Nuclear Futures?

A Survey of Nuclear Energy in Eastern Europe

Prof. Dr. Christian von Hirschhausen

Cand.Ing. Sophia Rüster

EE²

Technische Universität Dresden

DREWAG-Stiftungslehrstuhl EnErgiewirtschaft / EnergyEconomics

SESSA / Berlin
10.12.2004

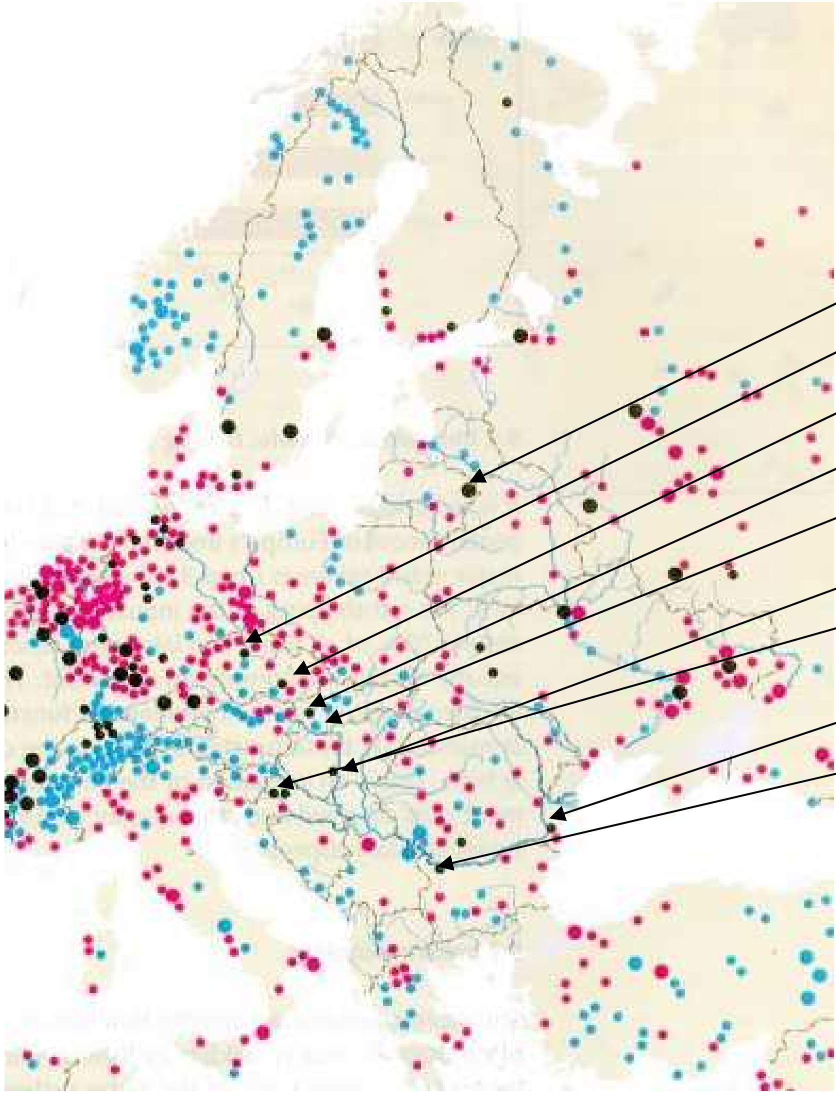
Agenda

1. Overview
   - Nuclear Power Plants in Eastern Europe
   - Technical Description / Share of Nuclear Energy
   - Failures & Accidents
   - Situation in Eastern Europe / Way of the EU
2. MIT-Study
   - Situation on Energy Markets in general
   - Costs of Electric Generation Alternatives
   - Results
3. Cost Comparison
   - Definition of Generation Costs
   - German versus Eastern European Country
   - Transport Costs
   - Net Present Value
4. Conclusion

