International Conference
**Nuclear Energy for New Europe 2006**
**Portorož, Slovenia, September 18-21, 2006**
http://www.djs.si/port2006

# Gen-III/III+ Reactors: Solving the Future Energy Supply Shortfall – The SWR-1000 Option

**Zoran V. STOSIC**

AREVA NP
Koldestr. 16, 91052 Erlangen, Germany
zoran.stosic@areva.com

## ABSTRACT

Deficiency of non-renewable energy sources, growing demand for electricity and primary energy, increase in population, raised concentration of greenhouse gases in the atmosphere and global warming are the facts which make nuclear energy currently the most realistic option to replace fossil fuels and satisfy global demand.

The nuclear power industry has been developing and improving reactor technology for almost five decades and is now ready for the next generation of reactors which should solve the future energy supply shortfall. The advanced Gen-III/III+ (Generation III and/or III+) reactor designs incorporate passive or inherent safety features which require no active controls or operational intervention to manage accidents in the event of system malfunction. The passive safety equipment functions according to basic laws of physics such as gravity and natural convection and is automatically initiated. By combining these passive systems with proven active safety systems, the advanced reactors can be considered to be amongst the safest equipment ever made.

Since the beginning of the 90's AREVA NP has been intensively engaged in the design of two advanced Gen-III+ reactors: (i) PWR (Pressurized Water Reactor) EPR (Evolutionary Power Reactor), and (ii) BWR (Boiling Water Reactor) SWR-1000.

The SWR-1000 reactor design marks a new era in the successful tradition of BWR technology. It meets the highest safety standards, including control of a core melt accident. This is achieved by supplementing active safety systems with passive safety equipment of diverse design for accident detection and control and by simplifying systems needed for normal plant operation. A short construction period, flexible fuel cycle lengths and a high fuel discharge burn-up contribute towards meeting economic goals. The SWR-1000 completely fulfils international nuclear regulatory requirements.

## 1 THE NUCLEAR ENERGY: EXISTENTIAL OPTION FOR THE FUTURE

The world's population in 2005 was estimated to be 6.45 billion inhabitants – of which 2 billion today have no access to electricity – with an annual growth rate equal to 1.44% for the period 1995-2005 [1]. In the next 25 years, the world population will rise to about 8.12 billion [1] (Figure 1). According to projections the worldwide demand, which was 16900 TWh in 2005, will reach the level between 25100 (low estimation) and 38200 TWh (high estimation) in 2030 [1] (Figure 1), in the course of which, the electricity consumption will grow twice as fast as the demand for the primary energy.

Furthermore, the present reserves of non-renewable energy sources are estimated to be 43-52 years for oil, about 45 years for gas and 198-207 years for coal [2]. The share of non-renewable energy sources in power production of the world is about 64%-67% [3] (Figure 2).

Production of electricity by fossil energy power plants causes a huge amount of $CO_2$ (Carbon Dioxide) emission to be thrown out into the atmosphere. Production of 1 kWh causes 0.72-0.95 kg of $CO_2$ emission from the power plants using the coal, 0.68 kg of $CO_2$ emission using the oil and 0.37 kg of $CO_2$ emission from the plants using the gas (Figure 3) [4].

