Nuclear Power in the Gulf Cooperation Council (GCC) States: Promise, Strategies and Challenges

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ABSTRACT

Nuclear power is a mature industry with an incredible record of safety and reliability, without the emission of greenhouse gases, and becoming economically attractive for private investment. The current interest in nuclear power for meeting future electricity and seawater desalination needs in the Gulf Corporation Council (GCC) states and other courtiers in the Middles East is prudent, logical and timely. An achievable goal for the GCC states would be to secure 30% of their future needs for electricity and process heat for industrial applications and seawater desalination from nuclear power by 2030. This is equivalent to completing the construction of two, 1500 MWe nuclear power plants each year starting in 2016. Accomplishing this goal requires a multi-facet approach to addressing many challenges that include: (a) encouraging and stimulating private investments in nuclear energy, (b) establishing specialized higher education and vocational training programs that are among the world's best; (c) maintaining close cooperation with the International Atomic Energy Agency (IAEA), the Arab Atomic Energy Agency (AAEA) and countries with advanced nuclear technology and capabilities, (c) establishing a viable heavy industry and international alliances on all aspects of the fuel cycle; (d) collaborating with other courtiers in the Middle East on the development of a common electric grid; (e) investing in mining and exploration of uranium resources, (f) identifying and licensing suitable sites for future construction of nuclear plants; (g) establishing a regulatory and safety board that has a government oversight and an effective technical and R&D infrastructure, making it possible to build and operate new nuclear plants within 40 - 50 months, (h) seeking IAEA technical assistance to ensure safety and compliance at all levels; and (i) considering standardization versus diversification in nuclear reactor types.

1. INTRODUCTION

Water, energy, and the environment are closely intertwined. While clean air and water are essential elements of life, clean, inexpensive, and reliable energy is needed to support future economical growth in the world. The economies in the Middle East have been growing (> 5%) at twice the rate of the advanced economies in the world. Between 2005 and 2006, the electricity generation in the Middle East grew 8.9%, and the demand for electricity is expected to grow at about 7 - 10% annually during the next 10 years, almost triple the projected growth rate of the average global demand (~ 2.5 - 3%). As shown in Figure 1, in 2006, the electricity demand in the Arab World (138 GW) was 3.1% of the total world demand and is projected to increase to 8.5% (500 GW) of the total world demand by 2030 (KHATIB 2007).

The World Energy Council estimates that the six Gulf Cooperation Council (GCC) countries (Bahrain, Saudi Arabia, Qatar, Oman, Kuwait and the United Arab Emirates) would require 100,000 megawatts of additional electrical power to meet the surging demand over the next 10 years and more than an additional 200,000 MWe by 2030, of which 90,000 megawatts could be provided by nuclear power, significantly contributing to reducing the emission of greenhouse gases in the region. Such an ambitious target is equivalent to completing the construction of two 1500 MW nuclear power plants each year starting in 2016. At such time, the price of oil could reach or exceed US$200 per barrel, making the economics of nuclear power exceedingly attractive. Such an interest, driven by economics and environmental concerns, would be constrained by the availability of uranium and the future success in developing a proliferation proof fuel cycle, while ensuring reliable access, at reasonable cost, to nuclear fuel.

Nuclear power is critical to meeting future global energy needs and reducing the emission of greenhouse gases. It currently provides between 2% - 97% of the electricity generation in many countries, representing 2/3 of the world population. The world's electricity generation from nuclear power is projected at 164 billion MWh in 2015 and 206 billion MWh in 2030. These projections represent an increase of 19% and 49% compared to the 2007 level (Figure 2). The global share of nuclear power is projected to continue to be about 6% of the world's total energy demand (Figure 2). Thus, nuclear power could provide up to 20%, or even higher, of the global electricity generation by 2030, compared to 16% at present (Table 1).

The ever depleting sources and increasing cost of fossil fuels and the negative impact of burning these fuels on the environment have reached an alarming level. The increases in the emission of greenhouse gases and the acid rain caused by the high rate of economic

Growth world wide, particularly in the Middle East and on the Indian continent and in Asia, have stimulated a large global interest to invest in nuclear power.

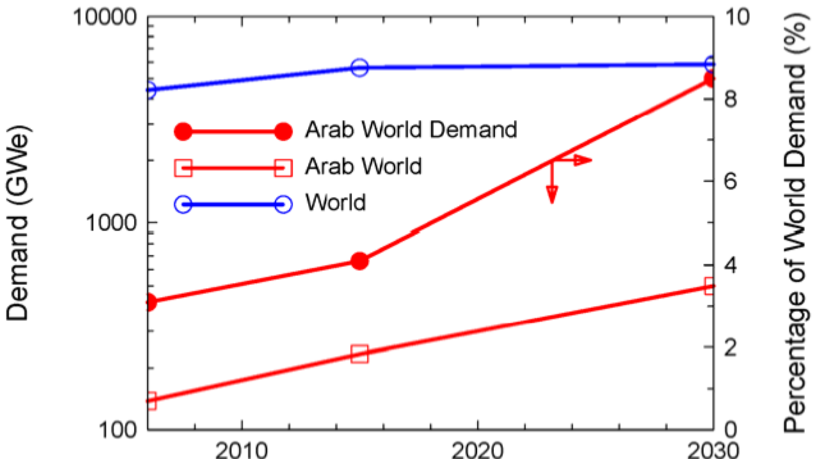

Figure 1 Electricity Demand in the Arab World(KAHTIB 20070

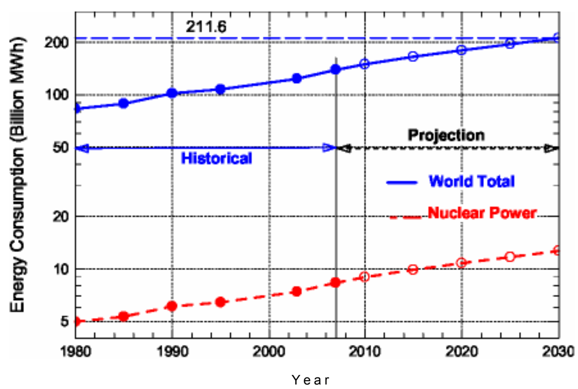

Figure 2 World Energy Consumption and Nuclear Power Contribution.

Global nuclear power industry is mature and has incredible records of safety and reliability. It is becoming increasingly attractive for private investments, let alone for the absence of the greenhouse gas emissions. The successful experience for more than forty years in the United States of America (USA), France, United Kingdom (UK), other member countries of the European Union, Japan, South (or Federal Republic of) Korea, China, India and other countries, has been a land mark for the sustainability, reliability and the environmental friendliness of nuclear power. The recently expressed interest in nuclear power by the Gulf Corporation Council (GCC) states and other countries in Middle East is a logical, prudent, and timely decision. Many other countries in the world have recognized the potential of nuclear power and are actively constructing new plants. There are many advanced reactor designs of the Generations III and III+ to choose from. These reactor types are being marketed by various companies and international alliances competing for shares of the global market.

The Generation-III and III+ nuclear reactors that are being constructed and/or planned for construction in various countries share many of the advanced design and safety features (ADVANCED NUCLEAR POWER REACTORS 2007). They offer passive and/or redundant safety systems, all digital control, advanced but simple nuclear reactor designs, effective fuel rod designs for achieving high burnup (> 50 MWD/kg), high plant thermal efficiency, modularity in construction and shorter construction schedule (36 – 50 months), safe decay heat removal for up to 72 hours without interference by the operator, large design margins, longer refuelling cycle (18 - 24 months), and longer operation life (50 – 60 yrs). These reactors fall in one of three categories: Boiling Water Reactors (BWRs), Pressurized Water Reactors (PWRs), and Heavy-water moderated, Pressurized Water Reactors (HPWRs). The construction schedules of the new reactors in South Korea, Japan, and China have been reduced significantly to 36 - 50 months.

In addition to presenting and discussing the design highlights of the Generation III and III+ reactors, the objectives of the paper are to review the current and future prospect of nuclear power in the world and to examine its potential for supporting future economical development in the GCC countries and other countries in the Middle East region. Also discussed are the challenges that need to be addressed and the choices that need to be made in conjunction with the introduction of nuclear power in the GCC and the Middle East countries. The following two sections review the current status and the future use of nuclear power in the world and the different reactor types competing for global market shares.

Table 1 Global Electricity Supply from Nuclear Power (WORLD NUCLEAR ASSOCIATION 2007a).

