CURRENT TECHNOLOGY TRENDS ON NUCLEAR POWER

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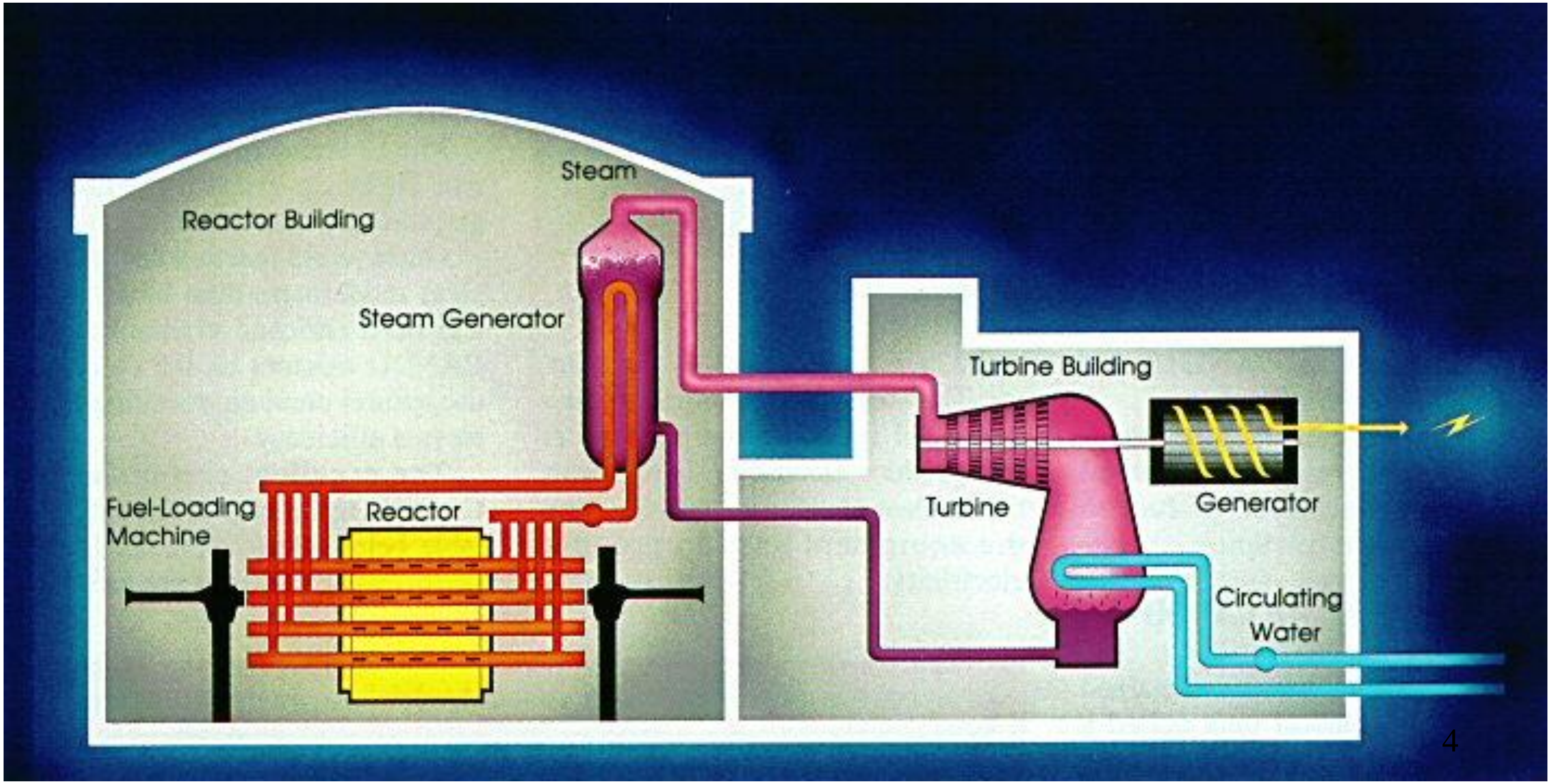
Nuclear Energy

- Nuclear Energy, Its Uses and History
- Nuclear Power Technology
- Brief History of Nuclear Energy
- Nuclear Power Capacity and Power Generation
- Types of Nuclear Reactors – pros and cons
- BWR, PWR, AGR, HTGR, GT-MHR
- Cost of Nuclear Power
- Environmental Considerations
- Risks, Conclusions, Recommendations

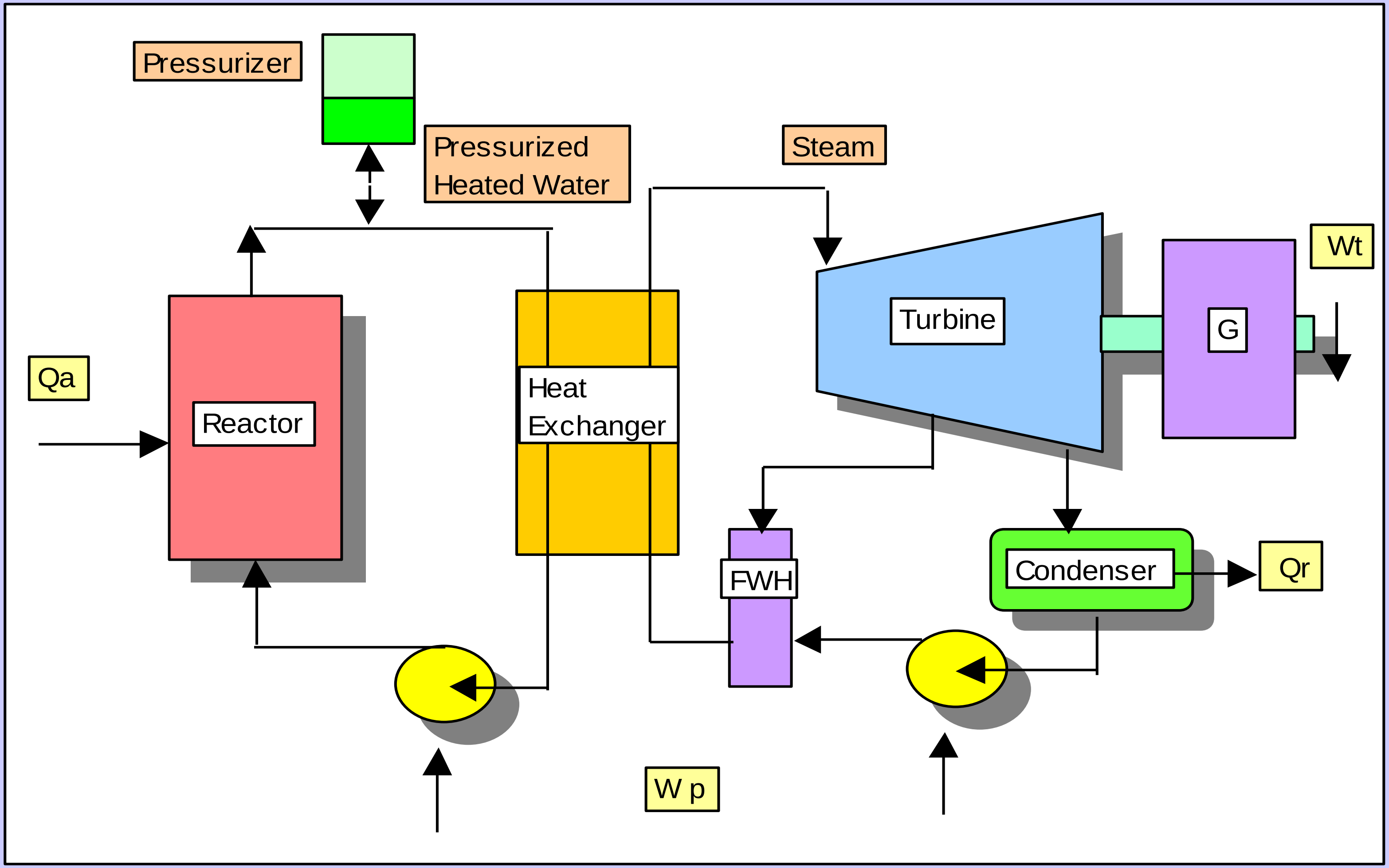
Uses of Nuclear Technology

- Medicine
- Food and Agriculture
- Measurement & Analytics
- Industry
- Environment
- Nuclear Power – Fission, Fusion

Nuclear Power Technology



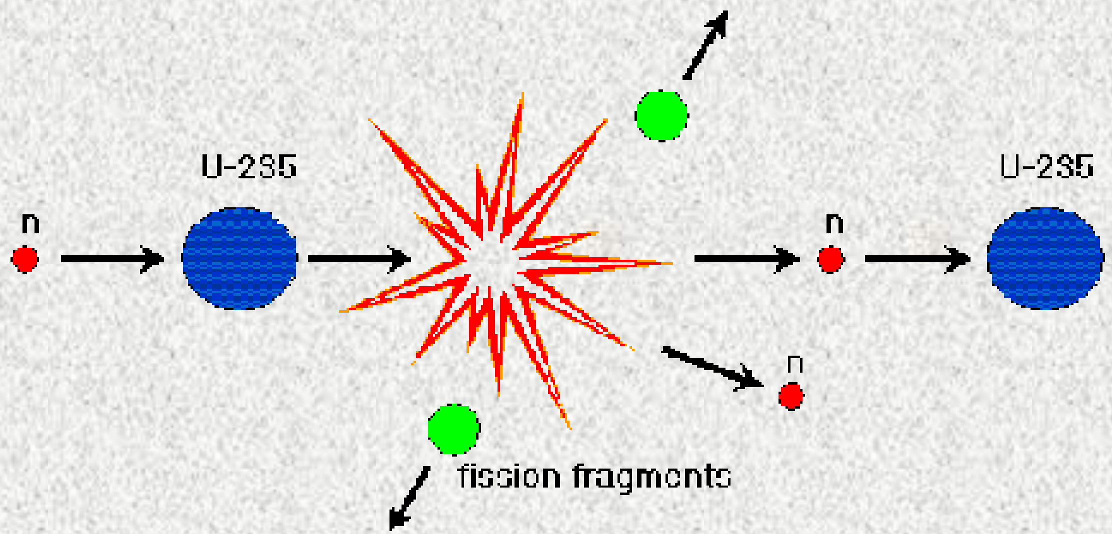
Basic Nuclear Power Cycle



Nuclear Power

- **Nuclear power –** most controversial of all forms of power generation

- **Operating principle –** Controlled nuclear fission in a reactor using uranium as fuel produces heat, which is captured to produce steam. The steam is used to drive a steam turbine, which in turn drives an electric generator.



Brief History of Nuclear Technology

- The science of atomic radiation, atomic change and nuclear fission was developed from 1895 to 1945, much of it in the last six of those years.
- Over 1939-45, most development was focused on the atomic bomb.
- From 1945 attention was given to harnessing this energy in a controlled fashion for naval propulsion and for making electricity.
- Since 1956 the prime focus has been on the technological evolution of reliable nuclear power plants – see commercialization of nuclear energy

Nuclear energy goes commercial -1

- Westinghouse designed the first fully commercial PWR of 250 MWe, Yankee Rowe, which started up in 1960 and operated to 1992

- Boiling water reactor (BWR) was developed by the Argonne National Laboratory, and the first one, Dresden-1 of 250 MWe, designed by General Electric, was started up earlier in 1960

- Canadian reactor (CANDU) used natural uranium fuel and heavy water as a moderator and coolant started up in 1962

Nuclear energy goes commercial -2

- France started out with a gas-graphite design similar to Magnox and started up in 1956

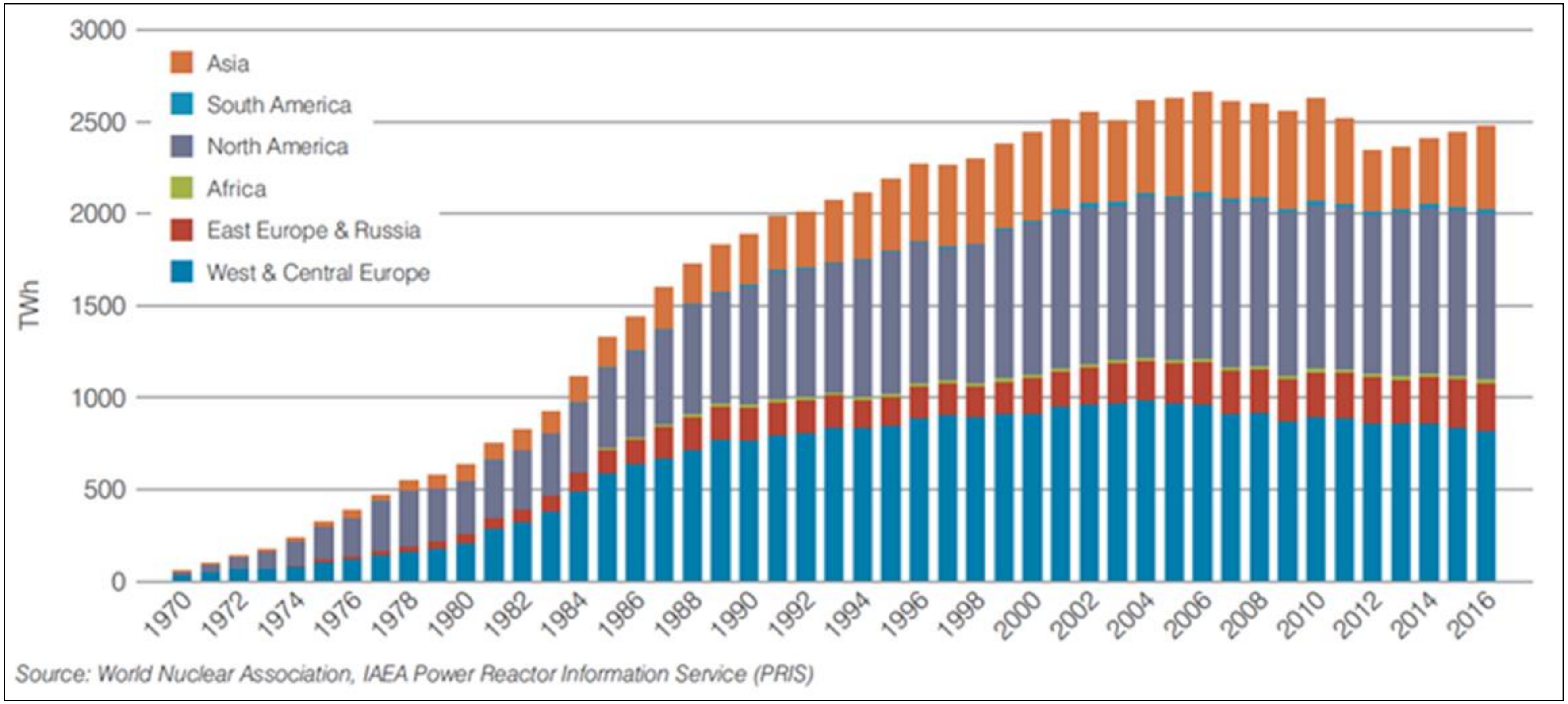
- In 1964, two Soviet nuclear power plants were commissioned: a 100 MW boiling water graphite channel reactor and a new design (210 MW) pressurized water reactor (PWR) water cooled power reactor (VVER)

- A high-power channel reactor RBMK (1,000 MW started in 1973, and a VVER with a rated capacity of 440 MW began operating (later 1,000 MW standard design)

Nuclear energy goes commercial -3

- In Kazakhstan, the world's first commercial prototype fast neutron reactor (the BN-350) started up in 1972 with a design capacity of 135 MWe, to produce electricity and heat to desalinate seawater
- USA, UK, France and Russia had a number of experimental fast neutron reactors from 1959, the last of these closing in 2009
- Around the world, most countries have chosen light-water designs for their nuclear power , so that today 69% of the world capacity is PWR and 20% BWR.

