POTENTIAL OF SMALL AND MEDIUM SIZED REACTORS (SMR) TO SUPPORT THE GNEP VISION

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ABSRACT

This study of small and medium sized reactors (SMR) was undertaken to answer the following questions:

- Do we need SMRs?
- If so, how many?
- Should SMRs be a part of the GNEP vision?

To answer these questions, a comprehensive worldwide review was undertaken to determine:

- The status of SMRs - in order to ascertain whether future SMRs would be able to fulfill the market needs.
- Projections for energy demand – and the share of nuclear generated electricity as a subset of future growth in electricity demand
- Market assessment of potential future demand for SMRs

This study concludes that until 2050, demand for nuclear generated electricity would require new nuclear capacity of some 1000 GWe. SMRs could potentially capture up to 30% (300 GWe) of the new nuclear capacity for electricity generation. At 600 MWe each, this means 500 new SMR reactors, or 1000 new SMRs of 300 MWe capacity. In addition, SMRs have clear advantage and potential to capture a large share of new nuclear reactors for non-electricity applications (e.g. process heat, desalination, hydrogen generation, etc.).

In order to fulfill the GNEP vision of global nuclear expansion - while enhancing the proliferation resistance of nuclear power - it is recommended that SMRs should be maintained as an integral part of the GNEP program.

It is worthwhile to promote design(s) of a GNEP-SMR through an international program - with a selective group of countries - in order to steer the design(s) of the SMR in the most desirable and useful direction.

There is a need and opportunity for SMRs to satisfy growing energy needs in developing countries - in economic, safe and proliferation resistant manner – which will help fulfill the GNEP vision.

ACKNOWLEDGMENT

The author would like to thank Westinghouse for furnishing the information summarized in Sections D.4 and D.5 regarding the PBMR and the IRIS SMRs.

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ACRONYMS and ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
AFC	Advanced Fuel Cycle
AFCI	Advanced Fuel Cycle Initiative
AGR	Advanced Gas Cooled Reactor
AHTR	Advanced High Temperature Reactor
ANS	American Nuclear Society
APR, APWR	Advanced Pressurized Water Reactor
bcm	Billion cubic meter (of natural gas) (10^9 cubic meter)
Billion kWh	10^9 kWh = Terawatt hour (TWh) = 10^{12} Watt hour
Bi	Bismuth
BNFL	British Nuclear Fuel Ltd.
BWR	Boiling Water Reactor
^{o} C	Degrees Celsius
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CEO	Chief Executive Officer
Dollar	US dollar
DOE	US Department of Energy
% e	Percent of nuclear-generated electricity
%/year	percent per capita per year increase (in the MIT's study)
EIA	Energy Information Administration of DOE
ENHS	Encapsulated Heat Source
EU	European Union
FBR	Fast Breeder Reactor
FR	Fast Reactor
FSU	Former Soviet Union
GCR	Gas Cooled Reactor
Generation IV	DOE's Generation IV program
GIF	Generation IV International Forum
GJ/hr	Gigajoule per hour (10^9 joules per hour)
GNEP	Global Nuclear Energy Partnership
GNEP-SMR	SMR which fulfills the GNEP vision
GTHTR	Gas Turbine High Temperature Reactor
GT-MHR	Gas Turbine Modular Helium Reactor
GW	Giga Watt (10^9 Watt)
GWe	Gigawatt Electric (10^9 Watt electric)
GWd/t	Gigawatt-day per tonne (fuel burnup)
H	High estimate (MIT's study)
H_2	Hydrogen
HDI	Human Development Index
HEU	Highly Enriched Uranium
HTGR	High Temperature Gas cooled Reactor
HTR	China's pebble bed reactor

HTTR	High Temperature Test Reactor
HWLWR	Heavy Water Moderated Light Water Cooled Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency of the OECD
IEO	International Energy Outlook of DOE/EIA
IPP	Independent Power Projects or Independent Power Producers
kgHM	kilogram Heavy Metal
kWh	Kilowatt hour
L	Low estimate (MIT's study)
LMFBR	Liquid Metal Fast Breeder Reactor
LMR	Liquid Metal Cooled Reactor
LWGR, LGR	Light Water Cooled Graphite Moderated Reactor
LWR	Light Water Reactor
M	Medium SMR (300-700 MWe)
mb/d	million barrel (oil) per day
MIT	Massachusetts Institute of Technology
MOX	Mixed oxide fuel
MPa	Mega pascal
MSR	Molten Salt Reactor
MT	Metric Tons
Mtoe	Million metric tons of oil equivalent
MTHM	Metric Tons Heavy Metal
MW	Megawatt (10^6 Watt)
MWe	Megawatt net - electric (10^6 Watt electric)
MWt	Megawatt thermal (10^6 Watt thermal)
NE	Office of Nuclear Energy, Science and Technology
NPP	Nuclear Power Plant
NPT	Non Proliferation Treaty
NRC	US Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
Pb	Lead
PBMR	Pebble Bed Modular Reactor
PHWR	Pressurized Heavy Water Reactor
PM	Prime Minister
PRIS	IAEA's Power Reactor Information System
PWR	Pressurized Water Reactor
Pu	Plutonium
R&D	Research and Development
RBMK	Russia's LGR-type reactor
RD&D	Research Development and Demonstration
RS-MHR	Remote Site Modular Helium Reactor
S	Small SMR (150-300 MWe)
SMR	Small and Medium-Sized Reactor
SNF	Spent Nuclear Fuel
STAR	Secure Transportable Autonomous Reactor
TEC	Total Electricity Consumption (MIT's study)

Tonne, t	Metric ton
Th	Thorium
TJ	Terajoule (10^{12} joules)
TRISO	Fuel coating system that uses three types of coatings, low density pyrolithic carbon, high density pyrolithic carbon and silicon carbide
TRU	Transuranium
TWh	Terawatt hour = Billion kilowatt hour (10^{12} watt hour)
U	Uranium
UIC	Uranium Information Center
UK	United Kingdom
UO_2	Uranium dioxide
US or USA	United States of America
USD	US Dollar
USNRC	US Nuclear Regulatory Commission
UN	United Nations
VS	Very Small SMR (smaller than 150 MWe)
VHTR	Very High Temperature Reactor
VVER	Water Cooled Water Moderated Russian Pressurized Water Reactor
WEC	World Energy Council
WEO	World Energy Outlook
WNA	World Nuclear Association
WWER	Water Cooled Water Moderated Russian Pressurized Water Reactor
Zr	Zirconium

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A. Background

A.1 Global Nuclear Energy Partnership (GNEP)[1]

The President announced the Advanced Energy Initiative in the State of the Union Address on January 31, 2006. The President's initiative includes the Global Nuclear Energy Partnership (GNEP)[1], which was highlighted by the Secretary of Energy in the fiscal year 2007 budget briefing on February 6, 2006.
The GNEP vision is a comprehensive strategy to enable the expansion of emissions-free nuclear energy worldwide by demonstrating and deploying new technologies to recycle nuclear fuel, minimize waste, and improve our ability to keep nuclear technologies and materials out of the hands of terrorists. The implementation of the GNEP vision requires three Major System technology demonstration projects – collectively referred to as the GNEP Technology Demonstration Program.

The Secretary stated "GNEP brings the promise of virtually limitless energy to emerging economies around the globe, in an environmentally friendly manner while reducing the threat of nuclear proliferation. If we can make GNEP a reality, we can make the world a better, cleaner, safer place to live."

The key elements of the GNEP vision are provided below.

- Expand the Use of Nuclear Energy Both Domestically and Internationally
- Address the Nuclear Waste Management Issue
- Promote Nuclear Non-Proliferation

A.2 Small and Medium Sized Reactors (SMR)

Reactors up to 700 MWe have been defined as SMRs[2] whereas those reactors larger than 700 MWe are considered Large reactors. The following definition of SMRs have been used within the 700 MWe range[2] :

Medium reactors:	300 - 700 MWe
Small reactors:	150 – 300 MWe
Very small reactors:	<150 MWe

Medium sized reactors are eminently power reactors whose objective is electricity generation. They can also be applied as cogeneration plants (CHP) supplying both electricity and heat, but the main product remains electricity. As such, they are intended for introduction into interconnected electric grid systems of suitable size (at least 6 to 10 times the unit power) and operated as base load plants. If operated in the cogeneration mode, the heat supply would be up to about 20% of the energy produced. Economic competitiveness with equivalent alternative fossil-fueled plants is expected to be achievable under most conditions.

Small reactors are either power or cogeneration reactors which may have a substantial share of heat supply. Due to its size, small reactors for electricity generation only, or operated in the cogeneration mode, are generally not expected to be economically competitive with medium or large sized nuclear power plants (see additional comments on SMR's economic competitiveness in section D.5). They are therefore intended for special situations (i.e. 'niche') where the interconnected grid size does not admit larger (medium or large size) units; and where alternative energy options are relatively expensive due to long transmission lines (e.g. remote and isolated sites)[a]

Very small reactors are not intended for electricity production under commercially competitive conditions as base load units integrated into interconnected electrical systems. Clearly, very small reactors of current designs are not to be regarded as competitors of large, medium or even small power reactors, of which they are *not* scaled-down versions. Very small reactors address specific objectives such as the supply of heat and electricity, or heat only (at either high or low temperature) for industrial processes, oil extraction, desalination, district heating, propulsion of vessels; or energy supply of concentrated loads in remote locations. They could also serve as focal projects and effective stimulus for the development of nuclear infrastructure in countries that are starting a new nuclear power program.

> Adding small increments of new capacity to electric markets will better match new electric supply with demand growth, thus preventing an oversupply of electricity and allowing a quicker recovery of the capital costs
> Corbin A. McNeill, Former Exelon CEO, May 3, 2001

The design of SMRs in the past, primarily emphasized improvements in safety, reliability and economics, while at the same time recognizing the differences in the design of SMRs vs. large reactors. Although several important design features necessary to achieve the GNEP objectives (in particular proliferation resistance) were not considered during earlier design of SMRs in the 1990s, a more recent evaluation[3] of SMRs have considered such issues as proliferation resistance, as well as other modern and innovative design features that may help achieve the GNEP goals.

Some design features of SMRs that are important in particular in developing countries are: proliferation resistance and robustness against terrorist actions, passive safety systems, simplicity of operation; and robustness against operator errors.

[a] India and South Africa are examples of countries that have selected small SMRs to avoid long transmission lines

Although the SMR has economic disadvantage compared to a large reactor- due to economy of scale - it features several advantages (note however that Westinghouse has claimed recently – as explained later in section D.5 describing the IRIS SMR - that SMR does not suffer an economic disadvantage in comparison with a large reactor). For example, SMR is more suitable for a small size of electricity grid, inadequate infrastructure; and for non-electrical applications (e.g. water desalination). SMR may also be suitable to situations where incremental increases in plant capacity are being sought, where siting flexibility is required, or where multi-purpose or multi-applications of nuclear power plants (NPP) is being considered (e.g. hydrogen generation, co-generation, desalination, etc.), as well as for non-energy uses of nuclear technology (e.g. nuclear medicine, education, research and development (R&D), material research, advanced technology development in other technological fields, public health, isotopes production, etc.).

> "We are planning around providing between 4000 and 5000 megawatts of power from the PBMRs," Public Enterprises Minister Alec Erwin told delegates at the High Temperature Reactor Conference in Johannesburg yesterday. This amount of power equates to between 20 and 30 PBMRs of about 165 megawatts each. "This initial order for the reactors allows us to construct a business case for the reactor industrialization process. Our target is to have the first reactor linked to the grid around 2013/14."
>
> Erwin said nuclear energy was critical to South Africa's long-term energy supply
>
> South Africa Dispatch, October 4, 2006

SMR is attractive to developing countries, which typically suffer from shortage of investment capital and small turnover of capital in the electricity market. Due to its smaller scale, SMR can also be used as a 'learning curve' of nuclear technology in developing countries.

In non-developing countries SMR may be attractive in electricity market deregulation (i.e. ownership by independent producers) and where there is shortage of appropriate sites for large NPPs.

In the following sections we will evaluate the current status of SMRs and their potential to supply part of the projected global energy demand.

Appendix B lists 26 different SMR concepts in various stages of design as of 2005[3].

A market assessment can be performed by considering two types of data: (1) Market energy demand, and (2) Inventory of SMRs that may be available to supply the demand.

> There are many sites around the world where dispersed populations or isolated industrial and mining facilities are a potential market for modular small nuclear reactors. What is a challenge however, is ensuring that you have sufficient nuclear professionals, both for the utility and the regulator, to staff these new remote sites - US NRC Commissioner Jeffrey S. Merrifield, - Johannesburg, South Africa, October 2, 2006

The SMRs listed in Appendix B indicate that the market is indeed ready to supply and compete for new SMRs orders. However, most of the SMRs under development fall under the category of *medium* and *small* reactors rather than *very small* reactors (< 150 MWe). Thus additional development effort may be required for very small reactors in particular, in order to prepare for potential demands in non-energy uses of nuclear technology, as well as in small remote sites with a need for a reliable long-term small energy needs..

Appendix B also indicates that several SMRs currently under development could support the GNEP vision (see section A.1). Additional SMR development effort may yield a better design, by emphasizing such attributes as: passive safety systems, simplicity, need for minimal supporting nuclear infrastructure, improved economics, long core life, absence of weapons-useable material in fresh fuel, central fuel reprocessing facilities in supplier states, effective IAEA safeguards; and robust NPPs against sabotage or terrorism.

B. World Nuclear Power Plants

In order to perform market assessment of SMRs it is necessary to examine the current inventory of the world nuclear power plants (NPPs) and the fraction of SMRs within the world inventory. Furthermore, those countries which already operate NPPs are most likely to either build new SMRs for domestic use or for export to other countries. As indicated in the next section, in addition to those countries which already have nuclear technology, numerous non-nuclear countries are also candidates for SMRs.