Country	Electricity Generation		Operating Reactors	
	Total (MWh)	*% of total demand*	*Number*	*Total Power (MWe)*
Argentina	7,200	6.9	2	935
Armenia	2,400	42	1	376
Belgium	44,300	54	7	5,728
Brazil	13,000	3.3	2	1,901
Bulgaria	18,100	44	2	1,906
Canada	92,400	16	18	12,595
China	51,800	1.9	11	8,587
Czech Republic	24,500	31	6	3,472
Finland	22,000	28	4	2,696
France	428,700	78	59	63,473
Germany	158,700	32	17	20,339
Hungary	12,500	38	4	1,826
India	15,600	2.6	17	3,779
Japan	291,500	30	55	47,577
Lithuania	8,000	69	1	1,185
Mexico	10,400	4.9	2	1,310
Netherland	3,300	3.5	1	485
Pakistan	2,600	2.7	2	400
Romania	5,200	9.0	2	1,310
Russia	144,300	16	31	21,743
Slovakia	16,600	57	5	2,064
Slovenia	5,300	40	1	696
South Africa	10,100	4.4	2	1,842
South Korea	141,200	39	20	17,533
Spain	57,400	20	8	7,442
Sweden	65,100	48	10	9,086
Switzerland	26,400	37	5	3,220
Taiwan	38,300	20	6	4,884
Ukraine	84,800	48	15	13,168
United Kingdom	69,200	18	19	11,035
USA	787,200	19	104	99,049
World total	**2,658, 000**	**16**	**439**	**372,002**

2. GLOBAL STATIS OF NUCLEAR POWER

Most current operating nuclear reactors in the world are of the Generation-II types, developed and constructed in the sixties and seventies and have since been retrofitted with improved safety and control capabilities. As shown in Table 1, there are 439 operating reactors world wide, with a total installed capacity of 372,002 MWe. These reactors generate 2,658 billion KWh of electricity, representing 16% of the world's total electricity demand (U.S. DOE 2007a,b,c, World Nuclear Association 2007a, IAEA 2007).

There are an additional 349 reactors, either under construction, planned or proposed. The 33 nuclear reactors currently under construction have a total installed capacity of 26,838 MWe and the 94 reactors planned have a total installed capacity of 101,595 MWe. The additional 222 reactors proposed have a total installed capacity of 193,095 MWe. The completion of these reactors would increase the world's total electricity generation capacity from nuclear energy by an additional 321,528 MWe (86.4%). At a projected 6% share of the global electricity generation, nuclear power is expected to provide as much as 20% of the electricity generation in the World by 2030 (Figure 2).

As shown in Table 1, the percentage of the electricity demand provided by nuclear power varies from one country to another. It averages 78% in France, 69% in Lithuania, 57% in Slovakia, 54% in Belgium, 48% in both Sweden and Ukraine, 44% in Bulgaria, 42% in Armenia, 40% in Slovenia, 39% in South Korea, 38% in Hungary, 37% in Switzerland, 32% in Germany, 31% in Czech Republic, 30% in Japan, 28% in Finland, 20% in both Spain and Taiwan, 19% in USA, 18% in UK, 16% in Canada, 9% in Romania, and 6.9% in Argentina (Figure 3).

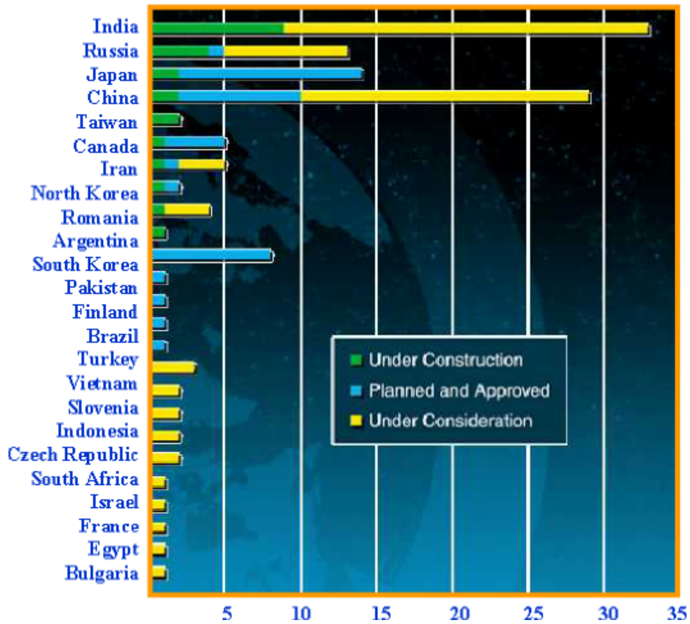

Figure 3 Nuclear Reactor under Construction, Planned, and under Consideration World Wide.

The share of electricity generation from nuclear power in India and China is 2.6% and 1.9% of the current demand, but rising fast (Table 1). China has 5 new reactors under construction with a total installed capacity of 4,540 MWe and 30 additional reactors (32,000 MWe) planned. India has 6 new reactors under construction with an installed capacity of 2,976 MWe and 10 more reactors planned (8,560 MWe). Nuclear energy is a national strategic priority in South Korea because it imports 97% of its energy needs.

2.1 Specific Examples

The 104 nuclear reactors operating in USA provide 19% of the electricity needs. They generated 787,200 MWh of electricity in 2006 (Table 1), 3 times more than in 1979. The average capacity factor for the operating reactors in the USA has exceeded 90% during the last five years. The United States Nuclear Regulatory Commission (USNRC) has recently approved 48 of these reactors for a 20 year life-extension operation license, 9 additional reactor applications are either submitted or currently under review, and 22 more applications are expected in 2007 - 2009. The USNRC has also approved 11 of the currently operating reactors for power-up rates ranging from 1.7% to 8%, with 9 more reactor applications currently under review. The increase in the electricity generation capacity during the last 10 to 15 years in USA, as a result of the high capacity factor and the power-up rates, is equivalent to adding 10 1 500-MWe new nuclear reactors to the operating fleet in the USA.

There are 20 reactors currently operating in Korean and 8 more either under construction or planned to start construction before 2011 (Table 1 and Figure 3). In 2005 the capacity factor of the nuclear reactor plants in South Korea averaged 96.5%, one of the highest in the world. Nuclear power is expected to provide 60% of the electricity needs in South Korea by 2035. The Korean Standard Nuclear Plant (KSNP), which incorporates some of the design features of the System 80 and many of the US advanced LWR design requirements, is the type used for all 1000 MWe plants built in Korea. Eight of these plants are currently in operation in South Korea. (Both System 80 and the Generation-III System 80+ have received design certifications from USNRC, but are not currently being marketed by Westinghouse.)

In late 1990, work started on the improved KSNP or KSNP$^+$ design (later renamed Optimized Power Reactor (OPR-1000), with improved components designs and safety features and optimized plant layout to reduce the construction cost and schedule. The construction of the first two KSNP$^+$ 1000 MWe (or OPR-1000) units started in 2006 and 2007. These units are expected to enter commercial operation in 2010 and 2011. The construction of two additional OPR-100 units is expected to start in 2008 and 2009 (NUCLEAR POWER IN KOREA 2007). The design of the Korean's next generation Advanced Pressurized water Reactor (APR-1400) for generating more tha1400 MWe, was completed in 1999 and expected to enter operation after 2010 (NUCLEAR POWER IN KOREA 2007).

2.2 Nuclear Desalination

The lack or shortage of potable water is an ever increasing threat to sustaining economical development and supporting population growth in many areas of the world. It is estimated that 20% of the world population does not have access to sources of fresh or potable water; a percentage that is expected to increase in the future (FAIBISH AND KONISHI 2003, PANTELL 1993). More than 15,23 operating desalination units in the world, 60% of which are in the Middle East, have a capacity of approximately 32.4 million m^3/day of potable water (EJJEH 2007). About 19.7% of the world's seawater desalination capacity is produced in North America and the Caribbean (Figure 4). This figure presents the current desalination capacities in the different regions of the world.

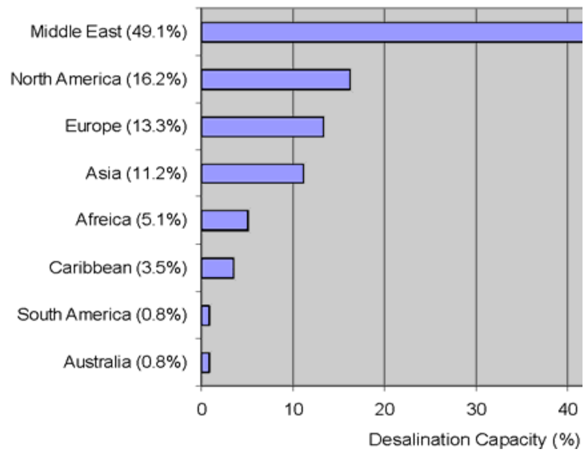

Figure 4 Desalination Capacities Worldwide (EJJEH 2007).