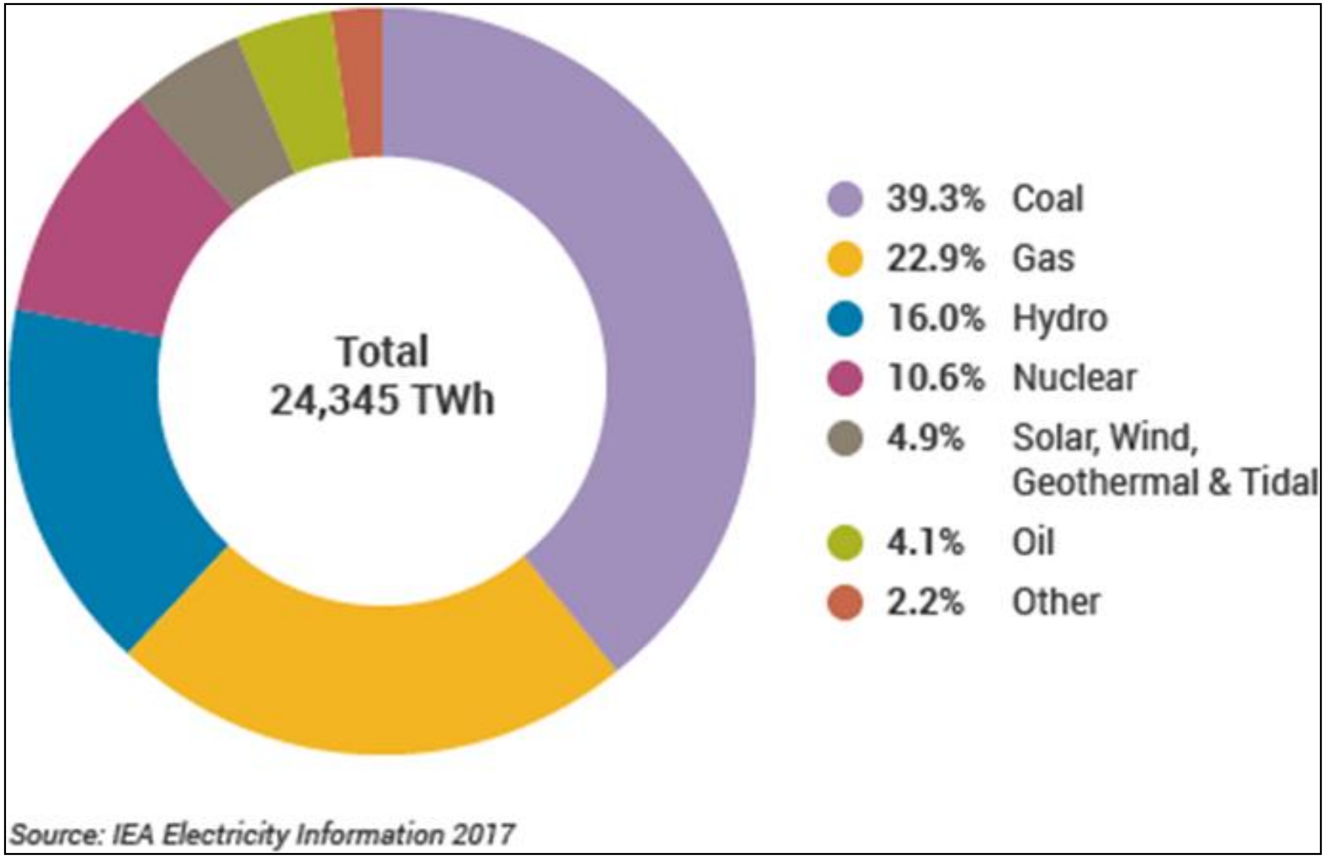
Global Nuclear Power Generation



Source: World Nuclear Association, IAEA Power Reactor Information Service (PRIS)

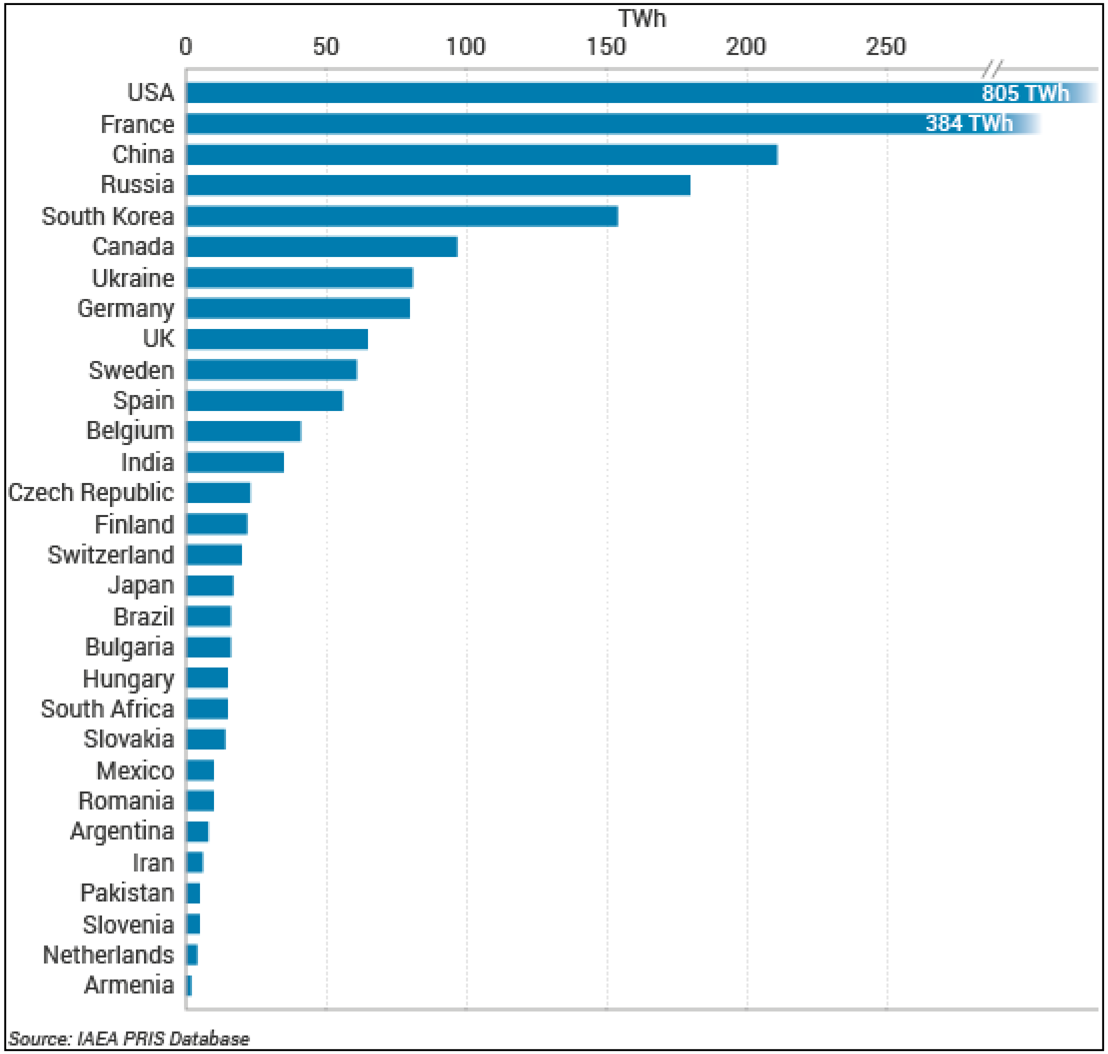
http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx

World Electricity Production by Source 2015



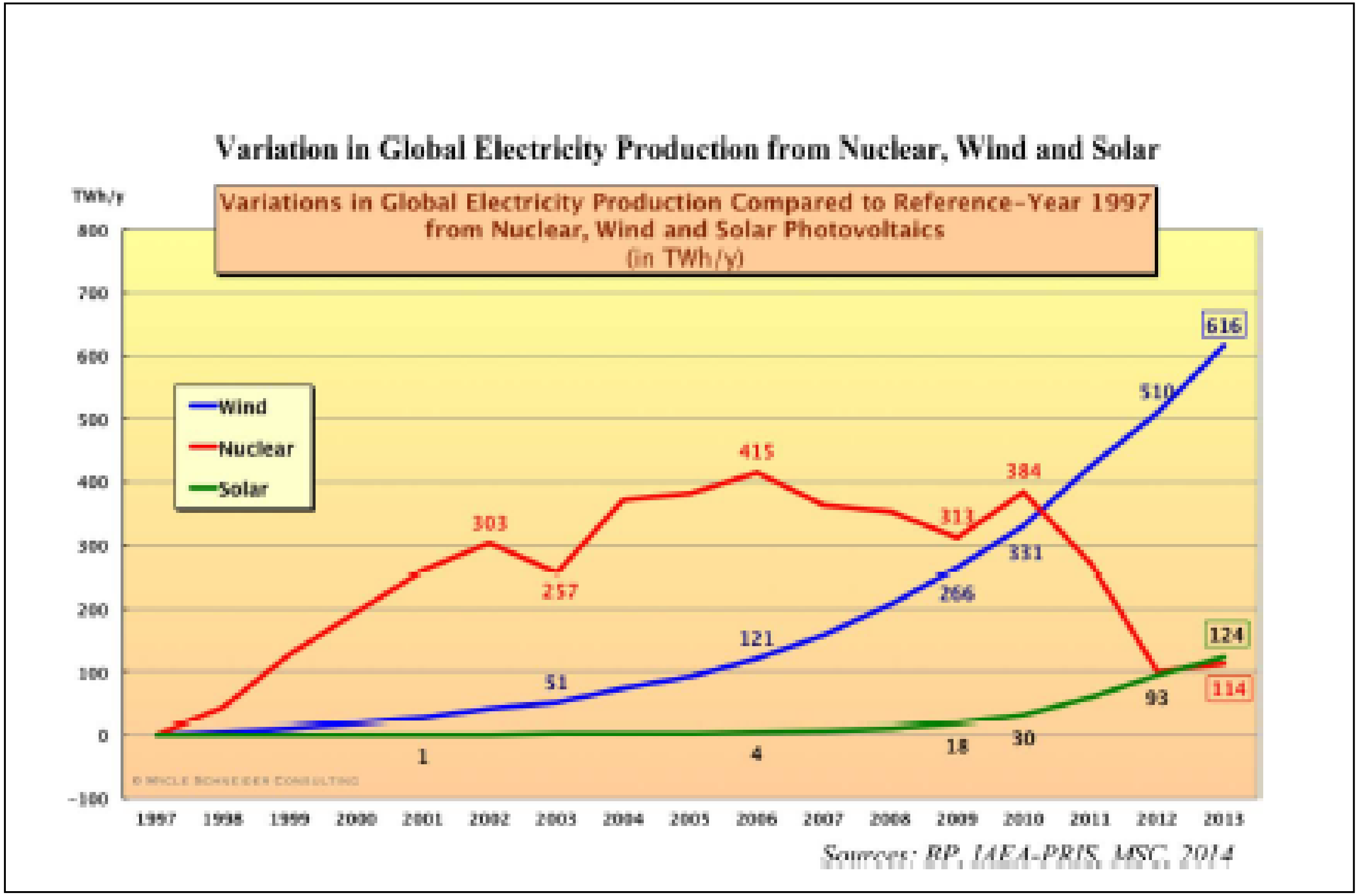
Source: IEA Electricity Information 2017

World Electricity Production by Country 2015



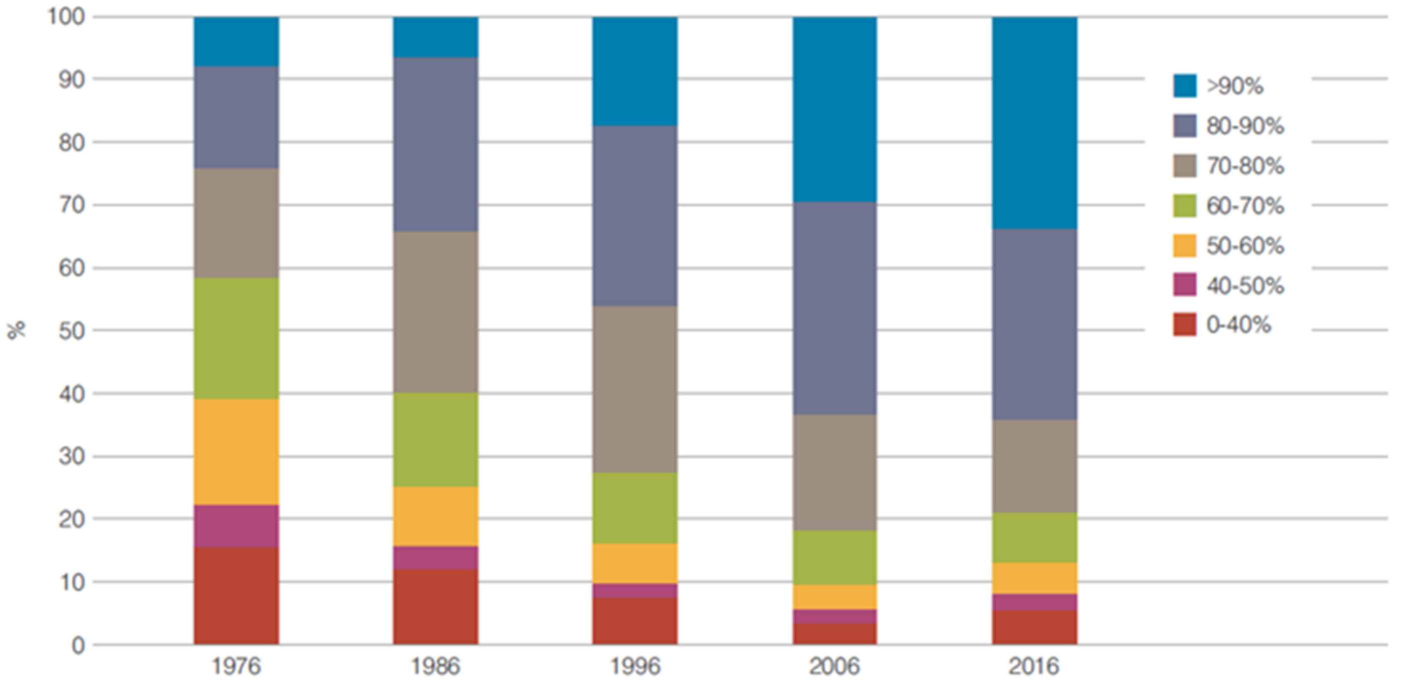
Source: IAEA PRIS Database

Variation in Global Electricity Production from Nuclear, Wind and Solar



Sources: BP, IAEA-PRIS, MSC, 2014

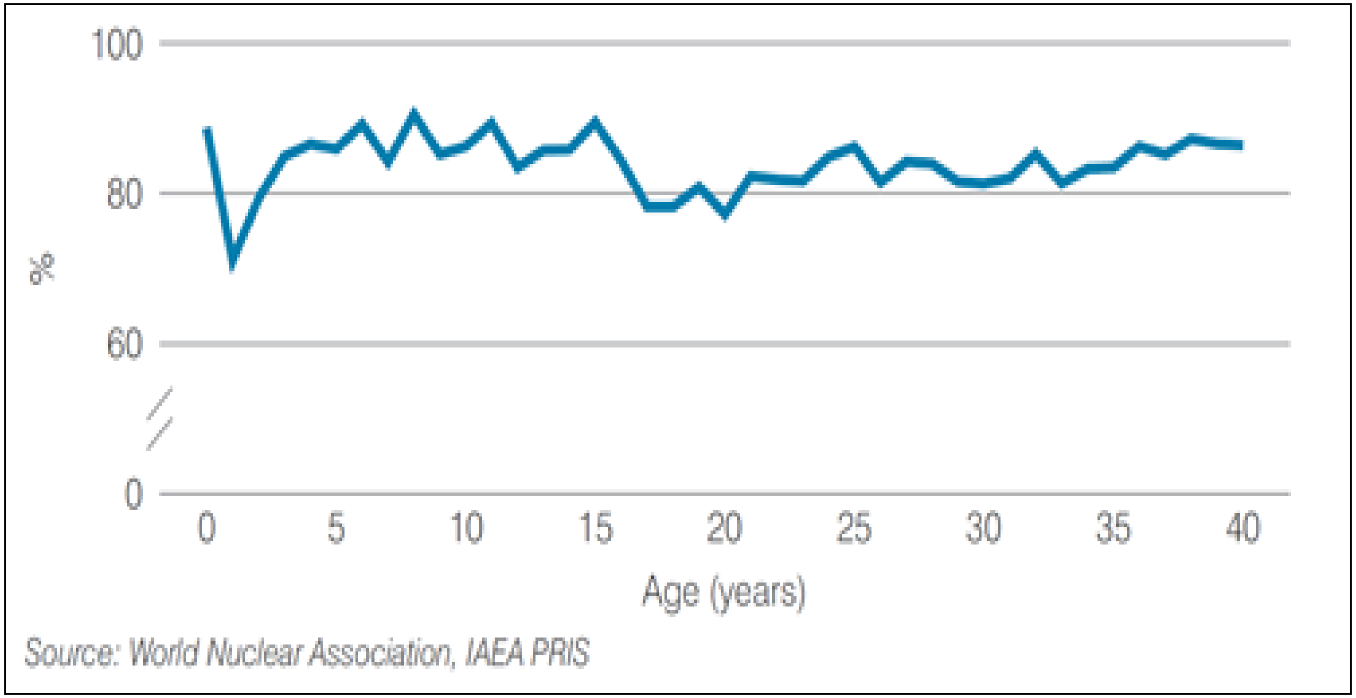
Long-term Trends in Capacity Factors



Source: World Nuclear Association, IAEA PRIS

The performance of nuclear reactors has improved substantially over time. Over the last 40 years, the proportion of reactors reaching high capacity factors has increased significantly. For example, 64% of reactors achieved a capacity factor higher than 80% in 2016, compared to 24% in 1976.