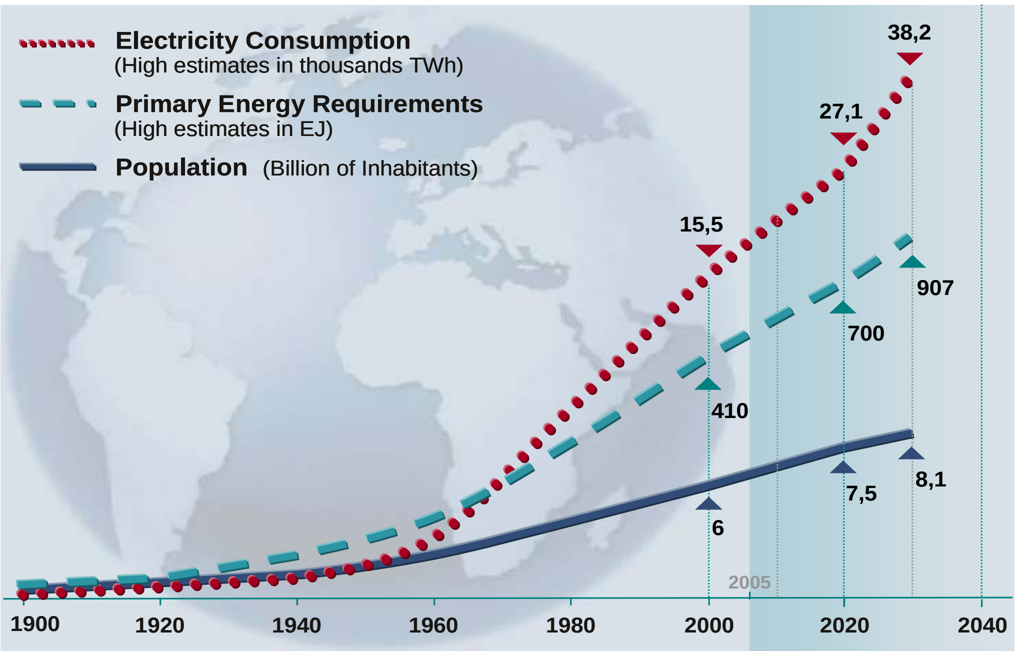


**Figure 1: World Population and Energy/Electricity Demand**

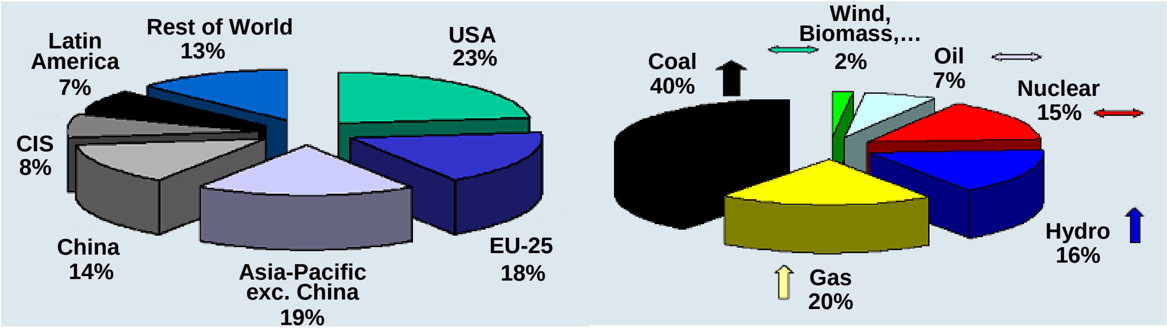


**Figure 2: World Electricity Consumption Share in 2005 by Regions and by Energy Sources**

$CO_2$ constitutes 76% of greenhouse gases [3] which surround the surface of our planet and make life possible. From the incoming solar radiation, part is absorbed by the Earth's surface warms it. Some of the solar radiation is reflected by the atmosphere and some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the Earth's surface and the troposphere. A rise in $CO_2$ increases the greenhouse gas layer and less radiation passes back through the atmosphere and the surface gains more heat causing the increase of greenhouse effect and thus the global warming.

In the last century the Industrial Revolution caused a dramatic rise in $CO_2$. Measurements of $CO_2$ in deep ice at Vostok station in Antarctica showed that the 400 thousand year average of $CO_2$ concentration equal to 220-230 ppmv increased in last 50-60 years to 380-400 ppmv resulting in a global temperature rise of 0.4-0.8 $^{o}$C [5], [6], [7]. This has also had an effect on average glacier thickness, with a reduction of about 14 m and sea level rise of about 0.1-0.2 m in last 50 years [6], [7], [8]. In addition, melting of the Arctic ice cap has also been observed and some projections estimate 54% of 1955 ice volume will remain in year 2050 [8]. Since ice is white and thus highly reflective most of the Sun's energy is reflected from these surfaces back into space. With a reduction of the ice cover, even more energy is absorbed thereby accelerating global warming.

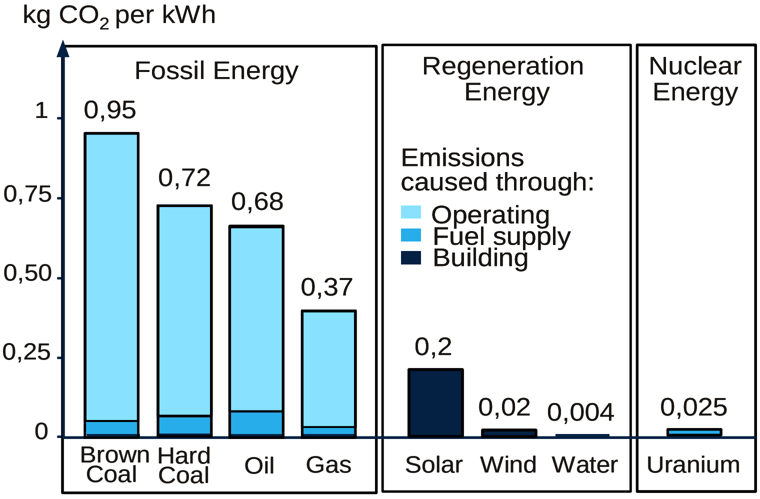


**Figure 3: $CO_2$ Emissions by Electricity Production in different Power Plants**

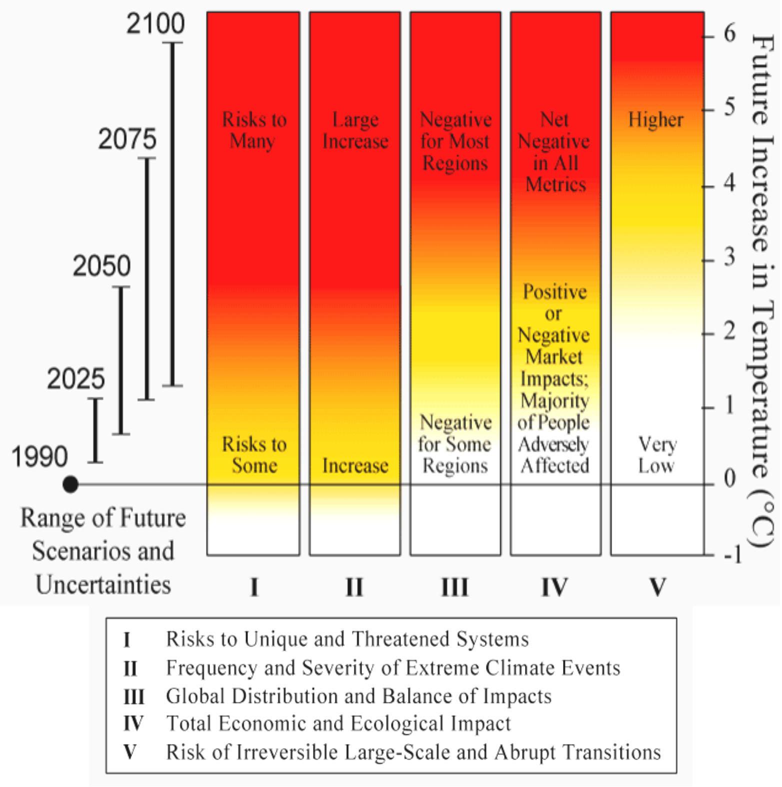


**Figure 4: Impacts and Risks of Global Warming**

According to global warming predictions, in the year 2100 the $CO_2$ atmospheric concentration will reach 600-1000 ppm causing a global temperature increase of a further 5-8 °C and a sea level rise of further 0.6-1.2 m [9], [10]. By some climate scenario projections the risk of irreversible large-scale and abrupt transitions are already expected with the global temperature increase of 5-6 °C [10], [11] (Figure 4) [12]. This includes: (i) Significant slowing (even shut-down) of *Termohaline Circulation* possible by 2100, and (ii) Melting and collapse of ice sheets adding substantially to sea-level rise (very low before 2100; likelihood higher on multi-century time scale) [12].