Most seawater desalination uses fossil fuels, thus contributing to the increase in the emission of greenhouse gases. Desalination technologies currently in use are energy intensive. Some use process heat, electricity, or both and each is best suited for meeting specific needs. Multi-Stage Flash (MS F) evaporation process that uses process steam and electricity is the most widely used for seawater desalination. Multi Effect Desalination (MEF) uses more process steam, but less electricity than MSF. The Reverse Osmosis (RO) driven by electric pumps is most effective for treating brackish water and uses only electricity. The MSF-RO hybrid exploits the best features of the MSF and RO processes using both process steam and electricity.

The MFE process consumes about 8 tons of steam and 4 kWh of electricity per cubic meter of fresh water produced, the MEF process consumes 12 tons of process steam and 2 kWh of electricity per cubic meter of fresh water produced, while the RO consumes about 3.5 – 5.5 kWh of electricity, with energy recovery, or 8 kWh of electricity, without energy recovery, to produce a cubic meter of fresh water (EJJEH 2007). The current estimate of the net cost seawater desalination, based on a 20 year life and 6% interest rate, using fossil fuels is US$0.403 to US$0.479 per cubic meter of fresh water produced using MSF and about US$0.598/m3 of fresh water using RO (EJJEH 2007).

In addition to the seawater desalination, process steam provided by nuclear power plants could be used to support a wide range of uses in agriculture, manufacturing, and district cooling and heating, effectively improving the economics of the nuclear power plants. It is worth noting, however, that current and future growths in nuclear power generation in the world are focused solely on electricity generation, which is subject to the plant’s thermodynamic efficiency of 30 - 39%. The balance of the reactor thermal power is rejected into the atmosphere or in nearby water ways.

The technology of the dual purpose nuclear power plants for electricity generation and seawater desalination is proven with demonstrated feasibility in a number of countries, particularly Russia-Kazakhstan, India and Japan. Other countries with current interest or active research in this area includes Argentina, Algeria, Canada, China, Israel, Morocco, Pakistan, Republic of Korea, Russia, Spain, Tunisia, UK and USA. However, the use of nuclear desalination on a large scale in the future would vary from one region to another in the word, depending on many factors, chief among them are the economics compared to using fossil fuels and renewable energy such as solar power, the local population growth rate, the fossil fuel prices, and the local scarcity of fresh water.

Planning new cities and communities to accommodate future population growth in the GCC countries and the Middle East region should include at its core maximizing the use of the thermal energy generated in the nuclear reactors and fossil fuel plants to more than 80% (EL-GENK AND TOURNIER 2002). As the sources of fresh water in the world are becoming increasingly inadequate for sustaining future population growth, particularly in developing and underdeveloped countries and in arid and semiarid regions in Asia, Africa, and the Middle East, new approaches for using an increasing fraction of the thermal power generated by the nuclear reactors for desalination need to be investigated. This would require some changes in the layout and integration of the existing plants to not only generate electricity, but also produce process heat and steam for seawater desalination, various industrial applications, and district heating and cooling.

A worthy and achievable goal for the GCC countries and others in the Middle East is to increase the energy utilization from nuclear power plants to more than 80% of that generated in the reactors. This could be divided between electricity generation (35-39%), seawater desalination (25%), and process steam and heat for industrial applications (16 - 20%). In addition to contributing to energy and water self-sufficiency, this strategy would: (a) support future job creation and sustainable economical growth, with no or significantly reduced emission of greenhouse gasses, and (b) reduce the cost of electricity generation to become close or comparable to using fossil fuels in the GCC countries. At present this cost averages 13 - 17 US$/MWh, but would increase as the cost of fossil fuels continues to increase. On January 2, 2008 crude-oil futures hit $100 a barrel for the first time in a single floor trade in the New York Mercantile Exchange's benchmark February 2008 contract.

2.3 Looking Forward

The improved economics and the realization of the vital role nuclear power in meeting future global needs of electricity, process heat, and fresh water are reflected in the sharp increase in the construction of new plants and the expressed interest by many countries to add nuclear power to their future energy mix. The countries in the Middle East that have expressed such an interest recently include Libya, Morocco, Algeria, Egypt, Jordan, Yemen, Iran, Israel, and GCC countries. However, as the use of nuclear power increases the price of uranium also increases. It has increased precipitously during the last few years from less than US$30/lb to more than US$120/lb today, and is expected to reach or exceed US$200/lb within the next 5 years. Therefore, securing and confirming uranium resources and the future investments in the exploration and development of uranium in the Middle East and neighboring countries in Africa are critical to the sustainability and future growth of nuclear power in the region.

2.4 Uranium Supply and Nuclear Fuel Cycle Issues

Figure 5 shows the distribution of the uranium sources in the world. The current uranium demand is 67 Kt/yr, which exceeds the uranium production world wide by 25 Kt/yr. The balance is provided from the stockpiles accumulated before 1980, which would be exhausted within the next 10 years. In order to match future demand the world's uranium production would need to increase by more than 50% (ENERGY WATCH GROUP 2006).

Future expansion of nuclear power world wide would be limited by the availability of uranium resources. The expected shortage of uranium within the next 10 -15 years and the current shortage of processing and manufacturing facilities world wide would be a major hindrance to meeting future needs for nuclear fuel. Such shortages are caused by the underinvestment for more than 20 years. However, the recent and expected increases in the prices of uranium in the future might stimulate additional investments for the exploration of the ore and the construction of new fuel fabrication and manufacturing facilities (SCI ENCE DAILIY 2007).

Investing in the exploration and extraction of uranium is not only timely, but becoming increasingly profitable and attractive for investments by the public and private sectors. Securing future supplies of uranium ore and developing international alliances for the extraction, conversion, and enrichment of uranium, the fabrication of nuclear fuel elements, and the processing of spent fuel would be necessary.

These alliances can also develop safe and secure options for the disposal and storage of the nuclear waste, which are critical to the future growth of nuclear power world wide (U.S. DOE 2007d). At some point in the future, as the uranium supply becomes short of meeting demand, recycling the plutonium produced in operating Light Water Reactors (LWRs) and using it with uranium as Mixed Oxide (MOX) fuel in operating reactors might become necessary, subject to satisfying proliferation concerns. Some countries have acquired a lot of experience in the processing and fabrication of MOX fuel and its use in commercial reactors, particularly France, Canada, Belgium, and Russia.

Another consideration in the future development of the nuclear fuel cycle is to investigate the technology and possible construction of fast neutron spectrum, liquid metal reactors. These reactors would efficiently burn the transunranic elements produced in LWRs, with no or little proliferation concerns, and help achieving a significant reduction of the amount of nuclear waste.

The US Global Nuclear Energy Partnership (GNEP) initiative, an alliance that currently includes 19 countries (U.S. DOE 2007a), aims to:

(a) Facilitate cooperation among member countries in promoting future expansion of the peaceful, clean, sustainable, safe, and secure use of nuclear energy worldwide and in cooperation with the IAEA, while reducing the risk of nuclear proliferation,

(b) Develop, demonstrate and deploy advanced reactors for efficiently burning transuranic elements from recycled spent fuel discharged from exiting nuclear reactors, and

(c) Establish agreement among nations by which supplier countries, with the fuel enrichment and processing capabilities, to provide other (or user) countries a guaranteed access to nuclear fuel for their power needs at a reasonable cost, and take back spent fuel for processing and dispose of the nuclear waste (U.S. DOE 2007d).

While the GNEP initiative spares the user countries the investment in an expensive fuel cycle infrastructure, supplier countries would need to find a satisfactory and workable solution to the nuclear waste disposal issue. It is projected that by 2050 more than 200,000 tons of spent fuel, containing approximately 2,000 tons of transuranic elements and 8,000 tons of nuclear waste, will be generated per year (RICHTER 2006). The next section presents a summary of the current, under construction, and planned commercial nuclear power plants in the world (Figure 3).

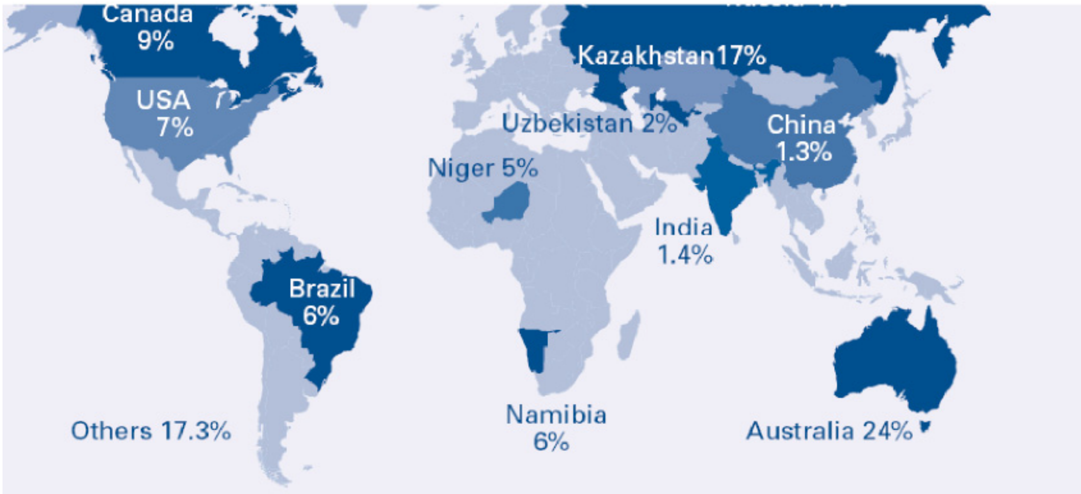

Figure 5 Global Sources of Uranium (NEA/IAEA 2006).