Long-term Trends in Capacity Factors



Source: World Nuclear Association, IAEA PRIS

There is no significant age-related trend in the median capacity factor for reactors over the last ten years.

It appears that nuclear power plants are capable of retaining their capacity factors and reliability over the age of the nuclear plant.

Number of nuclear power plant constructions started each year from 1954 to 2013.

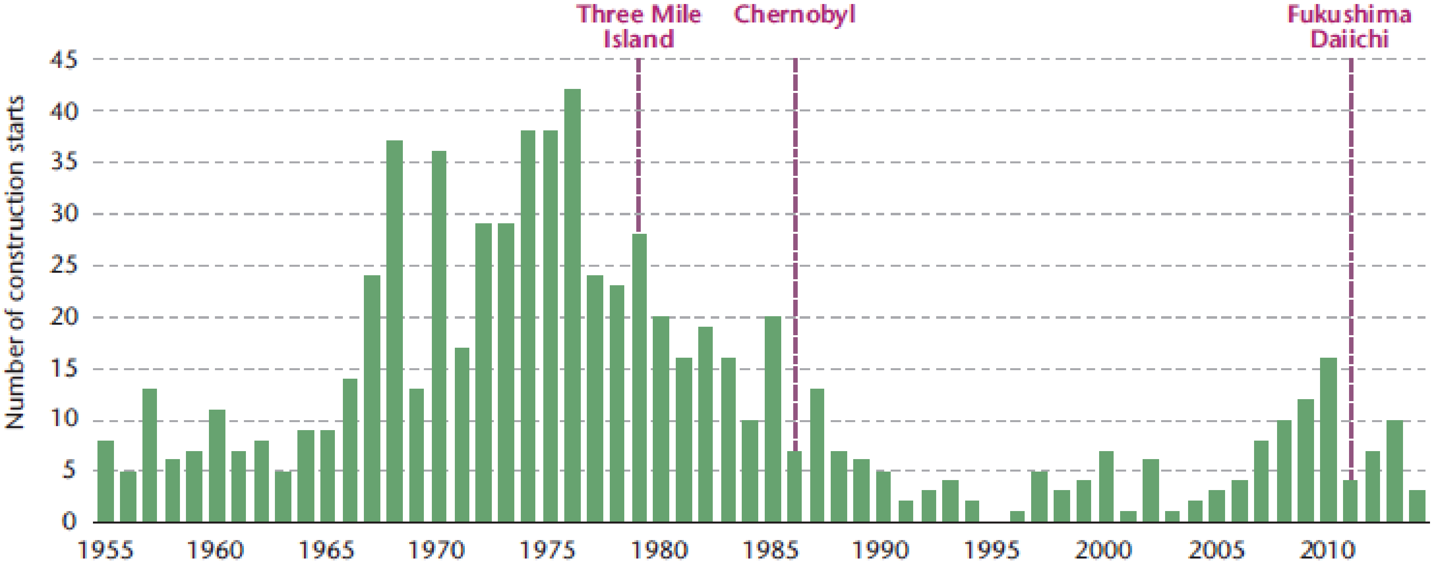
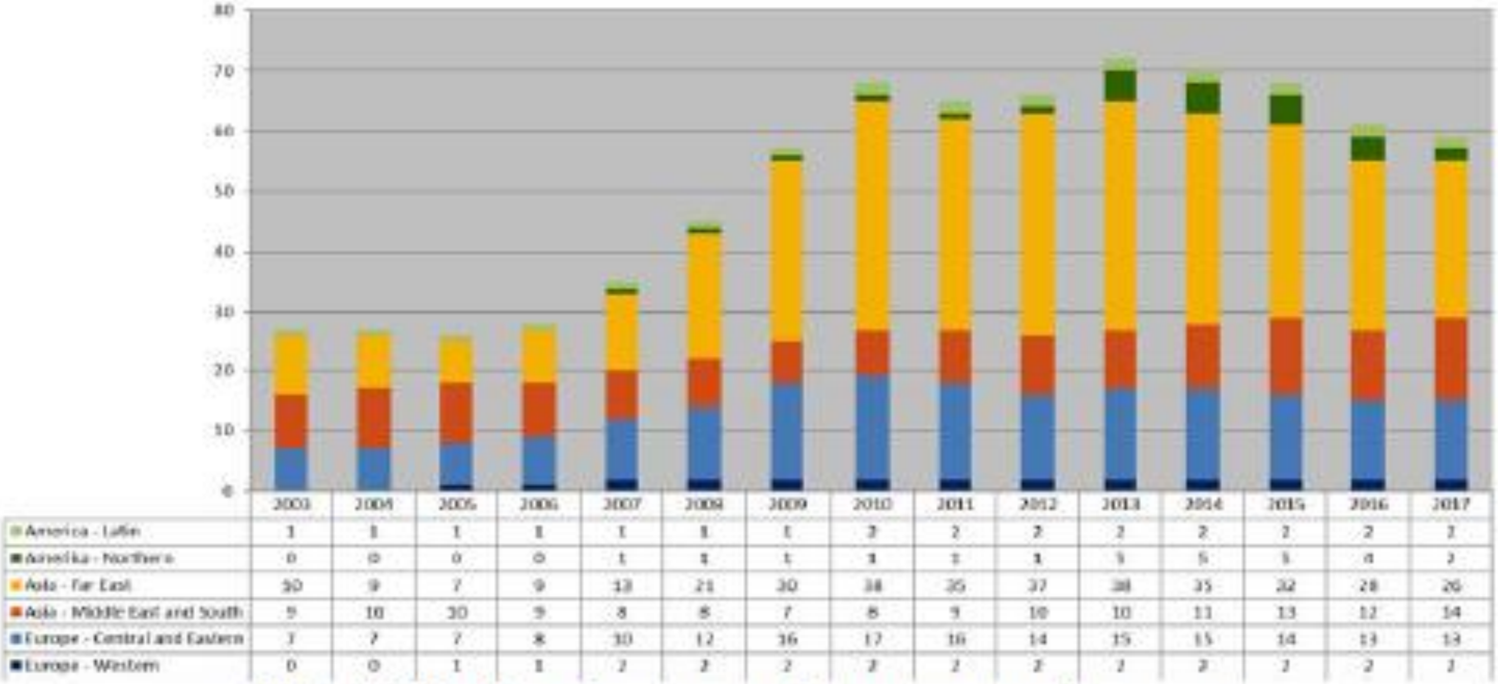


Figure 1: Nuclear reactor construction starts, 1955 to 2014

Source: IAEA Power Reactor Information System (PRIS).

The number of nuclear power plant constructions started each year, from 1954 to 2013. Note the increase in new constructions from 2007 to 2010, before a decline following the 2011 Fukushima Daiichi nuclear disaster.

No. of NPPs in Operation and Under Construction every year



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
America - Latin	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
America - Northern	0	0	0	0	1	1	1	1	1	1	5	5	5	4	2
Asia - Far East	10	9	7	9	13	21	30	38	35	37	38	35	32	28	26
Asia - Middle East and South	9	10	10	9	8	8	7	8	9	10	10	11	13	12	14
Europe - Central and Eastern	7	7	7	8	10	12	16	17	16	14	15	15	14	13	13
Europe - Western	0	0	1	1	2	2	2	2	2	2	2	2	2	2	2

FIG. A-1. Number of reactors under construction by region.

(Source: IAEA Power Reactor Information System http://www.iaea.org/pris*)*

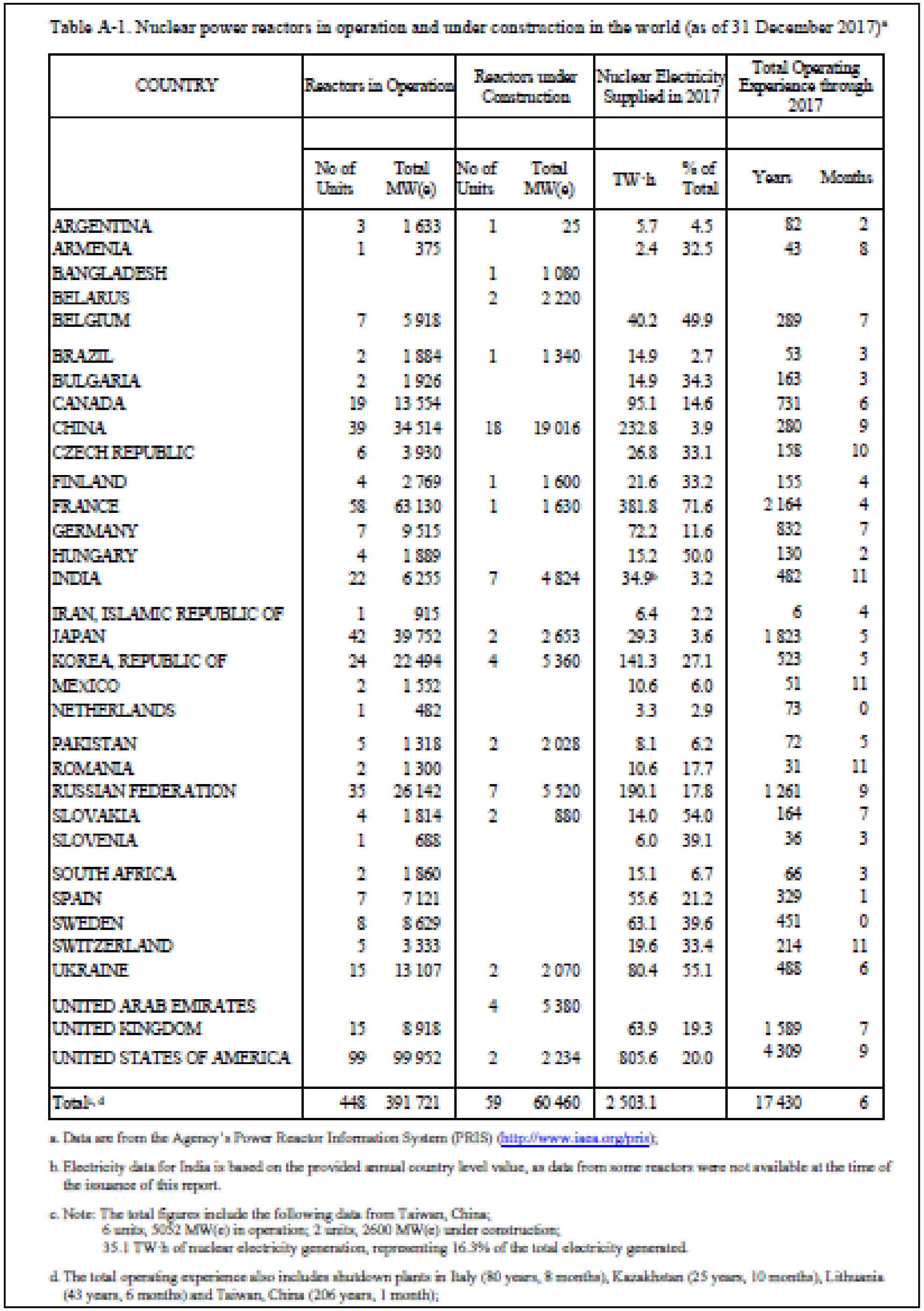


Table A-1. Nuclear power reactors in operation and under construction in the world (as of 31 December 2017)[a]

COUNTRY	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2017		Total Operating Experience through 2017	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TW·h	% of Total	Years	Months
ARGENTINA	3	1 633	1	25	5.7	4.5	82	2
ARMENIA	1	375			2.4	32.5	43	8
BANGLADESH			1	1 080				
BELARUS			2	2 220				
BELGIUM	7	5 918			40.2	49.9	289	7
BRAZIL	2	1 884	1	1 340	14.9	2.7	53	3
BULGARIA	2	1 926			14.9	34.3	163	3
CANADA	19	13 554			95.1	14.6	731	6
CHINA	39	34 514	18	19 016	232.8	3.9	280	9
CZECH REPUBLIC	6	3 930			26.8	33.1	158	10
FINLAND	4	2 769	1	1 600	21.6	33.2	155	4
FRANCE	58	63 130	1	1 630	381.8	71.6	2 164	4
GERMANY	7	9 515			72.2	11.6	832	7
HUNGARY	4	1 889			15.2	50.0	130	2
INDIA	22	6 255	7	4 824	34.9[b]	3.2	482	11
IRAN, ISLAMIC REPUBLIC OF	1	915			6.4	2.2	6	4
JAPAN	42	39 752	2	2 653	29.3	3.6	1 823	5
KOREA, REPUBLIC OF	24	22 494	4	5 360	141.3	27.1	523	5
MEXICO	2	1 552			10.6	6.0	51	11
NETHERLANDS	1	482			3.3	2.9	73	0
PAKISTAN	5	1 318	2	2 028	8.1	6.2	72	5
ROMANIA	2	1 300			10.6	17.7	31	11
RUSSIAN FEDERATION	35	26 142	7	5 520	190.1	17.8	1 261	9
SLOVAKIA	4	1 814	2	880	14.0	54.0	164	7
SLOVENIA	1	688			6.0	39.1	36	3
SOUTH AFRICA	2	1 860			15.1	6.7	66	3
SPAIN	7	7 121			55.6	21.2	329	1
SWEDEN	8	8 629			63.1	39.6	451	0
SWITZERLAND	5	3 333			19.6	33.4	214	11
UKRAINE	15	13 107	2	2 070	80.4	55.1	488	6
UNITED ARAB EMIRATES			4	5 380				
UNITED KINGDOM	15	8 918			63.9	19.3	1 589	7
UNITED STATES OF AMERICA	99	99 952	2	2 234	805.6	20.0	4 309	9
Total[c, d]	448	391 721	59	60 460	2 503.1		17 430	6

