps meet the 21st century's greatest challenges: making energy available to all, protecting the planet, and acting responsibly towards future generations.

With EPR and SWR-1000, AREVA NP has developed advanced design concepts of Gen–III+ NPPs which fully meet the most stringent requirements in terms of nuclear safety (including control of core melt accidents), operational reliability and economic performance. Both reactors are further improvements of the plants currently operating worldwide, having higher availability and minimizing the effects on the environment. EPR and SWR-1000 also offer exceptional resistance to external hazards, especially airplane crashes and earthquakes.

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[1] The term *sustainable development* was defined in 1987 by the Brundtland Commission of the UN in its report "Our Common Future" *as the capacity to meet the needs of the present without compromising the ability of future generations to meet their own needs.*

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