Agenda

1. Overview
   - Nuclear Power Plants in Eastern Europe
   - Technical Description / Share of Nuclear Energy
   - Failures & Accidents
   - Situation in Eastern Europe / Way of the EU
2. MIT-Study
   - Situation on Energy Markets in general
   - Costs of Electric Generation Alternatives
   - Results
3. Cost Comparison
   - Definition of Generation Costs
   - German versus Eastern European Country
   - Transport Costs
   - Net Present Value
4. Conclusion

Nuclear Power Plants in Eastern Europe



Country	Location
Lithuania	Ignalina
Czech Republic	Temelin Dukovany
Slovakia	Bohunice Mochovce
Hungary	Paks
Slovenia	Krsko
Romania	Cernavoda
Bulgaria	Kosloduy
Russia	10 locations
Ukraine	4 locations

- Traditional Power Plant
- Water Power Plant
- Nuclear Power Plant

http://maps.unomaha.edu/Peterson/funda/MapLinks/EuropeOverview/tfsv1map4.jpg

Technical Description I

	Location	Type of Reactor	Capacity (MW/net)	Legal Status	Technical Status
CZ	Temelin Dukovany	DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 440/213	1 x 981 1 x 981 4 x 417	- - -	- - modernization program
SK	Bohunice Mochovce	DWR, WWER 440/230 DWR, WWER 440/213 DWR, WWER 440/213 DWR, WWER 440/213	2 x 408 2 x 408 2 x 408 2 x 408	closure in 2006 closure in 2008 - under construction	improvements in safety, 1996 started program of incremental reconstruc-tion → life time increase
H	Paks	DWR, WWER 440/213	4 x 430	closure > 2020	recent problems of block 2 resolved
SLO	Krsko*	Westinghouse DWR	1 x 632	closure in 2023	modernization took place
RO	Cernavoda	Canadian Deuterium-Uranium-Reactor, CANDU 600	1 x 630 1 x 630 3 x 630	- under construction 1 block completion 2006 2 blocks completion 2010	safety improvements
LT	Ignalina	RBMK 1500, water coo-ling, graphitemoderator	2 x 1185	1 block closure in 2007 1 block closure in 2008	adjustment: 1300MW gross, improvements
BG	Kosloduy Belene	DWR, WWER 440/230 DWR, WWER 440/230 DWR, WWER 1000 DWR, WWER 1000	2 x 408 2 x 408 2 x 953 2 x 953	closed in 2003 closure in 2006 modernization construction stop in 1990	improvements in controle technology/cooling/ radiation- & fire protection completion unrealistic

Sources: Jahrbuch der Atomwirtschaft 2001;
http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity;
http://www.iaea.org/programmes/a2/index.html