In contrast with fossil fuels, by using nuclear energy, the production of 1 KWh of electricity results in only 0.025 kg of $CO_2$ emissions (Figure 3) [4] – about 40 times less than burning brown coal. Due to this point alone, nuclear energy must be considered the most realistic option for the future. Even the founder of Greenpeace Patrick Moore said [13] that ‘nuclear energy is the only non greenhouse gas-emitting power sourced that can effectively replace fossil fuels and satisfy global demand’.

At present nuclear energy accounts for 15% of the worldwide electricity production (Figure 2). Almost 2/3 of the world’s population use nuclear power. In January 2006 there were worldwide 443 nuclear power plants operating and 27 under construction [1]. By the end of 2005 the installed capacity in operating NPPs (Nuclear Power Plants) was about 370 GW with a further 22 GW under construction [1] (Figure 5). At the end of 2005 an additional 50 GW of nuclear capacity was planned [14]. Shutdown of some power plants will reduce the present capacity of about 230 GW but the extension of the lifetime and power up-rates of existing NPPs will provide an additional 170 GW [4]. According to predictions [4] in 2025, 487 GW of installed nuclear capacity will be necessary. The resulting worldwide supply shortfall will reach about 177 GW.

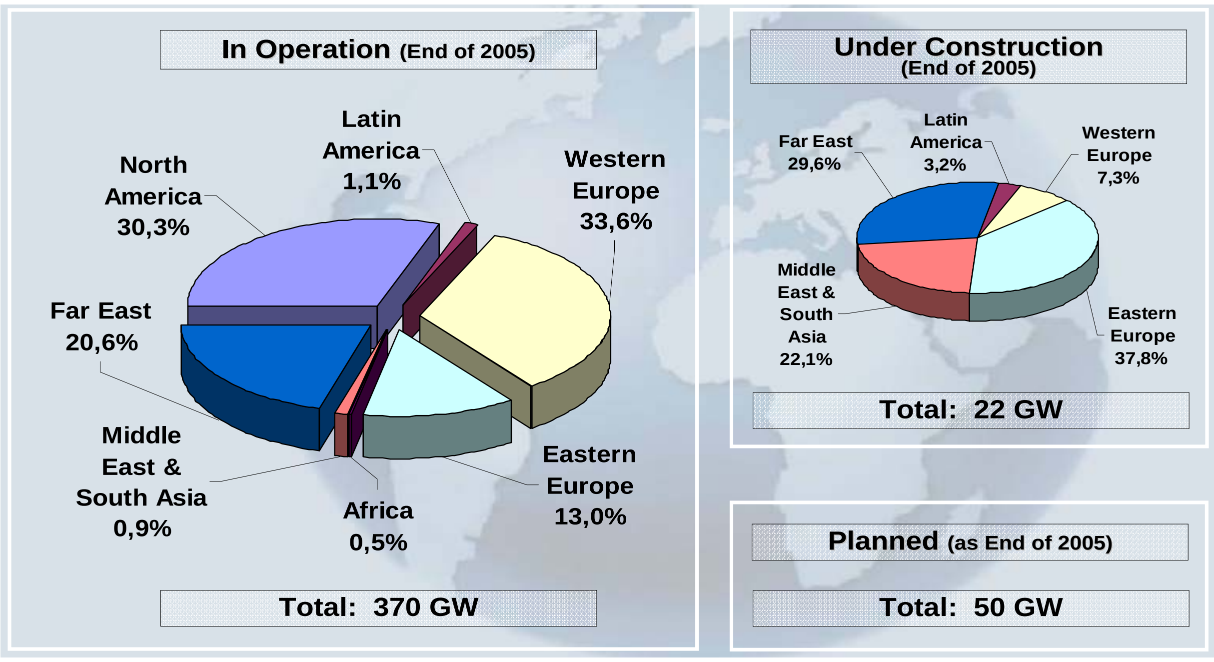


**Figure 5: Generating World Capacity of NPPs by Region**

By the end of 2005 in Europe there were 205 NPPs operating and 10 were under construction [1]. A total of 172.2 GW are installed in these NPPs – about 46% of the world's installed nuclear capacity is located in Europe. According to some forecasts [1], [15], [16], by 2030 the electricity demand in Western Europe will increase from 2995 TWh in 2005 to 3756 TWh per year. This additional annual 760 TWh consumption is equivalent to about 1.7 times the total oil production of Kuwait [15]. If the present 30-32% nuclear share of electricity production in Europe is maintained, 300 new nuclear TWh will be needed – equivalent to 40000 new nuclear MWe installed [15], [16]. Those 40000 new nuclear MWe installed would primarily be generated by new advanced Gen-III/III+ reactors.

## 2 ADVANCED GENERATION REACTORS

For almost five decades the nuclear power industry has been developing and improving reactor technology and is preparing for the next generations of reactors.

Several generations of reactors are commonly distinguished [17], [18]:

(i) Gen-I reactors were developed in 1950-60s and outside the UK none are still running today.

(ii) Gen-II reactors are most commercial power reactors in operation elsewhere: PWR, BWR, CANDU, VVER/RBMK including modernisation, up-rating and plant life extension.

(iii) Gen-III/III+ reactors are advanced water cooled reactors. The first were in operation in Japan and others are ready or under construction. These are EPR, SWR-1000, ABWR, AP1000, ACR1000, VVER91 – some specifications of reactors being marketed are summarised in Table 1.

(iv) Gen-IV designs are still on the drawing board and will not be operational before 2020 at the earliest. These are future additional reactor concepts (V)HTR, GFR, SFR, SCWR, LFR, MSR.

(v) Thermonuclear fusion reactors are still in the experimental phase through ITER. The first plasma will be possible by 2016 and operation of ITER is planned for 2035. The first commercial SSTR (Steady State Tokamak Reactor) will not be in operation before 2050.

