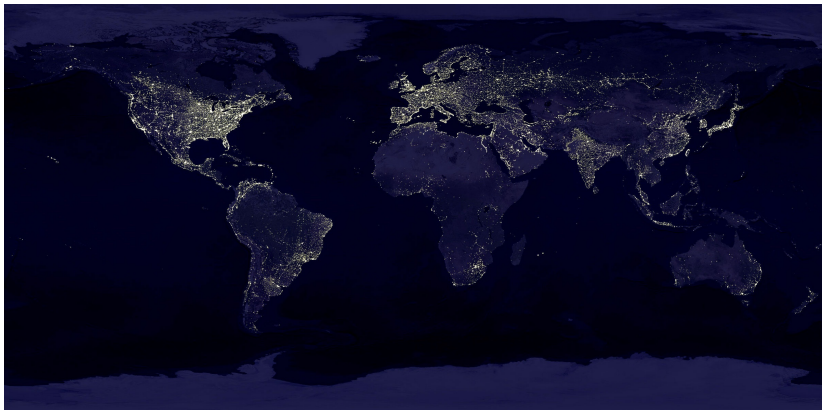


Seminar:  
Nuclear power plants under construction in the world  
Selected Readings in Reactor Technology

Vladimir Radulovič  
mentor: prof. dr. Borut Mavko

04.05.2010

# World Energy Needs



*Planet Earth during the night - montage of around 100 satellite images*

# Nuclear power

## A short history

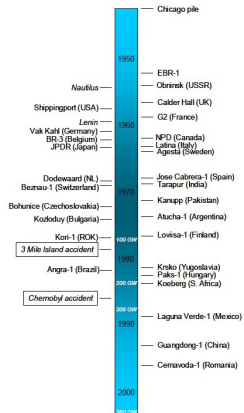
- First power: **EBR-I** reactor near the town of Arco in Idaho (1951)  
Day 1: sufficient power for  $4 \times 200W$  lightbulbs  
Day 2:  $P_e = 200kW$ , or enough to light up the whole building  
Today: historic landmark
- First power from a commercial plant: **NPP Obninsk** in the USSR (1954)  
 $P_e = 5MW$ , shut-down in 2002
- **Calder Hall** NPP in the UK (1956)
- **Shippingport** Reactor in Pennsylvania, US (1957)



# Nuclear power

## A short history

- World nuclear power in 1960  
≈ 1GW
- World nuclear power in 1970  
≈ 100GW
- World nuclear power in 1990  
≈ 300GW
- **Three Mile Island** and **Chernobyl** accidents in 1979 and 1986 - many projects suspended
- World nuclear power today  
≈ 370GW









# China

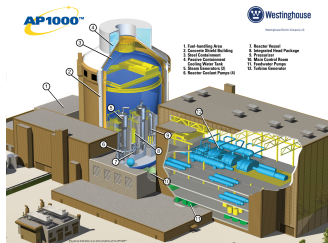
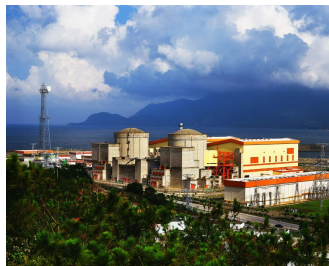
## Overview

- 50GW till 2020
- 8 new NPPs in the last 5 years, 21 currently under construction
- Construction of 27 NPPs to start in next 3 years
- Main source of energy: coal  
⇒ large scale logistics problem  
⇒ high pollution
- 1970s onwards: nuclear technology exploitation, initially acquired from France, Canada, the USSR and the US
- Domestic development efforts

# China

## Reactor types

- **CPR-1000** reactor = domestic effort based on Areva's PWR reactors in Daya Bay; basis of short-term nuclear strategy
- First four Westinghouse **AP1000** 3rd generation reactors being built at Sanmen and Haiyang, further 8 in planning, further 30 proposed; basis of long-term nuclear strategy
- Two Areva **EPR** reactors being built at Taishan
- **CAP1400** reactor = enlarged version of the AP1000 reactor, developed indigenously since 2009