DWR: Druckwasserreaktor → Pressurized Water Reactor
* 50 % Property of Croatia

Technical Description II

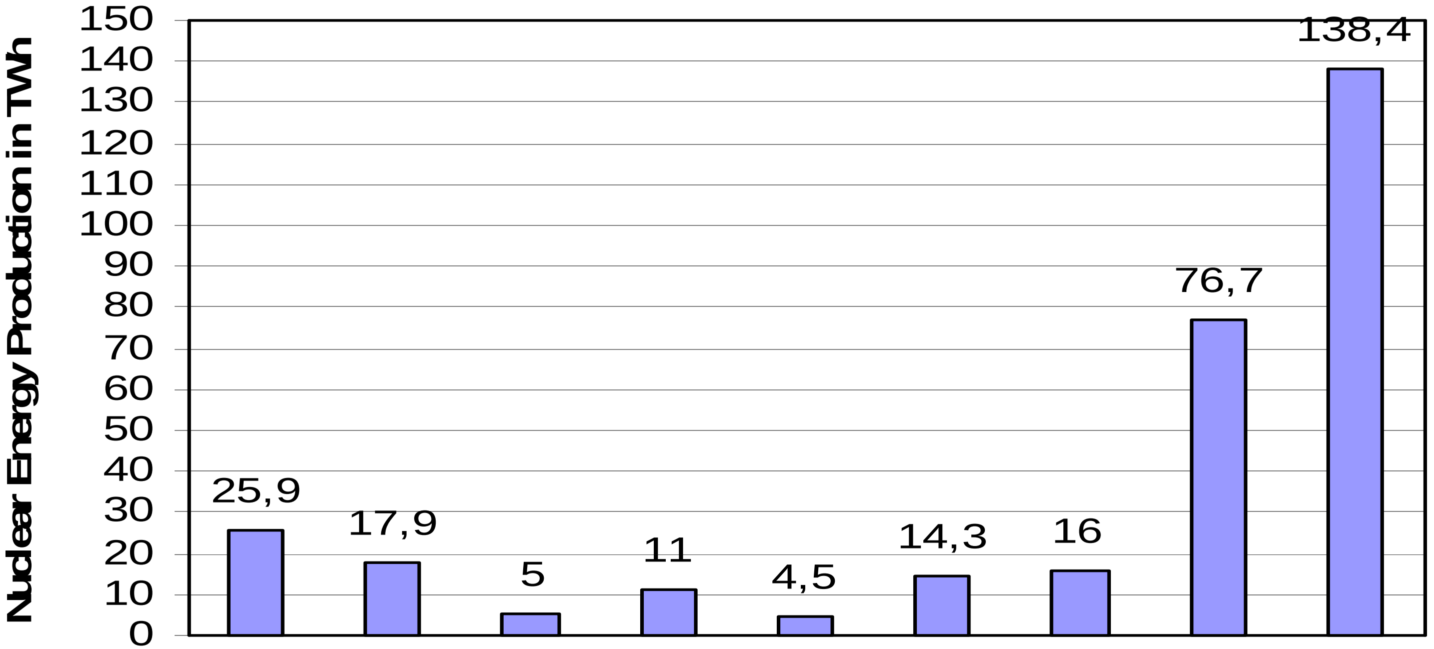
	Location	Type of Reactor	Capacity (MW/net)	Legal Status	Technical Status
UA	Rowno Rowno South-Ukraine Kmelnitzki Kmelnitzki Saporoschje	DWR, WWER 440 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000	2 x 370 2 x 950 3 x 950 2 x 950 2 x 950 6 x 950	- - - - under construction -	- 1 just finished 10/04 - 1 just finished 08/04 - -
RUS	Bilibinsk Nowo Woronesch Nowo Woronesch Kola Belojarsk Kursk Kursk Sosnowi Bor Smolensk Kalinin Kalinin Balachowo Balachowo Rostow Rostow	LWGR DWR, WWER DWR, WWER 1000 DWR, WWER 440 SNR, FBR BN 600 LWGR, RBMK 1000 LWGR, RBMK 1000 LWGR, RBMK 1000 LWGR, RBMK 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000 DWR, WWER 1000	4 x 11 2 x 385 1 x 953 4 x 410 1 x 560 4 x 925 1 x 925 4 x 925 3 x 925 2 x 953 1 x 953 4 x 953 1 x 953 1 x 953 1 x 953	- - - - - - under construction - - - under construction - under construction - under construction	total capacity of nuclear power plants increases → 2010 about 170 TWh per year

DWR = Druckwasserreaktor → Pressurized Water Reactor
SNR = Schneller Brüter → Fast-Breeder Reactor

LWGR = Water Cooling, Graphite Moderator

Sources: http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity, http://www.iaea.org/programmes/a2/index.html; Jahrbuch der Atomwirtschaft 2001

Share of Nuclear Energy (2003)



Country	CZ	SK	SLO	H	RO	LT	BG	UA	RUS
Nucl. Power Prod. in TWh	25,9	17,9	5	11	4,5	14,3	16	76,7	138,4
Total Power Prod. in TWh	83,2	31,1	12,3	33,7	48,6	17,9	42,5	167	836,9
Share in %	31,1	57,6	40,7	32,6	9,3	79,9	37,6	45,9	16,5

Source: http://www.iaea.org/programmes/a2/index.html

Failures & Accidents I

Tschernobyl: 26.04.1986 Great Super-GAU

Planned Experiment:

Do the turbines produce enough electricity for the emergency-cooling of the reactor in the case of a blackout? Test arrangement: average protection system disconnected → reactor unprotected!