### Table 1: Advanced Gen-III/III+ Reactors being marketed

| **Country and developer** | **Reactor** | **Size MWe** | **Design Progress** | **Main Features (improved safety in all)** |
|---|---|---|---|---|
| US-Japan<br>(GE-Hitachi-Toshiba) | ABWR | 1300 | Commercial operation in Japan since 1996-7.<br>In US: NRC certified 1997, FOAKE. | • Evolutionary design<br>• More efficient, less waste<br>• Simplified construction (48 months) and operation |
| USA<br>(Westinghouse) | AP-600<br>AP-1000<br>(PWR) | 600<br>1100 | AP-600: NRC certified 1999, FOAKE.<br>AP-1000 NRC certification 2005. | • Simplified construction and operation<br>• 3 years to build<br>• 60-year plant life |
| France-Germany<br>(AREVA NP) | EPR<br>(PWR) | 1600 | Future French standard.<br>French design approval.<br>Being built in Finland.<br>US version being developed. | • Evolutionary design<br>• High fuel efficiency<br>• Low cost electricity |
| USA<br>(GE) | ESBWR | 1550 | Developed from ABWR, under certification in USA | • Evolutionary design<br>• Short construction time |
| Japan<br>(utilities, Westinghouse, Mitsubishi) | APWR | 1500 | Basic design in progress, planned at Tsuruga | • Hybrid safety features<br>• Simplified construction and operation |
| South Korea<br>(KHNP, derived from Westinghouse) | APR-1400<br>(PWR) | 1450 | Design certification 2003, first units expected to be operating in 2012. | • Evolutionary design<br>• Increased reliability<br>• Simplified construction and operation |
| Germany<br>(AREVA NP) | SWR-1000<br>(BWR) | 1200 | Under development, pre-certification in USA. | • Innovative design<br>• High fuel efficiency |
| Russia (Gidropress) | V-448<br>(PWR) | 1500 | Replacement for Leningrad and Kursk plants. | • High fuel efficiency |
| Russia (Gidropress) | V-392<br>(PWR) | 950 | Two being built in India, bid for China in 2005. | • Evolutionary design<br>• 60-year plant life |
| Canada (AECL) | CANDU-6<br>CANDU-9 | 750<br>925+ | Enhanced model.<br>Licensing approval 1997 | • Evolutionary design<br>• Flexible fuel requirements<br>• C-9: Single stand-alone unit |
| Canada (AECL) | ACR | 700<br>1000 | ACR-1000 proposed for UK.<br>Undergoing certification in Canada | • Evolutionary design<br>• Light water cooling<br>• Low-enriched fuel |
| South Africa (Eskom, Westinghouse) | PBMR | 165<br>(module) | Prototype due to start building 2006 | • Modular plant, low cost<br>• Direct cycle gas turbine<br>• High fuel efficiency |
| USA-Russia et al<br>(General Atomics - OKBM) | GT-MHR | 285<br>(module) | Under development in Russia by multinational joint venture | • Modular plant, low cost<br>• Direct cycle gas turbine<br>• High fuel efficiency |

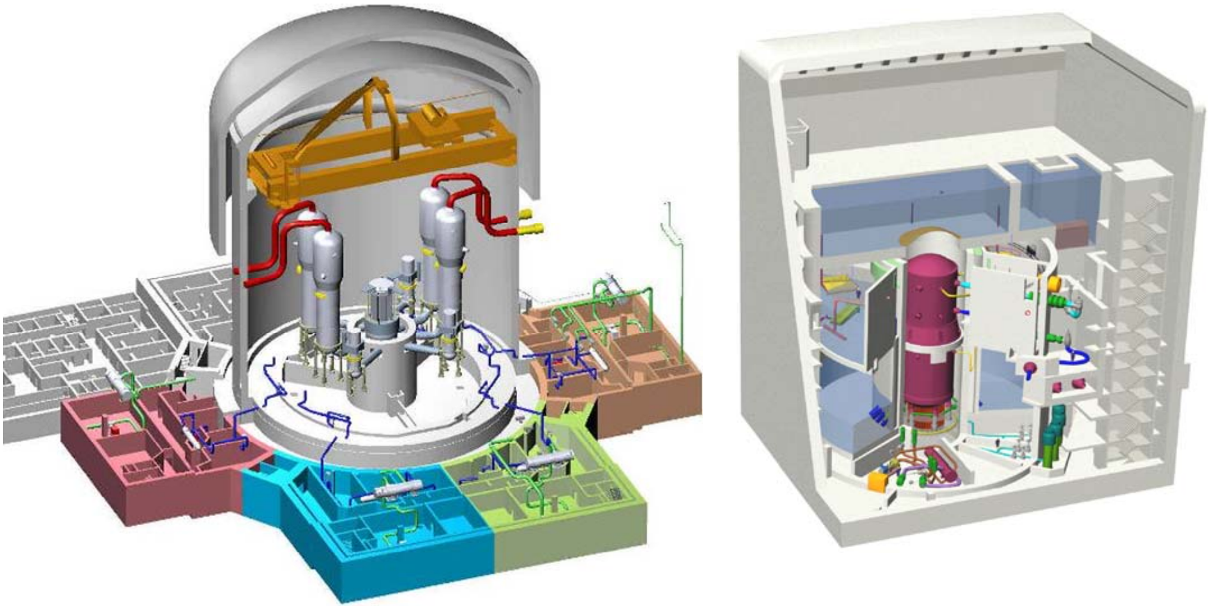


**Figure 6: Gen-III+ Reactors of AREVA NP**
**Left – EPR (Evolutionary Power Reactor), Right – SWR-1000**

The Gen-III/III+ reactors have:

- A standardised design for each type to expedite licensing, reduce capital cost and reduce construction time;
- Simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets;
- Higher availability and longer operating life - typically 60 years;
- Reduced possibility of core melt accidents;
- Decreased effect on the environment;
- Higher burn-up to reduce fuel use and the amount of waste;
- Burnable absorbers ("poisons") to extend fuel life.

The greatest departure from Gen-II designs is that many Gen-III/III+ incorporate passive or inherent safety features which require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures.

Since the beginning of the 90's AREVA NP has been intensively engaged in the design of new advanced Gen-III+ reactors (Figure 6):

1) Design of the PWR EPR in a joint venture of French and German vendors, utilities and regulators, and
2) Design of the next generation BWR SWR-1000 in a joint venture of German, Finnish and other European utilities with Siemens/Framatome (compliance with German and Finnish regulations required as design basis).