According to the IAEA's Power Reactor Information System (PRIS)[3], as of June 2005, 146 SMRs were operated worldwide, accounting for 61 GWe of electricity generation, and 12 more were under construction. These were mostly earlier generation reactors still in operation and a few prototype or tests reactors, intended to support development and deployment of new larger-capacity commercial plants. Their share in worldwide nuclear electricity production was around 16.5%.

Today there are[5] some 440 nuclear reactors in 31 countries with a combined capacity of 370 GWe (see Appendix A). In 2005 these NPPs provided 2626 billion kWh, or over 16% of the world electricity. The IAEA has significantly increased its projection of world nuclear generating capacity. It now anticipates at least 60 new plants in the next 15 years, making 430 GWe in place in 2020 - 130 GWe more than projected in 2000, and 16% more than are actually operating in 2006. The change is based on specific plans and actions in a number of countries, including China, India, Russia, Finland and France, coupled with the changed outlook due to the Kyoto Protocol. This would give nuclear power a 17% share in electricity production in 2020. The fastest growth is expected in Asia.

Note that the list of the world nuclear power plants[5] displayed in Appendix A indicates that the total addition of nuclear electricity (under construction + on order or planned + proposed) represents an addition of 209,356 MWe (250 NPPs) to the existing 370,721 MWe (442 NPPs), or an additional capacity of 56%. The average size of an NPP is thus 837 MWe. Note however that a number of NPPs will be retired within this time frame. Out of the 250 new NPPs in Table A.3, there are 117 SMRs if all 50 reactors in China are SMRs, or 67 NPPs without China. The corresponding capacity of new SMRs is 61, 583 MWe (30%) with China and 25,703 MWe (12%) without China. 157 of the 442 (35%) operating units world wide are SMRs. 86 out of 104 (84%) units - world wide - no longer in service, are SMRs[16].

The types, number and power supplied worldwide in 2003 by all nuclear power plants is listed below in Table 1.A (IAEA's PRIS data base 2003). A similar summary for operating SMR nuclear power plants was prepared from the data base of reference 16 (as of December 31, 2004) and is displayed in Table 1.B. Note that data in Table 1.B are similar to the above quoted PRIS data of June 2005.

TABLE 1.A - Number and Power (in MWe) of Reactors, by Type and Continent

Code	Type	Europe	Africa	Americas	Asia	Total
AGR	Advanced Gas Cooled Reactor	14 (8,360)				14 (8,360)
BWR	Boiling Water Reactor	20 (17,261)		36 (31,639)	34 (28,156)	90 (77,056)
FBR	Fast Breeder Reactor	2 (793)			2 (261)	4 (1,054)
GCR	Gas Cooled Reactor	19 (3,125)				19 (3,125)
HWLWR	Heavy-Water-Moderated, Light-Water-Cooled				1 (148)	1 (148)
LWGR	Light Water Cooled Graphite Reactor	18 (12,594)				18 (12,594)
PHWR	Pressurized Heavy Water Reactor	1 (650)		22 (14,436)	16 (4,815)	39 (20,001)
PWR	Pressurized Water Reactor	109 (106,560)	2 (1,842)	71 (65,917)	40 (32,093)	222 (206,412)
WWER	Water Cooled Water Moderated Power Reactor	32 (18,553)			1 (376)	33 (18,929)
Total		215 (167,896)	2 (1,842)	129 (119,992)	94 (65,849)	440 (347,679)

Source: 2003 Power Reactor Information System (PRIS) database, IAEA (2003).

TABLE 1.B - Number and Power (in MWe) of Operating SMRs, by Type and Continent as of December 31, 2004 (Source: Nuclear News, March 2005)

Type	Europe	Africa	America	Asia	Total
AGR	14 (8380)				14 (8380)
BWR	6 (2520)		8 (4986)	10 (4245)	24 (11751)
LMFBR	2 (793)			1 (246)	3 (1039)
GCR	8 (2284)				8 (2284)
LWGR	4 (44)				4 (44)
PHWR	1 (655)		12 (6329)	18 (6229)	31 (13213)
PWR	35 (14326)		8 (4264)	14 (7005)	57 (25595)
Total*	70 (29002)		28 (15579)	43 (17725)	141 (62306)

* India's 11 PHWR and 2 BWR, Pakistan's 1 PHWR, UK's 6 GCR, and 2 LMFBR are *small* SMRs; 7 NPPs are *very small* SMRs

Note the difference dates of Tables 1.A and 1.B (2002-2003 data base for Table 1.A vs. the end of 2004 for Table 1.B). During 2002-2004 10 SMRs GCR with a total capacity of 646 MWe were taken out of service in the Europe (UK), 3 SMRs PWR with a total capacity of 1446 MWe were taken out of service in Europe; and one SMR HWLWR was taken out of service in Japan.

Current plans for constructions of new SMRs – assuming all China's new 50 NPPs will be SMRs – is 117 NPPs with a total capacity of 61.5 GWe. If we also add, the anticipated orders for new PBMR SMRs, new IRIS SMRs and other SMRs under development (see Appendix B), it is expected that the share of SMRs as a fraction of the total NPPs market will be maintained or increased. As of the end of 2004, the 440 operating NPPs had a net capacity of 365,769 MWe[16]. Therefore, the *number* of SMRs constitute 32% of the NPPs (141/440 = 0.32), and their share of the *capacity* is 17% (62.3/365.7=0.17).

Capital costs for each PBMR module are expected to be a fraction of the cost of current reactors - roughly $125 to $150 million for a 125 MW plant - thus decreasing investment risk. At $1,100 per kilowatt to construct, the PBMR can be competitive with other energy sources.

Corbin A. McNeill, Former Exelon CEO, May 3, 2001

C. World Energy Demand

Since the world share of nuclear-generated electricity is around 16.5%, the potential of nuclear energy to supply a larger share of the world electricity, as well as to supply the world energy demand for other applications such as district heating, water desalination, industrial process heat; and high temperature heat source for hydrogen generation could imply a large expansion for nuclear power.

In order to obtain some perspective on potential market penetration of nuclear energy, we examine below the world energy demand.

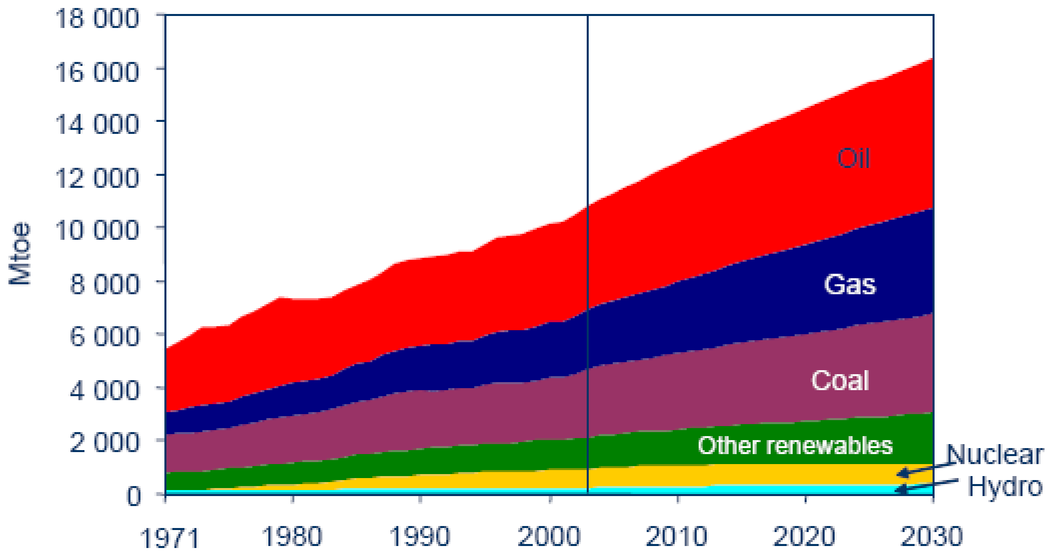

Figure 1 - World Primary Energy Demand [b]

The International Energy Agency (IEA), in its World Energy Outlook 2005 predicts the world primary energy outlook (Figure 1). This prediction indicates that if governments continue with current policies (*Reference Scenario*) – the world's energy demand in 2030 would be more than 50% higher than in 2005, i.e. the energy need will grow at an average annual rate of 1.6%. More than two third of the growth in the world energy use will come from developing countries, where economic and population growth are the highest.

Fossil fuels continue to dominate energy supplies[c], meeting more than 80% of the projected increase in primary energy demand in this scenario. Oil remains the single largest fuel, with two-thirds of the increase in oil use coming from the transport sector. Demand reaches 92 million barrels per day (mb/d) in 2010 and 115 mb/d in 2030. Natural gas demand grows faster, driven mainly by power generation. It overtakes coal as the world's second-largest primary energy source before 2015. In this scenario, the share of

[b] IEA- World Energy Outlook 2005 –reference 7
[c] F. Birol, IEA, July 2006 – reference 8

coal in world primary demand declines a little, with demand growth concentrates in China and India. Nuclear power's market share declines marginally, while that of hydropower remains broadly constant. The share of non-hydro renewables, including biomass, geothermal, solar, wind, tidal and wave energy, will remain flat at 11%. The World *Alternative Policy Scenario* takes into account all the new measures that governments are currently considering to curb energy use and to reduce emissions for energy-security and environmental reasons. Under these new assumptions, primary energy demand grows by 1.2% per year to 2030, 0.4% less than in the Reference Scenario. Demand for oil would be 10% lower in 2030 than in the Reference Scenario, but oil would still account for 34% of world primary energy demand. Two thirds of the savings would come from the transport sector. Natural gas demand in 2030 would also be 10% lower in 2030 than in the Reference Scenario. Most of the savings would come from power generation. The energy savings associated with the alternative scenario vs. the reference scenario is shown in Figure 2.

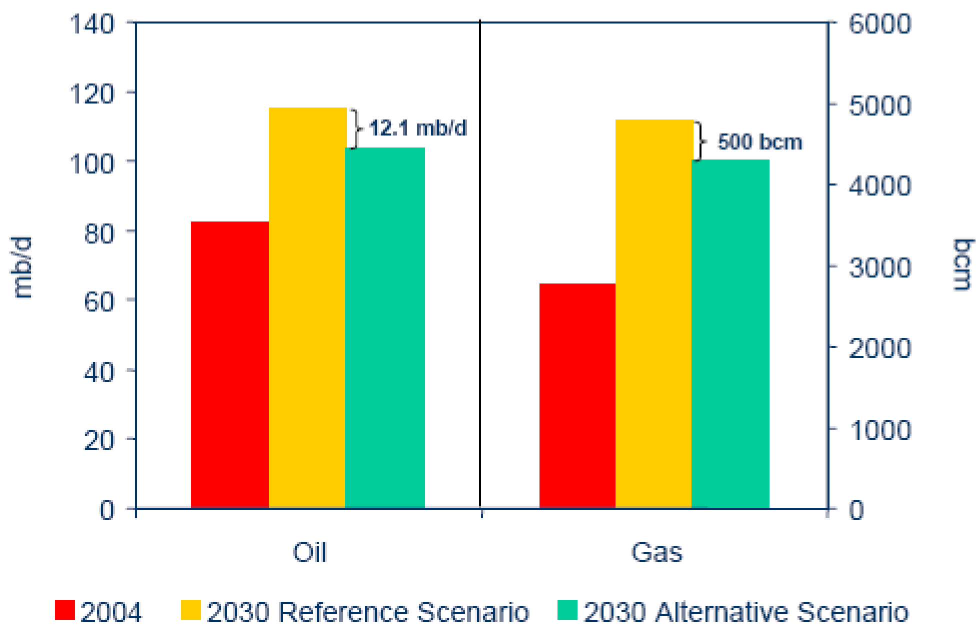

Figure 2 –Oil/Gas Demand in the Reference and Alternative Scenarios [c]

It should be noticed that the European Union has outlined recently ambitious energy goal, whereby action plan to cut Europe's energy consumption by 20% before 2020 has been outlined by the European Commission[d]. The Energy Efficiency Action Plan proposes more than 75 ambitious measures for energy efficiency, including tougher energy standards for electrical goods, low-energy building strategy and more fuel efficient cars. The plan is expected to deliver an annual saving to the EU of approximately 100 billion euro ($125 billion) and help the EU meet its Kyoto Protocol target to cut emissions by 8%. If this plan will be implemented, the energy demand in the European Union will follow the *Alternative Scenario* rather than the *Reference Scenario*.

[d] BBC News, October 19, 2006- EU sets 'ambitious' energy goals

The reason for the IEA's prediction of slow growth in nuclear power is the need for replacing retiring nuclear power plants at the same time that expanding demand is expected in developing countries. Nuclear power generation will increase in absolute terms, but its share in the global energy market will fall. Nearly 40% of existing nuclear plants will be retired. In 2004 the IEA's prediction[10] of the nuclear market share was below (see Table 2 below) that of its own prediction in 2005[8] .

"I see three major global challenges today: the inexorable growth of energy demand and the need to make energy accessible to all, the greater awareness of energy issues, and the unavoidable change in energy mix driven by technological progress"
Pierre Gadonneix, CEO of Electricitè de France (EdF) and Chairman of World Energy Council (WEC), September 6, 2006

IEA's World Energy Outlook 2005 predicts that the global electric power sector will need about 4,800 GW of new capacity between now and 2030 to meet the projected increase in electricity demand and to replace aging infrastructure. Just over half of this amount will be needed in developing countries. OECD countries will need nearly 2,000 GW, including replacements. Nearly a third of the current installed capacity in the OECD could be retired by 2030.