The Accident:

- Short time before the start of experiment: reactor capacity fell because of an error in operation.
- Employees eliminated braking bar, safety status fell again, experiment starts anyway!
- Too much cooling pumps connected → water boiled (instead of vaporizing).
- Insufficient cooling.
- Capacity increased, average protection system disconnected, manual switching on neccesary.
- Construction fault of RBMK-reactor: braking bars run in too slowly, graphite at their top.
- Graphite accelerates chain reaction → further escalation of the capacity.
- Strong heat → channels of the braking bars deformed, braking bars seized → disaster.
- Hydrogen & oxygen were generated → detonating gas explosion.
- Big part of the reactor content flew out to the environment.

The Results:

-32 People died immediatly or during the following weeks because of falling debris and the high radiation, thousands of deads as a result of late effects (cancer & high infant mortality).

Source: http://www.reyl.de/tschernobyl/

Failures & Accidents II

Paks / Hungary

10.04.2003: leakiness at block 2 → emission of radio-active gas
classification 3rd degree (highest one) → closure of the reactor until 03.09.2004

Temelin / Czech Republic

Until September 2004 more than 70 failures, some examples follow:
13.10.2000: problems with the controls of block 1 → automatic shut down
26.10.2000: main circulation pumps dropped out → reactor was shut down
16.12.2000: again malfunction of pumps → automatic shut down
12.01.2001: leaky lines → oil emission → fire in secondary cycle
08.03.2001: regulation valves faulty → shut down of the reactor
01.06.2001: failure in primary cycle of block 1→ 80.000 ltrs of radioactive water left
21.06.2001: vibrations of the turbine → base plate dropped → material damaged
17.09.2001: reduced oil pressure → reactor was shut down
01.11.2001: failure in cooling system of block 1 → leaky pump
11.01.2002: electricity supply of turbine cooling blackout
06.07.2002: turbine vibrations in block 2 → overheating → short-circuit
03.06.2003: discovery of leakiness in secondary cycle of block 1
19.03.2004: discovery of disruptions in turbine rotor of block 2
16.08.2004: leakiness in generator system of block 1
20.09.2004: leakiness in generator cooling system of block 1 → shut down of reactor

Sources: http://www.haea.gov.hu; http://www.anti.atom.at/

Situation in Eastern Europe

Three Tasks in the Nuclear Sector

Improvement of safety	Finish constructions	Construction of new NPP
- existing NPP economic, often completely deducted → just operating costs - partially russian types → safety problems!! →credits by EURATOM & European Bank of Re-building and Development →Tacis-program: 774 Mio € (former Soviet Union) →Phare-program: 192 Mio € (Eastern Europe)	- financial problems in many Eastern European states → constructions stopped - uncertain future (financial problems, safety regulations of the EU, …)	- new NPP mostly not economic (compare with the following study) → alternative: gas- and vapour power plants (cheaper & faster construc-tion) - NPP = base load, base load in most Eastern European countries in over-capacity → construction of peak load power plants more important

Way of the European Union

Aims of the European Commission:
Short-term: **technical improvements, operational safety increase**
Long-term: **closure of dangerous Nuclear Power Plants, modernization of newer NPPs**

Financial Possibilities:
- **PHARE-program/TACIS-program**
- **credits by Euratom**
- **funds of the European Bank of Rebuilding and Development**

Political Possibilities:
- **commissions and workgroups, e.g. the CONCERT-group**
- **European Nuclear Installations Safety Group (ENIS)**

Progress until today:
- **agreements about the closure of not retrofitable reactors in Lithuania, Slovakia and Bulgaria**
- **starting of PHARE-programs**
- **permanent operational aid in some power plants**
- **improvements of safety-standards of the power plants, that are in construction in Slovakia, Ukraine, Russia (→ TACIS- and PHARE-programs, e.g. the Ukraine got 100 million $)**
- **improvements of operating control (supply of equipment)**
- **improvements of energy strategies, the development of renewable energy sources & efficiency**