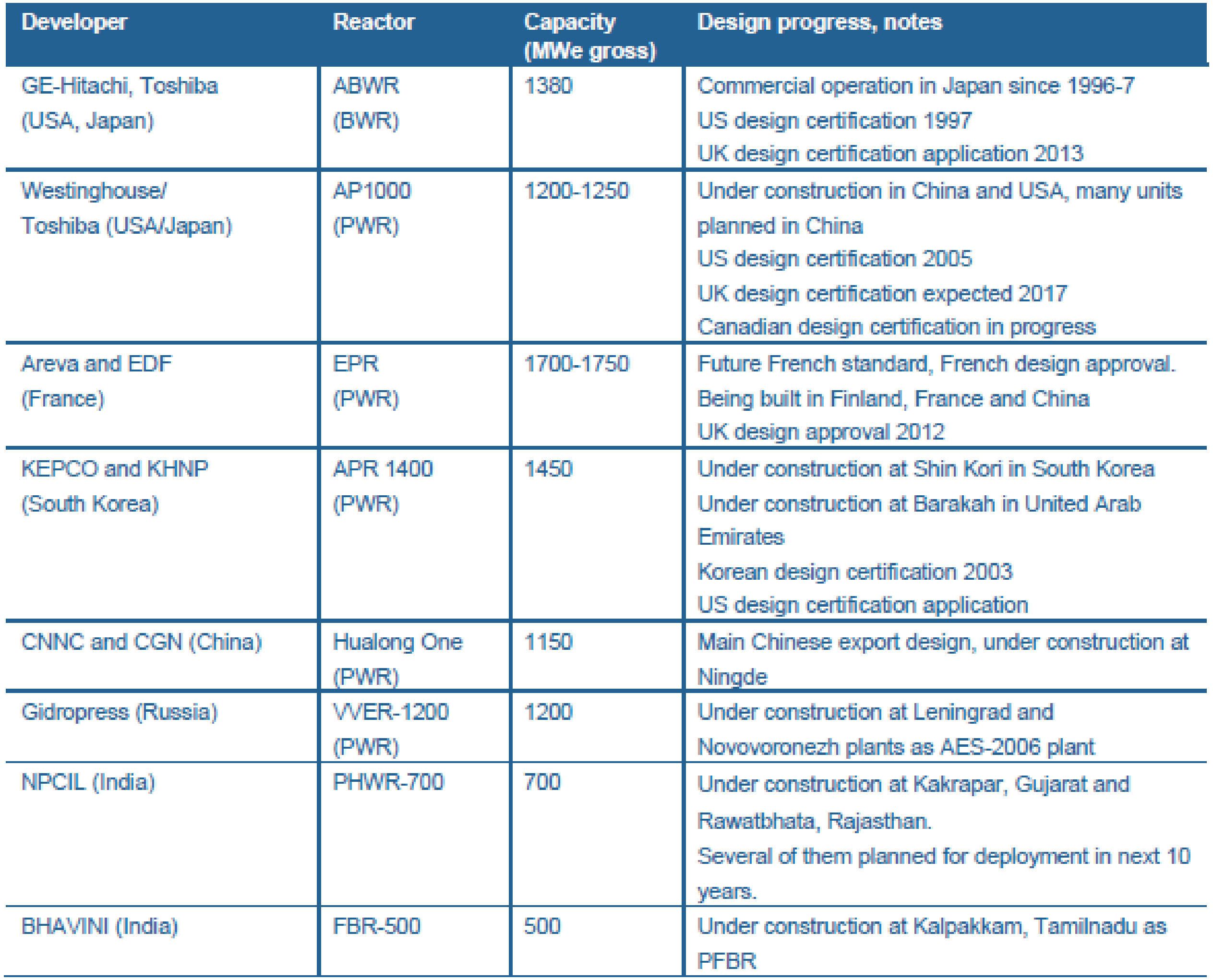
a. Data are from the Agency's Power Reactor Information System (PRIS) (http://www.iaea.org/pris);

b. Electricity data for India is based on the provided annual country level value, as data from some reactors were not available at the time of the issuance of this report.

c. Note: The total figures include the following data from Taiwan, China;
6 units, 5052 MW(e) in operation; 2 units, 2600 MW(e) under construction;
35.1 TW·h of nuclear electricity generation, representing 16.3% of the total electricity generated.

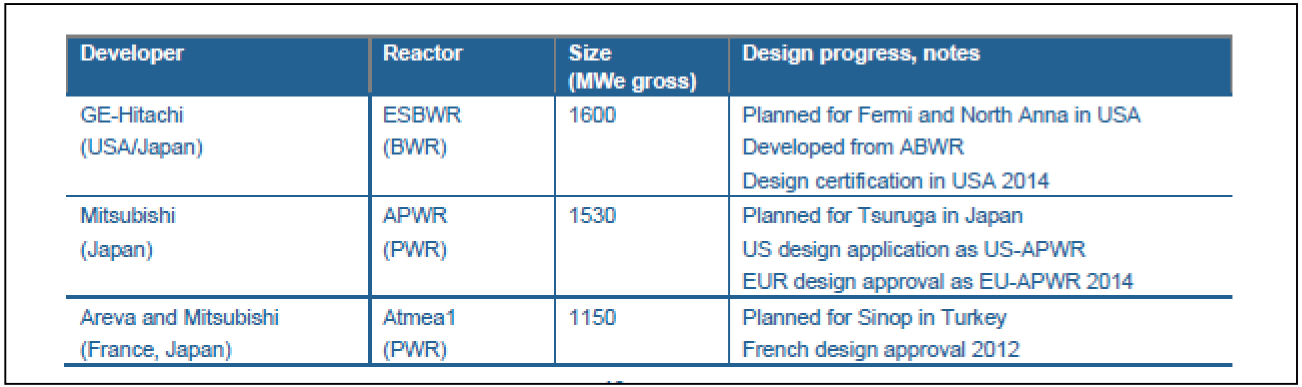
d. The total operating experience also includes shutdown plants in Italy (80 years, 8 months), Kazakhstan (25 years, 10 months), Lithuania (43 years, 6 months) and Taiwan, China (206 years, 1 month);

Commercially Available Reactor Designs (units under construction or constructed)

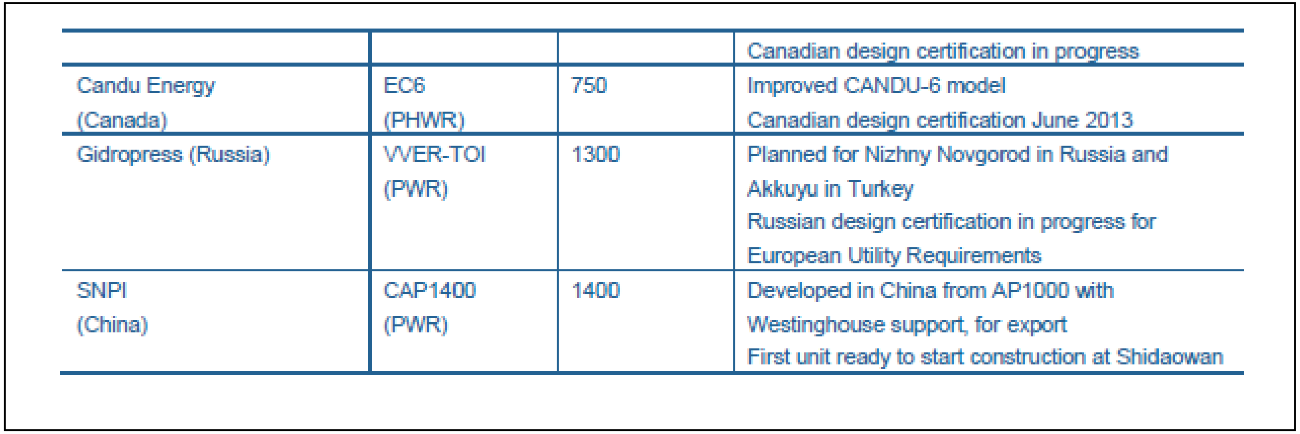


Developer	Reactor	Capacity (MWe gross)	Design progress, notes
GE-Hitachi, Toshiba (USA, Japan)	ABWR (BWR)	1380	Commercial operation in Japan since 1996-7 US design certification 1997 UK design certification application 2013
Westinghouse/ Toshiba (USA/Japan)	AP1000 (PWR)	1200-1250	Under construction in China and USA, many units planned in China US design certification 2005 UK design certification expected 2017 Canadian design certification in progress
Areva and EDF (France)	EPR (PWR)	1700-1750	Future French standard, French design approval. Being built in Finland, France and China UK design approval 2012
KEPCO and KHNP (South Korea)	APR 1400 (PWR)	1450	Under construction at Shin Kori in South Korea Under construction at Barakah in United Arab Emirates Korean design certification 2003 US design certification application
CNNC and CGN (China)	Hualong One (PWR)	1150	Main Chinese export design, under construction at Ningde
Gidropress (Russia)	VVER-1200 (PWR)	1200	Under construction at Leningrad and Novovoronezh plants as AES-2006 plant
NPCIL (India)	PHWR-700	700	Under construction at Kakrapar, Gujarat and Rawatbhata, Rajasthan. Several of them planned for deployment in next 10 years.
BHAVINI (India)	FBR-500	500	Under construction at Kalpakkam, Tamilnadu as PFBR

Commercially Available Reactor Designs (available but no units under construction)



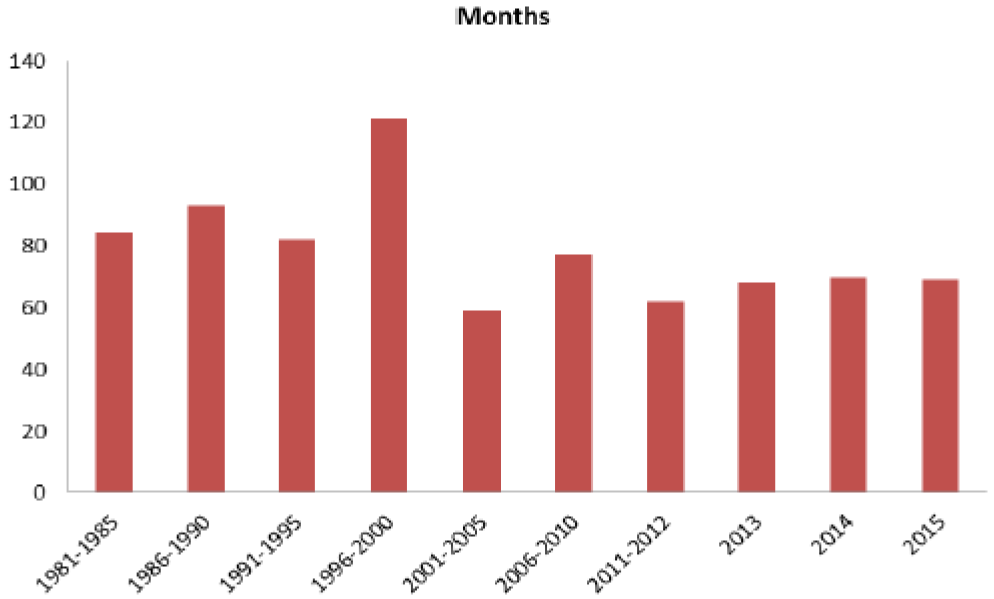
Developer	Reactor	Size (MWe gross)	Design progress, notes
GE-Hitachi (USA/Japan)	ESBWR (BWR)	1600	Planned for Fermi and North Anna in USA Developed from ABWR Design certification in USA 2014
Mitsubishi (Japan)	APWR (PWR)	1530	Planned for Tsuruga in Japan US design application as US-APWR EUR design approval as EU-APWR 2014
Areva and Mitsubishi (France, Japan)	Atmea1 (PWR)	1150	Planned for Sinop in Turkey French design approval 2012



			Canadian design certification in progress
Candu Energy (Canada)	EC6 (PHWR)	750	Improved CANDU-6 model Canadian design certification June 2013
Gidropress (Russia)	VVER-TOI (PWR)	1300	Planned for Nizhny Novgorod in Russia and Akkuyu in Turkey Russian design certification in progress for European Utility Requirements
SNPI (China)	CAP1400 (PWR)	1400	Developed in China from AP1000 with Westinghouse support, for export First unit ready to start construction at Shidaowan

There are many future reactor technologies which are in various stages of R&D: small modular reactors (SMRs) and fast neutron reactors (Generation IV technology)

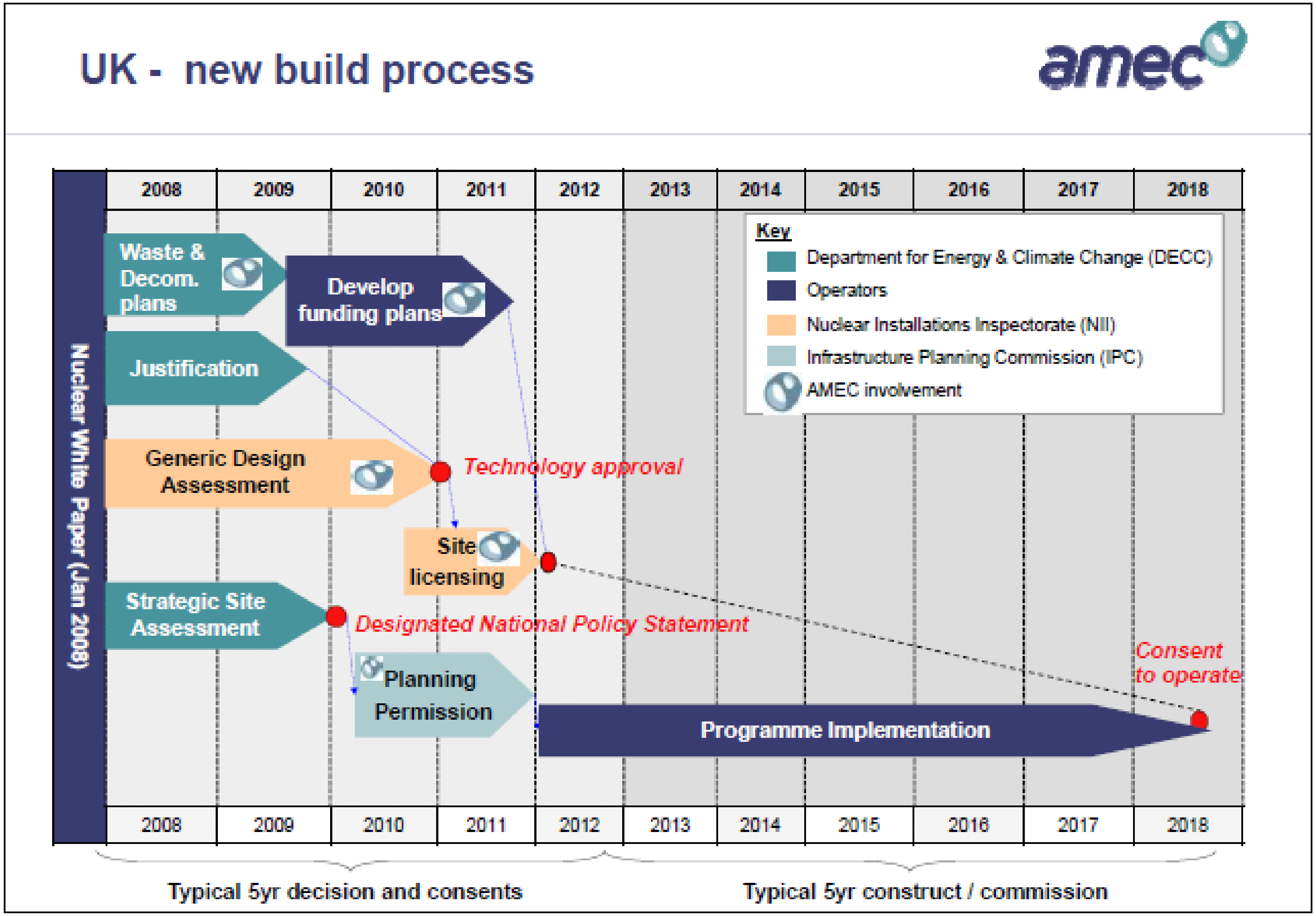
Average Construction Time (1981-2015)



Source: IAEA (2016) Power Reactor Information System

The average construction time of 34 units started in 2003 was about 9.4 years. The median reactor was constructed in 5.75 years in 2015.