A breakdown of the market share in electricity generation was predicted by IEA World Energy Outlook 2004 as shown below:

TABLE 2 – Market Shares in Electricity Generation (%)[e]

	OECD		**Transition Economies**		**Developing Countries**	
	2002	**2030**	**2002**	**2030**	**2002**	**2030**
Coal	38	33	22	16	45	47
Oil	6	2	4	2	12	5
Gas	18	29	37	54	17	26
Nuclear	23	15	18	11	2	3
Hydro	13	11	19	15	23	16
Renewables	3	10	0	2	1	3

[e] IEA World Energy Outlook 2004 – reference 10

The International Energy Agency took a bold step today. For the first time in its 32-year history, the IEA called on the world to create more nuclear energy.
The agency warned an oil shortage is coming.
Nuclear allows governments to hold energy in their own hands rather than depend on others for their energy, and so it's a very attractive option.
Carola Hoyos, Chief Energy Correspondent with the Financial Times, November 7, 2006

The uncertainty surrounding the outlook for global energy markets has rarely been greater[8]. For as long as the world economy continues to expand, we can be sure that demand for oil and other forms of energy will increase. But the rate of growth in primary energy needs and the mix of fuels will depend on what action governments decide to take to curb demand and emissions, and on developments in energy technology.

Other factors, including extreme weather, natural disasters and geopolitics, will complicate the ability to anticipate with confidence near- medium- and long-term energy-market developments. Energy security is more than ever a matter of managing risk and coping with uncertainty.

D. Market Assessment

D.1 SMRs Assessment in Developing Countries

Due to their lower power output, their simplified designs and their high safety margins, SMRs are prime candidates for deployment in developing countries with small electricity grids or with a need to satisfy demand for non-electricity applications, such a district heating or production of potable water.

Among the developing countries with ongoing nuclear power programs, China and India represent a substantial market for SMRs. In China, there is an ambitious nuclear power program firmly supported by the government. In addition to some imported medium size units, a series of domestically designed medium sized reactors, as well as some small and very small units (including heat-only reactors), are expected to be constructed. In India, there is continuing firm governmental support for the nuclear power program, and a large demand for new capacity. The country is expected to proceed with its program based on domestically designed SMRs. In 1998 it was estimated that the market for SMRs in the above two countries is of the order of 20 to 30 units, more than half of which correspond to medium sized reactors [f]. However, as noted earlier India alone is planning to add 16 GWe by 2020, which could imply the addition of 27 reactors, sized at 600 MWe each. Similarly, China plans to add some 40 new NPPs by 2020, some of which are likely to be SMRs.

Argentina, Iran, Korea and Pakistan have ongoing nuclear power programs, including reactors under construction. In Argentina, follow-up nuclear power plants are expected to be in the medium sized range; the development of a very small

[f] Kupitz, J et al , 1998 – reference 11

domestically designed reactor has been pursued, and there is a plan to build a first unit. In Iran, the construction of two large power reactors has been restarted, and there are plans to acquire some small units. In Pakistan, a further small reactor is expected to be followed by a series of medium sized units. Though large power reactors are the basis for the ongoing nuclear program in Korea, more units in the medium range are expected. Also, implementation of a domestically designed very small reactor is expected. The estimate in 1998 for these four countries was 10 to 15 units until 2015[11].

Among countries which have not yet initiated nuclear power projects, Turkey and Indonesia are in the acquisition stage of their first units. Both have intended to go nuclear for a long time. Malaysia and Thailand performed studies indicating the convenience of the nuclear option. All four countries are potential markets for medium sized reactors, and in addition Indonesia might implement a very small unit at a remote site. The implementation of 5 to 10 SMRs is expected for this group of countries.

The North African countries (Algeria, Egypt, Libya, Morocco and Tunisia) show a high degree of interest in initiating nuclear power programs. All have performed studies and preparations, including, in some cases, attempts to acquire nuclear power reactors. It is expected that further attempts will finally succeed, leading to the implementation of 5 to 10 SMRs, including very small, small and medium sized units.

Several other countries which have not yet initiated nuclear power projects have performed studies and indicated interest in launching nuclear programs. Belarus has persistent energy supply constraints and might acquire some medium sized units. In Chile, nuclear power could contribute to energy supply diversification in a fast growing economy with corresponding energy and electricity demand growth. In Croatia, a follow-up unit to the 600 MWe plant built in Slovenia was planned; new attempts could lead to a medium sized unit.

Israel has consistently indicated interest in nuclear power; it has a solid nuclear technology infrastructure and could implement a nuclear project, subject to the success of the Middle East peace process. This also applies to Syria, which intends to proceed with medium sized units. Portugal was on the verge of launching a nuclear power program in the past, but has since desisted; new attempts to implement medium sized units could succeed. Saudi Arabia has very large oil and gas resources, but energy supply diversification seems advisable; a nuclear power program starting with a very small or small reactor might be launched.

In addition, some other countries have indicated interest in nuclear power and in SMRs in particular, performing studies and building infrastructures: Peru, Uruguay and Bangladesh are examples. There are others, such as Cuba, Romania and the Philippines, where the construction of SMRs was suspended. In these countries, completing these projects would have priority over the initiation of new plants. The estimated market for SMRs in the above group of countries is 5 to 10 units altogether.

These results indicated in 1998[11] a market with wide range 50 to 90 units to be implemented up to 2015. The outcome will probably not evolve in all countries according to either the high or the low estimates. Also, it was recognized that forecasts, just like national development plants, tend to err on the optimistic side. Therefore, an overall market estimate of 60 to 70 units by 2015 seemed reasonable in 1998. Doubling of these estimates by 2040 is reasonable.

SMRs and Non-Electricity Applications

SMRs have a wide application potential for various industrial heat processes. This includes SMRs that are designed for heat-only production or for co-generation of heat and electricity. Due to their reduced power output, which meets the requirements of developing countries with small electricity grids, SMRs have a broad application potential. Prime candidates for near term industrial process heat applications are mostly in the low temperature range, e.g. district heating, desalination of seawater and process steam and heat supply for industry. In particular, desalination of seawater with nuclear energy is receiving increasing international attention to cope with current and future shortages of potable water.

D.2 SMR Market Assessment of 1996[2]

The world market for SMR until 2015 was assessed by B.J. Csik of the IAEA in 1996[2]. The market was assessed by individual countries, taking into account energy demand and supply patterns, growth rates, energy resources, economic and financial resources, electric grids, industrial and technical development, infrastructure availability, environmental and nuclear safety concerns and other policy issues. The market assessment included *all applications* of these reactors, i.e. electricity generation as well as the supply of process heat and district heating.

The market assessment was based on the assumption that suitable nuclear reactors will be available both for domestic implementation and for export, when required by interested buyers. Suitability is interpreted by meeting the technical and economic conditions as defined by potential buyers, which are often called user requirements. The user requirements must be reasonable and not be a wish-list containing a collection of desirable goals impossible to achieve simultaneously. The nuclear reactors must be licensable; the technical features must not require further research to demonstrate their viability and reliability; the costs must be within an acceptable range. Understanding the costs and benefits in the wider sense instead of only in monetary terms, the buyers must find a favorable cost/benefit ratio.

It was expected[2] that SMRs will be deployed primarily in countries which have already started nuclear projects, in particular in countries which have developed SMR designs themselves. Thus, projects would be supplied predominantly by domestic sources; later, the export market is expected to attain more importance. It was further expected that over two thirds of the SMR units would be in the medium size range, i.e. from 300 to 700 MWe, and the rest would be smaller.

About one third of the SMRs to be implemented were expected to supply heat and/or electricity to integrated seawater desalination plants. More than half of these reactors would be below 300 MWe. The overall market was estimated at about 60 to 100 SMR units to be implemented up to the year 2015. It was recognized that forecasts, just like national development plans, tend to err on the optimistic side. Therefore, an overall market estimate of 70 to 80 units seemed reasonable.

Table 3 lists SMRs under construction at the time of this market assessment[2].

Table 3- SMRs Under Construction (early 1990s)[2]

Country	Reactor	Net Capacity (MWe)
Argentina	ATUCHA-2	692
India	KAIGA-1	202
India	Kaiga-2	202
India	RAJASTHAN-3	202
India	RAJASTHAN-4	202
Korea	WOLSONG-2	650
Korea	WOLSONG-3	650
Korea	WOLSONG-4	650
Pakistan	CHASNUPP-1	300
Romania	CERNAVODA-2	650
Slovakia	MOCHOVCE-1	388
Slovakia	MOCHOVCE-2	388
Slovakia	MOCHOVCE-3	388
Slovakia	MOCHOVCE-4	388

In addition, construction has been suspended - but was expected to proceed - on the following reactors:

Cuba - Juragua-1 - 408 MWe
Cuba - Juragua-2 - 408 MWe
Romania - Cernavoda-3 - 625 MWe
Romania - Cernavoda-4 - 625 MWe
Romania - Cernavoda-5 - 625 MWe

A short list of countries is shown (Table 4), which contains those countries that were assessed as having a potential demand for SMRs within the period considered (until 2015), and which therefore deserved a more thorough consideration.

TABLE 4 - List Of Countries For Further SMRs Consideration[2]

First Nuclear Projects Started	**No Nuclear Power Projects Started**
Argentina	Algeria
Canada	Belarus
China	Chile
Hungary	Croatia
India	Egypt
Iran	Indonesia
Italy	Israel
Korea	Libya
Mexico	Malaysia
Pakistan	Morocco
Poland	Portugal
Russia	Saudi Arabia
South Africa	Syria
USA	Thailand
	Tunisia
	Turkey

The following factors which affect the market were listed in this IAEA study: (1) Energy resources and supply diversification; (2) Economic and financial resources; (3) Interconnected electrical systems; (4) Growth rate; (5) Energy demand pattern; (6) Electricity supply structure; (7) Industrial and technical development; and (8) Environmental and nuclear safety concerns.

The results of the SMR market assessment are displayed in Table 5.

These results indicate a total market for SMRs by 2015 between 60 and 100 reactors.

At the high estimate (100 reactors), 45 reactors were estimated to be supplied domestically and 55 reactors by foreign suppliers. At the low end, 32 reactors were estimated to be supplied domestically and 28 reactors by foreign suppliers.

Several of the countries listed in Table 5 were considering SMRs combined with desalination. This market was estimated between 25 and 40 SMRs by 2015, with 40% to be supplied by medium sized SMRs and 60% by small and very small SMRs.

TABLE 5 - SMR Market Assessment By Geographic Areas[2]

HIGH ESTIMATE						LOW ESTIMATE			
Region	**Size**	**2001-2005**	**2006-2010**	**2011-2015**	**Total 2001-15**	**2001-2005**	**2006-2010**	**2011-2015**	**Total 2001-15**
North America	M S VS	0 0 0	2 0 0	1 0 0	3 0 0	0 0 0	0 0 0	0 0 0	0 0 0
South and Central America	M S VS	0 0 1	0 0 0	4 1 0	4 1 1	0 0 0	0 0 0	2 1 0	2 1 0
European Union	M S VS	1 0 1	4 0 2	7 0 2	12 0 5	0 0 0	2 0 2	6 0 1	8 0 3
Africa	M S VS	0 0 1	2 0 2	3 3 1	5 3 4	0 0 0	0 0 0	5 0 1	5 0 1
Middle East, South & Middle Asia	M S VS	1 2 0	5 5 0	10 1 1	16 8 1	1 1 0	3 4 0	5 0 1	9 5 1
Southeast Asia and the Pacific	M S VS	0 0 0	2 0 0	4 0 1	6 0 1	0 0 0	1 0 0	2 0 0	3 0 0
Far East	M S VS	5 0 2	4 2 2	2 1 3	11 3 7	3 0 1	4 1 2	4 1 2	11 2 5
Eastern Europe	M S VS	1 0 1	4 0 2	7 0 2	12 0 5	0 0 0	2 0 2	6 0 1	8 0 3
World Total	M S VS	7 2 5	21 7 6	38 6 8	66 15 19	4 1 1	11 5 4	27 2 5	42 8 10

M= 300-700 MWe; S= 150-300 MWe; VS= <150 MWe

D. 3 The MIT Study[4]

In 2003 the Massachusetts Institute of Technology (MIT) has conducted an interdisciplinary study on the future of nuclear energy[4]. This study used the United Nations (UN) Human Development Index (HDI), that has been used by the IEA[10], as the empirical dividing line of 4000 kWh annual per capita electricity use, between advanced and developing economies. The HDI is based on health, education and economic criteria, and is correlated with the per capita consumption of electricity as shown in Figure 3.