## 3 THE SWR-1000 GEN-III+ OPTION

With the SWR-1000, AREVA NP has developed a design concept for a medium-capacity NPP that is ready for commercial deployment and which fully meets the most stringent requirements in terms of nuclear safety, operational reliability and economic performance [18], [19], [20] (Figure 6 – Right). The basic design concept of the SWR-1000 as well as the systems and components provided for normal plant operation are based on the extensive and comprehensive experience gained from today's BWR NPPs [18], [19], [20]. This proven technology is incorporated into the SWR-1000 design. Some key technical data are presented in Table 2 and main features and safety objectives of SWR-1000 are discussed below.

**Table 2: Key Technical Data of SWR-1000**

| | |
|---|---|
| Thermal power | 3,370 MW |
| Net power output | 1,250 MW |
| Net efficiency | 37 % |
| Type of fuel assemblies | ATRIUM 12 |
| Number of fuel assemblies | 664 |
| Number of control rods | 157 |
| Height of active core | 3.0 m |
| Average power density | 51 kW/l |
| RPV overall height | 23.81 m |
| RPV inside diameter | 7.12 m |
| Design pressure | 88 bar |
| No. of reactor water recirculation pumps | 8 |
| Plant design life | 60 years |
| Plant construction period | 48 months |

### 3.1 Improving Design by Simplifying Systems Engineering

Operating experience from existing BWR plants has been applied to simplify systems engineering for the SWR-1000 design. Such design simplifications include:

- A single-train feedwater heating system
- No feedwater tank
- 3 main steam lines
- 2 feedwater lines
- Replacement of redundant subsystems of the complex active RHR (Residual Heat Removal) system with simple passive systems (Figure 7).

The active core height has been reduced from 3.71 to 3.0 m. As a result, the core can be positioned lower inside the RPV (Reactor Pressure Vessel) providing a much larger water inventory above the core for accident control purposes.

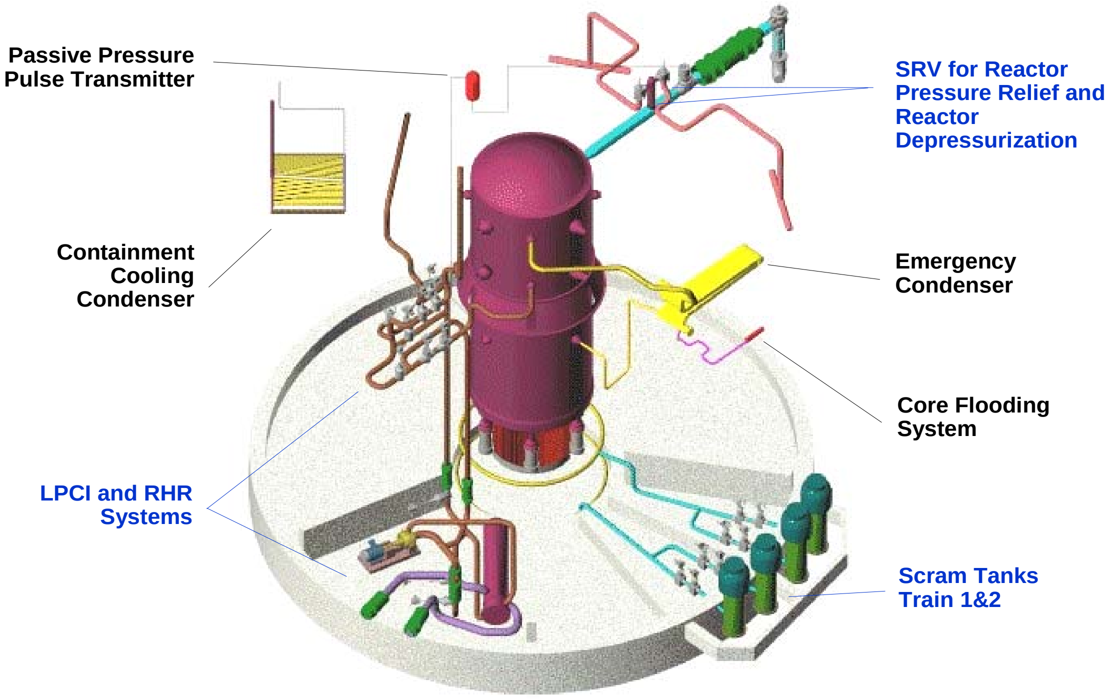


**Figure 7: SWR-1000 Passive Safety Systems**

The fuel assemblies have been enlarged from 10×10 to a 12×12 rod array. This reduces the total number of fuel assemblies in the core and thus also the number of control rods and their drives as well as in-core neutron flux monitors. The fuel utilization benefits and operational flexibility afforded by recirculation pump operation drove the economic evaluation strongly in favour of forced coolant circulation. The circulation is provided by 8 internal, 'wet-motor' pumps that require no mechanical seals or oil supply. The fuel pool cooling systems, previously located outside the fuel pool, have been replaced by coolers installed inside the fuel pool. The fuel pool cleanup system has been combined with the reactor water cleanup system that is designed for operation under low-pressure conditions.

The auxiliary power supply system is a 2-train design. Thanks to the simplifications in plant design, fewer drives have to be supplied with power. The emergency power supply system, with its emergency diesels and batteries, is likewise a 2-train design. The provision of only 2 emergency power supply trains is permissible since the plant's passive systems effectively represent more than a third redundant train.

## 3.2 Passive Safety Systems

Inside the containment, which like all pressure suppression types, is subdivided into a pressure suppression chamber and a drywell, there is additional 4 large core flooding pools in the drywell. The core flooding pools serve as a heat sink for passive heat removal from the RPV (Figure 8) by emergency condensers and the SRVs (Safety-Relief-Valves).