3. COMMERCIAL NUCLEAR REACTORS WORLD WIDE

Several Generation-III and III+ PWR and BWR types are currently under construction in China, South Korea, France, Finland, Japan, Russia and many other countries (Figure 3). The designs of these reactors are greatly simplified, equipped with redundant and/or passive safety systems, capable of achieving high fuel burnup, and have a greatly reduced probability of a core meltdown. They offer improved plant layout and integration, a shorter construction schedule and lower construction and operation cost. All reactor constructions planned and/ or under consideration are of the Generation-III and III+ types (U.S. DOE 2007b). Figure 3 compares the nuclear reactors currently under construction (in green), planned and approved (in blue), and under consideration (in yellow) in various countries (U.S. DOE 2006).

While operating commercial nuclear reactors in the world during the last 40 years are of the Generation-II PWRs, BWRs, HPWR, and Gas Cooled Reactors (GCRs), most have successfully achieved fuel burnup in excess of 40 MWD/kg. The Generation III and III+ reactors offer up to 60 years of operation life and higher fuel burnup up to 65 MWD/kg. These reactors also employ advanced fuel rod designs with burnable poisons and a cladding liner to protect against pellet cladding interaction (PCI). Most of these reactors are partially modular for shorter construction schedule (39-50 months) and offer relatively low construction capital cost estimated at US$1200/kWe to US$2000/kWe. However, the exact capital cost and that of electricity generation will vary from one country to another.

Table 2 lists the present certification status of the Generation III and III+ reactor designs by USNRC. The reactors already certified by USNRC are scheduled for construction in USA and many countries. China has recently contracted with Westinghouse (WH) to build 4 AP1000 reactors and several are planned for construction in USA.

China has also signed an agreement with France in November, 2007 to construct two European Pressurised water Reactors (EPRs). These are in addition to one being constructed in Finland and one planned for construction in France. Several Advanced Boiling Water Reactors (ABWRs) have been constructed and others are currently under construction in Japan.

The construction of the first two, Generation-III APR-1400 in the Republic of Korea has been authorized in 2006 and in February 2007 a contract was issued, to a consortium led by Hyundai, to build the two reactors at a projected capital cost of $5 billion (or US$1850/kWe). The construction of these 2 APR-1400 units is scheduled to start in 2008 and 2009 and to be completed within 51 months. Two additional APR-1400 units are scheduled for construction in 2010 and 2011. The APR-1400 reactor offers enhanced safety, a 60-year operation life, a higher fuel burnup, and a simplified design. The capital cost for construction is about 10% lower than for the KSNP+/OPR-1000 reactors. The expected electricity generation cost using APR-1400 reactors is US$36/MWh. The next sub-sections briefly review the salient features of the Generation III and III+ reactor designs listed in Table 2.

3.1 Advanced Boiling Water Reactor (ABWR)

The compact, modular design of the ABWR (Figure 6) significantly reduces the cost and time of construction and the cost of operation (GE ENERGY 2007a). The construction of the most recent ABWR in Japan took only 39 months to complete, a record for a reactor with high generating power of 1350 to 1600 MWe. Four of the ABWRs built by GE-Hitachi-Toshiba and are currently in commercial operation in Japan have an estimated capital cost of US$2000/kW. The ABWR currently under construction in Japan has a projected lower capital cost of US$1 ,700/kW. In addition, two ABWRs are being constructed in Taiwan and 4 more are planned for construction in Japan and USA (Figure 6). The ABWR has received USNRC final certification in May 1977 (Table 2) and has been certified for the European requirements. The Hitachi's 600, 900, 1700 MWe ABWR designs are complete. The smallest (ABWR-600) is standardized for a 34 months construction schedule at a significantly lower cost.

Table 2 The Certification Status of Generations III and III+ Reactor Designs by USNRC.

Reactor Design/Type	Vender	Approx. Capacity MWe	Certification Status		
			Certified	Undergoing Certification (Target)	Pre-certification (Target)
AP600/PWR*	WH	650	Yes		
AP100/PWR*	WH	1117	Yes		
ABWR/BWR*	GE et al.	1371	Yes	--------	
ESBWR*	GE	1550	----	Yes (2007)	
EPR/PWR*	AREVA	1660	-----	--------	Yes (2009)
System 80+/PWR*	WH	1300	Yes		
APR-1400#	Hyundai Construction Company	1400	----	------	-------
US APWR/PWR#	Mitsubishi	1600	-----	Yes (2011)	
CANDU 700 PHWR*	AECL et al.	700	-----	------	Yes (N/A)
CANDU1000 PHWR#	AECL et al.	1000	------	------	----------
IRIS/PWR#	WH et al.	360	-----	---------	Yes (2010)
PBMR/HTGR#	Eskom, WH	180	-----	---------	Yes (N/A)
GT-MHR/HTGR#	GA	325	------	---------	Yes (N/A)

** Generation III, # Generation III+*

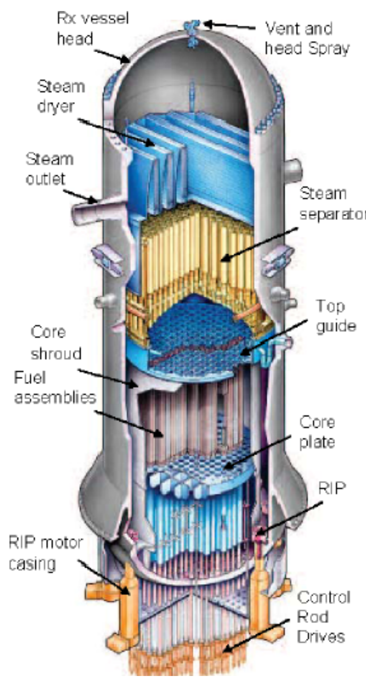

Figure 6 ABWR Cutaway View (GE ENERGY 2007a).

The ABWR vessel is made of a single forging with no nozzles greater than 2 inches in diameter anywhere below the top of the reactor core (Figure 6). This reactor design eliminates the external recirculation pumps. They are replaced by ten internal recirculation pumps mounted to the bottom head of the reactor vessel (Figure 6). The reliability and durability of the Reactor Internal Pumps (RIPs) have been proven and only two pumps will need to be removed for servicing during an outage. These and other design simplifications have eliminated over 50% of the welds and all the piping and pipe supports in the primary system.

The ABWR plant has three independent and redundant safety systems that are mechanically separated by fire walls. Each system is located in a different quadrant of the reactor building and has both high and low pressure water injection capabilities and a dedicated heat exchanger for the removal of decay heat. The three systems are also electronically independent. Each has redundant sources of AC power and a dedicated emergency diesel generator. They would keep the reactor core covered at all times. In the event of a loss of coolant accident, the plant response is fully automated so that operator interference is not required for 72 hrs after a reactor scram.

3.2 Economic Simplified Boiling Water Reactor (ESBWR)

The Economic and Simplified Boiling Water Reactor (ESBWR) has an installed thermal capacity of 4500 MW (or electrical capacity of 1590 MWe) and is cooled by natural circulation during normal operation (GE ENERGY 2007b). It employs passive safety systems that rely on gravity, single phase convection, and the phase-change processes of evaporation and condensation for the removal of the decay heat, following a reactor shutdown.

The ESBWR vessel has a diameter of 7.1 m, the same as the ABWR, but it is significantly taller (27.7 m) than the ABWR (21.1 m). The ESBWR active core height (3.0 m) is about 20% shorter than a ABWR (3.7 m), but the fission power density is higher, 54 MW/m3 versus 51 MW/m3 in ABWR (Figure 7).