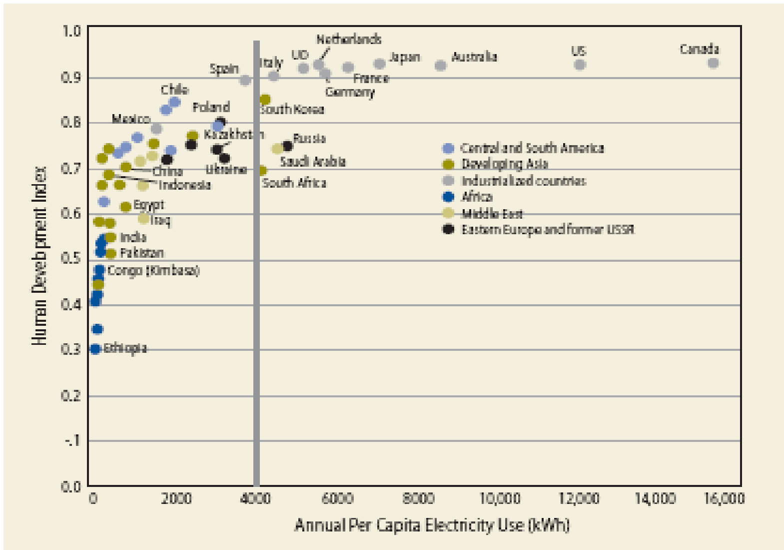

Figure 3 – HDI vs. Per Capita Electricity Consumption[4, 10]

The per capita electricity growth rate in the developed countries was assumed to be between 0.5% and 1% (EIA World Energy Outlook 2001). Various growth rates were assumed for different countries in accordance with the HDI index. Countries with significantly lower than 4000 kWh per capita consumption were assumed to have the highest growth rate, whereas the developed countries were assumed to have the lowest growth rate. The MIT's projected world wide electricity consumption and nuclear capacity until 2050 is shown in the following tables[4]:

COUNTRY	TOTAL POPULATION (millions)		TOTAL ELECTRICITY CONSUMPTION (billion kWhrs)		PER CAPITA CONSUMPTION (kWhrs/per)		NUCLEAR PRODUCTION (billion kWhrs)						NUCLEAR EQ. "CAPACITY" (GWe)			%/year TEC	%/year LOW NUCLEAR	%/year HIGH NUCLEAR
DEVELOPED WORLD	2000	2050	2000	2050*	2000	2050*	2000	%	2050 L	% L	2050 H	% H	2000	2050 L	2050 H			
USA	283	397	3,621.0	8,349	12,785	21,026	717	20%	2,505	30%	4,174	50%	82	286	477	1.7%	2.5%	3.6%
France	59	62	408.5	701	6,896	11,342	315	77%	561	80%	596	85%	36	64	68	1.1%	1.2%	1.3%
Japan	127	109	943.7	1,334	7,425	12,212	274	29%	534	40%	800	60%	31	61	91	0.7%	1.3%	2.2%
Germany	82	71	501.7	712	6,117	10,061	151	30%	285	40%	427	60%	17	33	49	0.7%	1.3%	2.1%
Korea, South (ROK)	47	52	254.1	461	5,436	6,980	97	38%	230	50%	323	70%	11	26	37	1.2%	1.8%	2.4%
United Kingdom	59	59	345.0	563	5,807	9,551	79	23%	169	30%	281	50%	9	19	32	1.0%	1.5%	2.6%
Canada	31	40	499.8	1,080	16,249	26,724	60	12%	324	30%	540	50%	7	37	62	1.6%	3.4%	4.5%
Spain	40	31	201.2	259	5,040	8,289	56	28%	104	40%	156	60%	6	12	18	0.5%	1.2%	2.1%
Sweden	9	8	139.2	201	15,740	25,887	51	37%	101	50%	141	70%	6	11	16	0.7%	1.3%	2.0%
Belgium	10	10	78.1	120	7,623	12,537	45	58%	72	60%	96	80%	5	8	11	0.9%	0.9%	1.5%
Taiwan	22	23	139.0	233	6,277	8,054	35	25%	93	40%	140	60%	4	11	16	1.0%	2.0%	2.8%
Finland	5	5	82.0	122	15,848	26,064	23	28%	49	40%	73	60%	3	6	8	0.8%	1.5%	2.4%
Switzerland	7	6	52.6	68	7,338	12,069	19	37%	34	50%	47	70%	2	4	5	0.5%	1.1%	1.8%
Netherlands	16	16	100.7	165	6,349	10,441	4	4%	17	10%	33	20%	0	2	4	1.0%	2.9%	4.3%
Norway	4	5	112.5	202	25,172	41,399	0	0%	20	10%	40	20%	0	2	5	1.2%	—	—
Australia	19	27	188.5	429	9,849	16,198	0	0%	43	10%	86	20%	0	5	10	1.7%	—	—
New Zealand	4	4	33.3	64	8,818	14,503	0	0%	6	10%	13	20%	0	1	1	1.3%	—	—
Austria	8	6	54.8	72	6,778	11,147	0	0%	7	10%	14	20%	0	1	2	0.5%	—	—
Denmark	5	5	33.9	53	6,377	10,488	0	0%	0	0%	0	0%	0	0	0	0.9%	—	—
Israel	6	10	34.9	96	5,777	9,501	0	0%	10	10%	19	20%	0	1	2	2.0%	—	—
Ireland	4	5	20.8	48	5,475	9,005	0	0%	0	0%	0	0%	0	0	0	1.7%	—	—
China, Hong Kong	7	8	35.4	63	4,975	8,182	0	0%	0	0%	0	0%	0	0	0	1.2%	—	—
Italy	58	43	283.7	348	4,932	8,111	0	0%	35	10%	70	20%	0	4	8	0.4%	—	—
Greece	11	9	46.1	64	4,345	7,146	0	0%	0	0%	0	0%	0	0	0	0.7%	—	—
Subtotal	**924**	**1,010**	**8,211**	**15,810**	**8,888**	**15,659**	**1,926**	**23%**	**5,197**	**33%**	**8,071**	**51%**	**220**	**593**	**921**	**1.3%**	**2.0%**	**2.9%**

TABLE 6 - Electricity Consumption Projections and Nuclear Power Growth Scenario (Developed World)[4]

COUNTRY	TOTAL POPULATION (millions)		TOTAL ELECTRICITY CONSUMPTION (billion kWhrs)		PER CAPITA CONSUMPTION (kWhrs/per)		NUCLEAR PRODUCTION (billion kWhrs)						NUCLEAR EQ. "CAPACITY" (GWe)			%/year TEC	%/year LOW NUCLEAR	%/year HIGH NUCLEAR
DEVELOPING WORLD More Advanced	2000	2050	2000	2050*	2000	2050*	2000	%	2050 L	% L	2050 H	% H	2000	2050 L	2050 H			
Kuwait	2	4	29.0	100	15,157	24,927	0	0%	0	0%	0	0%	0	0	0	2.5%	—	—
United Arab Emirates	3	4	36.0	84	13.811	22,714	0	0%	0	0%	0	0%	0	0	0	1.7%	—	—
Singapore	4	5	25.9	49	6,458	10,620	0	0%	0	0%	0	0%	0	0	0	1.3%	—	—
Saudi Arabia	20	60	114.9	554	5,645	9,284	0	0%	0	0%	0	0%	0	0	0	3.2%	—	—
Puerto Rico	4	5	19.1	39	4,869	8,008	0	0%	0	0%	0	0%	0	0	0	1.4%	—	—
Bulgaria	8	5	34.4	32	4,330	7,121	15	44%	16	50%	23	70%	2	2	3	–0.1%	0.1%	0.8%
South Africa	43	47	181.5	326	4,191	6,893	13	7%	65	20%	130	40%	1	7	15	1.2%	3.3%	4.8%
Portugal	10	9	41.1	61	4,108	6,756	0	0%	6	10%	12	20%	0	1	1	0.8%	—	—
Hungary	10	7	35.1	43	3,521	5,791	14	40%	22	50%	26	60%	2	2	3	0.4%	0.9%	1.2%
Libya	5	10	18.0	56	3,411	5,609	0	0%	6	10%	11	20%	0	1	1	2.3%	—	—
Brazil	170	247	360.6	989	2,116	4,000	4	1%	148	15%	297	30%	0	17	34	2.0%	7.7%	9.2%
Mexico	99	147	182.8	587	1,849	4,000	7	4%	88	15%	176	30%	1	10	20	2.4%	5.1%	6.6%
Iraq	23	54	25.4	214	1,106	4,000	0	0%	0	0%	0	0%	0	0	0	4.4%	—	—
Costa Rica	4	7	5.9	29	1,465	4,000	0	0%	0	0%	0	0%	0	0	0	3.2%	—	—
Ecuador	13	21	9.7	85	764	4,000	0	0%	0	0%	0	0%	0	0	0	4.4%	—	—
Cuba	11	11	13.8	43	1,235	4,000	0	0%	0	0%	0	0%	0	0	0	2.3%	—	—
Algeria	30	51	21.8	205	721	4,000	0	0%	20	10%	41	20%	0	2	5	4.6%	—	—
Thailand	63	82	90.3	330	1,437	4,000	0	0%	33	10%	66	20%	0	4	8	2.6%	—	—
Syria	16	36	17.7	145	1,092	4,000	0	0%	0	0%	0	0%	0	0	0	4.3%	—	—
Egypt	68	114	64.7	455	953	4,000	0	0%	46	10%	91	20%	0	5	10	4.0%	—	—
Malaysia	22	38	58.6	151	2,637	4,000	0	0%	15	10%	30	20%	0	2	3	1.9%	—	—
Chile	15	22	37.9	89	2,491	4,000	0	0%	0	0%	0	0%	0	0	0	1.7%	—	—
Mongolia	3	4	2.7	17	1,078	4,000	0	0%	0	0%	0	0%	0	0	0	3.7%	—	—
Turkey	67	99	114.2	395	1,713	4,000	0	0%	40	10%	79	20%	0	5	9	2.5%	—	—
Oman	3	9	7.5	35	2,968	4,000	0	0%	0	0%	0	0%	0	0	0	3.1%	—	—
Croatia	5	4	12.6	17	2,716	4,000	0	0%	0	0%	0	0%	0	0	0	0.6%	—	—
Peru	26	42	18.3	168	713	4,000	0	0%	0	0%	0	0%	0	0	0	4.5%	—	—
China	1,275	1,462	1,206.3	5,848	946	4,000	12	1%	877	15%	1,754	30%	1	100	200	3.2%	9.0%	10.5%
Argentina	37	55	80.8	218	2,182	4,000	6	7%	44	20%	87	40%	1	5	10	2.0%	4.2%	5.6%
Lebanon	3	5	8.6	20	2,472	4,000	0	0%	0	0%	0	0%	0	0	0	1.7%	—	—
Uruguay	3	4	7.4	17	2,203	4,000	0	0%	0	0%	0	0%	0	0	0	1.7%	—	—
Albania	3	4	5.4	16	1,716	4,000	0	0%	0	0%	0	0%	0	0	0	2.2%	—	—
Jordan	5	12	7.1	47	1,443	4,000	0	0%	0	0%	0	0%	0	0	0	3.8%	—	—
Korea, North (DROK)	22	28	31.1	112	1,395	4,000	0	0%	22	20%	45	40%	0	3	5	2.6%	—	—
Venezuela	24	42	75.1	169	3,107	4,000	0	0%	17	10%	34	20%	0	2	4	1.6%	—	—
Dominican Republic	8	12	8.8	48	1,052	4,000	0	0%	0	0%	0	0%	0	0	0	3.4%	—	—
Poland	39	33	119.3	133	3,091	4,000	0	0%	13	10%	27	20%	0	2	3	0.2%	—	—
Jamaica	3	4	6.3	15	2,433	4,000	0	0%	0	0%	0	0%	0	0	0	1.8%	—	—
Zimbabwe	13	24	10.5	94	830	4,000	0	0%	0	0%	0	0%	0	0	0	4.5%	—	—
Colombia	42	71	40.3	283	958	4,000	0	0%	0	0%	0	0%	0	0	0	4.0%	—	—
Tunisia	9	14	9.6	56	1,011	4,000	0	0%	0	0%	0	0%	0	0	0	3.6%	—	—
Bosnia and Herzegovina	4	3	2.6	14	648	4,000	0	0%	0	0%	0	0%	0	0	0	3.4%	—	—
Iran	70	121	111.9	486	1,591	4,000	0	0%	97	20%	194	40%	0	11	22	3.0%	—	—
Romania	22	18	45.7	73	2,036	4,000	5	10%	15	20%	22	30%	1	2	2	0.9%	2.3%	3.2%
Yugoslavia	11	9	31.5	36	2,989	4,000	0	0%	0	0%	0	0%	0	0	0	0.3%	—	—
Panama	3	4	4.7	17	1,629	4,000	0	0%	0	0%	0	0%	0	0	0	2.6%	—	—
El Salvador	6	11	4.1	41	648	3,749	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—

TABLE 7 - Electricity Consumption Projections and Nuclear Power Growth Scenario (More Advanced Developing)[4]

COUNTRY	TOTAL POPULATION (millions)		TOTAL ELECTRICITY CONSUMPTION (billion kWhrs)		PER CAPITA CONSUMPTION (kWhrs/per)		NUCLEAR PRODUCTION (billion kWhrs)						NUCLEAR EQ. "CAPACITY" (GWe)			%/year TEC	%/year LOW NUCLEAR	%/year HIGH NUCLEAR
DEVELOPING WORLD Less Advanced	2000	2050	2000	2050*	2000	2050*	2000	%	2050 L	% L	2050 H	% H	2000	2050 L	2050 H			
India	1,009	1,572	509.9	5,099	505	3,243	15	3%	765	15%	1,530	30%	2	87	175	4.7%	8.1%	9.6%
Philippines	76	128	37.8	378	500	2,946	0	0%	38	10%	76	20%	0	4	9	4.7%	—	—
Morocco	30	50	14.3	143	480	2,849	0	0%	14	10%	29	20%	0	2	3	4.7%	—	—
Honduras	6	13	3.6	36	560	2,797	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Indonesia	212	311	86.1	861	406	2,765	0	0%	172	20%	344	40%	0	20	39	4.7%	—	—
Sri Lanka	19	23	6.2	62	325	2,669	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Bolivia	8	17	3.6	36	433	2,125	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Zambia	10	29	5.8	58	560	1,995	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Vietnam	78	124	24.0	240	307	1,937	0	0%	24	10%	48	20%	0	3	5	4.7%	—	—
Nicaragua	5	11	2.2	22	429	1,896	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Guatemala	11	27	4.8	48	421	1,807	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Pakistan	141	344	58.3	583	413	1,694	1	1%	87	15%	175	30%	0	10	20	4.7%	10.5%	12.1%
Paraguay	5	13	2.0	20	355	1,552	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—

TABLE 8 - Electricity Consumption Projections and Nuclear Power Growth Scenario (Less Advanced Developing)[4]

COUNTRY	TOTAL POPULATION (millions)		TOTAL ELECTRICITY CONSUMPTION (billion kWhrs)		PER CAPITA CONSUMPTION (kWhrs/per)		NUCLEAR PRODUCTION (billion kWhrs)						HUCLEAR EQ. "CAPACITY" (GWe)			%/year TEC	%/year LOW NUCLEAR	%/year HIGH NUCLEAR
DEVELOPING WORLD Least Advanced	2000	2050	2000	2050*	2000	2050*	2000	%	2050 L	% L	2050 H	% H	2000	2050 L	2050 H			
Papua New Guinea	5	11	1.5	15	319	1,397	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Ghana	19	40	5.5	55	284	1,369	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Ivory Coast	16	32	3.6	36	222	1,103	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Cameroon	15	32	3.4	34	227	1,044	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Kenya	31	55	4.4	44	145	801	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Myanmar	48	69	4.5	45	94	656	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Senegal	9	23	1.2	12	130	541	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Nigeria	114	279	14.8	148	130	530	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Bangladesh	137	265	12.5	125	91	473	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Tanzania	35	83	2.6	26	75	316	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Yemen	18	102	3.0	30	162	291	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Sudan	31	64	1.8	18	59	288	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Nepal	23	52	1.4	14	62	273	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Congo, DR	51	204	4.6	46	90	225	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Angola	13	53	1.1	11	84	208	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Uganda	23	102	1.3	13	56	129	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Ethiopia	63	186	1.5	15	24	81	0	0%	0	0%	0	0%	0	0	0	4.7%	—	—
Subtotal *	4,614	7,395	4,224	21,315	916	2,882	91	2%	2,690	13%	5,347	25%	10	307	610	3.3%	7.0%	8.5%

** For all developing countries in Tables A2.1 b, c, and d.*

TABLE 9 - Electricity Consumption Projections and Nuclear Power Growth Scenario (Least Developed)[4]

The MIT study projected energy growth between the EIA's predictions[g] (until 2020) of "business as usual" and "low growth" scenarios. The "business as usual" scenario projects[g] the following growth rate of electricity for the Industrialized, US, FSU and Developing countries respectively: 1.8%, 1.9%, 1.8%, 4.2%. This yields world average growth rate, between 1999 and 2020, of 2.7%. The MIT study capped the projected electricity production growth rate of any country at 4.7%/year.