## China

## Plants under construction and firmly planned

Plant	Region	Power [MWe]	Type	Project control	Construction start	Operation start
Lingao 1&2	Guangdong	2x1080	CPR-1000	CGNPC	2005,2006	2010,2011
Qinshan 1&2	Zhejiang	2x650	CNP-600	CNNC	2006,2007	2001,2012
Hongyanhe 1-4	Liaoning	4x1080	CPR-1000	CGNPC	2007-2009	2012-2014
Ningde 1-4	Fujian	4x1080	CPR-1000	CGNPC	2008,2010	2012-2015
Fuqing 1&2	Fujian	2x1080	CPR-1000	CNNC	2008,2009	2013,2014
Yangjiang 1-4	Guangdong	4x1080	CPR-1000	CGNPC	2008-2011	
Fangjiashan	Zhejiang	2x1080	CPR-1000	CNNC	2008,2009	2013, 2014
Sanmen 1&2	Zhejiang	2x1250	AP1000	CNNC	2009	2013,2014
Haiyang 1&2	Shandong	2x1250	AP1000	CPI	2009,2010	2013,2014
Taishan 1&2	Guangdong	2x1700	EPR	CGNPC	2009,2010	2013,2014
Shidaowan	Shandong	210	HTR	Huaneng	2010?	2013 ali 2014
Hongsha 1&2	Guangxi	2x1080	CPR-1000	CGNPC	2010	2014?
Fuqing 3-6	Fujian	4x1080	CPR-1000	CGNPC	2010?	?
Changjiang 1&2	Hainan	2x650	CNP-600	CNNC	2010	2014,2015
Tianwan 3&4	Jiangsu	2x1060	VVER-1000	CNNC	2010	?
Hongshiding 1&2	Shandong	2x1080	CPR-1000	CNEC/CNNC	?	2015
Ningde 5&6	Fujian	2x1080	CPR-1000	CGNPC	?	?
Dafan 1&2	Hubei	2x1250	AP1000	CGNPC	2010	?
Xiaomoshan 1&2	Hunan	2x1250	AP1000	CPI	2010	2015-2018
Taohuajiang 1-4	Hunan	4x1250	AP1000	CNNC	2010	2015
Pengze 1&2	Jianxi	2x1250	AP1000	CPI	2010	2013-2014
Haiyang 3&4	Shandong	2x1250	AP1000	CPI	2010?	?
Tianwan 5&6	Jiangsu	2x1200	VVER-1200	CNNC	2010	?
Wuhu 1&2	Anhui	2x1250	AP1000	CGNPC	2011	2016
<b>Total 57</b>		<b>Total 63130MWe</b>				



# Russia

## Power reactors in operation

Reactor	Type V=PWR	MWe net, each	Commercial operation	Scheduled close
Balakovo 1	V-320	950	5/86	2015
Balakovo 2	V-320	988	1/88	2017
Balakovo 3-4	V-320	950	4/89, 12/93	2018, 2023
Beloyarsk 3	BN600 FBR	560	11/81	2010
Bilibino 1-4	LWGR EGP-6	11	4/74-1/77	2019-21
Kalinin 1-2	V-338	950	6/85, 3/87	2014, 2016
Kalinin 3	V-320	950	12/04	2034
Kola 1-2	V-230	411	12/73, 2/75	2018, 2019
Kola 3-4	V-213	411	12/82, 12/84	2011, 2014
Kursk 1-2	RBMK	925	10/77, 8/79	2021, 2024
Kursk 3-4	RBMK	925	3/84, 2/86	2013, 2015
Leningrad 1-2	RBMK	925	11/74, 2/76	2019, 2022
Leningrad 3-4	RBMK	925	6/80, 8/81	2025, 2011, +15 yr
Novovoronezh 3-4	V-179	385	6/72, 3/73	2016, 2017
Novovoronezh 5	V-187	950	2/81	2035 after upgrade
Smolensk 1-3	RBMK	925	9/83, 7/85, 1/90	2013, 2020
Rostov 1	V-320	990	3/01	2030
Total: 31		21,821 MWe		

# Russia

## Under construction

- 9 reactors currently under construction
- **Rosatom** announcement in 2006: 23% of total power from nuclear power plants by 2020
- In other words:  $2 \times 1200MW$  per year from 2011 to 2014, followed  $3 \times 1200MW$  per year till 2020



*Nuclear power plant in Beloyarsk*

Plant	Reactor Type	MWe	Status, Start Construction	Commercial operation
Kalinin 4	V-320	1000	Const	10/2011
Vilyuchinsk	KLT-40S	40 x 2	Const 5/09	2012
Beloyarsk 4	BN-800 FBR	880	Const	2014
Novovoronezh II -1	VVER 1200/ V-392M	1200	Const 6/08	2012-13
Leningrad II-1	VVER 1200/ V-491	1200	Const 10/08	10/2013
Novovoronezh II -2	VVER 1200/ V-392M	1200	Const 7/09	2015
Volgodonsk/Rostov 3	VVER 1000/ V-320	1100	Const 1983, resumed 9/09	2013 or 2014
Leningrad II -2	VVER 1200/ V-491	1200	Const 4/10	2016
<b>Subtotal of 9 under construction</b>		<b>7860 gross, 7550 net</b>		