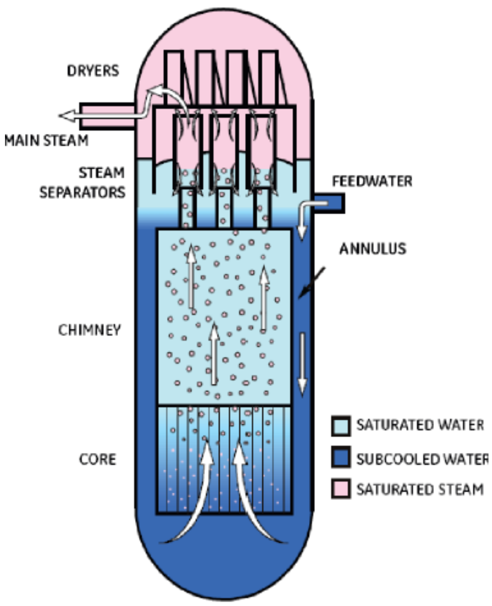

Figure 7 A Schematic View of the ESBWR (GE ENERGY 2007b).

The taller reactor vessel, shorter core height, and lower flow restrictions, enhance natural circulation cooling of the ESBWR core. The ESBWR design uses an isolation condenser system for the high pressure inventory control and decay heat removal. After the initiation of the automatic depressurization system, the low pressure inventory is controlled by a gravity driven cooling system. The containment cooling is provided by a passive cooling system that includes a gravity-driven water flow from 3 separate pools. The partitioned chimney above the core stabilizes and directs the steam flow out of the reactor and the recirculation of the water through the down-comer (Figure 7). The tall, open down-comer increases the driving head for natural circulation, reduces pressure losses or flow resistance, and increases the water inventory in the reactor vessel for decay heat removal.

The ESBWR uses fine motion control rod drives for changing the reactor operating power. The reactor core remains covered in all design bases accidents with no fuel overheating (GE ENERGY 2007b). In addition to its redundant and passive operation and safety features, the ESBWR is designed for significantly short construction schedule and low construction and operating cost.

Currently, the ESBWR is undergoing certification by USNRC (Table 2). Two utilities in the USA, Entergy and Dominion, have expressed interest in the future construction of this reactor design. Their applications to the USNRC for a Combined Construction and Operation Licence (COL) in expected early in 2008.

3.3 European (or Evolutionary) Pressurized Water Reactor (EPR)

The first 1600 MWe EPR is currently under construction in Finland and expected to start operation in 2011 (Figure 8). A 2nd 1650 MWe EPR is planned for construction in France and operation start in 2012. Starting in 2020, additional EPRs will be built to replace the 58, Generation-II PWRs currently operating in France (Table 1). AREVA has been actively marketing the EPR to countries in North Africa and the Middle East, China, Vietnam, USA, and elsewhere in the world.

In November 2007, AREVA in conjunction with China Guangdong Nuclear Power Corp. have agreed to build two EPRs and provide the materials and services required to operate them. These two reactors represent the 3rd and 4th EPR to be built.

The reactor design, introduced by AREVA-NP in the United States under the name Evolutionary PWR (EPR), is currently under review for pre-certification by the USNRC (Table 2). Applications for a Combined Construction and Operation License (COL) by the electric utilities in USA for 5 EPRs are expected to be submitted to USNRC in 2008. The USA EPR design has 4 redundant safety systems, each capable of cooling down the reactor after shutdown, but no passive systems. It is designed to prevent a core meltdown and mitigate any possible consequences through the use of a core catcher that would prevent the penetration of a molten core through the reactor containment.

The EPR containment has a two-layer concrete wall that is 2.6 meters thick, designed to withstand airplane crashes and earthquakes (Figure 8). The reactor vessel is designed with fewer welds and made of optimized steel that is resistant to aging. The EPR fuel burnup target is 65 MWD/kg with 92% availability during an operation life of 60 years at a plant thermal efficiency of 36%. The reactor core can use either 5% enriched uranium oxide or mixed uranium plutonium oxide (MOX) fuel and up to 100% MOX loading.

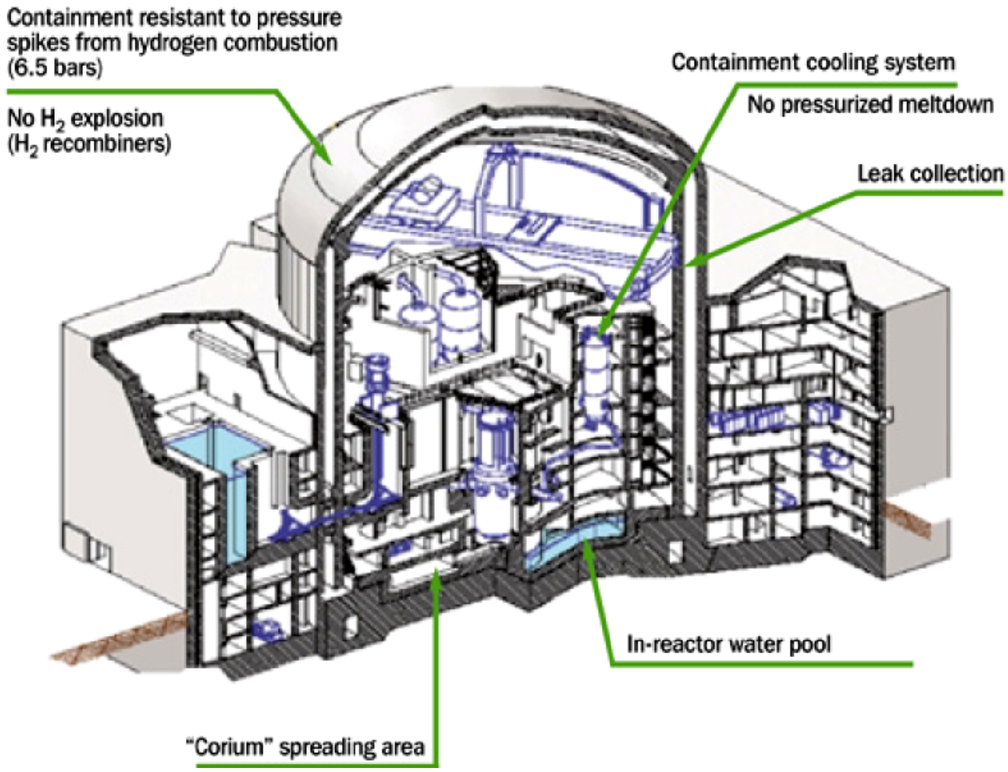

Figure 8 A Layout of EPR Power Plant (NUCLEAR PICTURES 2007).

3.4 Mitsubishi Advanced Pressurized Water Reactor (APWR)

This generation-III advanced design, developed by Mitsubishi Heavy Industries of Japan for 1538 MWe, has been selected by Japan Atomic Power Company for the construction of two units, the first of which is slated for completion in 2014. The APWR with both passive and active cooling systems is designed to achieve a high fuel burnup of 55 MWD/kg. The US-APWER version is for 1,700 MWe with a target capital cost of US$1500/kW, and has a 24-months fuel cycle length. This design employs high-performance steam generators, a steel neutron reflector around the core to increase the fuel economy, and a redundant core cooling system. It has a huge refueling water storage pool inside the containment building and fully digital instrumentation and control systems.

The US-APWR has 4 primary coolant loops and uses advanced steam generators with high corrosion resistance steel for increasing the plant thermal efficiency to 39%, the highest ever for a Light Water Reactor (LWR) plant. Each of the four redundant safety systems of the APWR is capable of supplying 50% of the needed makeup water. The high fuel burnup and the high fuel density pellets (97%TD) reduce the spent fuel assemblies per MWh generated by ~ 28%. The low power density APWR core can use enriched uranium oxide and MOX fuels. The volume of the plant building is 20% smaller than of a similar size LWR plant. A pre-application design certification of the US-APWR to the USNRC began in July, 2006, with a design certification application target of March, 2008, and a process completion in 2011 (Table 2).

3.5 Westinghouse AP600 and AP1000

Westinghouse has developed the AP600 and AP1000 Generation-III+, advanced PWRs. They are designed for thermal powers of 1933 MW and 3400 MW and electrical powers of 600 MWe and 1117-1154 MWe. The design simplicity of these reactors enhances safety and operation and reduces construction cost and schedule. The passive safety systems use the natural forces of gravity, evaporation and condensation processes, compressed air, and natural circulation. They have no pumps, fans, diesel generators, chillers, rotating machinery, or a reliance on AC power (CUMMINS and CORLETTI 2003; MATZIE 2003). The core cooling system provides passive decay heat removal with a passive water injection, passive containment cooling, and a long safe shutdown (>72 hrs), without an operator interference. Both AP600 and AP1000 designs use decay heat to derive the core cooling by natural circulation. The very large refuelling pool in the reactor containment is filled with borated water and serves as the heat sink for the heat exchanger of the passive residual heat removal system (Figure 9). It also supplies water to the vessel direct water injection lines. The two-loops, 1090 MWe AP1000 plant retains the same basic design as that of the AP600. The AP1000 has 50% fewer valves, 83% less piping, 50% less seismic building volume than a similar power rating PWR (CUMMINS and CORLETTI 2003 and WESTINGHOUSE 2007). The fuel supply system for the AP1000 consists of two Delta-125 steam generators, each connected to the reactor pressure vessel by a single hot leg and two cold legs with a coolant circulation pump.