The final global growth scenario of the MIT study[4] is given in Table 11 below. By 2050, 1000 to 1500 reactors of 1000 MWe capacity could be deployed worldwide.

[g] U.S. DOE/EIA, International Energy Outlook 2002

COUNTRY	TOTAL POPULATION (millions)		TOTAL ELECTRICITY CONSUMPTION (billion kWhrs)		PERCAPITA CONSUMPTION (kWhrs/per)		NUCLEAR PRODUCTION (billion kWhrs)						NUCLEAR EQ. "CAPACITY" (GWe)			%/year TEC	%/year LOW NUCLEAR	%/year HIGH NUCLEAR
Former Soviet Union	2000	2050	2000	2050*	2000	2050*	2000	%	2050 L	% L	2050 H	% H	2000	2050 L	2050 H			
Russia	145	104	767.1	904	5,272	8,671	115	15%	271	30%	452	50%	13	31	52	0.3%	1.7%	2.8%
Ukraine	50	30	151.7	120	3,061	4,000	65	43%	60	50%	72	60%	7	7	8	–0.5%	–0.2%	0.2%
Slovakia	5	5	25.2	36	4,668	7,678	12	48%	22	60%	25	70%	1	2	3	0.7%	1.2%	1.5%
Czech Republic	10	8	54.7	74	5,325	8,758	10	19%	22	30%	30	40%	1	3	3	0.6%	1.5%	2.1%
Lithuania	4	3	6.9	12	1,866	4,000	5	77%	10	80%	10	85%	1	1	1	1.1%	1.2%	1.3%
Slovenia	2	2	10.6	13	5,342	8,786	4	35%	7	50%	8	60%	0	1	1	0.5%	1.2%	1.6%
Armenia	4	3	4.9	13	1,291	4,000	2	32%	5	40%	6	50%	0	1	1	1.9%	2.4%	2.8%
Estonia	1	1	5.4	5	3,848	6,329	0	0%	0	0%	0	0%	0	0	0	–0.2%	—	—
Tajikistan	6	10	12.5	39	2,060	4,000	0	0%	0	0%	0	0%	0	0	0	2.3%	—	—
Kazakhstan	16	15	48.3	61	2,989	4,000	0	0%	6	10%	12	20%	0	1	1	0.5%	—	—
Uzbekistan	25	41	41.9	162	1,684	4,000	0	0%	16	10%	32	20%	0	2	4	2.7%	—	—
Moldova	4	4	3.7	14	851	4,000	0	0%	0	0%	0	0%	0	0	0	2.8%	—	—
Kyrgyzstan	5	8	9.8	30	1,995	4,000	0	0%	3	10%	6	20%	0	0	1	2.3%	—	—
Belarus	10	8	26.8	33	2,629	4,000	0	0%	3	10%	7	20%	0	0	1	0.4%	—	—
Georgia	5	3	7.9	13	1,499	4,000	0	0%	1	10%	3	20%	0	0	0	1.0%	—	—
Turkmenistan	5	8	7.7	34	1,627	4,000	0	0%	3	10%	7	20%	0	0	1	3.0%	—	—
Azerbaijan	8	9	16.7	36	2,075	4,000	0	0%	4	10%	7	20%	0	0	1	1.5%	—	—
Subtotal	**306**	**261**	**1,202**	**1,598**	**3,925**	**6,118**	**213**	**18%**	**433**	**27%**	**677**	**42%**	**24**	**49**	**77**	**0.6%**	**1.4%**	**2.3%**
TOTALS	**5,844**	**8,666**	**13,636**	**38,723**	**2,333**	**4,468**	**2,230**	**16%**	**8,321**	**21%**	**14,094**	**36%**	**255**	**950**	**1,609**	**2.1%**	**2.7%**	**3.8%**

* Table represents 1% per year increase in electricity consumption from 2000 to 2050

** 2050 after cutoff numbers

*** Countries ranked by 2000 nuclear production

TABLE 10 - Electricity Consumption Projections and Nuclear Power Growth Scenario (Former Soviet Union)[4]

Region	Projected 2050 GWe Capacity	Nuclear Electricity Market Share	
		2000	2050
Total World	1000	17%	19%
Developed World	625	23%	29%
U.S.	300		
Europe & Canada	210		
Developed East Asia	115		
FSU	50	16%	23%
Developing world	325	2%	11%
China, India, Pakistan	200		
Indonesia, Brazil, Mexico	75		
Other developing countries	50		

TABLE 11 - MIT's Projection of The Global Growth Scenario of Nuclear Electricity[4]

By comparison, the annual growth rate of projected world energy demand between 2002 and 2030 is 1.7% according to the IEA's World Energy Outlook 2004[10] and the nuclear growth rate is projected to be just 0.4%[10] as Table 12 below shows.

	1971	2002	2010	2020	2030	2002 -2030*
Coal	1 407	2 389	2 763	3 193	3 601	1.5%
Oil	2 413	3 676	4 308	5 074	5 766	1.6%
Of which international marine bunkers	*106*	*146*	*148*	*152*	*162*	*0.4%*
Gas	892	2 190	2 703	3 451	4 130	2.3%
Nuclear	29	692	778	776	764	0.4%
Hydro	104	224	276	321	365	1.8%
Biomass and waste	687	1 119	1 264	1 428	1 605	1.3%
Of which traditional biomass	*490*	*763*	*828*	*888*	*920*	*0.7%*
Other renewables	4	55	101	162	256	5.7%
Total	5 536	10 345	12 194	14 404	16 487	1.7%

* Average annual growth rate.

TABLE - 12 World Primary Energy Demand (Mtoe)[10]

The world consumption of electricity is expected to grow at 2.5% annually during the same period (2002-2030)[10]. IEA's projected high growth rate of electricity demand by developing Asian countries (2002-2030) is 5.2%/year for Indonesia, 4.9% for India and 4.5% for China.

It is interesting that the IEA projected[10] just 376 GWe of nuclear electricity in 2030, up from 359 GWe in 2002. New nuclear plants with combined capacity of 150 GWe are expected to be built around the world[10], many of which replacing retiring nuclear power plants. Note that this projected nuclear capacity is substantially lower than the projected nuclear capacity of the MIT study[4].

Judging by the recent 'nuclear renaissance' around the world, it is likely that the MIT projection is more realistic.

In Section B it was shown that 35% of the 442 (371 GWe) operating NPPs worldwide are SMRs – primarily at the medium sized range. It was also shown that 250 NPPs (209 GWe) are under construction or planned, and of these 250 units, 117 (47%) are SMRs - if China's 50 NPPs will be in the SMR range - or 67 units (27%) without China. The corresponding capacities of SMRs with and without China are 30% and 12% respectively. We also noted that fully 84% of the world NPPs that are no longer in service, were SMRs (these were used as a "learning curve" by various countries).

It is therefore reasonable to assume that roughly 30% (in capacity) of future NPPs could be SMRs.

This is particularly reasonable if many of the new NPPs will be built in non-OECD countries. Thus, for a projected future growth of nuclear electricity (until 2050) of 1000 GWe[4], 300 GWe may be in SMRs. For an average SMR size of 300 MWe, this implies 1000 units of new SMRs units by 2050, or 500 units of 600 MWe.

Section D.4 below shows that this estimate is in general agreement with a recent market assessment for the Pebble Bed Modular Reactor (PBMR).

D.4 Market Assessment of the PBMR[h]

The Pebble Bed Modular Reactor (PBMR) Ltd. is currently conducting a market study, with the objective to define the potential global market –until 2040 - for the 165 MWe PBMR[h] . This is an elaborate and good quality market study that takes into account numerous factors and considerations.

Due to the timeliness and relevance of the PBMR study to this assessment of the SMR market, it is being discussed below in some details.

The PBMR study uses both top-down and bottom-up estimates of all countries in the world, to determine which countries are potential PBMR customers.

At the top-down approach - with the doubling of the global electricity demand by 2040 - and nuclear power constituting 15% of the generated power, it is estimated that 900 GWe of new nuclear capacity will be required to satisfy this demand and to replace retiring NPPs. 109 units – 165 MWe each - will be required if PBMR will be used to replace just 2% of this capacity (18 GWe); and 273 units will be required to replace 5% of the new nuclear capacity (45 GWe).

The largest potential in the bottom-up approach (country by country assessment) was identified in the developed countries – where the total potential demand for new nuclear capacity to 2040 is projected at 82 GWe. Second tier potential in large consumer countries were identified in countries like China, India and Mexico, with an additional new nuclear capacity of 60 GWe. This leads to an estimate of 170 units of PBMR by 2040 which amounts to about 3% of the global new electricity demand by 2040. This assessment considered only the potential market for electricity generation but not for process heat.

Table 13 describes the PBMR[h] projected electricity demand growth (based on OECD-IEA and DOE-EIA data) and the capability of nuclear power to fulfill this demand.

Year	**2005**	**2015**	**2025**	**2040**
South Africa – Total electricity demand	41 GW	64 GW	83 GW	120 GW
Global – Total electricity demand	3007 GW	4097 GW	4984 GW	6675 GW
Capacity of currently installed nuclear plant	373 GW	325 GW	200 GW	100 GW
Nuclear proportion of world demand	12.4%	10.0%	12.5%	15.0%
Total required nuclear capacity	373 GW	410 GW	623 GW	1001 GW

[h] Private communication with Westinghouse, October 21, 2006

Replacement of existing nuclear plants		48 GW	173 GW	273 GW
New nuclear sites		37 GW	250 GW	628 GW
Combined nuclear plant construction		85 GW	423 GW	901 GW

TABLE 13 – Electricity and Nuclear Power Demand Growth[h]

The reason for the drop in nuclear power share by 2015 is that according to this market assessment, there are insufficient plants currently under construction or in advanced stage of planning, to be generating electricity by 2015. This trend will change however in later years by governments and market conditions.

The following features of the PBMR are highlighted by the market assessment: inherent safety; low carbon emission, low required capital investment, incremental capacity expansion, short-time return on capital investment, short construction of just two years to full load, and reduced financial risk (attractive to financial investors); proliferation resistant (high fuel burn-up results in plutonium isotope mix which makes extraction economically unattractive); fuel design (no fission product release); on-line refueling (improves operational economics); load-following capability; on-site spent fuel and waste storage and later reprocessing; reduced exclusion zone; access to small electrical grid.

These features indicate that the PBMR will help support the GNEP vision.

In the PBMR market assessment, the target market concentrates on those countries where small, nuclear capacity is needed and can be suitably added at a competitive price, where customers are capable of financing and operating the plants, and host governments recognise their responsibilities to provide nuclear regulation, nuclear liability protection and align themselves with international non-proliferation practices.

The analysis screens the countries based on electricity demand, energy resources and risk, and estimates the number of PBMR units that may be built in each country. In addition, countries are excluded if they do not meet one or more exclusive criteria.

> We estimate that the PBMR can be built in 18 to 24 months, as opposed to 48 to 72 months or more for large reactors. Speed to market is essential if the PBMR is to compete effectively with coal and natural gas-fired plants in a deregulated market
> Corbin A. McNeill, Former Exelon CEO, May 3, 2001

Energy forecast was taken from the DOE-EIA and the OECD-IEA. The level of natural resources for each country was assessed to determine if sufficient reserves were available to preclude the use of nuclear generation as a form of electricity supply in a country. The natural resources considered were natural gas, oil, coal and hydro power. The projected electricity maximum power demand was calculated from the electricity demand forecast based on a 60% load factor (average annual load divided by peak annual load). For each fuel resource it was assumed that if the ratio of the fuel resource (i.e. gas, coal, oil) to the electricity load demand is small, then the country would not have sufficient fuel reserve and was a potential candidate for PBMR.

Countries were assessed to have interest in nuclear energy if: nuclear power currently exists in that country, the country has a nuclear operating and regulatory structure; and the country signed the Non-Proliferation Treaty (NPT). Countries that fulfilled these criteria were assumed to be potential candidates for PBMR. Countries with declared non-nuclear zone, were excluded (e.g. Australia, Denmark, Estonia, Greece, Italy, Ireland, Latvia, Poland, Portugal, Luxembourg, Austria, Iceland, New Zealand, Norway – although the policy in some of these countries may change within the forecast period)

Countries were also assessed for commercial and political risks for export transactions and direct investment. Countries judged to have satisfactory risks were candidates for PBMR.

It was further assumed that the minimum load is 40% of the peak load; and that the maximum demand of a country is greater than 825 MW. For a system with a maximum demand of 825 MW, a single 165 MW PBMR would constitute 50% of the minimum load (825 x 0.4 x 0.5 = 165 MW). It was also assumed that 60% of the increase in minimum load could be met by PBMRs.