# South Korea

## Overview

- 1st NPP in operation: Kori-1 (1978)
- Major boost in the nuclear field: 8 NPPs under construction in the 80s (Westinghouse and Framatome PWRs)
- Domestic development: **KSNP** and **KSNP+** renamed **OPR1000** in 2005



*Ulchin nuclear power station*  
4× OPR1000

# South Korea

## Power reactors in operation

Reactor	Type	Net capacity	Commercial Operation	Planned Close
Kori 1	PWR - Westinghouse	587 MWe	4/78	2017
Kori 2	PWR - Westinghouse	650 MWe	7/83	
Wolsong 1	PHWR - Candu	679 MWe	4/83	
Kori 3	PWR - Westinghouse	950 MWe	9/85	
Kori 4	PWR - Westinghouse	950 MWe	4/86	
Yonggwang 1	PWR - Westinghouse	950 MWe	8/86	
Yonggwang 2	PWR - Westinghouse	950 MWe	6/87	
Ulchin 1	PWR - Framatome	950 MWe	9/88	
Ulchin 2	PWR - Framatome	950 MWe	9/89	
Yonggwang 3	PWR (Syst 80)	1000 MWe	12/95	
Yonggwang 4	PWR (Syst 80)	1000 MWe	3/96	
Wolsong 2	PHWR - Candu	700 MWe	7/97	
Wolsong 3	PHWR - Candu	700 MWe	7/98	
Wolsong 4	PHWR - Candu	700 MWe	10/99	
Ulchin 3	OPR-1000	1000 MWe	8/98	
Ulchin 4	OPR-1000	1000 MWe	12/99	
Yonggwang 5	OPR-1000	1000 MWe	5/02	
Yonggwang 6	OPR-1000	1000 MWe	12/02	
Ulchin 5	OPR-1000	1000 MWe	7/04	
Ulchin 6	OPR-1000	1000 MWe	8/05	
Total: 20		17,716 MWe		

# South Korea

## Under construction

- 6 reactors currently under construction
- **APR-1400** development: 1992-1999
- Designed to withstand a magnitude 7 earthquake - strong selling point
- Large promotion efforts

Reactor	Type	Net capacity	Start construction	Commercial operation
Shin Kori 1	OPR-1000	1000 MWe	June 2006	12/2010
Shin Kori 2	OPR-1000	1000 MWe	June 2007	12/2011
Shin Wolsong 1	OPR-1000	1000 MWe	November 2007	3/2012
Shin Wolsong 2	OPR-1000	1000 MWe	September 2008	1/2013
Shin Kori 3	APR-1400	1350 MWe	October 2008	9/2013
Shin Kori 4	APR-1400	1350 MWe	September 2009	9/2014
Shin Ulchin 1	APR-1400	1350 MWe	March 2011	12/2015
Shin Ulchin 2	APR-1400	1350 MWe	March 2012	12/2016
Shin Kori 5	APR-1400	1350 MWe	8/2014	12/2018
Shin Kori 6	APR-1400	1350 MWe	8/2015	12/2019
Shin Wolsong 3	APR-1400	1350 MWe		6/2020
Shin Wolsong 4	APR-1400	1350 MWe		6/2021
Total 12		<b>14,800 MWe</b>		



# India

## Overview

- Planned increase of nuclear power to 20GW by 2020 and to 63GW by 2032
- Largely independent nuclear programme (including mining, fuel and heavy water production, fuel reprocessing)
- India is excluded from the **Non Proliferation Treaty** on account of its nuclear weapons capability
- 1st nuclear test in 1974 - "peaceful nuclear explosion"

# India

## Overview

- Planned increase of nuclear power to 20GW by 2020 and to 63GW by 2032
- Largely independent nuclear programme (including mining, fuel and heavy water production, fuel reprocessing)
- India is excluded from the **Non Proliferation Treaty** on account of its nuclear weapons capability
- 1st nuclear test in 1974 - "peaceful nuclear explosion"
- Majority of India's power reactors are **PHWRs** - first one built in cooperation with Canada and was started up in 1973 (Rajasthan-1)
- 1990s - very low capacity factors on account of India's isolation, considerable growth by the end of the century
- Recent builds: Tarapur 3&4 (2005,2006) - PHWRs, 490MW of power