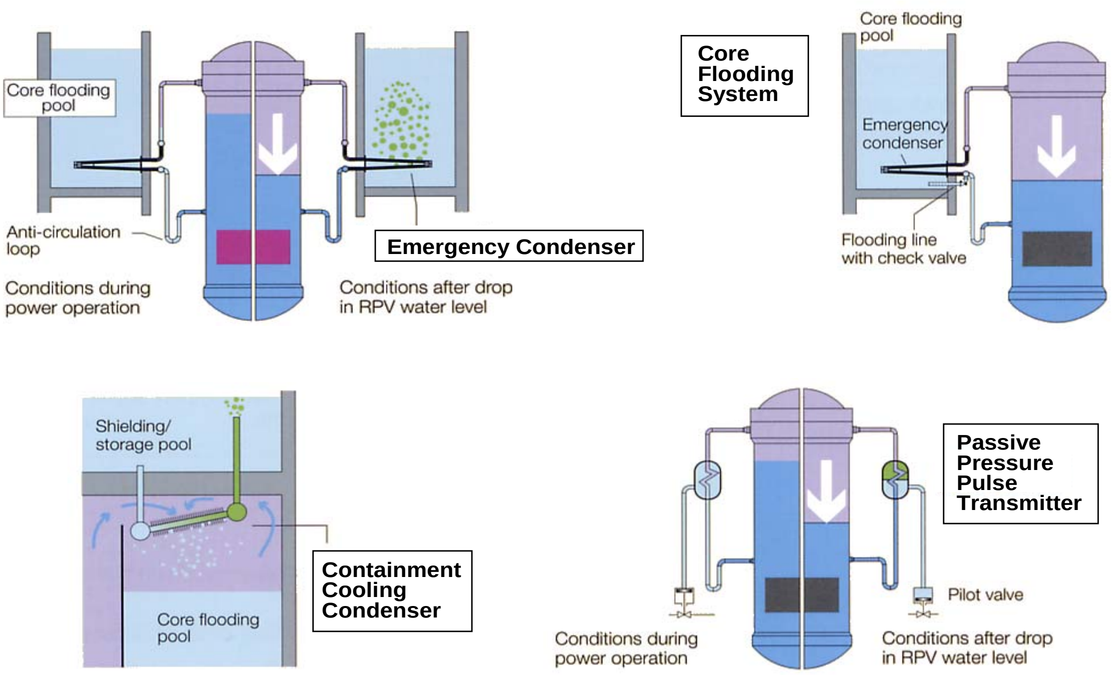


**Figure 8: SWR-1000 Passive Safety in Action**

The containment houses the systems which interact directly with the RPV and also accommodates the new equipment provided for passive accident control (Figures 7 and 8). This comprises:

- SRVs with their additional passive pilot valves
- Emergency condensers for passive removal of heat from the RPV to the water of the core flooding pools
- Containment cooling condensers for passive heat removal from the containment to the shielding/storage pools situated above

- Passive flooding lines
- Passive pressure-pulse transmitters provided for safety function actuation.

**Emergency Condensers.** The emergency condensers (Figure 8) serve to remove heat from the reactor upon a drop in RPV water level. The tubes of the emergency condensers are submerged in the core flooding pools and are filled with water when the water level in the RPV is normal. If reactor water level should drop, the water drains from the tubes. Steam from the reactor then enters the tubes and condenses, the resulting condensate flows back into the RPV due to gravity. The emergency condensers come into action automatically without any need for electric power or switching operations.

**Containment Cooling Condensers.** If the containment temperature should rise due to a release of steam into the drywell atmosphere, the containment cooling condensers (Figure 8) remove heat from the containment to the water of the shielding/storage pool located above it. These components require neither electric power nor switching operations to begin.

**Core Flooding System.** When reactor pressure has been sufficiently reduced by depressurization, water from the core flooding pools (Figure 8) flows due to gravity into the RPV through flooding lines equipped with self-actuating check valves.

**Passive Pressure Pulse Transmitters.** The passive pressure pulse transmitters (Figure 8) are small heat exchangers that operate according to the same principle as the emergency condensers. Upon a drop in reactor water level, pressure builds up on their secondary sides. This pressure is then used to initiate safety-related switching operations (for reactor scram, automatic depressurization and containment isolation at the main steam lines), without any need for electric power or I&C signals.

## 3.3 Combining Active and Passive Safety

Incorporation of passive safety equipment together with proven active safety systems provides an optimum combination of diverse design features offering the following advantages:

- Simplification of systems engineering
- Reduction of dependence on external power supplies and complex control systems
- Significant reduction in effects of common cause faults
- Low susceptibility to human error, as the passive systems are not accessible to operating personnel during plant operation
- Lower cost and effort for inspection and maintenance.

Moreover, by combining active and passive safety systems of diverse design, the effects of Common Cause Failures are significantly reduced and the frequency of core damage states caused by plant-internal events is more than 2 orders of magnitude lower than that of contemporary plants. From a deterministic viewpoint, taking single failures into account, this design concept also allows all postulated DBAs (Design Basis Accidents) to be controlled with the passive systems alone.

## 3.4 Core Melt Control

Despite the much lower probability of occurrence of a core melt accident, design features are nevertheless provided for controlling an event of this kind in such a way that the consequences of the accident remain restricted to the plant and there is no need for wide-scale emergency response actions in the vicinity of the plant, such as evacuation or relocation.

Compared to existing NPPs, the probability of occurrence of a core melt accident has been substantially reduced even further.

Early reactor core melt due to a plant-internal event involving loss of coolant is only possible if all options available for feeding coolant into the RPV should fail. The effects of a core melt accident can be controlled by the following means (Figure 9):

- Core melt is retained inside the RPV by cooling the RPV exterior. For this purpose the bottom of the drywell is flooded using water from the core flooding pools.
- The containment atmosphere is inerted with nitrogen to prevent hydrogen combustion.
- The containment is designed to accommodate the pressure build-up due to hydrogen released by a 100% zirconium-water reaction of the core's zirconium inventory.