Typical 5-year Decision and Consents



UK - new build process

amec

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Nuclear White Paper (Jan 2008)

Waste & Decom. plans

Develop funding plans

Justification

Generic Design Assessment

Technology approval

Site licensing

Strategic Site Assessment

Designated National Policy Statement

Planning Permission

Programme Implementation

Consent to operate

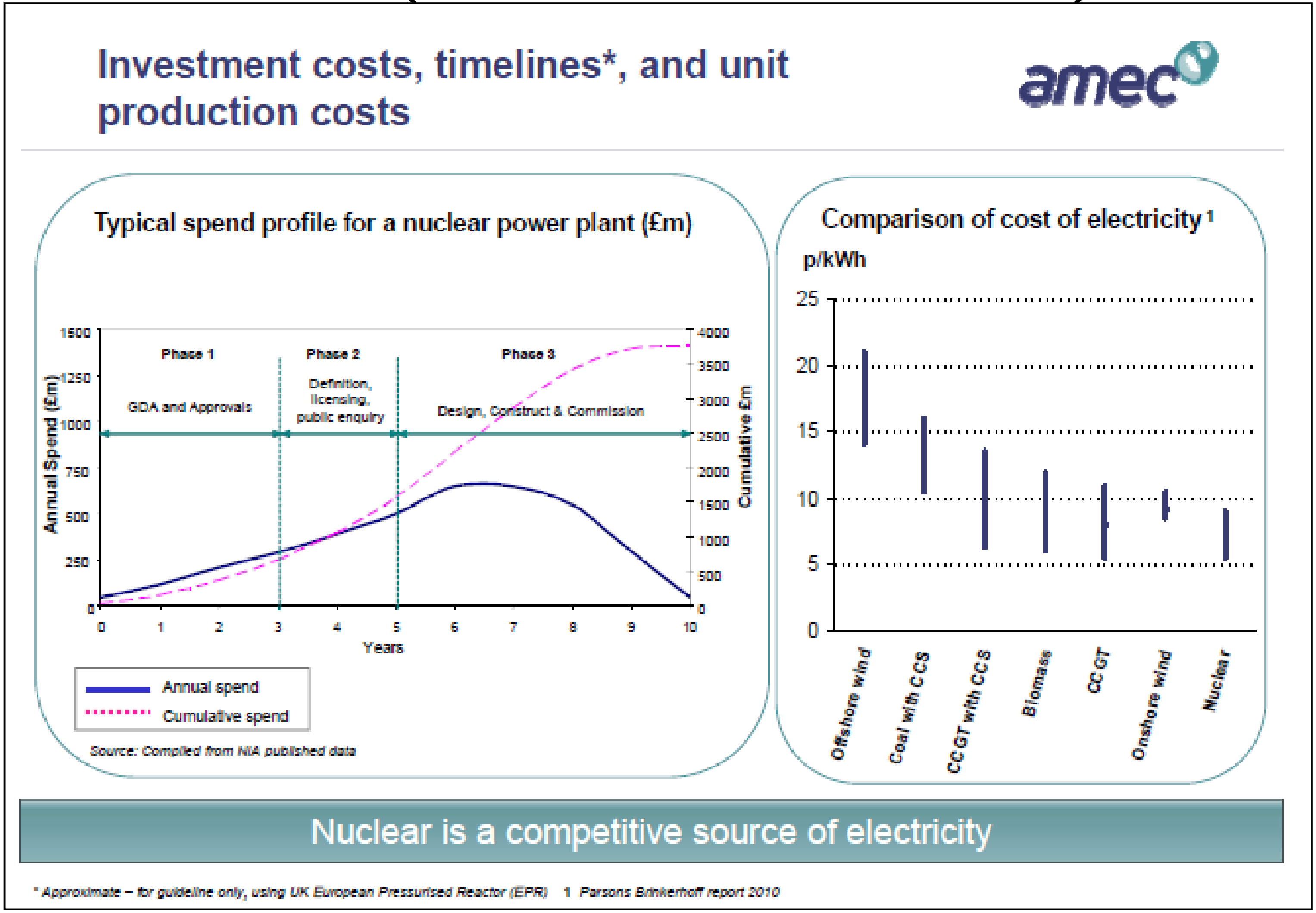
Key

- 🟦 Department for Energy & Climate Change (DECC)
- 🟦 Operators
- 🟧 Nuclear Installations Inspectorate (NII)
- 🟦 Infrastructure Planning Commission (IPC)
- AMEC involvement

Typical 5yr decision and consents

Typical 5yr construct / commission

Typical Spend Profile for a Nuclear Plant (Million UK Pounds)



Investment costs, timelines*, and unit production costs

Typical spend profile for a nuclear power plant (£m)

Source: Compiled from NIA published data

Comparison of cost of electricity [1]

Nuclear is a competitive source of electricity

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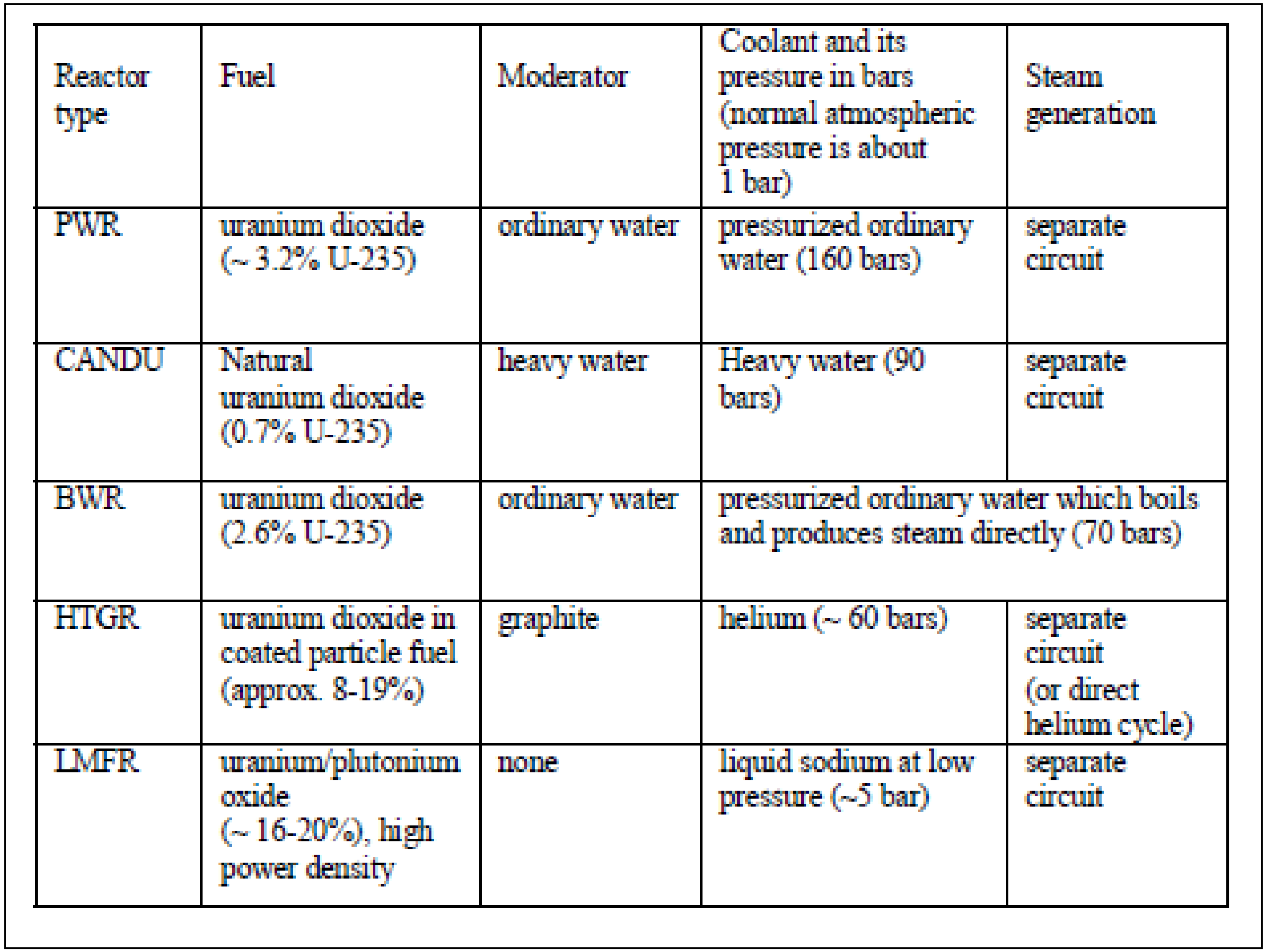
* Approximate – for guideline only, using UK European Pressurised Reactor (EPR)

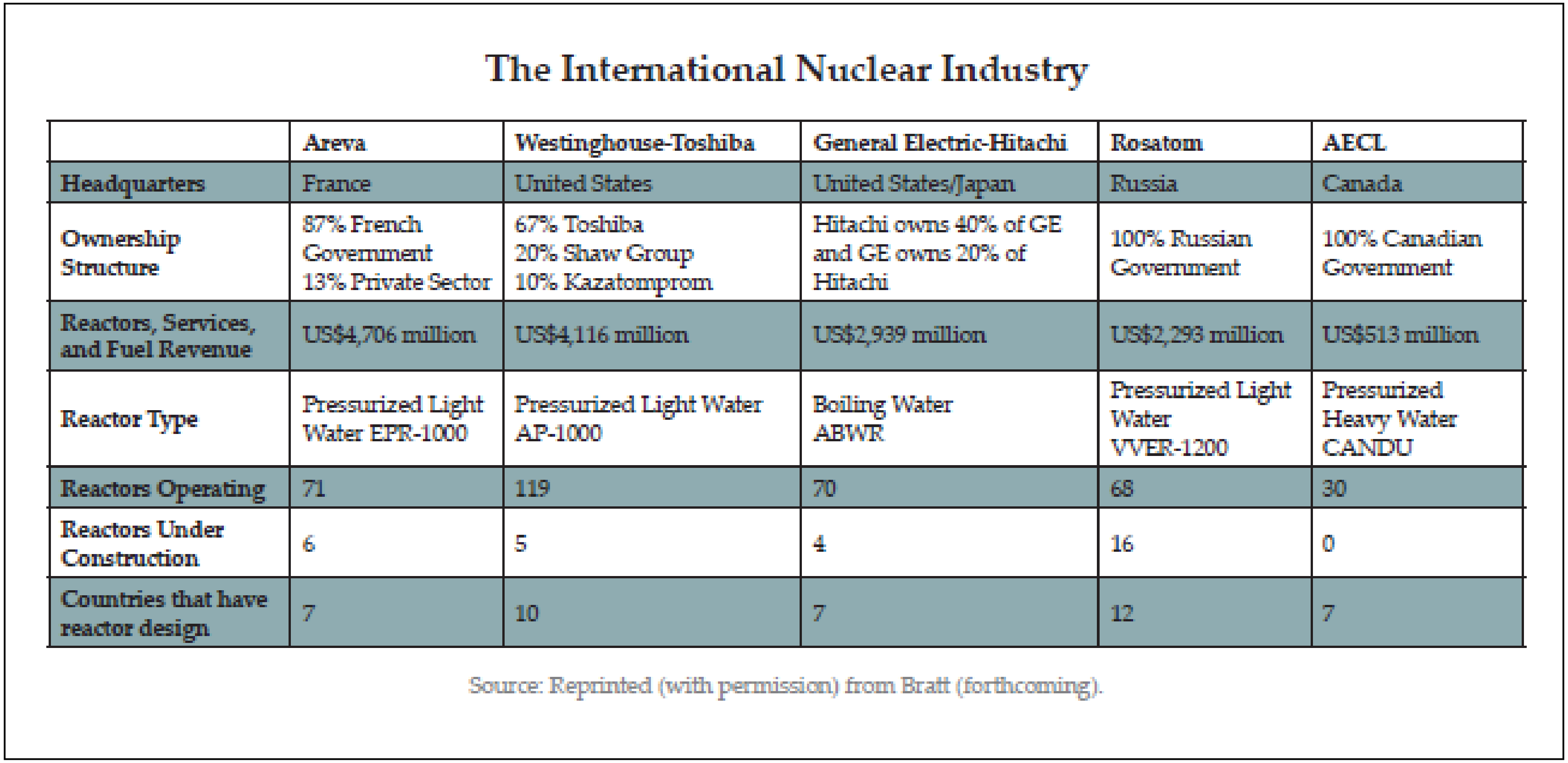
[1] Parsons Brinkerhoff report 2010

Characteristics of Reactors Relevant Today



Reactor type	Fuel	Moderator	Coolant and its pressure in bars (normal atmospheric pressure is about 1 bar)	Steam generation
PWR	uranium dioxide (~ 3.2% U-235)	ordinary water	pressurized ordinary water (160 bars)	separate circuit
CANDU	Natural uranium dioxide (0.7% U-235)	heavy water	Heavy water (90 bars)	separate circuit
BWR	uranium dioxide (2.6% U-235)	ordinary water	pressurized ordinary water which boils and produces steam directly (70 bars)	
HTGR	uranium dioxide in coated particle fuel (approx. 8-19%)	graphite	helium (~ 60 bars)	separate circuit (or direct helium cycle)
LMFR	uranium/plutonium oxide (~ 16-20%), high power density	none	liquid sodium at low pressure (~5 bar)	separate circuit

International Uranium Industry

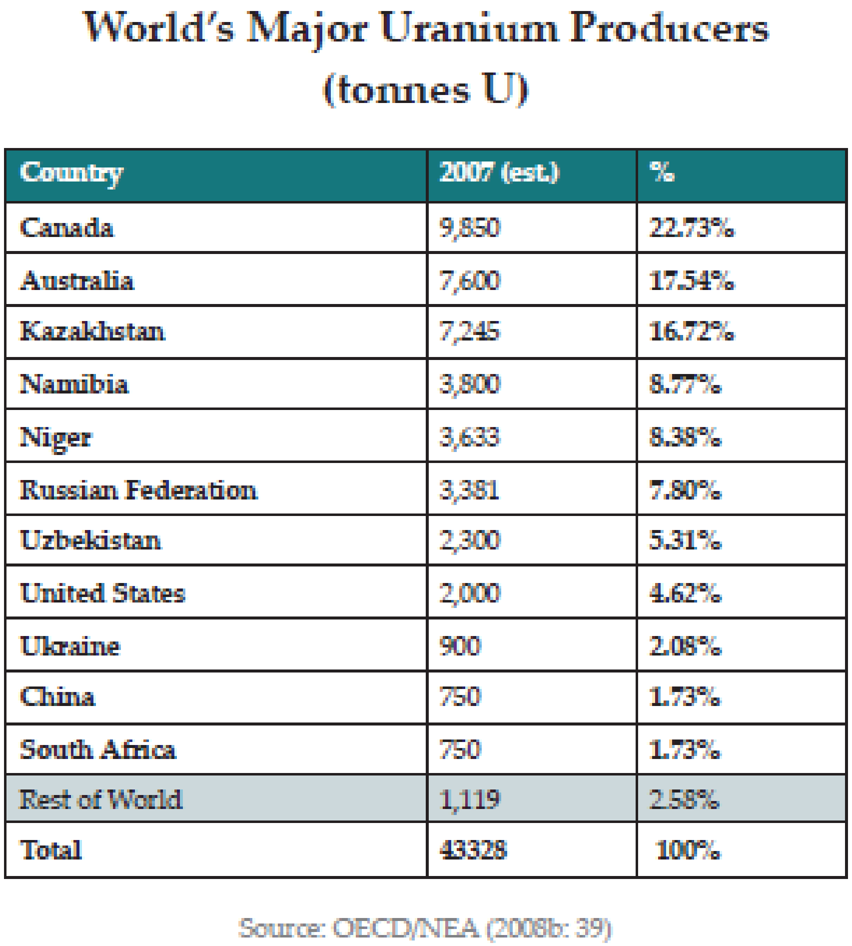


The International Nuclear Industry

	Areva	**Westinghouse-Toshiba**	**General Electric-Hitachi**	**Rosatom**	**AECL**
Headquarters	France	United States	United States/Japan	Russia	Canada
Ownership Structure	87% French Government 13% Private Sector	67% Toshiba 20% Shaw Group 10% Kazatomprom	Hitachi owns 40% of GE and GE owns 20% of Hitachi	100% Russian Government	100% Canadian Government
Reactors, Services, and Fuel Revenue	US$4,706 million	US$4,116 million	US$2,939 million	US$2,293 million	US$513 million
Reactor Type	Pressurized Light Water EPR-1000	Pressurized Light Water AP-1000	Boiling Water ABWR	Pressurized Light Water VVER-1200	Pressurized Heavy Water CANDU
Reactors Operating	71	119	70	68	30
Reactors Under Construction	6	5	4	16	0
Countries that have reactor design	7	10	7	12	7

Source: Reprinted (with permission) from Bratt (forthcoming).