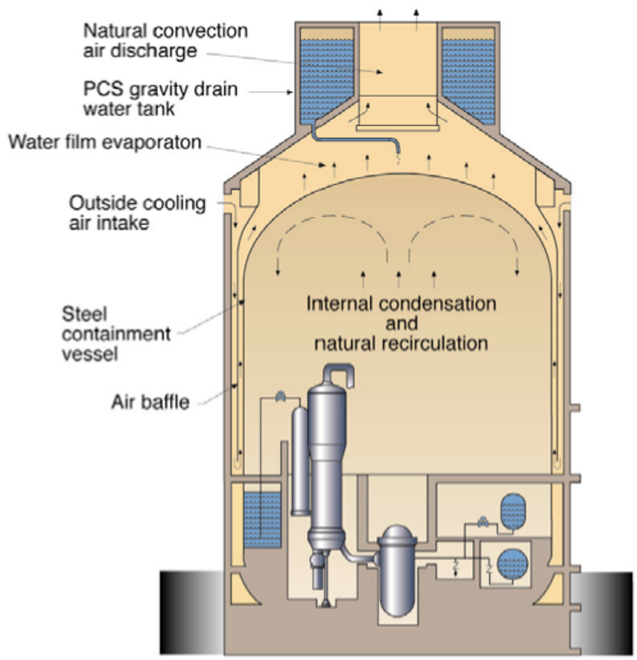

Figure 9 AP600 Passive Containment Cooling System (MODERN POWER SYSTEMS 2007).

The AP600 design for 600 MWe is identical to that of the AP-1000, except it has a shorter reactor vessel, smaller steam generators and pressurizer, and slightly shorter, canned coolant pumps with lower coolant flow rates. The modularized construction of the AP-600 and AP-1000 reactors significantly reduces the plant construction calendar time, for a site schedule of 36 months from first concert to fuel loading, and 60 months total schedule (WESTINGHOUSE 2007). The capital cost is projected at US$1000/kWe to US$1200/kWe and the total cost for electricity generation is estimated at US$32/MWh to US$36/MWh. The AP1000 fuel design is based on the 17x17 design used successfully at plants in the U.S. and Europe. Studies have shown that both the AP600 and AP1000 can operate with a full core loading of MOX fuel.

3.6 ACR-700 and ACR-1 000

The Atomic Energy of Canada limited (AECL) has developed the Generation-III Advanced CANDU Reactor (ACR-700) for generating 700 MWe and the Generation-III+ ACR-1000 for generating 1080 - 1200 MWe (Table 2). The modularity and the simplifications in these reactor designs reduce the capital cost and the construction schedule. These designs offer high capacity factor, low operating cost, increased operating life, simple component replacement, and enhanced safety features. They have modular horizontal fuel channels surrounded by a heavy water moderator, the same feature as in all CANDU type reactors (Figure 8), except for using: (a) slightly enriched uranium oxide fuel (2. uranium in the earlier CANDU 6 design, circulated through the fuel channels.

The ACR-700 design is simpler, more efficient, 40% cheaper and more compact (the Calandria inside diameter is 31.6% smaller and the heavy water mass inventory is 72% lower compared with the CANDU 6 (Figures 10 and 11), currently in operation in Canada, China, the Republic of Korea, India and Romania (HOPWOOD 2007). The light water coolant in the ACR designs operates at higher pressures and temperatures (12.1 MPa and 326 oC), increasing the plant thermal efficiency to 37%. The lower linear power and the higher critical heat flux in the rod bundles increase the operating and safety margins in the ACR designs. They are expected to have an operating life of 60 years with a reference fuel burnup of 20 MWD/kg.

The estimated capital cost of the ACRs is US$1 000/kWe and the cost of electricity generation is projected at US$280 to US$32/MWh. The construction schedule is estimated at 35 months with a total project construction time of 48 months. On June 19, 2002, the ATOMIC Energy of Canada Limited (AECL) has requested pre-application review of its ACR-700 for licensing in the United States (Table 2). The ACR passive safety features include two independent shutdown systems, and a gravity supply of emergency feed water to the steam generators. The low pressure and low temperature heavy water moderator surrounding the fuel channels (Figure 11) provide an additional passive heat sink, in the unlikely event that both the primary coolant and the emergency cooling systems were unavailable.

The water filled shield tank surrounding the Calandria (Figures 10 and 11) would contain and maintain a collapsed core in a cooled state, should the moderator cooling be impaired. The Emergency Core Cooling (ECC) system uses a burst disc which functions automatically when the primary system pressure drops below a prescribed level (HOPWOOD 2007). The steel lined, pre-stressed concrete containment structure of the ACR reactors forms a safe pressure retaining envelope boundary in the unlikely event of an accident. The heat removal from the containment atmosphere after an accident is provided by local air coolers and the hydrogen release into the containment is controlled using passive autocatalytic recombiners.

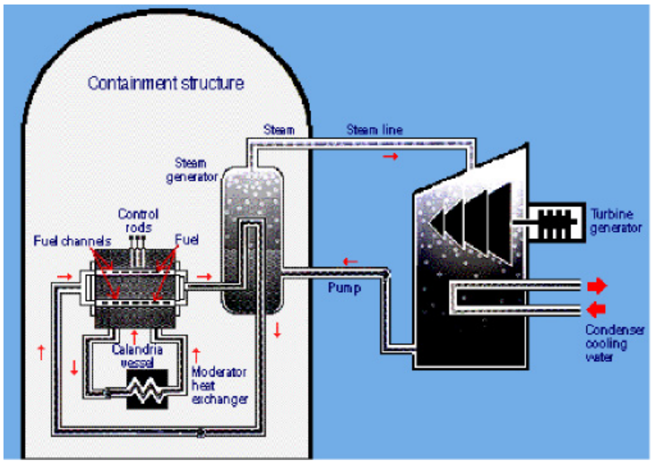

Figure 10 A Schematic of a Typical CANDU Reactor Power Plant (WORLD NUCLEAR ASSOCIATION 2007b)

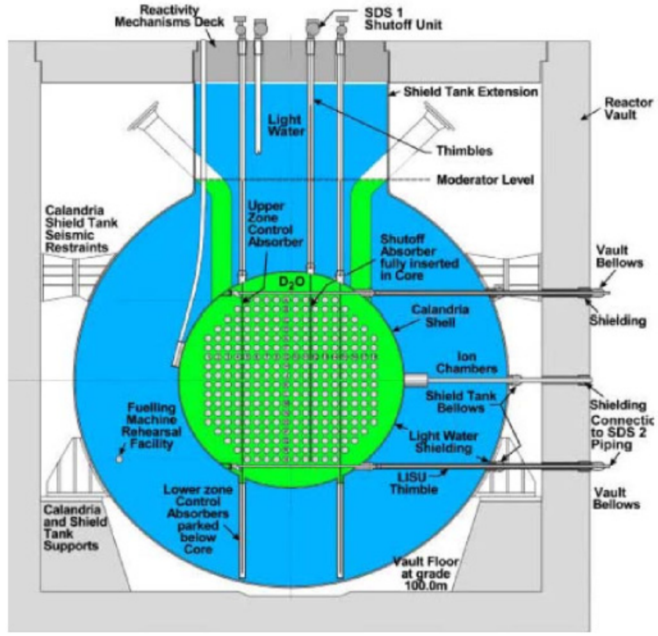

Figure 11 ACR Calandria & Shield Tank Assembly (HOPWOOD 2007).

3.7 VVER Advanced PWRs

The Russian's Generation-III VVER-1200, an APWR designed for the generation of 1150 - 1200 MWe, has a plant thermal efficiency of 36.56%, an operation life of 50 years, maximum fuel burnup of 70 MWD/kg, a 24 months fuel cycle, and an estimated capacity factor of 90%. The enhanced safety of the VVER-1200 include both active and passive safety features, double containment to resist earthquakes and aircraft impact, and a very low core damage frequency of 10-7. The first two VVER-1200 units will be built in Russia. The construction time is expected to be 54 months. The first unit is expected to begin operation in 2012 - 2013 and the second in 2013 – 2014. In September 2007, the AtomEnergoProm announced plans for the construction of an additional seven VVER -1200 by 2016 (SCHEIDER and FROGGATT 2007). The capital cost for the construction of the VVER-1200 is projected at US$1200/kWe, however, the actual cost of the first unit could be as much as US$2100/kWe. The larger power VVER-1500 design is currently under development and expected to be completed in 2008.