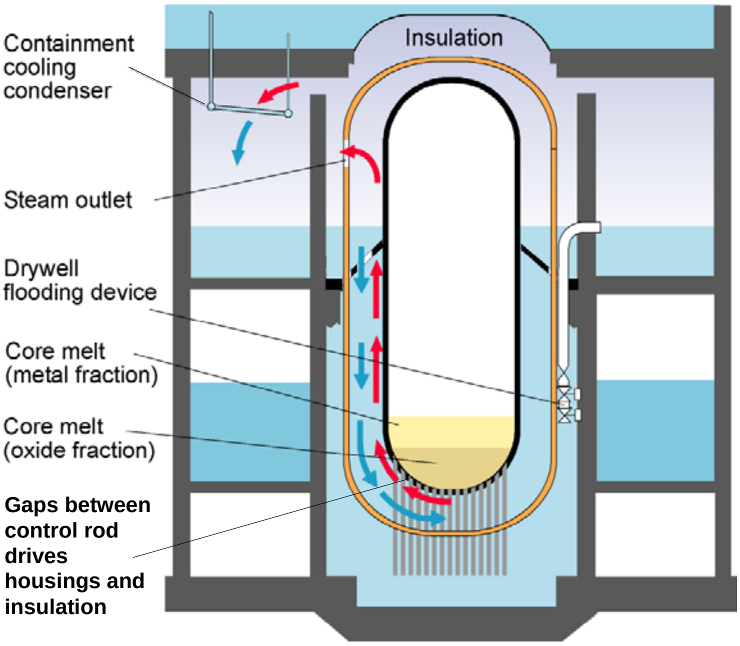


**Figure 9: SWR-1000 Core Melt Control**

- Passive heat removal from the containment is ensured via the containment cooling condensers without any release of radioactivity to the plant environs.

## 3.5 Buildings, Structures and their Protection

The reduced number of systems and components enables the plant building and structures to be considerably smaller and compacter (Figure 10).

The reactor building (Figure 10) is the only building protected against all three major postulated hazards (seismic events, aircraft crash and explosion pressure waves). The buildings containing the emergency diesels and safety-related cooling water systems (Figure 10) are protected against the effects of aircraft crash through physical separation and are designed to safely accommodate the loads imposed by a seismic event or an explosion pressure wave. Since none of the other buildings contain safety-related equipment or components with a high activity inventory, they are only designed to withstand seismic loading according to standard industrial practices.

## 3.6 Compliance with Regulatory Requirements

The design of the SWR-1000 has been based on the following nuclear codes and standards:

- German nuclear regulatory codes and standards as well as recommendations issued by the Groupe Permanent Réacteurs (GPR) and the German Reactor Safety Commission (RSK),
- International Atomic Energy Agency (IAEA) Guidelines
- European Utility Requirements (EUR)
- Finnish nuclear regulatory requirements set forth in the YVL Guides
- US Nuclear Regulatory Commission (NRC) Guides.

A preliminary safety assessment published by the Finnish Radiation and Nuclear Safety Authority (STUK) in response to the application submitted by TVO for a 'decision in principle' confirmed that the SWR-1000 is basically licensable in Finland.

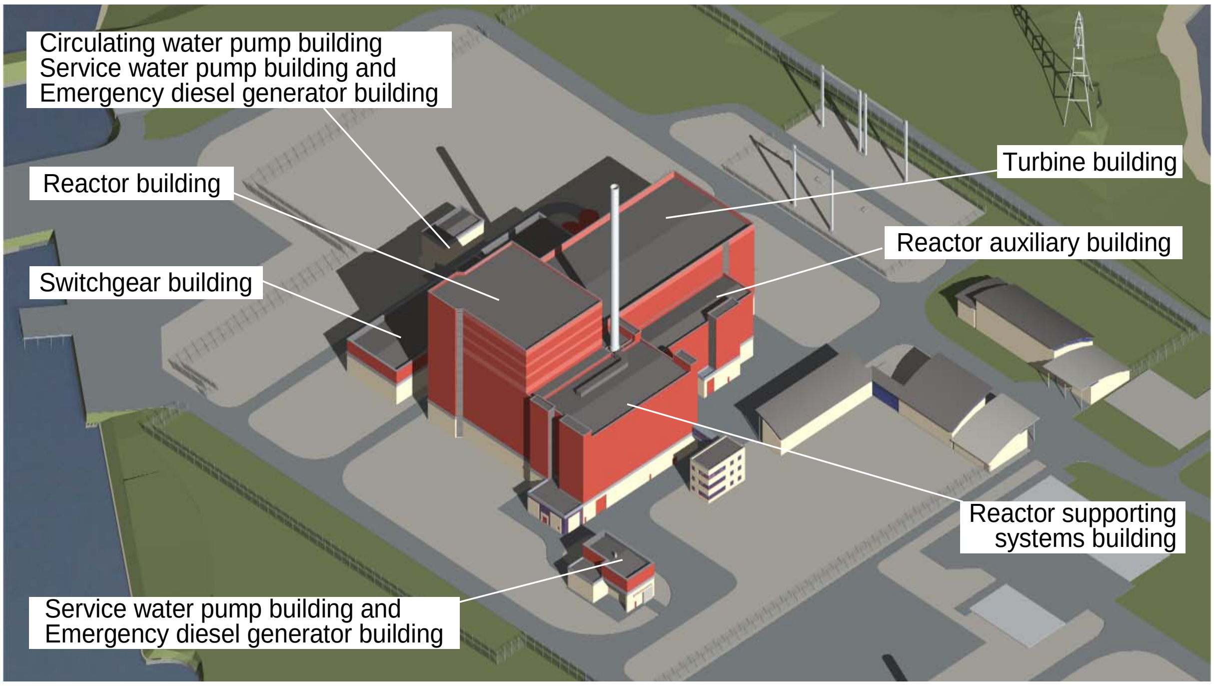
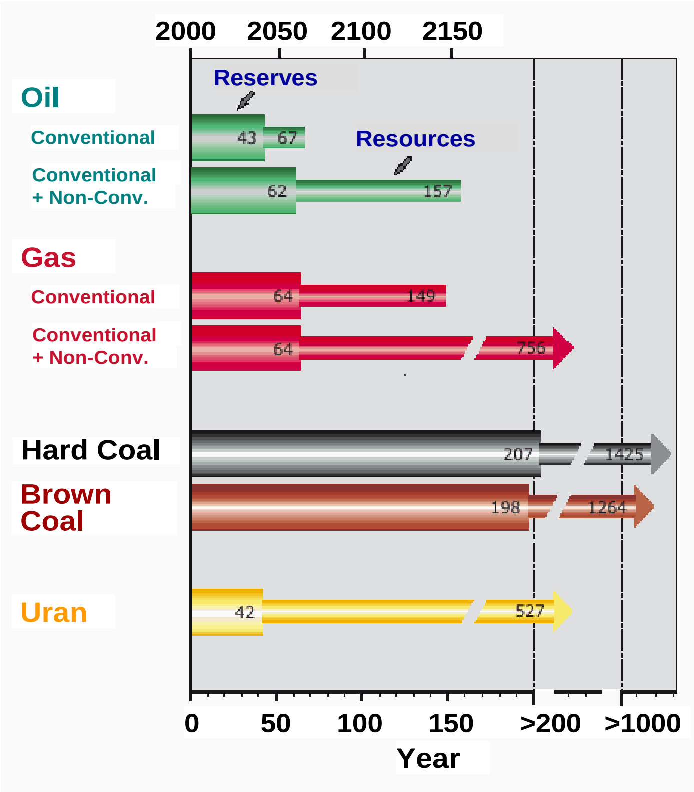