Source: European Union: http://europa.eu.int/scadplus/leg/de/lvb/127036.htm

Agenda

1. Overview
   - Nuclear Power Plants in Eastern Europe
   - Technical Description / Share of Nuclear Energy
   - Failures & Accidents
   - Situation in Eastern Europe / Way of the EU
2. MIT-Study
   - Situation on Energy Markets in general
   - Costs of Electric Generation Alternatives
   - Results
3. Cost Comparison
   - Definition of Generation Costs
   - German versus Eastern European Country
   - Transport Costs
   - Net Present Value
4. Conclusion

Situation on Energy Markets in general

Nuclear power plant:	**high capital costs, low marginal operating costs → just suitable for baseload**
Traditional industry:	**risks born by consumers rather than by suppliers**
Competitive generation:	**risks born by investors rather than by consumers**
Additional problem:	**regulatory & political challenges associated with obtaining a licence for building a nuclear power plant**

⬇

Investors favor less capital-intensive investments!

⬇

Can nuclear power plants be an attractive investment?

When are nuclear power plants economic?

Costs of Electric Generation Alternatives

	Nuclear	Coal	Gas
Construction costs	2000 $/kWe	1300 $/kWe	500 $/kWe
Operational costs → escalation rate	1.5 Cents/kWh 1.0 % per year	1.2 $/MMbtu 0.5 % per year	3.5 $/MMbtu 1.5 % per year
Construction period	5 years	4 years	2 years
Capacity factor	85 %	85 %	85 %
Equity	50 % 15 % nominal net of income taxes	40 % 12 % nominal net of income taxes	40 % 12 % nominal net of income taxes
Debt	50 % 8 % nominal	60 % 8 % nominal	60 % 8 % nominal
Inflation	3 %	3 %	3 %
Income tax rate	38 %	38 %	38 %
Project economic life	25 years	25 years	25 years

Source: „The Nuclear Power – An Interdisziplinary Study“, Massachusetts Institute of Technology, 2003

Results

Nuclear:	**7.0 cents/kWh**
Coal:	**4.4 cents/kWh**
Gas:	**4.1 cents/kWh**

Possibilities to reduce nuclear costs and resulting costs

- **Reduce construction costs (25%):** → **5.8 cents/kWh**
- **Reduce construction time by 1 year:** → **5.6 cents/kWh**
- **Reduce costs of capital to be equivalent to coal & gas:** → **4.7 cents/kWh**

⬇

A new nuclear power plant is much more expensive than gas or coal, even if costs were reduced!

Source: „The Nuclear Power – An Interdisziplinary Study“, Massachusetts Institute of Technology, 2003

Agenda

1. Overview
   - Nuclear Power Plants in Eastern Europe
   - Technical Description / Share of Nuclear Energy
   - Failures & Accidents
   - Situation in Eastern Europe / Way of the EU
2. MIT-Study
   - Situation on Energy Markets in general
   - Costs of Electric Generation Alternatives
   - Results
3. Cost Comparison
   - Definition of Generation Costs
   - German versus Eastern European Country
   - Transport Costs
   - Net Present Value
4. Conclusion

Definition of Generation Costs

Generation Costs = Capital C. + Fuel C.+ Personnel C. + Auxiliary C. + Disposal C.