World’s Major Uranium Producers (tonnes U)



World’s Major Uranium Producers
(tonnes U)

Country	2007 (est.)	%
Canada	9,850	22.73%
Australia	7,600	17.54%
Kazakhstan	7,245	16.72%
Namibia	3,800	8.77%
Niger	3,633	8.38%
Russian Federation	3,381	7.80%
Uzbekistan	2,300	5.31%
United States	2,000	4.62%
Ukraine	900	2.08%
China	750	1.73%
South Africa	750	1.73%
Rest of World	1,119	2.58%
Total	**43328**	**100%**

Source: OECD/NEA (2008b: 39)

Reactor types under construction worldwide (2014)

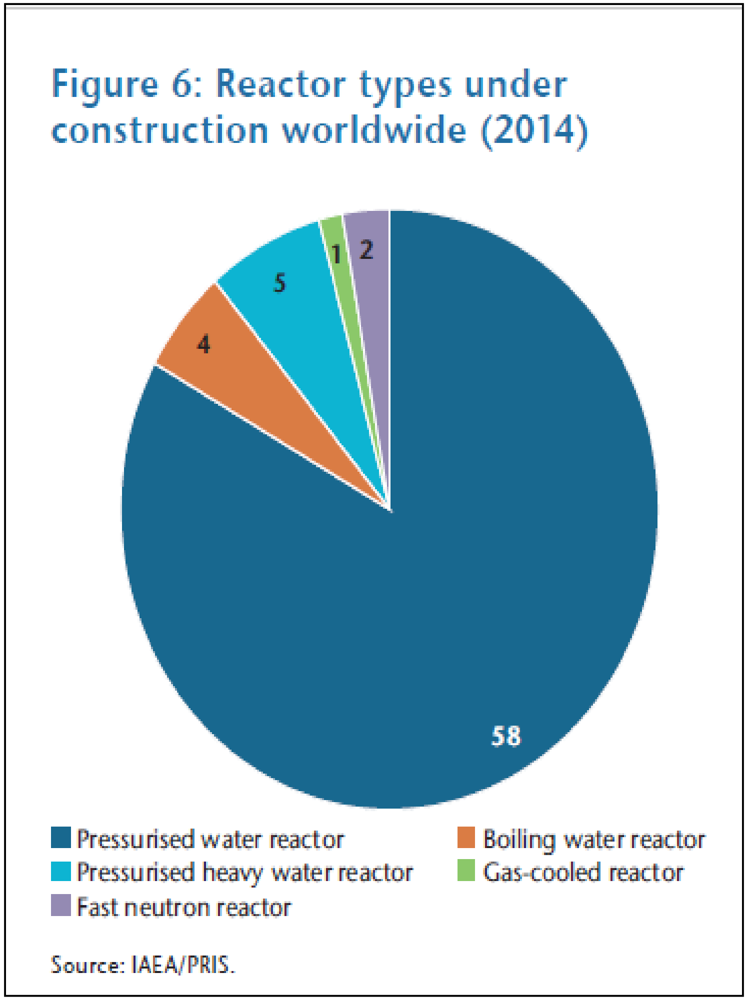


Figure 6: Reactor types under construction worldwide (2014)

Source: IAEA/PRIS.

For the 70 reactors under construction, nearly 89% are LWRs, mostly PWRs with 7% as PHWRs as second choice. Two FNRs are in Russia (BN-800) and in India (PFBR). One high temperature GCR is being built in China. The is a consolidation of reactor technology towards LWRs. Nearly half of reactors are Generation III LWR reactors with enhanced safety features against severe accidents and improved fuel economy.

Examples of Generation III Reactor Design

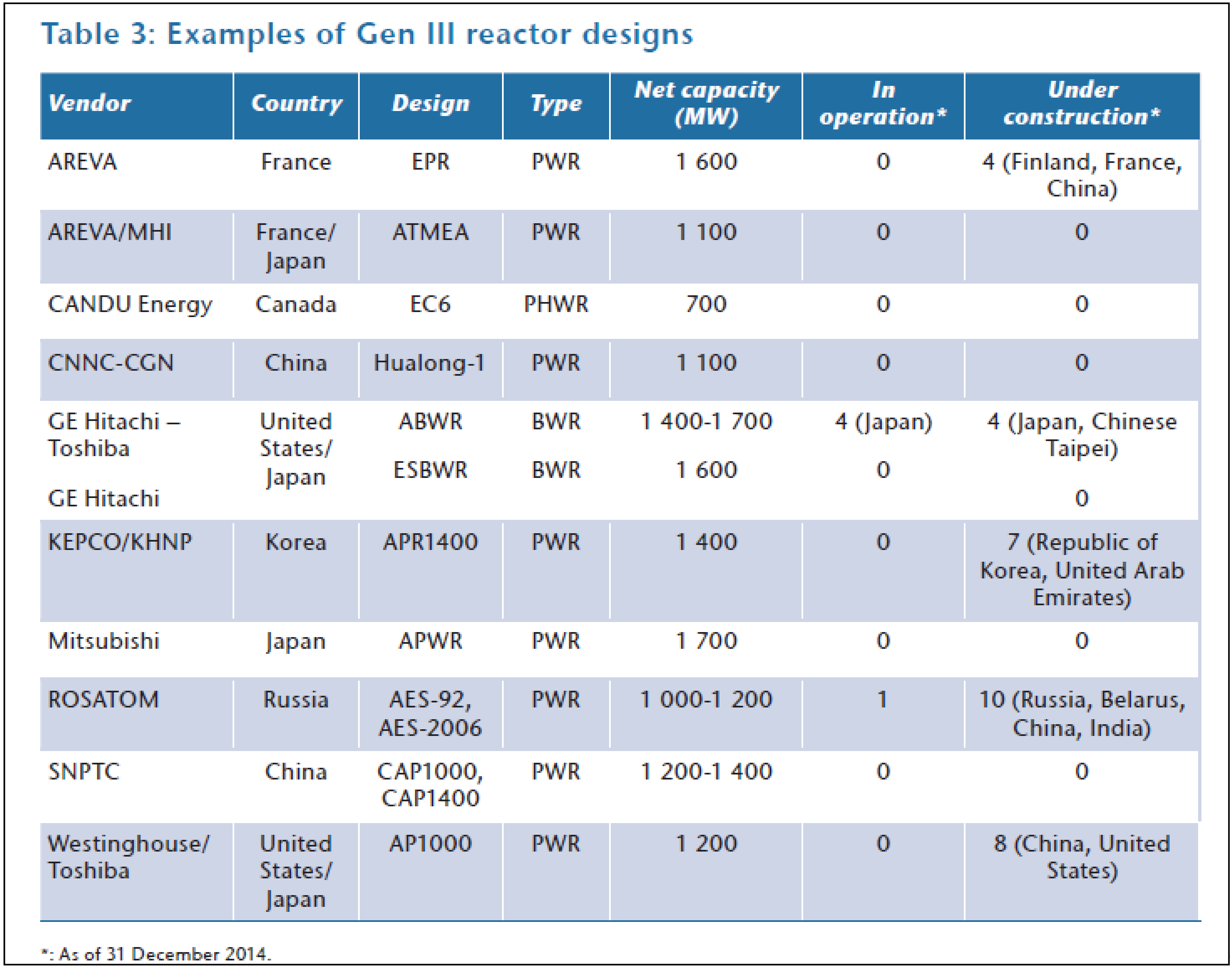


Table 3: Examples of Gen III reactor designs

Vendor	Country	Design	Type	Net capacity (MW)	In operation*	Under construction*
AREVA	France	EPR	PWR	1 600	0	4 (Finland, France, China)
AREVA/MHI	France/ Japan	ATMEA	PWR	1 100	0	0
CANDU Energy	Canada	EC6	PHWR	700	0	0
CNNC-CGN	China	Hualong-1	PWR	1 100	0	0
GE Hitachi – Toshiba	United States/ Japan	ABWR	BWR	1 400-1 700	4 (Japan)	4 (Japan, Chinese Taipei)
GE Hitachi		ESBWR	BWR	1 600	0	0
KEPCO/KHNP	Korea	APR1400	PWR	1 400	0	7 (Republic of Korea, United Arab Emirates)
Mitsubishi	Japan	APWR	PWR	1 700	0	0
ROSATOM	Russia	AES-92, AES-2006	PWR	1 000-1 200	1	10 (Russia, Belarus, China, India)
SNPTC	China	CAP1000, CAP1400	PWR	1 200-1 400	0	0
Westinghouse/ Toshiba	United States/ Japan	AP1000	PWR	1 200	0	8 (China, United States)

*: As of 31 December 2014.

Small Modular Reactors (SMRs) Design

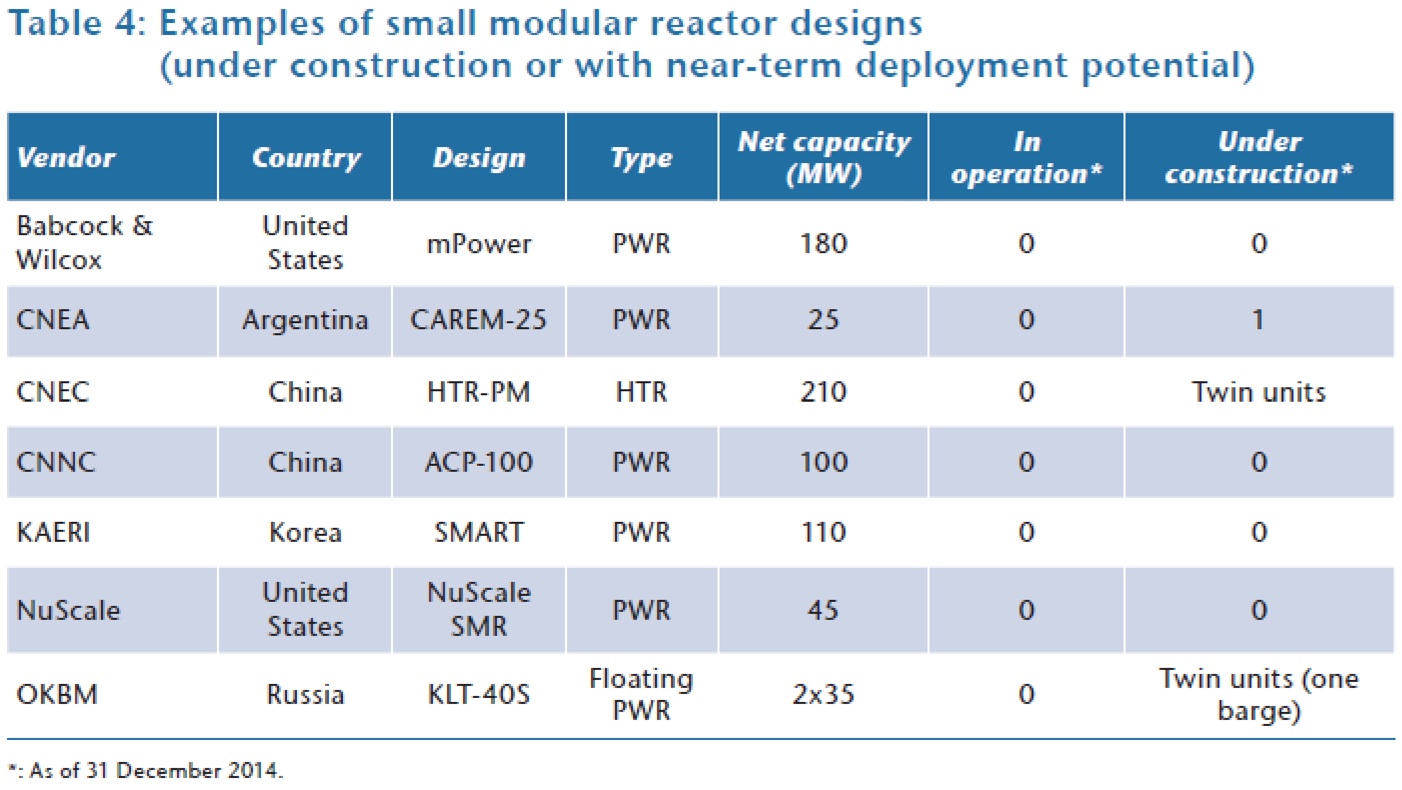


Table 4: Examples of small modular reactor designs (under construction or with near-term deployment potential)

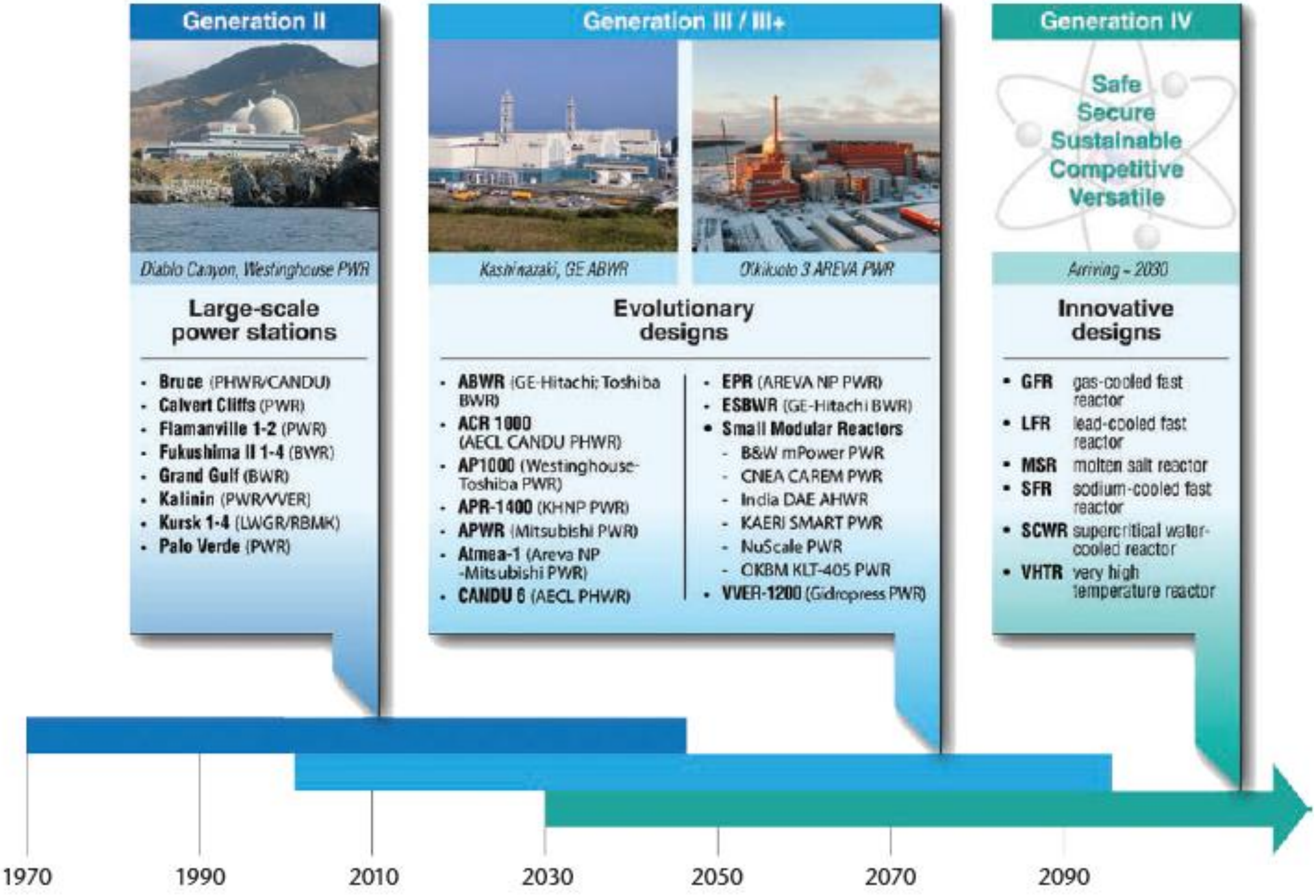
Vendor	*Country*	*Design*	*Type*	*Net capacity (MW)*	*In operation**	*Under construction**
Babcock & Wilcox	United States	mPower	PWR	180	0	0
CNEA	Argentina	CAREM-25	PWR	25	0	1
CNEC	China	HTR-PM	HTR	210	0	Twin units
CNNC	China	ACP-100	PWR	100	0	0
KAERI	Korea	SMART	PWR	110	0	0
NuScale	United States	NuScale SMR	PWR	45	0	0
OKBM	Russia	KLT-40S	Floating PWR	2x35	0	Twin units (one barge)

*: As of 31 December 2014.