3.8 Small Power Reactors

There are a number of small power reactors developed to target the electricity generation market in countries with small electric grids and some are for the generation of electricity and co-generation of process heat for seawater desalinations. One of these reactors is the Russian VVER-300, a 295 MWe unit designed for 60 year operation life at 90% capacity factor. The first VVER-300 unit is slated for construction in Kazakhstan.

The Korean Atomic Research Institute (KAERI) has been developing the System-integrated Modular Advanced Reactor (SMART), a PWR with a thermal power 300 MW. It has integral steam generators and advanced passive safety features, design life of 60 years, 36 months refuelling cycle, and < 36 months projected construction schedule. The SMART plant base design would generate 99 MWe at a thermal efficiency of 30%, and provide process heat for a seawater desalination capacity of 40,000 m3 per day at an estimated cost of ~ US$0.5 /m3. The conceptual design of the SMART was completed in March of 1999 and the basic design was completed in March of 2002. A one-fifth scale plant is being constructed in the Republic of Korea for operation in 2007 - 2008 (KANG et al. 2007).

A number of small, medium, and large size reactor designs, some gas cooled, are also being developed and would be available for commercial use early in the next decade. These include the Gas Turbine-Modular Helium cooled Reactor (GT-MHR), the Pellet Bed Modular Reactor (PBMR) being developed by an Eskom-Westinghouse alliance, and the International Reactor Innovative and Secure (IRIS), a 335 MWe, 1000 MW thermal, Generation-III+ APWR. The IRIS design is being developed by an international consortium consisting of twenty-one organizations from ten countries led by Westinghouse. The design is expected to be completed in the 2012 to 2015 timeframe.

The IRIS integral reactor vessel houses the nuclear core and all the major reactor coolant system components including the pumps, the steam generators, the pressurizer and the steel neutron reflector. This vessel is larger than a traditional PWR pressure, but the size of the IRIS containment is a fraction of the size of corresponding power loop PWR containment.

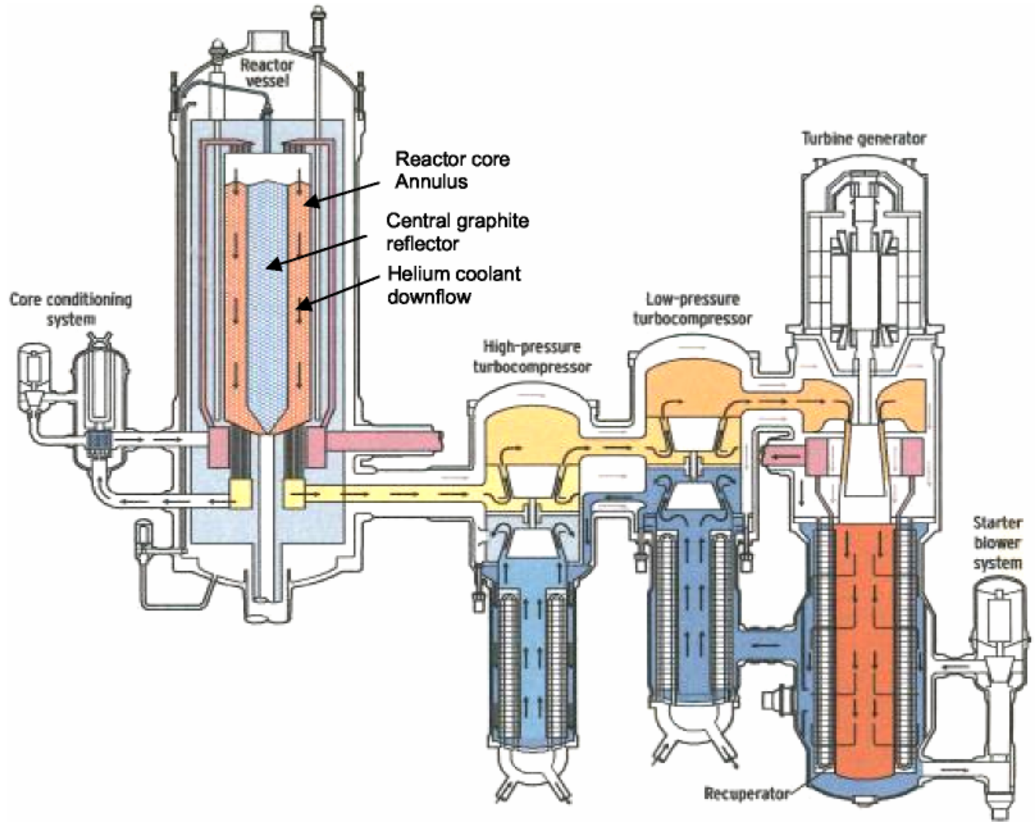

Figure 12 A Cross-Section of the PBMR Plant Layout (WEIL 2001).

The helium cooled GT-MHR and PBMR would operate at high temperatures up to 850 - 950 oC, for a plant thermal efficiency in excess of 40%. They can also be used for the co-generation of hydrogen using thermo-chemical processes. The PBMR is being developed by ESKOM, the South African utility, jointly with Westinghouse. The plant design consists of 8 - 10 reactor modules, each rated at 165 MWe. The PBMR is a High Temperature Reactor (HTR), with a closed Brayton Cycle (CBC), gas turbine power conversion.

The PBMR plant design includes a capacity to store 10 years of spent fuel on site with additional storage capability in onsite concrete silos. The reactor core is based on the German high-temperature gas-cooled reactor technology and uses spherical fuel elements. The PBMR steel pressure vessel, 6.2 m in inner diameter and about 27 m high, encloses a metallic barrel that supports an annular core of graphite fuel pebbles and graphite neutron reflectors at the center and on the outside of core annulus. The PBMR has two separate reactivity control and shutdown systems: the control rods inserted in vertical borings in the outer graphite reflector and the small neutron absorbing spheres dropped into the borings in the central reflector (Figure 12).

The PBMR fuel pebbles are comprised of silicon carbide and pyrolitic carbon coated micro-spheres of enriched uranium dioxide or uranium-oxy-carbide encased in graphite. When fully loaded, the PBMR core would contains approximately 452,000 pebbles. The helium coolant enters the reactor vessel from the top at about 500°C and 9 MPa, flows down through the core annulus, and exits through the bottom of the vessel at about 900 °C (Figure 12). The heated gas exiting the reactor drives a single shaft, power turbine-compressor unit that is coupled to an electrical generator for converting the reactor thermal power to electricity at a thermal efficiency of 40% - 50% (Figure 12).

The PBMR uses a continuous refueling process. The fuel pebbles removed from the bottom of reactor are transported to the top, checked for fuel burnup, and either re-introduced into the reactor if the target burn-up has not been reached or routed to the spent fuel tanks. The PBMR Module Building is designed to withstand significant external forces such as aircraft impacts, tornados or explosions. It encloses a reinforced concrete containment of the reactor pressure vessel (RPV) and the power conversion unit (PCU). The containment walls surrounding the RPV are 2.2 m thick and the thickness of the reinforced concrete roof and the walls of the module building above ground level is 1.0 m (Figure 12). The capital cost of a 1000 MWe block of 10 PBMR modules is projected at up to US$2090/kWe and the cost of electricity generation is estimated at US$1 8/MWh to US$34/MWh, including the full fuel cycle and decommissioning costs.

The design and development of the General Atomics GT-MHR is being carried out in Russia under a joint agreement with USA. The plant consists of two interconnected pressure vessels enclosed within a below-ground concrete containment structure (LaBAR, et al. 2003). One vessel contains the reactor system and the second vessel contains the entire power conversion system and three compact heat exchangers (Figure 13).

The turbo-machine's generator, the power turbine and the two compressors are mounted on a single shaft rotating on magnetic bearings. The 95% recuperator effectiveness in the helium direct CBC loop increases the plant's thermal efficiency to 48%. The TRISO fuel particles similar to the PBMR provide containment of the fission products under reactor operating conditions. They also serve as an excellent containment of the radionuclides during the storage of spent fuel. They could maintain their structural integrity for a million years or more in a geologic repository environment.