(fix) *(var.)* *(var.)* *(var.)* *(var.)*

$$GC = \frac{r * OC}{1 - e^{-rT}} + \frac{c_F}{\eta * H_U} + \frac{E * c_E}{\tau} + c_A + c_D$$

Assumptions:

		Germany	*Eastern Europe*
Overnight Costs	OC	1 500 €/kW	1 150 €/kW
Discount Rate	r	0,12/year	0,15/year
Life Time	T	60 years	40 years
Specific Fuel Costs	c_F	3,5 Mio €/t	3,0 Mio €/t
Efficiency	η	0,32	0,32
Net Calorific Value	H_U	0,82 bn kWh/t	0,82 bn kWh/t
Number of Employees	E	0,08/MW	0,16/MW
Specific Personnel Costs	c_E	61 600 €	20 000 €
Full Load Hours	τ	7008 h	6570 h
Auxiliary Costs	c_A	0,05 ct/kWh	0,04 ct/kWh
Disposal Costs	c_D	1 ct/kWh	0,8 ct/kWh
Resulting Variable Costs	VC	0,0245 €/kWh	0,0203 €/kWh
Resulting Fixed Costs	FC	0,0206 €/kWh	0,0197 €/kWh
Resulting Total Costs	TC	0,0451 €/kWh	0,0400 €/kWh

Results: (last three rows)

Sources:
Steven Stoft
„Power System Economics“
2002
Prof. Gampe
Technical University of Dresden

German versus Eastern European Country

Annual Revenue Requirement per kW (ARR) – Base: European Pressurized Reactor

$$ARR = FC + Cf * VC$$

$$FC = \frac{r * OC}{1 - e^{-rT}}$$

T: Life Time of NPP
OC: Overnight Costs
FC: Fixed Costs
Cf: Capacity Factor
VC: Variable Costs
r: Discount Rate

Assumptions:

	OC	r	T	Cf	VC (gross)
Germany	1 500 €/kW	0,12/year	60 years	0,80	0,0306 €/kWh
Eastern European Country	1 150 €/kW	0,15/year	40 years	0,75	0,0271 €/kWh

Results:

	FC	ARR
Germany	180,13 €/kWy	0,0451 €/kWh
Eastern European Country	172,93 €/kWy	0,0400 €/kWh

Sources: Steven Stoft „Power System Economics“ 2002;
Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Transport Costs

Is it economic to trade nuclear electricity from East to West Europe?

Total Costs = Production Costs + Transport Costs

Transport Costs = average distance * average costs per km

$$TrC = 2000km * 0{,}05 \frac{ct}{100km * kWh} = \underline{\underline{0{,}01 \frac{€}{kWh}}}$$

	Germany	Eastern Europe
Production Costs	0,0451 €/kWh	0,0400 €/kWh
Transport Costs	0,0000 €/kWh	0,0100 €/kWh
Sum	0,0451 €/kWh	0,0500 €/kWh

Transport of nuclear electricity from Eastern to Western Europe is not economic.

Agenda

1. Overview
   - Nuclear Power Plants in Eastern Europe
   - Technical Description / Share of Nuclear Energy
   - Failures & Accidents
   - Situation in Eastern Europe / Way of the EU
2. MIT-Study
   - Situation on Energy Markets in general
   - Costs of Electric Generation Alternatives
   - Results
3. Cost Comparison
   - Definition of Generation Costs
   - German versus Eastern European Country
   - Transport Costs
   - Net Present Value
4. Conclusion

Conclusion

- **Nuclear Energy is considered as a serious option by many new member countries and even also by Russia und the Ukraine.**

- **Back of the rough calculations indicate that East European nuclear generation costs are lower than West European, but only a small margin.**

- **Intensive East-West-trade of nuclear electricity seems unlikely.**

Thank you very much for your attention!

Types of Reactors I

Pressurized Water Reactor:

- water = cooling and moderator
- primary (cooling-) cycle and secondary cycle
- failures sometimes in the cooling cycle
- American Westinghouse or Sowjet WWER

WWER 440/230:
= oldest of the WWER series
- different construction- and safety faults (= reactor of high risk)
- European Union: Agenda 2000, 15.07.1997: this type of reactor can not be modernized
→ necessity of closure in close future

WWER 440/213:
= technical further development of WWER 220/230
- tower of condensation → in case of a leak in Primary Cycle, resulting vapour can condense -
- still construction faults (e.g. insufficient fire protection, just 1 standby-system for 2 reactors)

WWER 1000:
- same reactor pressure tank, higher power density → quicker corrosion of the walls!