SMRs perform a useful role as they can be constructed in regions or countries that have small grid systems that cannot support large NPPs. However, the economics of SMRs have yet to be proven.

Evolution of Nuclear Reactor Technology
The BNPP is an example of PWR (Gen II)

Figure 7: Evolution of fission reactor technology



Generation II – Large-scale power stations

- **Bruce** (PHWR/CANDU)
- **Calvert Cliffs** (PWR)
- **Flamanville 1-2** (PWR)
- **Fukushima II 1-4** (BWR)
- **Grand Gulf** (BWR)
- **Kalinin** (PWR/VVER)
- **Kursk 1-4** (LWGR/RBMK)
- **Palo Verde** (PWR)

Generation III / III+ – Evolutionary designs

- **ABWR** (GE-Hitachi; Toshiba BWR)
- **ACR 1000** (AECL CANDU PHWR)
- **AP1000** (Westinghouse-Toshiba PWR)
- **APR-1400** (KHNP PWR)
- **APWR** (Mitsubishi PWR)
- **Atmea-1** (Areva NP -Mitsubishi PWR)
- **CANDU 6** (AECL PHWR)
- **EPR** (AREVA NP PWR)
- **ESBWR** (GE-Hitachi BWR)
- **Small Modular Reactors**
  - B&W mPower PWR
  - CNEA CAREM PWR
  - India DAE AHWR
  - KAERI SMART PWR
  - NuScale PWR
  - OKBM KLT-405 PWR
- **VVER-1200** (Gidropress PWR)

Generation IV – Innovative designs

GFR	gas-cooled fast reactor
LFR	lead-cooled fast reactor
MSR	molten salt reactor
SFR	sodium-cooled fast reactor
SCWR	supercritical water-cooled reactor
VHTR	very high temperature reactor

Pros and Cons of the Reactor Technologies

- Boiling water reactor (BWR): uses ordinary water as coolant and moderator; water in reactor is permitted to boil, and steam generated drives a ST; uses enriched uranium as fuel
- Pressurized water reactor (PWR) uses ordinary or light water as coolant and moderator under pressure so it can not boil; heat from the primary water cooling system is captured in a heat exchanger and transferred to water in a secondary system, which is allowed to boil; uses enriched uranium as fuel
- Advanced gas cooled reactor (AGR) employs graphite as moderator and CO2 as coolant; the CO2 carries the heat to a heat exchanger where it. is used to generate steam to drive a turbine; unique to UK

Pros and Cons of the Reactor Technologies

- CANDU reactor of Canada uses heavy water as moderator and coolant; no need to enrich uranium; can be refueled without shutting down; heavy water coolant is kept under pressure so it can not boil and heat is transferred to a light water system in a steam generator and the secondary system drives a steam turbine like a PWR does

- High temperature gas cooled reactor (HTGR) uses graphite as moderator and helium as heat transfer agent; operates at much higher temperature and is more efficient

- GT modular helium reactor (GT-MHR) is a development of the HTGR and uses helium as coolant but uses a gas turbine, instead of a steam turbine, driven directly by the high temperature helium; can reach conversion efficiency of 48%

Most Appropriate Technology for Philippines for 1,000+ MW NPP

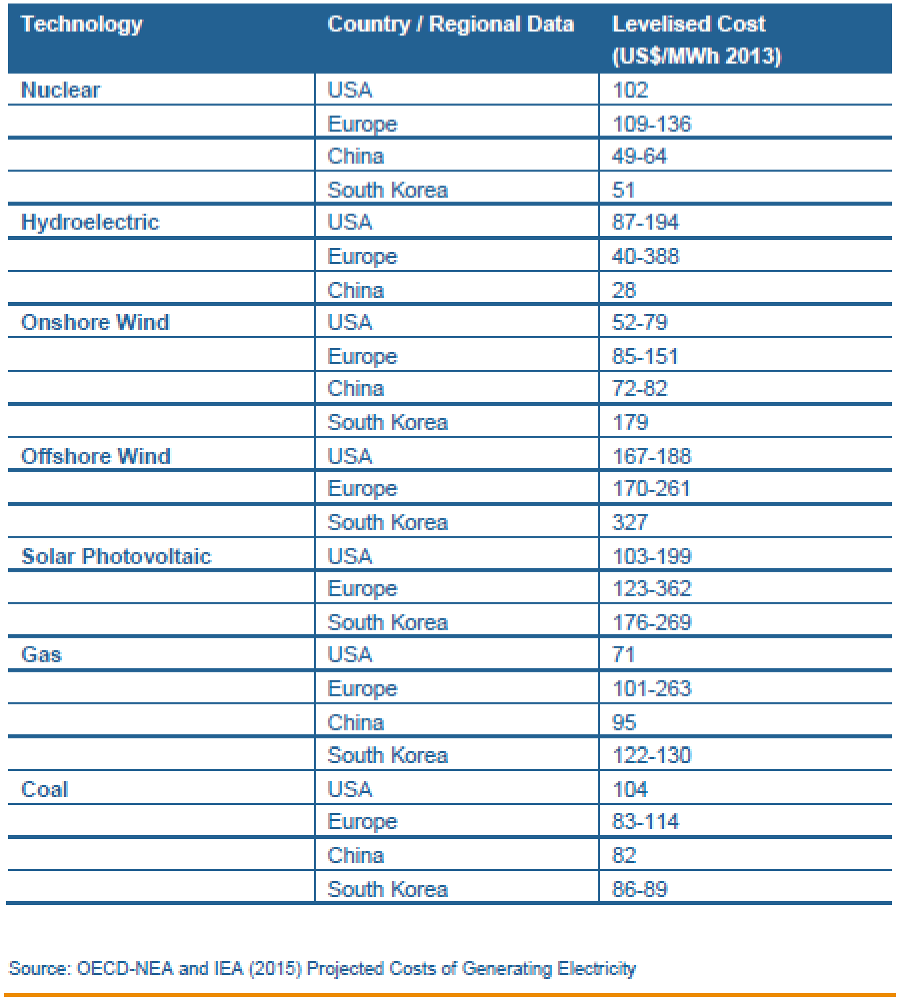
- Pressurized Water Reactor (PWR) – most common (69%) – light water reactor (LWR)

- Boiling Water Reactor (BWR) – next popular at 20% - light water reactor (LWR)

- Pressurized Heavy Water Reactor (PHWR) – 89% of new construction is LWR and 7% is next choice as heavy water reactor (HWR)

- Advanced Gas Cooled Reactor (AGR) – unique to UK only

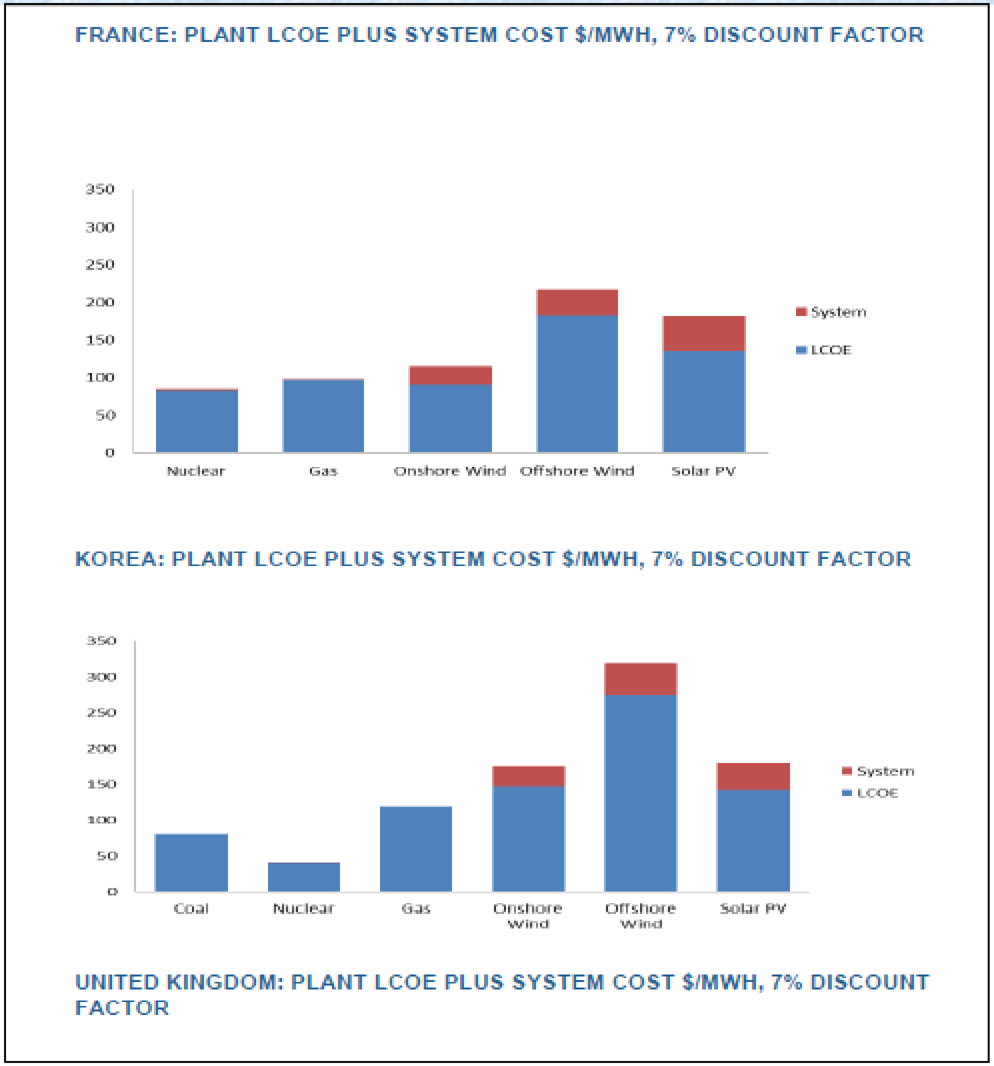
Levelized Cost by technology and country (at 10% discount rate)



Technology	Country / Regional Data	Levelised Cost (US$/MWh 2013)
Nuclear	USA	102
	Europe	109-136
	China	49-64
	South Korea	51
Hydroelectric	USA	87-194
	Europe	40-388
	China	28
Onshore Wind	USA	52-79
	Europe	85-151
	China	72-82
	South Korea	179
Offshore Wind	USA	167-188
	Europe	170-261
	South Korea	327
Solar Photovoltaic	USA	103-199
	Europe	123-362
	South Korea	176-269
Gas	USA	71
	Europe	101-263
	China	95
	South Korea	122-130
Coal	USA	104
	Europe	83-114
	China	82
	South Korea	86-89

Source: OECD-NEA and IEA (2015) Projected Costs of Generating Electricity

Levelized Cost plus System Cost, $/MWh (at 7% discount rate)