The following *exclusion* criteria were used by the PBMR market assessment: maximum demand < 825 MW; medium or long term political risk; sufficient oil, gas or hydro reserve; commercial risk; and country not a signatory to the NPT.

Countries that develop their own PBMR (e.g. China, Honk Kong), and France (that uses its own technology) were also excluded.

Although Russia, Ukraine, Romania and Bulgaria have significant commercial activity in the power sector, it was noted that many of the Eastern European countries have significant surplus of capacity since demand has fallen by up to 40% from its highest levels as these countries have transitioned into the more efficient free market economy. Thus these countries were excluded from the target market during the period 2015-2025, but were added (to a second tier list) in the 2025-2040 time frame.

The combined 1st tier and 2nd tier lists shown in Table 14 below yield the number of 165 MW PBMRs that could be attractive to prime target countries.

Target Countries	**Potential Number of 165 MWe PBMR Units**		
	Short Term (2015-2025)	**Long Term (2025-2040)**	**Total Units (2015-2040)**
1st Tier List	164	332	496
2nd Tier List	76	290	366
Total PBMR Units	240	622	862

TABLE 14 – Potential Market For 165 MWe PBMR Units[h]

Assuming that 1 in 4 units in the 1st tier list and 1 in 8 in the 2nd tier list can be converted into PBMR orders yields 170 units, which constitutes about 3 % of the projected new nuclear capacity (170 x 165 MWe = 28 GWe; and 28 GWe/ 900 GWe = 0.031).

The market assessment also considered the market in countries where the lowest maximum annual demand is 500 MWe rather than 825 MWe. After the exclusion criteria were applied, two additional countries were added to the list and three potential African countries were identified.

D.5- Market Assessment of IRIS by Westinghouse [i]

Westinghouse together with a 10 country consortium has been developing the IRIS SMR (see Appendix B and reference 3 for detailed description of IRIS). In carrying out the IRIS development, Westinghouse recognized the advantages that the SMR could offer –as elaborated throughout this report - e.g. small grid size, scattered population centers, remote areas requiring smaller localized energy source, limited financial capabilities, need for cogeneration, etc. These characteristics are representative of countries that currently do not have nuclear power plants. This gives DOE an opportunity to expand the GNEP vision in particular to such countries, by using reactor designs that fulfil the GNEP vision.

Westinghouse believes that this market has to be penetrated first – in the short term - by existing reactor designs (e.g. IRIS, PBMR, etc.). In the long–term (more than a decade or two) improved proliferation resistance concepts will be developed and introduced to the market, however - since the emerging SMR market, both in the US and abroad, can not wait for these improved designs – it is logical to capture the market with existing SMR designs, first through the deployment of current US SMRs, and introducing later the more advanced SMRs – with increased proliferation resistance. Such a market strategy could help support the long-term GNEP vision.

> Tarapur-3 is India's 16th operating NPPs, raising the total installed capacity to about 3900 MWe. According to government projections, the nuclear capacity is to increase to 4120 MWe by 2007, to 10,280 MWe by 2012 and to 20,000 MWe by 2020
> Nuclear News, October 2006

Westinghouse assessed the cost of SMR compared with a large sized reactor and has shown that the 'economy of scale' is not always detrimental to the SMR. Beside the fact that often large reactors can not be accommodated by an emerging country - because of the size of the grid and financial constraints – there are other considerations in favour of SMRs. For example, in India - which has been using both 200 MWe and 700 MWe nuclear power plants - the higher capital cost of the 200 MWe SMR, is offset due to the ability of the SMR to be built close to the load centers, thus avoiding the need for new transmission lines. Additional cost saving is achieved by standardized design and by mass production of SMRs.

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[i] Private communication with Westinghouse, October 31, 2006

The IRIS design has followed Westinghouse's design philosophy of the AP1000 by eliminating and simplifying safety systems, using passive safety systems and as a result – improving its operation and maintenance cost, and its overall economics.

A cost comparison can be made between one large nuclear power plant and four SMRs having similar total capacity.

The factors that produce the SMRs cost savings – compared with a large nuclear power plant - are: factory fabrication of the SMR modules; serial module fabrication; bulk ordering; supply/demand match; multiple units at the same site (saving in direct and indirect cost); faster learning curve (saving in construction and operation of series of units at the same site); specific design (cost saving due to the specific design concept characteristics- such as simplification, passive safety, etc.); construction schedule (gradual capacity increase to fit energy demand growth); financial (smaller capital cost for SMR); opportunity for generating cash flow – from completed units - when constructing multiple units at the same site; improved availability; reduced construction time per unit; and tailoring the required plant size to the load.

When these cost saving factors are quantified – based on actual industrial experience - the cost of four SMRs is estimated to be approximately the same as that of a single large NPP. Furthermore, the smaller capital cost requirement of the modular SMR, as well as the substantial reduction in the cash outflow of four staggered SMR modules, makes the modular SMR particularly attractive to developing countries. Such an analysis justifies the economic competitiveness of the modular SMR.

It is estimated that up to 100 IRIS modules could be sold by 2030. (Note from the text box insert on the previous page that India alone intends to add 16 GWe of nuclear capacity between 2007 and 2020. At 200 MWe per SMR, this implies the addition of 80 SMRs).

D.6 - Market Assessment of SMRs as Part of GNEP

The preceding sections have defined the projected global power demand of the electricity sector. Based on current forecast of energy demand and the anticipated share of nuclear power in filling this energy demand, an estimate of required new construction of nuclear power plants was given as 1000 GWe until 2050. Based on past trends of the nuclear power market, it can be assumed - in a top down approach – that some 30%, or 300 GWe, of this market could be fulfilled until 2050 by SMRs (i.e. nuclear reactors smaller than 700 MWe). This estimate of 300 GWe is in general agreement with the PBMR market assessment discussed in

> The NRC has received a series of letters from utilities in the USA expressing interest in submitting 19 applications for combined construction and operating licensees by December 2008, with the total number of potential reactor orders potentially exceeding 25 units. This is due to a large need for increased base-load power in the 2014 -15 time range, and will include Generation III and Generation III+ reactors
> US NRC Commissioner Jeffrey S. Merrifield, - Johannesburg, South Africa, October 2, 2006

section D.4, where (see Table 14) a potential market of 142 GWe (862 PBMR units x 165 MWe/unit) has been identified - in a bottom up approach on a country by country basis – just for electricity generation. When other applications – such as process heat, district heating, and desalination - are added to electric power generation; and the capacity of each potential nuclear power plant is increased to 700 MWe – covering the entire SMR range- it can be readily assumed that a prediction of 300 GWe is a conservative estimate.

News releases during the past few months indicate that a number of countries have seriously considered adding nuclear energy to supply the growing demand for energy and as a replacement for retiring nuclear power plants. This recent 'nuclear renaissance' has resulted in an increased forecast of the demand for nuclear capacity during the next few decades[j]. When we consider the recent statement by USNRC Commissioner Merrifield on October 2, 2006, where orders for new reactors in the USA could exceed 25, it seems that the EIA's prediction on June 2006, of 6 GWe is an underestimation, since 25 new reactors-1000 MWe each- would add some 25 GWe by 2020 (some of this new nuclear capacity will replace retiring NPPs). However, it is unclear if any of these new orders would include SMRs.

The objectives of the GNEP program were defined in section A.1 - as a comprehensive strategy to expand the use of nuclear energy both domestically and internationally, address the nuclear waste management issue; and promote nuclear non-proliferation.

In order to assess the market for SMRs within the context of the GNEP vision, the following questions should be addressed:

1. Does GNEP intends to help promote and export US nuclear technology as part of the global expansion of nuclear energy, or does expanding the use of nuclear energy, the primary objective of GNEP irrespective of who the nuclear vendors are?
2. Would the currently proposed designs of future SMRs adequately fulfill the GNEP vision?
3. Are SMRs expected to capture a significant share of an expanding global nuclear market?
4. Is it necessary to develop a new SMR that will fulfill all of the GNEP objectives, or can currently proposed designs be modified in order to meet the GNEP objectives?

Brief answers to these questions are given below:

1. It is natural and desirable that the US government would help promote US made products however, it should be realized that the nuclear industry is a global enterprise that often encompass more than a single country. We note

[j] DOE/EIA International Energy Outlook(IEO) 2006 (June 2006)[12] has increased the world's nuclear powered generating capacity in the IEO2006 reference case from 361 GWe in 2003 to 438 GWe in 2030, in contrast with projections of declines in nuclear power capacity in past IEOs. In the US, nuclear capacity is expected to increase by 3 GWe due to plant up-rating and by 6 GWe as a result of new construction.

for example that Westinghouse was owned by BNFL of the UK and is now owned by a Japanese corporation. Similarly, Areva is a French-German corporation. In contrast, many other nuclear corporations in several countries are state-controlled (e.g. China, Russia, India, Pakistan, Iran, etc.). Major vendors in the US nuclear industry include US corporations (GE), Westinghouse, Japanese corporations, Areva, and others. The global competition for new SMRs is expected to be quite stiff and national interest is expected to play a major role (e.g. Chinese reactors built by Chinese corporations, etc.). Thus, the SMR is expected to play a significant role in the global expansion of nuclear energy – which is one of the GNEP objectives- but it is not clear what role would US corporations play in this expansion.

2. Appendix B lists 26 different SMR concepts in various stages of design as of 2005. These concepts are being pursued by 11 different countries, including the USA. Since many of these SMR concepts have been developed over several years or even decades, whereas the GNEP program and the associated AFCI program are relatively new, it is unlikely that all the concepts listed in Appendix B were designed specifically to fulfill the GNEP objectives. However, it appears that many of the SMR concepts[3] have adapted some features which could help fulfill the GNEP objectives (e.g. many concepts can use MOX fuel that would be available from fuel reprocessing; some concepts are designed with a core life of one to two decades; some concepts would replace the entire reactor after utilizing its fuel; some concepts use on-line refueling with TRISO particles that are not the most desirable weapon fuel – all of each will enhance proliferation resistance)
3. SMRs are expected to capture a significant share of an expanding global nuclear market. As this report shows, a conservative estimate of the global nuclear capacity expected to be filled by SMRs is some 300 GWe by 2050. With an average SMR unit size (see unit size in Appendix B) of 300 MWe, this implies 1000 new SMR units.
4. It is not necessary to develop a new SMR that will fulfill all of the GNEP objectives, i.e. a GNEP-SMR. However the GNEP program could “adapt” one or more successful and advanced designs of an SMR (from Appendix B). The adapted designs could be reviewed in detail, in order to determine if and how they could best be modified to fulfill *all* of the GNEP objectives. This approach would lead to a timely and economic approach to designing a GNEP-SMR.

Section D.4 above (PBMR Market Assessment) identified potential user countries for SMRs under certain requirements and constraints.

Similarly we can identify a few major consumer countries – that could be served as a case study - with potential to incorporate SMRs under similar constraints.

These constraints and requirements include:

Acceptable reactor safety (preference for inherent and passive safety features), proliferation resistance and signatory to the NPT, environmental consideration, minimal waste and capability for a closed fuel cycle (participation in multi-national fuel cycle centers), spent fuel management, economical or suitable for particular market conditions; acceptable commercial, political and direct investment risks , suitable for non-energy use of nuclear technology, can be accommodated by the grid size, has a regulatory and legal framework, and has the necessary infrastructure.

In addition, countries should satisfy some exclusion criteria such as: changing the status of declared nuclear-free country, or stopping the phasing out of nuclear energy as Sweden and probably Germany are likely to do; and possession of adequate alternative energy resources (coal, oil, gas, hydro-power).

Two other considerations should be evaluated:

1. Large consumer countries that are likely to absorb many new SMRs (hundreds of new units) – such as China, India, Russia, South Africa, Argentina, and France (although France may pursue primarily large nuclear power plants) are likely to buy and install only "home made" SMRs. This in turn would make it more difficult to influence the design of the GNEP-SMR, in particular with respect to the requirement of 'proliferation resistance'. The reason is that firstly, many of the new SMR designs are at advanced stage of development; and secondly these countries may put a lesser emphasize than the USA on 'proliferation resistance'. Nevertheless, it is this writer's belief that it is worthwhile to promote a GNEP-SMR through an international program like the GIF in order to *attempt* steer the SMR design in the most desirable direction.
2. Energy security and diversification of energy resources has become recently a factor of paramount importance to many countries, including those countries that possess plenty of alternative energy resources. Consequently, using excluding criteria that include alternative energy sources – as was done in the PBMR market assessment described in section D.4 above – may not be justified. This is particularly true if the reduction of CO_2 is considered an additional constraint by such countries.

Example of market assessment in three specific countries is given below.

Brazil

Just as reinforcement to such an approach, Brazil has announced on October 23, 2006[k] that it plans to build seven new nuclear power plants by 2025 in order to raise the current nuclear contribution to the energy grid from 2.5% to 5.6% by 2025. It intends to finish its Angra 3 nuclear power plant by 2010. Brazil's Angra 1 is a 626 MWe Westinghouse PWR and Angra 2 and 3 are

[k] "Brazil plans to build seven nuclear reactors" – MercoPress-Falklands-Marvinas & South Atlantic News, October 23, 2006

1275 MWe KWU (now Areva) PWRs. Brazil's projected net electricity consumption – according to the EIA's IEO2006- is expected to grow from 371 TWh in 2003 to 784 TWh in 2025. Thus a growth in nuclear powered electricity from 2.5% to 5.6% would mean a total nuclear generating capacity by 2025 of: (1.275 + .626)GWe x (5.6/2.5) x (784/371) = 9 GWe. It is likely that Brazil intends to add 7 plants, each of 1275 MWe capacity, rather than SMRs. This does not preclude adding SMRs for specific applications (e.g. process heat, desalination, etc). Brazil has another open issue with respect to proliferation resistance. At present, Brazil gets its enriched Uranium from Holland, however it intends to enrich its own nuclear fuel using its new enrichment plant. We note however that Brazil is a signatory to the NPT.