Fast-Breeder Reactor:

-**additional to energy production: resulting plutonium**
- fast neutrons necessary → sodium as coolant, 3 cycles
- sodium and water react heavy exotherm → risk of fire

Source: http://www.wien.gv.at/wua/atom/glossar/w.htm#wwer440213

Types of Reactors II

Reactor Bolshoi Moshchosti Kanalni (RBMK):

- boiling water reactor with pressure tubes & graphite moderator
- Soviet construction, 14 worldwide, all in former Soviet Union
- risk of leakages at the pressure tubes → cooling stops in case of failure→ chain reaction continues (moderator graphite is still there) → overheating/fire (→ disaster of Tschernobyl)

RBMK 1000: **→ Tschernobyl**
RBMK 1500: **→ Ignalina (Lithuania) = biggest reactor of the world**

Canadian Deuterium-Uranium Reactor (CANDU):

- **cooling and moderator: weavy water (deuterium)**
- safetiest existing reactor!

Advanced Gas Cooled Reactor (AGR):

- **cooled by carbondioxide, moderator: graphite, fuel: uranoxide**
= military development (reactors with graphite moderator are suited for plutonium production for nuclear weapons)

European Pressurized Water Reactor (EPR):

= future type (constructed by Siemens/Framatom/Electricité de France & German Energy Suppliers)
- different improvements, e.g. EPR forms „nuclear island“: whole plant-system wrapped by concrete
- fuel: MOX, lifetime: 60 years
- could be the safetiest power plant

Sources: http://www.wien.gv.at/wua/atom/glossar/w.htm#wwer440213;
Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Sources I

Amberger Bürgerinitiative: http://www.asamnet.de/oeffentl/bi/310304g.htm

Antiatom International: http://www.unet.univie.ac.at/~a9406114/aai/index.html

Apfelbeck, Baidatsch, Pessier, 2004: „Comparing Efficiency in Central European Electricity Distribution“, Dresden University of Technology

Atw – International Journal for Nuclear Energy, 2003, Booklet 10, pp. 624-641

Booklet of the conference “Atomausstieg in Osteuropa”, 30.04.-01.05.1999, Dresden

Bundesministerium für Umwelt, Naturschutz, Reaktorsicherheit: Themenpapier Atomkraft http://www.google.de/search?q=rowno+rum%C3%A4nien+atom&btnG=Suche&hl=de

City Wien: http://www.wien.gv.at

Deutch, J./Moniz, E.J., Massachusetts Institute of Technology 2003, „The Nuclear Power – An Interdisziplinary Study“, Washington D.C.

Die Partei, Landesverband Hessen: http://www.reyl.de/tschernobyl/osteuropa.html

Energy, Information, Administration, Official Energy Statistics from the U.S. Government http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity

Europäische Union/Energie: http://europa.eu.int/scadplus/leg/de/s14000.htm

Greenpeace Deutschland: http://archiv.greenpeace.de

Hungarian Atomic Energy Authority: http://www.haea.gov.hu

Sources II

International Atomic Energy Agency: http://www.iaea.org/programmes/a2/index.html

Jahrbuch der Atomwirtschaft 2001, INFORUM Verlag u. Verw. Ges., Bonn

Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Österreichisch-Tschechisches Anti-Atom-Kommitee: http://www.anti.atom.at

Sattari, J., Research Project Energy Policy: http://www.anti-atom.de

Umweltinstitut München e.V.: http://www.umweltinstitut.org

Voß, Prof. Dr.-Ing. Alfred, IER Uni Stuttgart, Forum in Berlin, 12.03.2003
“Nachhaltigkeit & Klimaschutz – Wettbewerbsfähigkeit & Versorgungssicherheit: ohne Kernenergie möglich?”

Wirtschaftsverband Kernbrennstoff-Kreislauf e.V. Berlin: http://www.kernbrennstoff.de

World, Economy, Ecology & Development: http://www.weed-online.de

World Information Service on Energy: http://www.antenna.nl/wise/