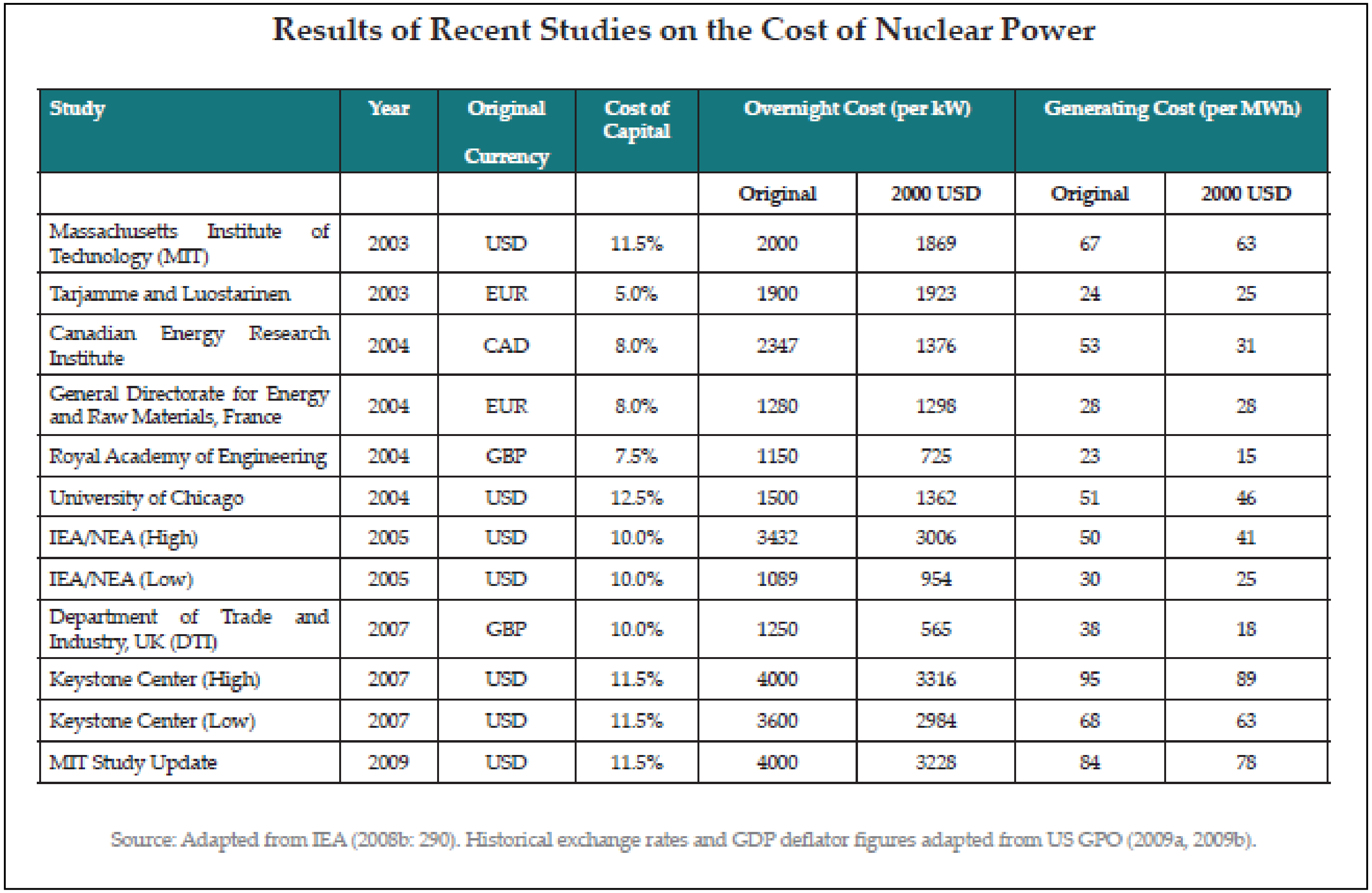


FRANCE: PLANT LCOE PLUS SYSTEM COST $/MWH, 7% DISCOUNT FACTOR

KOREA: PLANT LCOE PLUS SYSTEM COST $/MWH, 7% DISCOUNT FACTOR

UNITED KINGDOM: PLANT LCOE PLUS SYSTEM COST $/MWH, 7% DISCOUNT FACTOR

Cost of Nuclear Power

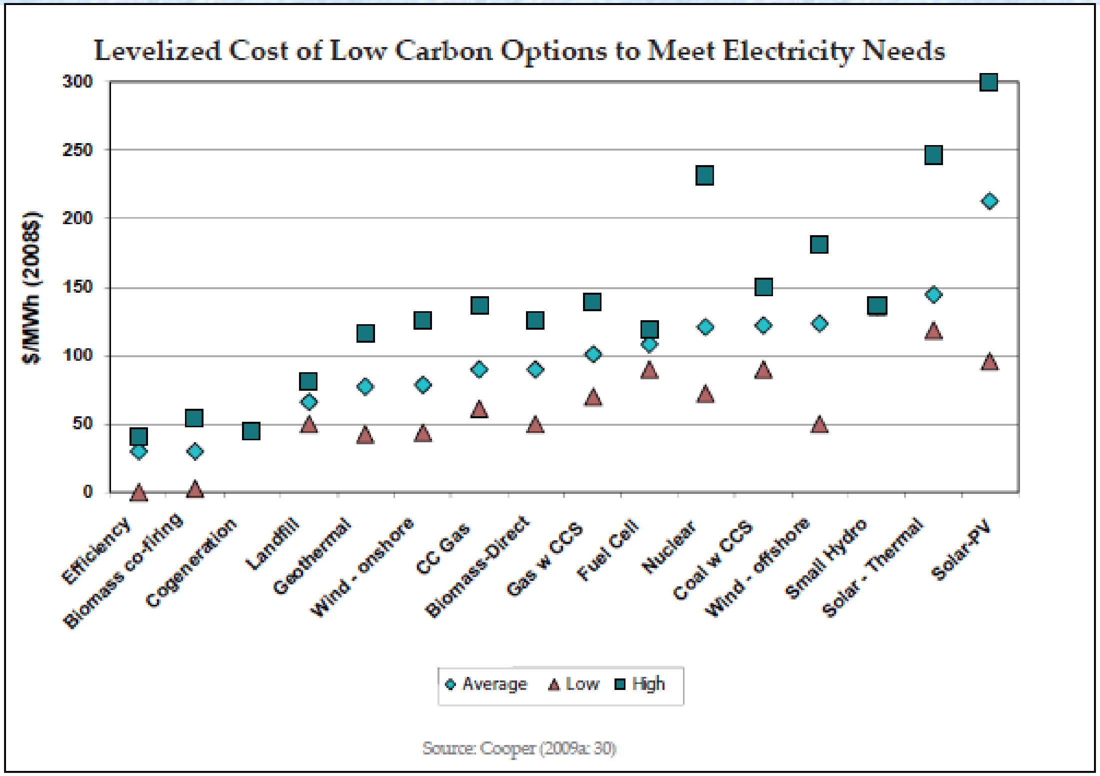


Results of Recent Studies on the Cost of Nuclear Power

Study	Year	Original Currency	Cost of Capital	Overnight Cost (per kW)		Generating Cost (per MWh)	
				Original	2000 USD	Original	2000 USD
Massachusetts Institute of Technology (MIT)	2003	USD	11.5%	2000	1869	67	63
Tarjamme and Luostarinen	2003	EUR	5.0%	1900	1923	24	25
Canadian Energy Research Institute	2004	CAD	8.0%	2347	1376	53	31
General Directorate for Energy and Raw Materials, France	2004	EUR	8.0%	1280	1298	28	28
Royal Academy of Engineering	2004	GBP	7.5%	1150	725	23	15
University of Chicago	2004	USD	12.5%	1500	1362	51	46
IEA/NEA (High)	2005	USD	10.0%	3432	3006	50	41
IEA/NEA (Low)	2005	USD	10.0%	1089	954	30	25
Department of Trade and Industry, UK (DTI)	2007	GBP	10.0%	1250	565	38	18
Keystone Center (High)	2007	USD	11.5%	4000	3316	95	89
Keystone Center (Low)	2007	USD	11.5%	3600	2984	68	63
MIT Study Update	2009	USD	11.5%	4000	3228	84	78

Source: Adapted from IEA (2008b: 290). Historical exchange rates and GDP deflator figures adapted from US GPO (2009a, 2009b).

Levelized Cost of Low Carbon Options to Meet Electricity Needs



Levelized Cost of Low Carbon Options to Meet Electricity Needs

Source: Cooper (2009a: 30)

LCOE = [fixed cost (capital x CRF + fixed O&M) + variable cost (fuel, O&M)]/[annual kWh]
CRF = capital recovery factor = i / (1 – (1+i)^-t)

Nuclear Energy Cost Competitive

Estimated Levelized Cost of New Electric Generation in 2016

Plant Type	Capacity Factor (%)	Average Levelized Costs for Power Plants Entering Service in 2016 (2007 dollars/megawatt-hour)				
		Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Solar PV	21.7	376.6	6.2	0.0	12.9	395.7
Solar Thermal	31.2	232.1	21.3	0.0	10.3	263.7
Wind - Offshore	33.4	193.6	27.5	0.0	8.6	229.6
Wind - Land	35.1	122.7	10.3	0.0	8.5	141.5
Advanced Coal with CCS	85	87.4	6.2	25.2	3.8	122.6
Nat .Gas Advanced CC with CCS	87	43.6	2.6	65.8	3.7	115.7
Hydro	52	97.2	3.3	6.1	5.6	114.1
Biomass	83	71.7	8.9	23.0	3.9	107.4
Advanced Nuclear	**90**	**84.2**	**11.4**	**8.7**	**3.0**	**107.3**
Geothermal	90	86.0	20.7	0.0	4.8	111.5
Conventional Coal	85	64.5	3.7	23.0	3.5	94.6
Natural Gas Conventional CC	87	23.0	1.6	55.7	3.7	83.9

COAL RESERVES, EXTRACTION RATE AND LIFETIME

Primary Energy Source	Proven Reserves (Jan. 1, 2000)	Annual Production 1999	Life Time (years)
Fossil Fuels:			
Coal (million short tons)	1,088,602	4,737	230
Petroleum (billion bbls) (crude oil & NGL)	1,017	71,854	39
Natural Gas(trillion ft3)	5,150	85	61

SOURCE: US DOE - EIA

- Coal is a finite fuel
- Proven reserves as of Jan. 1, 2000 = 1,088.6 billion short tons
- Annual extraction rate = 4.7 billion short tons
- Coal will still be available for the next 2-3 centuries = 230 years
- Total reserves for crude oil and NGL is 1,017 billion barrels as of Jan. 1, 2000; extraction rate stood at 71,854,000 barrels per day; may be gone after 39 years.
- Natural gas reserves is 5,150 trillion ft^3 while annual gas production stood at 85 trillion ft^3; may be gone after 61 years.

Remaining Lifetimes
(Years = Reserves / Extraction Rate

- Coal = 230 years
- Petroleum = 39 years
- Natural Gas = 61 years
- Uranium (fission) = 250 years
- Plutonium (breeder) = 500-1,000 years
- Uranium (fusion) = perhaps > 1,000 years
- Solar, Wind, Biomass, Ocean thermal, Ocean current, Tidal current = limitless (as long as the SUN shines and Earth spins)

Environmental Considerations

- **Advantages of Nuclear Power**
  - Cheap fuel
  - Clean operation
  - Low electricity cost

- **Disadvantages**
  - Long construction time
  - Catastrophic accident possible
  - Radioactive waste disposal problem
  - Decommissioning problem

Recent Nuclear Accidents and Disasters


WINDSCALE FIRE


THREE MILE ISLAND


CHERNOBYL DISASTER


FUKUSHIMA DISASTER

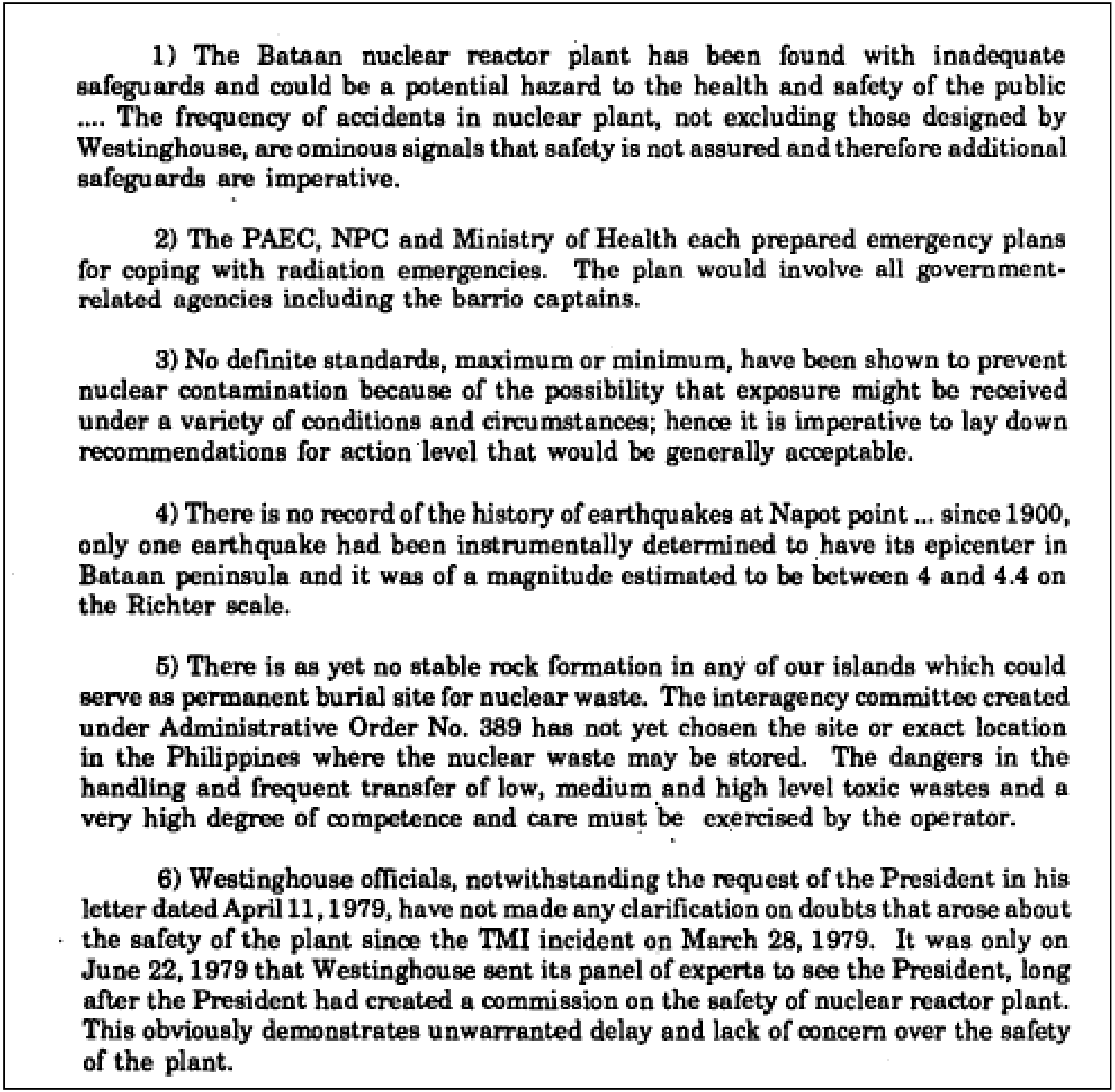
Actions by IAEA/Nuclear Industry after Major Incidents to raise safety

- After Three Mile Island – incorporate 11 upgrades for BNPP by Puno Commission
- After Chernobyl – after worst nuclear accident in history, lead to focus on safe reactor design:

a) RBMKs have no containment

b) Safety improvement on to all Soviet designed reactors - VVERs

- After Fukushima – majority of NPPs world wide conduced stringent stress tests on 12 action plans
- See Nuclear Safety Review (2012, 2013)



1) The Bataan nuclear reactor plant has been found with inadequate safeguards and could be a potential hazard to the health and safety of the public .... The frequency of accidents in nuclear plant, not excluding those designed by Westinghouse, are ominous signals that safety is not assured and therefore additional safeguards are imperative.

2) The PAEC, NPC and Ministry of Health each prepared emergency plans for coping with radiation emergencies. The plan would involve all government-related agencies including the barrio captains.

3) No definite standards, maximum or minimum, have been shown to prevent nuclear contamination because of the possibility that exposure might be received under a variety of conditions and circumstances; hence it is imperative to lay down recommendations for action level that would be generally acceptable.

4) There is no record of the history of earthquakes at Napot point ... since 1900, only one earthquake had been instrumentally determined to have its epicenter in Bataan peninsula and it was of a magnitude estimated to be between 4 and 4.4 on the Richter scale.

5) There is as yet no stable rock formation in any of our islands which could serve as permanent burial site for nuclear waste. The interagency committee created under Administrative Order No. 389 has not yet chosen the site or exact location in the Philippines where the nuclear waste may be stored. The dangers in the handling and frequent transfer of low, medium and high level toxic wastes and a very high degree of competence and care must be exercised by the operator.

6) Westinghouse officials, notwithstanding the request of the President in his letter dated April 11, 1979, have not made any clarification on doubts that arose about the safety of the plant since the TMI incident on March 28, 1979. It was only on June 22, 1979 that Westinghouse sent its panel of experts to see the President, long after the President had created a commission on the safety of nuclear reactor plant. This obviously demonstrates unwarranted delay and lack of concern over the safety of the plant.

Risks

- **Technology Risks –** Nuclear power generation technology is a mature technology and is well understood. Construction of a nuclear plant based on established technology should present no significant technical risk. Innovations are usually evolutionary in nature, based clearly on existing technology, therefore, the technical risks would remain *low for small improvements*.
- **Economic Risks –** most *significant risk is economic* because nuclear power is capital intensive. The cost of the plant is much higher than fossil-fired power plant but the cost of fuel is much lower, thus making the nuclear plant construction extremely sensitive to cost over-runs. In the US, it takes over 10 years to build so discount rates may change dramatically, together with fuel costs and regulatory changes which could easily affect the construction schedule by years with escalating interests and possible bankruptcy.
- **Standardized design –** the route around the above problems is to use standard design for rapid authorization and modular construction techniques. A 1,300 MW reactor was built in Japan in 4 years (1996).

Conclusions 1

1) The Philippines Nuclear Regulatory Framework is in its infancy but being put in place, mired by the mothballing of the BNPP due to safety and political issues. The existing institutions regulating nuclear energy, safety and efficiency needs to be strengthened or set up.
2) The BNPP is a Generation II nuclear power plant with numerous safety, locational and O&M issues requiring massive upgrades and investments and further site investigation

Conclusions 2

3) As a Pressurized Water Reactor (PWR) technology from US Westinghouse, its other similar sister power plants like in Korea have operated efficiently and safely over a long period of time
4) Converting the nuclear boiler of single pressure saturated steam to drive its large diameter turbine into a coal-fired or gas-fired triple pressure steam boiler to drive a smaller diameter steam turbine will result in costly operations due to higher fuel costs arising from lower thermal efficiencies (33% nuclear vs. 42% coal and 56% gas)

Recommendations 1

1) Upgrading the Generation II nuclear technology BNPP into the more safer and advanced Generation III, III+ or IV nuclear technologies will involve numerous and costly upgrades, but the site location issues remain, and in the event of a major unforeseen nuclear accident, its proximity to population centers in Bataan, Central Luzon and National Capital Region is a serious safety risk that may not mitigated by the country’s emergency, disaster and relief agencies
2) Even Russia, USA and Japan with its advanced nuclear technology compared to the Philippines have encountered tremendous difficulty and costs in mitigating and recovering from nuclear disaster of large nuclear power plants

Recommendations 2

3) Recent studies of converting the BNPP from a nuclear-fueled to a fossil-fueled power plant by replacing the nuclear reactor boiler of single pressure saturated steam to drive a large-diameter steam turbine-generator into a coal-fired or gas-fired boiler driving the same old large-diameter steam turbine-generator will result in long-term inefficiencies and higher fossil fuel costs (33% nuclear vs. 42% coal or 56% gas triple pressure steam systems) that will be endured by the converted fossil power plant during its 30-year economic life. The impact of lower net revenues (power sales less O&M costs less fuel costs) may not be sufficient to recover the up-front investments costs for conversion from nuclear to fossil energy.

Recommendations 3

4) The last alternative is to scrap the existing BNPP, sell off any of its usable components to any existing or similarly-design power plants (there is an existing nuclear industry dedicated to the manufacture of old nuclear technology components), or sell its metal scraps to recover valuable materials
5) The remaining alternative is to use Small Modular Reactors (SMRs) to minimize the catastrophic impact of nuclear accidents and ensure energy supply security by having the nuclear energy option available to the country in the long-term
6) The issues surrounding the BNPP should be discussed separately and in another more appropriate forum, but the DOE should be ready to respond to any query on BNPP.

THANK YOU

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