Thus Brazil -having plenty natural resources- is an example of a country with expected population of 247 million by 2050, the per capita consumption of electricity is expected to increase from 2116 kWh in 2000 to 4000 kWh in 2050, and it is expected to grow its nuclear share to 5.6% by 2025 by installing 9 GWe of nuclear capacity. The share of nuclear electricity is expected to more than double by 2050 (see Table 7). It is interesting that other predictions of nuclear generated electricity in Brazil amounts to just 2.5% (Table D18 of IEO2006). At least at present, it appears that SMRs may only be used in Brazil for combined heat and power projects (CHP), combined power and desalination, or to supply electricity to remote sites that can not be easily connected to the grid.

China

The MIT study[4] projects (see Table 7) that by 2050 China's population would increase to 1462 million, its per capita electricity consumption would increase from 946 kWh in 2000 to 4000 kWh, its nuclear production would increase from 1% of the total electricity generation in 2000 to between 15% and 30% which would correspond to between 100 GWe and 200 GWe of nuclear capacity. This represents an annual growth rate of between 9% and 10.5%. Although this growth rate seems too high, it is noted that as of today China has already 11 NPPs (9 PWR and 2 PHWR) with a total capacity of 8.7 GWe. On October 25, 2006 China announced that two additional NPPs with a capacity of at least 1000 MWe each would be built at the Shenzhen site and that China is striving to raise its share of nuclear electricity from the current 2% to more than 4% by 2020[1]. The IEA's WEO2004 projects that China will add new electricity generating capacity - of all fuel resources, not just nuclear - of 860 GWe between 2003 and 2030. It also predicts an annual growth rate of 4.4% for 2002-2030 – down from the annual growth of 8% in the 1990s. In 2003 electricity generation in China increased by 16% and during the first half of 2004 by 18%. The EIA's WEO2006 projects net electricity consumption for China to grow from 1671 TWh in 2003 to 5971 TWh in 2030 - an annual growth rate of 4.8%. The nuclear energy consumption is projected by WEO2006 to grow from 42 TWh in 2003 to 304 TWh in 2030, i.e. at an annual growth rate of 7.4%. Using China's existing nuclear capacity in 2003

[1] Morningstar-Dow Jones, October 25, 2006 – "China to add two nuclear reactors at Shenzhen power plant"

of 6.7 GWe and the above projections to 2030, we calculate a nuclear capacity of 48.5 GWe by 2030 (6.7 GWe x 304/42 = 48.5 GWe) – which is in line with recent declarations by China of their intention to add some 40 new nuclear power plants – 1000 MWe each- by 2020. The fraction of nuclear capacity is calculated from the above figures as 42/1671 = 2.5% in 2003 and 304/5971 = 5.1% in 2030, which is in line - although it seems to be a low prediction- with China's intention of having 4% of nuclear generated capacity by 2020. A longer term goal is 240 GWe by 2050.

China is an example of a country which is committed to have a large expansion of nuclear generated electricity. The main reasons that China has chosen nuclear energy are: increased demand and per capita consumption of electricity; energy security and the desire to diversify the energy resources; and environmental considerations such as reducing pollution from coal fired plants and reducing the generation of CO_2.

China has been expanding its nuclear infrastructure and has been aiming at indigenous nuclear products, but in addition would undoubtedly use products from the global nuclear market. It is also an important force in preserving and enhancing nuclear non-proliferation. Consequently, China's objectives may coincide with the general outline of the GNEP vision, however it remains to be seen if China would change the design of their nuclear reactors to fulfill *all* the GNEP objectives (e.g adaptation of a closed fuel cycle).

As for SMRs in China, it appears that China's large nuclear expansion is directed at generating base-load electricity for their expanding and upgraded electricity grid, which means the construction of large (>1000 MWe) nuclear power plants. However, undoubtedly China would also have a need to supply distributed electricity, or combined heat and power for water desalination and other industrial applications. Since China already has a small operating PBMR and has been developing a larger version (see Appendix B) it is likely that China would use its own PBMR design. A commercial prototype pebble bed reactor (HTR) is expected to start-up in 2010. If we conservatively assume that SMRs for special applications in China would amount to 10% of the planned addition of nuclear generating capacity of 48 GWe by 2030, this would amount to 30 new units of PBMR- 160 MWe each (see Appendix B).

Lithuania

Lithuania is one of the former Soviet Union countries that has transitioned successfully during the past decade to a market economy and has entered the European Union after fulfilling a set of required obligations. In 2004 it had a population of 3.7 million and a GDP per capita of $2710[13]. The per capita income (2001) was $3444. Its major infrastructure has been addressed and it has made substantial progress in aligning its legal system. It has also established independent regulatory agency, has transferred the district heating from energy companies to municipal authorities, and unbundled electricity generation and distribution to prepare for privatization. Its energy sector operates today on a largely commercial basis. Key reforms in the energy sector for the future will involve the progressive restructuring and privatization of the energy companies created out of the Lithuanian Energy Company, improving security of supplies (an important EU accession issue), and a range of issues concerning the closure of the two Ignalina Nuclear Power reactors which the EU deemed non-upgradeable to international safety standards at a reasonable cost but which produced 70–80 percent of the electricity consumed in Lithuania in 2004[13]. This percentage is second only to France in terms of the share of nuclear generated electricity.

Lithuania had started construction of three nuclear reactors Ignalina 1, 2 and 3. All three reactors are graphite moderated light water Russian RBMK reactors with a net electrical capacity of 1185 MWe each. Ignalina 1 started commercial operation in May 1985 and was shut down on 31 December 2004. Its capacity factor in 2004 was 68.7% and its lifetime capacity factor was 20.4%[14]. Ignalina 3 (1380 MWe) started construction in 1985 but it was suspended and cancelled. Ignalina 1 (1185 MWe) started commercial operation in August 1987 and is operating. It is expected to be shut down by the end of 2009. Its capacity factor in 2004 was 35.5% and its lifetime capacity factor is 28.5%[14]. The total production of electricity in Lithuania in 2001 was[15] 14.7 TWh, 4.4 TWh were imported into the country and 8.4 TWh was exported out of the country. Thus the total domestic supply of electricity in 2001 was 10.77 TWh – in addition to domestic supply of heat 42,557 TJ. The final consumption of energy (i.e. delivery to consumers) in 2001 was 6.4 TWh of electricity and 31, 934 TJ of heat.

In 2005 Lithuania's nuclear electricity generation was 10.3 TWh (see Appendix A) which constituted 70% of the electricity market (10.3 TWh/14.7 TWh = 0.70).

A single nuclear plant of 1185 MWe will produce 10.3 TWh/year at 100% capacity factor. The two Ignalina plants had a total production of 10.7 TWh in 2004 with the above quoted capacity factors[m].

It is clear from the above figures that Lithuania had over capacity of electricity in 2004 and could even manage with a single Ignalina reactor operating at a capacity factor of 90% to supply the electricity consumption of 9.3 TWh (final consumption of 6.44 TWh + energy sector of 2.88 TWh).

Since Lithuania plans to shut down Ignalina 2 in 2009, it could be a potential customer for SMRs under the GNEP-SMR. Lithuania fulfills all the constraints and requirements for the GNEP-SMR as outlined earlier in this report. It would be advisable for Lithuania to have several SMRs even for electricity base-load in order to increase the stability of its electrical grid, as well as to avoid electricity shortages when one or two large nuclear reactors are shut down for maintenance. An alternative for base load could be the Westinghouse AP600 (600 MWe). A single AP600 at 80% capacity factor

[m] It was noticed that IAEA's PRIS data base listed higher Load Factors for Ignalina 1 and 2.

would yield 4.2 TWh, so three AP600 could meet the projected demand until 2050 (see Table 7). In addition, Lithuania could use several smaller SMRs for combined heat and power applications and for other non-energy uses.

Similar analyses may be performed for other countries in order to determine whether a specific country could be a candidate for GNEP-SMR; and to define the approximate number of GNEP-SMRs that could be acquired by that country.

The PBMR market assessment described in section D.4 is an example of such an analysis, albeit it was done for a different purpose and thus contains somewhat different constraints and requirements.

E. Conclusions and Recommendations

Based on the review, data, and analysis of small and medium-sized reactors presented in this report, the following conclusions are drawn with respect to the potential of SMRs to support the GNEP vision. Much of the attention in this report was paid to nuclear generated electricity since this application is expected to create the largest demand for SMRs.

1. There is no doubt that we are in the midst of a renaissance of nuclear energy.
2. DOE has an opportunity to influence the choice of countries deploying SMRs, towards a proliferation resistance configuration.
3. There is a clear need and opportunity for SMRs to satisfy growing energy need in developing countries, in an economic, safe, and proliferation resistant manner, which is a primary objective of GNEP.
4. It may be advisable to implement the GNEP vision of expanding the use of nuclear energy, by using current US SMR designs to satisfy the short-term market needs; and introduce later improved SMR designs that fully satisfy the GNEP vision.
5. Nuclear generated electricity has several distinct advantages in comparison with fossil fuel-generated electricity:
    - Maintaining energy security at a stable price
    - Economical and competitive with all other energy sources
    - No CO_2 emission
    - It can help diversify the energy sources and reduce the demand for fossil fuel
    - It can be used for electricity generation as well as for non-electricity uses
6. Future global demand for nuclear generated electricity is conservatively estimated to reach 1000 GWe by 2050. A substantial part of the growth is expected to take place in developing countries in south-east Asia.

7. It is expected that SMRs will capture some 20-30% of the future market of nuclear reactors. For an average SMR size of 300 MWe, this implies some 1000 units by 2050..

8. The global market penetration of the 165 MWe PBMR has been estimated at some 170 units by 2040. This estimate does not include non-electricity uses. It uses exclusion criteria that exclude countries rich in natural resources- such as oil, gas, coal, and hydro-power. Such exclusion may not be appropriate for countries rich in natural resources, but whose policy calls for diversification of their energy sources.

9. A limited market assessment of the IRIS SMR has indicated potential market penetration of approximately 50 modules through 2025.

10. The following virtues of the SMR have been identified:

    - SMR's role has shifted from being exclusively for developing countries to a broader use
    - SMR is particularly useful to a small size of electricity grid, inadequate infrastructure; and non-electricity applications
    - SMR is advantageous for incremental increases in nuclear plant capacity, and when flexibility in plant siting is required.
    - SMR is attractive to developing countries that lack investment capital and have small turnover of capital in the electricity market. Due to its smaller scale, SMR can be used as a 'learning curve' of nuclear technology in developing countries. In non-developing countries SMR may be attractive in electricity market deregulation - where independent power producers could participate.
    - SMRs are often different from conventional nuclear power plants.
    - International cooperation and transferability of design certification of SMRs from one country to another - with government support – will help expand the market share of SMRs.
    - SMR with long-life core will enhance its proliferation resistance and safeguardibility.

11. The following list of future development of SMRs is suggested: employment of maximum passive safety features; enhancement of proliferation resistance; improvement of its economic competitiveness; formulation of legal and institutional framework; ensuring fuel supply and management of spent fuel; and identification of market demand and SMR's technological options suitable for each market.

12. The following recommendation is made with reference to potential demand for the GNEP-SMR discussed in this report:

    - It is suggested that in conjunction with additional development of SMRs as outlined in the previous conclusion, a more detailed assessment of the global demand for SMRs be done on a country by country basis - using the methodology described in sections D.4, D.5 and D.6. Such detailed analysis - which is beyond the scope of this report - would give decision makers a more detailed estimate of the future potential of SMRs in the 'nuclear renaissance'; and would help direct future development of SMRs in a direction dictated by market needs.

- The suggested additional - country by country assessment - should also pay particular attention to non-electricity applications of SMRs. Such uses could constitute a market niche for SMRs – which would compensate for the perceived disadvantage of the SMR compared with large nuclear power plants - due to considerations of the 'economy of scale'.

- Additional development effort may be required for very small reactors (<150 MWe), in order to prepare for potential demand in non-electricity uses of nuclear technology, as well as for demand by small remote sites with a special need for a reliable long-term, small energy source. Recent news releases indicate that Russia has pursued aggressively the potential market of very small reactors, and has just signed contracts for the supply of this type of reactors. Additional *focused* SMR development effort may yield a better design, by emphasizing such attributes as: passive safety systems, simplicity, minimal supporting nuclear infrastructure, improved economics, long core life, absence of weapons-useable material in fresh fuel, central fuel reprocessing facilities in supplier states, effective IAEA safeguards; and robust NPPs against sabotage or terrorism

> BEIJING, Oct. 16, 2006 (Xinhuanet) -- A Russian energy company has plans to construct a floating nuclear-energy plant on a football-field size barge to deliver electricity to inhabitants of northern territories near the White Sea. Rosenergoatom said the 200 million U.S. dollar facility will be constructed next year and will provide relatively inexpensive, reliable energy to 200,000 people in a region where harsh weather makes regular coal and oil fuel deliveries unreliable and expensive

13. Non-electricity uses of nuclear energy include the following applications: nuclear reactors for space; research reactors; radioisotopes in medicine; radioisotopes in industry; nuclear-powered ships; transport and the hydrogen economy; and nuclear desalination. All these non-electricity applications employ exclusively SMRs. It is expected - without any detailed analysis of these applications - that hundreds of additional SMRs could be deployed for such uses.

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APPEDIX A

WORLD NUCLEAR POWER PLANTS

The following list describes the current construction of new nuclear power plants.