# India

## Under construction

- 2×**PHWRs** under construction
- 2×**VVER-1000** reactors under construction
- 500MW **FBR** under construction: designed to be fueled with MOX and to breed fissile uranium and plutonium from fertile thorium and uranium:



Reactor	Type	MWe net, each	Project control	Commercial operation due
<b>Kaiga 4</b>	PHWR	202 MWe	NPCIL	3/2010
<b>Rajasthan 6</b>	PHWR	202 MWe	NPCIL	2/2010
<b>Kudankulam 1</b>	PWR (VVER)	950 MWe	NPCIL	9/2010
<b>Kudankulam 2</b>	PWR (VVER)	950 MWe	NPCIL	3/2011
<b>Kalpakkam PFBR</b>	FBR	470 MWe	Bhavini	9/2011
Total (5)		2774 MWe		



*Kalpakkam FBR  
construction*

# Europe

Bulgaria, Slovak Republic, Ukraine

- 2 NPPs under construction in Bulgaria, the Slovak Republic and the Ukraine
- Bulgaria: VVER-1000 (Belene 1&2)
- Slovak Republic: VVER-440 (Mochovce 3&4)
- Ukraine: VVER-1000 (Khmelnitsky 3&4)





# Europe

## France - Overview

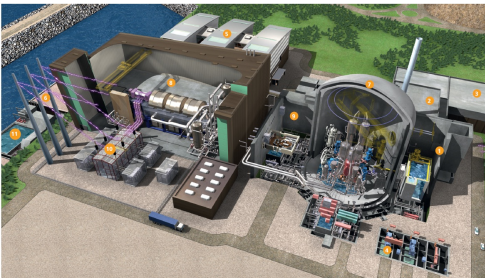
- France is the most active country in the nuclear field in Europe
- Over 75% of total power from NPPs
- Decision to go nuclear taken in 1974 (oil crisis, lack of energy sources)
- Very low electricity prices today
- All French reactors are PWRs of 3 standard types
- Successful marketing of its technology



# Europe

## France - Under construction

- 2007: construction started on the **Flamanville-3** unit, an **EPR** reactor (1650MW)
- Important for operating experience
- All French reactors to be changed with EPRs from 2020 onwards
- New EPR planned at Penly



# Europe

## Finland

- 2 NPPs with 2 modules each in operation in Finland
- Efficiency among the highest in the world - capacity factors up to 94%
- Constant upgrades to increase plant life and output power
- 2002: Decision to build a new power plant - would be the first in over a decade in Europe
- 2005: construction started on a 3rd unit at the **Olkiluoto** plant - an **EPR** reactor
- Expected start-up: 2012
- One further reactor in planning



# North and South America

## The US and Argentina

- The **US** are the largest producer of nuclear power in the world
  - 104 nuclear reactors in operation
  - Very few new nuclear plants in the past 3 decades
  - Currently completing **Watts Bar 2** unit, a 1160MW PWR (construction stopped in 1988)
  - 9 planned reactors of different types: (ABWR, AP1000, US EPR); total power = 11GW
- 2 PHWR reactors operating in **Argentina**; total power = 935MW
  - A third 692MW PHWR (Atucha-2) under construction in Buenos Aires, expected to come on-line in 2011





# Other countries

## Iran, Japan, Pakistan

- 54 NPPs in operation in **Japan**, producing 30% of total power
- First power plant operation start: 1966; nuclear power a strategic priority ever since
- Most reactors are BWRs, some PWRs
- **ABWR** Shimane-3 (1370MW) currently under construction
- Further 10 ABWR units and 3 APWR units planned
- First NPP in **Pakistan** started operation in 1972, powered by a PHWR
- Chashma-1, a 300MW PWR operational since 2000
- Construction on Chashma-2 begun in 2005



# Planned reactors in the world

Country	Planned reactors
Argentina	1
Belarus	2
Brasil	1
Canada	4
China	35
Czech Republic	2
Egipt	1
France	1
India	23
Indonesia	2
Iran	2
Japan	13
Kazakhstan	2
North Korea	1
South Korea	6
Pakistan	2
Romania	2
Russia	7
South Africa	3
Thailand	2
Ukraine	2
United Arab Emirates	3
UK	4
USA	9
Vietnam	2
<b>Total</b>	<b>132</b>

# Conclusion

- Nuclear energy  $\Rightarrow$  priority for many countries
- Major role in decarbonization of energy
- Large undertakings in the nuclear field - including nuclear fusion, the energy source of the future