Figure 10: SWR-1000 Plant General Layout

## 4 CONCLUSIONS

Taking into account the shortage of non-renewable energy sources (Figure 11), global warming risks and impacts (Figure 4), population increase and growing energy consumption (Figure 1) nuclear energy is the most realistic option to replace fossil fuels and satisfy global demand. Between 2000 and 2015 the world's population will be increasing at about 1.3% per year while the annual power consumption will rise by about 2.5% on average. From the point of view of satisfying the future energy supply shortfall, the Generation III/III+ reactors are essential. The Gen III/III+ reactors are further improvements of the plants currently operating worldwide (Figure 5), having reduced construction time and higher availability as well as increased safety by combining active and passive safety features and minimizing the effects on the environment.



Reserves = at prices and with technology of today, economically profitable quantities of energy stock of raw materials;

Resources = proven, but at present technically and/or economically unprofitable as well as not proven, but geologically possible, in the future profitable quantities of energy raw materials ("yet to find").

Figure 11: Non-Renewable Energy Sources

The SWR-1000 (Figure 6 – right; Table 2) is a new Gen-III+ BWR design of AREVA NP but is not in fact a new plant concept. Its starting point was a proven BWR design; based on NPP Gundremmingen, new technological developments and accumulated operating experience have been integrated into the advanced design. Simplification of overall plant design and introduction of passive safety systems (Figures 7 and 8) lead to lower investment and maintenance costs.

Systems and plant design were reviewed by expert groups of the European Utilities. The SWR-1000 has been designed to achieve high plant availability with short outages. Realistic average availability for a plant lifetime of 60 years and a 12 month cycle is 94.5%.

It seems that the SWR-1000 could be the most advanced BWR of Generation III+ reactors.

## REFERENCES

[1] Energy, Electricity and Nuclear Power Estimates for the Period up to 2030. *IAEA Reference Data Series No. 1*, July 2006.

[2] *Energie-Chronik*, March 2003.

[3] *Enerdata*, June 2006.

[4] R. Güldner, Nuclear Energy – Worldwide in the Upwind. *KTG Section Rhein/Main*, Offenbach, April 12, 2006 (in German).

[5] C. Le Quéré, How much of the recent $CO_2$ increase is due to human activities? http://www.realclimate.org/, 2005.

[6] M. E. Mann, R. S. Bradley and M. K. Hughes, Global-scale temperature patterns and climate forcing over the past six centuries. Nature No.430, pp.105, July 2004.

[7] Board on Atmospheric Sciences and Climate, Committee on Surface Temperature Reconstructions for the Last 2000 Years. *National Research Council, The National Academies Press*, 2006.

[8] World Glacier Monitoring Service, http://www.geo.unizh.ch/wgms/, 2006.

[9] S. Sun, J. E. Hansen, Climate Simulations for 1951–2050 with a coupled Atmosphere-Ocean Model, Journal of Climate, Vol. 16, pp.2807-2826, September 2003.

[10] J. T. Houghton, et al., Climate Change 2001: The Scientific Basis, *UNEP & WMO Intergovernmental Panel on Climate Change, Cambridge, University Press*, 2001.

[11] A. J. Thorpe, Climate Change Prediction: A challenging scientific problem, http://policy.iop.org/Policy/, 2005.

[12] *Vital Climate Graphics*, UNEP (United Nations Environment Programme) and GRID-Arendal, 2001.

[13] P. Moore, *The Miami Herald*. January 30, 2005.

[14] T. Kanoh, The Dream of a Nuclear Renaissance has come True. *Keynote Lecture on 14th Int. Conference on Nuclear Engineering – ICONE-14*, Miami, Florida, USA, July 17-20, 2006.

[15] E. Gonzalez, Nuclear Energy Development Perspectives in Europe. *Keynote Lecture on 14th Int. Conference on Nuclear Engineering – ICONE-14*, Miami, Florida, USA, July 17-20, 2006.

[16] *International Energy Outlook*, 2005.

[17] Advanced Nuclear Power Reactors, Nuclear Issues Briefing Paper 16. *Uranium Information Centre, A.B.N. 30 005 503 828*, August 2006.

[18] U. Stoll, Z. Stosic, W. Brettschuh and J. Tamminga, SWR-1000: The Boiling Water Reactor with a new Safety Concept. *Invited Lecture on ASME Workshop on 'Requirements and Capabilities for Thermal Hydraulic, CFD and Neutronic Analysis of Advanced Light Water Reactors', 14th Int. Conference on Nuclear Engineering – ICONE-14,* Miami, Florida, USA, July 17-20, 2006.

[19] SWR-1000: The Boiling Water Reactor with a New Safety Concept. *Published by Framatome ANP GmbH*, 2005.

[20] W. Brettschuh, J. Meseth, SWR-1000: A next Generation Boiling Water Reactor ready for Deployment. *Proceedings of ICAPP'05*, Seoul, Korea, May 15-19, 2005.