TABLE A.1 - POWER REACTORS UNDER CONSTRUCTION [5]

Start Operation*		Reactor	Type	MWe (net)
2006	China, CNNC	Tianwan 1	PWR	950
2007	Iran, AEOI	Bushehr 1	PWR	950
2007	India, NPCIL	Tarapur 3	PHWR	490
2007	China, CNNC	Tianwan 2	PWR	950
2007	India, NPCIL	Rawatbhata 5	PHWR	202
2007	Romania, SNN	Cernavoda 2	PHWR	650
2007	India, NPCIL	Kudankulam 1	PWR	950
2007	India, NPCIL	Kaiga 3	PHWR	202
2007	India, NPCIL	Kaiga 4	PHWR	202
2007	USA, TVA	Browns Ferry 1	BWR	1065
2008	India, NPCIL	Kudankulam 2	PWR	950
2008	India, NPCIL	Rawatbhata 6	PHWR	202
2009	Russia, Rosenergoatom	Volgodonsk 2	PWR	950
2009	Japan, Hokkaido	Tomari 3	PWR	866
2010	Korea, KHNP	Shin Kori 1	PWR	950
2010	Finland, TVO	Olkilouto 3	PWR	1600
2010?	Russia, Rosenergoatom	Balakovo 5	PWR	950
2010	Russia, Rosenergoatom	Kalinin 4	PWR	950
2010	India, NPCIL	Kalpakkam	FBR	470
2010	China, Guangdong	Lingao 3	PWR	935
2010	China, CNNC	Qinshan 6	PWR	650
2010	China, CNNC	Qinshan 7	PWR	650
2010	China, Taipower	Lungmen 1	ABWR	1300
2010-11	China, Taipower	Lungmen 2	ABWR	1300
2011	Korea, KHNP	Shin Wolsong 1	PWR	950
2011	China, Guangdong	Lingao 4	PWR	935
2011	Pakistan, PAEC	Chashma 2	PWR	300
2012	Korea, KHNP	Shin Wolsong 2	PWR	950
2012	Korea, KHNP	Shin Kori 2	PWR	950

2012	Russia, Rosenergoatom	Beloyarsk 4	FBR	750
2012	Japan, Chugoku	Shimane 3	PWR	1375
2012	China, CNNC	Sanmen 1 & 2	PWR	?
2012	China, CNNC	Yangjiang 1 & 2	PWR	?

Additionally, the following nuclear power plants are being planned:

TABLE A.2 - SOME POWER REACTORS PLANNED or ON ORDER [5]

Start operation	Start construction		Reactor	Type	MWe (each)
2008	resumed	Argentina, CNEA	Atucha 2	PHWR	692
2010-11	2006?	Japan, Tepco	Fuikishima I- 7 & 8	PWR	1325
2014-15	2007?	Japan, JAPC	Tsuruga 3 & 4	APWR	1500
2010-11	2006?	S Korea, KHNP	Shin-Kori 3 & 4	APR (KNGR)	1350
2012	2006?	Japan, EPDC	Ohma	ABWR	1350
2012?	2006?	Japan, Tepco	Higashidori 1-2 (Tepco)	ABWR	1320
2012+	2007	Japan, Tohoku	Higashidori 2 (Tohoku)	ABWR	1320
2015		S Korea, KHNP	Shin-Ulchin 1-2	APR (KNGR)	1350
		India, NPCIL	Rawatbhata 7 & 8	PHWR	490
		India, NPCIL	Kaiga 5 & 6	PHWR	490

A complete list of the world nuclear power plants is given below[n]:

TABLE A.3 - WORLD NUCLEAR POWER REACTORS 2005-06 AND URANIUM REQUIREMENTS [n]

21 September 2006

	NUCLEAR ELECTRICITY GENERATION 2005		REACTORS OPERABLE Sept 2006		REACTORS under CONSTRUCTION Sept 2006		REACTORS PLANNED Sept 2006		REACTORS PROPOSED Sept 2006		URANIUM REQUIRED 2006
	billion kWh	% e	No.	MWe	No.	MWe	No.	MWe	No.	MWe	tonnes U
Argentina	6.4	6.9	2	935	1	692	0	0	1	1000	134
Armenia	2.5	43	1	376	0	0	0	0	1	1000	51
Belgium	45.3	56	7	5728	0	0	0	0	0	0	1075
Brazil	9.9	2.5	2	1901	0	0	1	1245	0	0	336

[n] World Nuclear Association – Information and Issue Brief, September 21, 2006 – reference 6

Bulgaria	17.3	44	4	2722	0	0	2	1900	0	0	253
Canada*	86.8	15	18	12595	2	1540	2	2000	0	0	1635
China	50.3	2.0	10	7587	5	4170	13	12920	50	35880	1294
Czech Republic	23.3	31	6	3472	0	0	0	0	2	1900	540
Egypt	0	0	0	0	0	0	0	0	1	600	0
Finland	22.3	33	4	2696	1	1600	0	0	0	0	473
France	430.9	79	59	63473	0	0	1	1630	1	1600	10146
Germany	154.6	31	17	20303	0	0	0	0	0	0	3458
Hungary	13.0	37	4	1773	0	0	0	0	0	0	251
India	15.7	2.8	16	3577	7	3088	4	2800	20	10360	1334
Indonesia	0	0	0	0	0	0	0	0	4	4000	0
Iran	0	0	0	0	1	915	2	1900	3	2850	0
Israel	0	0	0	0	0	0	0	0	1	1200	0
Japan	280.7	29	55	47700	2	2285	11	14945	1	1100	8169
Kazakhstan	0	0	0	0	0	0	0	0	1	300	0
Korea DPR (North)	0	0	0	0	0	0	1	950	0	0	0
Korea RO (South)	139.3	45	20	17533	1	950	7	8250	0	0	3037
Lithuania	10.3	70	1	1185	0	0	0	0	1	1000	134
Mexico	10.8	5.0	2	1310	0	0	0	0	2	2000	256
Netherlands	3.8	3.9	1	452	0	0	0	0	0	0	112
Pakistan	1.9	2.8	2	400	1	300	2	600	2	1200	64
Romania	5.1	8.6	1	655	1	655	0	0	3	1995	176
Russia	137.3	16	31	21743	3	2650	8	9600	18	21600	3439
Slovakia	16.3	56	6	2472	0	0	0	0	2	840	356
Slovenia	5.6	42	1	696	0	0	0	0	0	0	144
South Africa	12.2	5.5	2	1842	0	0	1	165	24	4000	329
Spain	54.7	20	8	7442	0	0	0	0	0	0	1505
Sweden	69.5	45	10	8975	0	0	0	0	0	0	1435
Switzerland	22.1	32	5	3220	0	0	0	0	0	0	575
Turkey	0	0	0	0	0	0	3	4500	0	0	0
Ukraine	83.3	49	15	13168	0	0	2	1900	0	0	1988
United Kingdom	75.2	20	23	11852	0	0	0	0	0	0	2158
USA	780.5	19	103	98054	1	1065	2	2716	21	24000	19715

Vietnam	0	0	0	0	0	0	0	0	2	2000	0
WORLD**	**2626**	**16**	**442**	**370,721**	**28**	**22,510**	**62**	**68,021**	**160**	**118,825**	**65,478**
	billion kWh	**% e**	**No.**	**MWe**	**No.**	**MWe**	**No.**	**MWe**	**No.**	**MWe**	**tonnes U**
	NUCLEAR ELECTRICITY GENERATION 2005		**REACTORS OPERATING**		**REACTORS BUILDING**		**ON ORDER or PLANNED**		**PROPOSED**		**URANIUM REQUIRED**

Sources:

Reactor data: WNA to 21/9/06.
IAEA - for nuclear electricity production & percentage of electricity (% e) 5/06.
WNA: Global Nuclear Fuel Market (reference scenario) - for U.

Operating = Connected to the grid.
Building/Construction = first concrete for reactor poured, or major refurbishment under way.
Planned = Approvals and funding in place, or construction well advanced but suspended indefinitely.
Proposed = clear intention but still without funding and/or approvals.
TWh = Terawatt-hours (billion kilowatt-hours), MWe = Megawatt net (electrical as distinct from thermal), kWh = kilowatt-hour.

NB: 65,478 tU = 77,218 t U_3O_8

* In Canada, 'construction' figure is 2 laid-up Bruce A reactors.

** The world total includes 6 reactors on Taiwan with a combined capacity of 4884 MWe, which generated a total of 38.4 billion kWh in 2005 (accounting for 20% of Taiwan's total electricity generation). Taiwan has two reactors under construction with a combined capacity of 2600 MWe

APPENDIX B

SUMMARY TABLE OF INNOVATIVE SMR DESIGNS WITH CONVENTIONAL REFUELING SCHEMES

Current Status of SMRs

A recent IAEA publication[3] summarizes the status of innovative small and medium-sized reactors. The table below contains information from this IAEA publication.

TABLE B.1 – Summary Table Of Innovative SMR Designs With Conventional Refueling Schemes[3]

SMR Name	Size (MWt/MWe)	Type	Fuel	Application	Comments
IRIS (USA plus 10 countries consortium)	1000/335	Integral PWR	UO_2, MOX option	Electricity plus potable water or district heating or process heat	Licensing pre-application (2006); Final design approval 2010; First of a kind 2012-2015
SMART (Korea)	330/90	Integral PWR	UO_2	Electricity plus potable water	1/5th prototype-2008; Commercialization with desalination begins in 2009
CAREM-25 [CAREM-300]; (Argentina)	100/27 [900/300]	Integral PWR	UO_2, MOX option	Electricity plus desalination	Detailed design for 27 MWe; licensing pre-application; planning prototype construction
MARS (Italy)	600/150	Modular, loop, PWR	UO_2	Electricity plus desalination or district heating or process heat	Basic design-end of 2006; Final design-end of 2008; prototype construction -2012
SCOR (France)	2000/630	Integral PWR	UO_2, MOX option	Mainly electricity with desalination option	Conceptual design started in 2005; deployment target-next 15 years

IMR (Japan)	1000/350	Integral, modular PWR	UO_2, MOX option	Electricity	Conceptual design-2005; start licensing-2011; deployment after 2011
VBER-300 (Russia)	850/295	Loop, Modular PWR	UO_2, Thorium cycle option	Electricity plus potable water or district heating	Detailed design and licensing by 2008; Nuclear cogeneration by 2013; Floating NPP by 2012
VK-300 (Russia)	750/250	Integral, monolithic BWR	UO_2 Same as in VVER-1000	Electricity or electricity plus district heating or desalination	Detailed design completed; Financing first power unit in 2012 in Russia
CCR (Japan)	900/300	Modular BWR	UO_2, MOX option in a closed fuel cycle	Electricity plus potable water with option for district heating	Detailed design by mid-2010; Initiate construction actions by mid 2010
RMWR (Japan)	955/330	Integral tank type, modular	UO_2, MOX in closed fuel cycle	Electricity	Conceptual design; Detailed design by 2008; Could operate as a breeder with MOX and UO_2
AHWR (India)	920/300	Water cooled heavy water moderated pressure tubes	Pu-Th; ^{233}U-ThO_2 initially; closed fuel cycle later	Electricity plus desalination	Basic design completed; pre-licensing appraisal initiated
RUTA-70 (Russia)	70/no electricity	Integral, pool (non-pressurized)	UO_2	District heating or desalination (exit temperature 101°C)	Preliminary design; Deployment in 3 to 4 years after licensing
KAMADO (Japan)	1000/300	Pressure tubes-	UO_2, MOX option in a	Electricity plus	Preliminary conceptual design

		graphite moderated in a pool	closed fuel cycle	hydrogen; option for process steam	
PBMR (South Africa)	400/165	HTGR-pebble bed (900ºC core outlet)	UO_2 in TRISO coated particles	Electricity plus process heat; Options for H_2 and potable water	Site preparation 2007; Fuel loading mid 2010; Commercial acceptance-early 2011
GT-MHR (USA and Russia)	600/287	HTGR (850ºC core exit), prismatic core	UO_2 in TRISO particles; (U, MOX) in closed fuel cycle	Electricity plus potable water; H_2 production; Low temperature heat	Basic design; Pre-application licensing interaction with NRC; Targeted deployment around 2015
GTHTR-300 (Japan)	600/274	Prismatic core; pin in block fuel	UO_2 in TRISO coated particles in graphite fuel compact	Electricity plus process heat plus desalination	Detailed design by 2008; Prototype demonstration in 2008-2018
HTR-PM (China)	380/160	HTGR Pebble bed	UO_2 in TRISO coated particles	Electricity	Conceptual design; demo plant around 2010
FAPIG-HTGR (Japan)	220/100	HTGR pebble bed	UO_2 in TRISO coated particles	Electricity plus high temperature process heat	Pre-conceptual design
ACACIA (Holland)	60/18-23	HTGR Pebble bed	UO_2 in TRISO coated particles	Electricity plus process steam plus potable water	Pre-conceptual design; No further R&D is planned at the moment
KALIMER (Korea)	392/150	Sodium cooled fast reactor, pool type	Recovered LWR transuranics; Closed fuel cycle	Electricity	Conceptual design completed; Deployment by 2030

BMN-170 (Russia)	400/170	Sodium cooled fast reactor	Closed fuel cycle (U,Pu)	Electricity plus process heat plus district heating	Conceptual investigation
MDP (Japan)	840/325	Sodium cooled fast reactor; Modular pool type	Closed fuel cycle (U,Pu) U-Pu-Zr ternary alloy	Electricity	Preliminary conceptual design completed; presently no further R&D
RBEC-M (Russia)	900/340	Lead-bismuth cooled fast reactor	Closed fuel cycle (U,Pu) U-Pu nitride fuel	Electricity production in base load	Conceptual design; targeted deployment around 2025
PEACER-300; PEACER-550 (Korea)	850/300 (1560/550)	Lead-bismuth cooled fast reactor	Incineration of TRU and fission products; Closed fuel cycle	Electricity production and incineration of LWR fission products	Conceptual design completed; Initiate prototype construction related actions by 2010
Lead-bismuth cooled reactor (Japan)	1875/710 (per module)	Lead-bismuth fast reactor; tank type; modular	Nitride fuel; closed fuel cycle	Electricity	Conceptual design stage
AHTR (USA)	600 to 2400/300 to 1200	Molten salt very high temperature; Integral, pool type.	Same as HTGR with prismatic fuel; Liquid salt contains no fuel	Electricity plus high temperature heat for H_2 production	Pre-conceptual design; Part of Generation IV concepts; If selected- operating test reactor by 2012