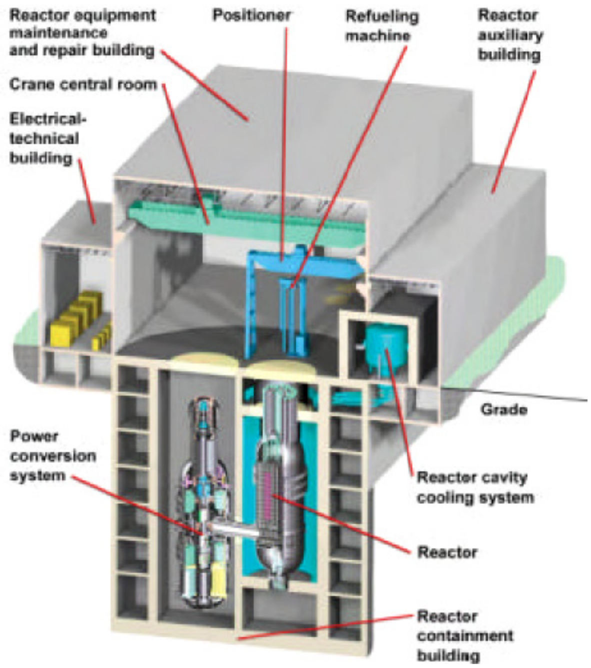

Figure 13 Cross-Sectional of the GT-MHR below Grade Installation (LaBAR et al. 2003)

The TRISO-coated fuel particles are mixed with a carbonaceous matrix and formed into cylindrical fuel compacts, approximately 13 mm in diameter and 51 mm long. The fuel compacts are loaded into fuel channels in the hexagonal graphite fuel elements of the GT-MHR core. The fuel elements are 793 mm long by 360 mm across flats. One hundred and two columns of the hexagonal fuel elements are stacked 10 elements high to form the GT-MHR annular core. It has outside of the reactor core annulus.

graphite reflectors blocks in the central region and on

The GT-MHR operates at a system pressure of 7.0 MPa and inlet and exit temperatures of 491 and 850 oC and has a nominal thermal power of 600 MW. The plant could generate 286 MWe at a thermal efficiency of 48%. The overnight capital cost for a GT-MHR plant of four standardized reactor modules is projected at ~US$975/kWe and the electricity generation coat is estimated at US$29/MWh, including capital, operation, maintenance, waste disposition, fuel, and decommissioning (LaBAR et al. 2003).

4. WORLD SUPPLIERS OF COMMERCIAL NULCEAR REACTORS

Western-Japanese alliances dominate the world supply of new reactors and are competing for global market shares. As with automobiles, there are many Generation-III and Generation-III+ reactor types to choose from. All share many of the advanced design features, design modularity and simplicity, redundant active and passive safety features, and modular features for reduced construction schedule and cost. Table 3 lists the current alliances and companies supplying nuclear reactors and the type of reactors they market and construct. All the Generation-III and III+ designs are PWRs, BWRs and HPWRs. Some have been constructed and operated, such as the ABWR and SEBWR, and others are being constructed for the first time, such as the EPR, VVER-1200 and AP1000.

AREVA (Table 3), a French public multinational industrial conglomerate, was created 3 September, 2001 by the merger of the French Commissariat à l'Energie Atomique (CEA) industry, Framatome, and Cogema (now AREVA NC). The French government owns more than 90% of AREVA, but the German government retains, through Siemens, 34% of the shares of AREVA's subsidiary, AREVA-NP Inc., in charge of building the EPR. In 2002, AREVA NP Inc. acquired the former Duke Engineering Services in USA, and has recently formed a joint venture named UniStar Nuclear with Constellation Energy in USA to develop, license, construct and operate EPR in the United States.

The Joint venture Atmea has been formed between AREVA NP and Mitsubishi Heavy Industry in Japan to develop 1100 MWe, APWR with 3 primary loops, extended life and the ability to fuel with either enriched uranium oxide and/or MOX fuel. This medium size reactor, intended to compete with the Westinghouse AP1000, is expected to be completed and ready for a license application in 2010.

Other alliances for supplying new power reactors include: (a) an alliance that include GE in USA and Hitachi and Toshiba in Japan, and (b) Westinghouse, majority owned by Toshiba and minority owed by IHI in Japan, the Shaw Group, Inc. in USA, and Kazatomprom in Kazakhstan (Table 3). These are in addition to the CANDU owner group in Canada, Gidropress in Russia, and the South Korean's Hyundai Construction Co.

Table 3 Global Suppliers of New Commercial Reactors.

Supplier	Alliance members	Reactor Design	Reactor Type
AREVA	France: Commissariat à l'Energie Atomique (CEA) industry, Framatome, and Cogema Germany: Siemens United States: Constellation Energy	EPR	Gen-III PWR
GE	USA: General Electric (GE) Japan: Hitachi and Toshiba	ABWR ESBWR	Gen-III and –III$^+$ BWR
WH	Westinghouse (WH) owned by Toshiba, (67%), and IHI (3%) in Japan, The Shaw Group, Inc. (20%) in USA, and Kazatomprom (10%) in Kazakhstan.	AP600 AP1000	Gen-III$^+$ PWR
CANDU Owners Group	Canadian Utilities: Ontario Power Generation, Hydro-Quebec, and New Brunswick Power Atomic Energy of Canada Limited	ACR700 ACR1000	Gen-III HPWR
Atmea	France: AREVA NP Japan: Mitsubishi Heavy Industry	APWR, 1100 MWe	Gen-III$^+$
Gidropress	Russia: Gidropress	VVER1200 VVER1500	Gen-III APWR Gen -III$^+$ APWR
Hyundai Construction	The Republic of Korea	OPR-1000 APR-1400	Gen-III APWR Gen -III$^+$ APWR

5. SUMMARY AND CONCLUSIONS

The current interest in nuclear power for meeting future electricity and seawater desalination needs in the Gulf Corporation Council (GCC) states and other courtiers in the Middles East is a prudent, logical and timely decision. The sources of fresh water in the world are increasingly becoming inadequate for sustaining future population growth. Pursuant to the recent experiences in many countries, a challenging, yet achievable goal for the GCC states and other countries in the Middle East is to embark on a program for securing 30% of their future needs of electricity and process heat for seawater desalination and other industrial uses from nuclear power by 2030. This is equivalent to completing the construction of 2, 1500 MWe nuclear power plants each year starting in 2016.

A worthy strategy for the GCC countries is to increase the energy utilization from nuclear power plants to more than 80% of that generated in the nuclear reactors. The reactor energy could be divided between electricity generation (35-39%), seawater desalination (25%), and process steam and heat for industrial applications (16-20%). This approach would require some changes in the layout and integration of the nuclear power plants, but contribute to energy and water self-sufficiency. It would support future job creation and economic growth, with no or significantly reduced emissions of greenhouse gasses, and help reduce the cost of electricity generation, making it comparable or close to that currently being generated using fossil fuels.

In addition to securing the financial resources for the construction of nuclear power plants in the GCC countries, other critical elements are:

- Availability of highly trained and technically skilled personnel
- Presence of a manufacturing infrastructure of heavy equipment
- Investments in exploration of uranium and other relevant processes of the nuclear fuel cycle. Investing in the exploration and extraction of uranium is not only timely, but becoming increasingly profitable and attractive for investments by the public and private sectors. Securing future supplies of uranium ore and developing international alliances would be necessary for the extraction, conversion, and fuel enrichment, as well as for the fabrication of nuclear fuel elements and the processing of spent fuel. These alliances can also develop safe and secure options for nuclear waste disposal and ensure nuclear non-proliferation, which are critical to future growth of nuclear power world wide
- Development of a sound disposal strategy of nuclear waste
- Development of a common electrical grid with neighbouring countries in the region and the Arab world. This would take advantage of the variations in load demand in the different time zones and the economics of scale associated with the construction of large (> 1000 MWe) nuclear power plants
- Development of higher education and vocational programs that are among the best in the world. These programs would be needed to train a cadre of highly qualified engineers and technicians on all aspect of nuclear power technology, reactor design, construction, maintenance, and operation as well as to establish an effect Research and Development (R&D) infrastructure
- Development of a regulatory, safety and licensing board of highly qualified personnel. This board would provide a government oversight with assistant from the IAEA and other countries with advanced capabilities and expertise.

Introducing nuclear power in the GCC and the Middle East countries would requires a multi-facet approach to the many challenges ahead and for making the proper choices. Some of these challenges and choices that need to be explored at the outset are:

1. Government, private or joint government-private financing,
2. Dual purpose nuclear power plants versus electrical power generation only,
3. Standardization versus diversification of nuclear reactors types; Generation-III and III+ Reactors (PWR, BWR, HPWR) or even Gas Cooled Reactors,
4. Total or partial local manufacturing of components versus a turn-key option,
5. Fuel cycle focus: exploration, mining and milling, conversion; enrichment, fabrication, spent fuel processing/storage, etc.,
6. Ensuring nuclear fuel supply, at reasonable cost, and the safe and secure management of nuclear waste, and
7. Streamline licensing and regulatory oversight to support short construction schedules and safe operation of nuclear power plants at a high capacity factor.

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