

DUAL FLUID REACTOR (DFR)

A NEW CONCEPT FOR A NUCLEAR POWER REACTOR

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FERURAY 15/22, 2014

Personnel

The Dual Fluid Reactor (DFR*) was developed at the Institute of Solid State Nuclear Physics by:

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- Dr. Armin Huke,
- Dr. Ahmed Hussein,
- Dr. Götz Ruprecht,
- Dipl.-Ing. Stephan Gottlieb, and
- Mr. Daniel Weißbach.
- Many consultants and supporters.

*Patent Pending in Germany, WO2013041085 A2

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- Total energy delivered by 1000MW in one year is 3.15×10^{16} J = 8.76 TWh.

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- Nuclear power plants provided 17.1% of the world's electricity production in 2012.
- 13 countries relied on nuclear energy to supply at least 25% of their total electricity.

Current Reactors World Wide

Country	Reactors	MW _e	BkWh	% Of Total
Argentina	2	935	5,903	4.7
Armenia	1	375	2,124	26.6
Belgium	7	5,927	38,464	51.0
Brazil	2	1,884	15,170	3.1
Bulgaria	2	1,906	14,861	31.6
Canada	20	14,135	89,060	15.3
China	17	12,860	92,652	2.0
Czech RP	6	3,804	28,603	35.3
Finland	4	2,752	22,063	32.6
France	58	63,130	407,438	74.8
Germany	9	12,068	94,098	16.1
Hungary	4	1,889	14,763	45.9
India	20	4,391	29,665	3.6
Iran	1	915	1,328	0.6
Japan	50	44,215	17,230	2.1
Korea Rep.	23	20,739	143,550	30.4
Mexico	2	1,530	8,412	4.7

Current Reactors World Wide

Country	Reactors	MW _e	BkWh	% Of Total
Netherlands	1	482	3,707	4.4
Pakistan	3	725	5,271	5.3
Romania	2	1,300	10,564	19.4
Russia	33	23,643	166,293	17.8
Slovakia	4	1,816	14,411	53.8
Slovenia	1	688	5,244	36.0
South Africa	2	1,860	12,398	5.1
Spain	8	7,560	58,701	20.5
Sweden	10	9,395	61,474	38.1
Switzerland	5	3,278	24,445	35.9
Taiwan, China	6	5,028	38,733	18.4
Ukraine	15	13,107	84,886	46.2
U.K.	18	9,938	63,964	18.1
U.S.	104	102,136	770,719	19.0
Total	440	374,411	2,346,194	NA

Reactors Under Construction World Wide

Country	Reactors	Total MW _e
Argentina	1	692
Brazil	1	1,245
China	28	27,844
China, Taiwan	2	2,600
Finland	1	1,600
France	1	1,600
India	7	4,824
Japan	2	2,650
Pakistan	2	630
Russia	11	9,297
Slovak Republic	2	880
S. Korea	4	4,980
Ukraine	2	1,900
United Arab Emirates	2	2,690
United States	3	3,399
Total	69	66,831

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- Long life of the resource.
- Safe production and operation.

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Energy Content of Various Sources

Source	Energy Density
Firewood (dry)	16 MJ/kg
Brown coal (lignite)	10 MJ/kg
Black coal (low quality)	13-23 MJ/kg
Black coal (hard)	24-30 MJ/kg
Natural Gas	38 MJ/m ³
Crude Oil	45-46 MJ/kg
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Energy Content of Wind and Solar

Source	Natural Energy Flows Providing 1 kW of Available Power	
Wind	Turbine Wind speed 45 km/hr	Turbine swept area 0.85 m ²
	Wind speed 14 km/hr	Turbine swept area 31.84 m ²
Solar PV	Surface perpendicular to the sun's rays at noon with sun directly overhead	Surface area 1m ²
	For an hourly average of 1kW taken over a day	Surface area 2.5 - 5 m ² depending on location

Source: http://www.mpoweruk.com/energy_resources.htm

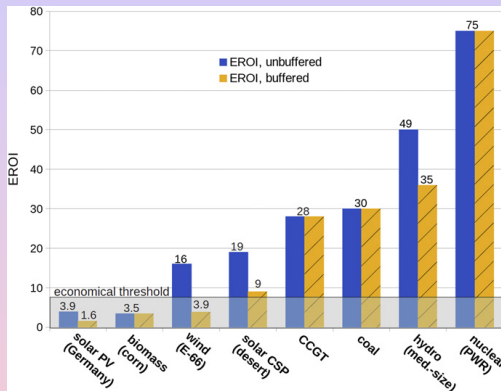


Fig. 3. EROIs of all energy techniques with economic “threshold”. *Biomass:* Maize, 55 t/ha per year harvested (wet). *Wind:* Location is Northern Schleswig Holstein (2000 full-load hours). *Coal:* Transportation not included. *Nuclear:* Enrichment 83% centrifuge, 17% diffusion. *PV:* Roof installation. *Solar CSP:* Grid connection to Europe not included.

Source:

“Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants.”

D. Weibach, G. Ruprecht, A. Huke, K. Czerski, S. Gottlieb, A. Hussein

Why Nuclear Power

Lifecycle Greenhouse Gas Emission Estimates
for Electricity Generators

Technology	Mean	Low	High
	g CO ₂ Eq./kWh _e		
Lignite	1,054	790	1,372
Coal	888	756	1,310
Oil	733	547	935
Natural Gas	499	362	891
Solar PV	85	13	731
Biomass	45	10	101
Nuclear	29	2	130
Hydroelectric	26	2	237
Wind	26	6	124

Source: http://www.cameco.com/common/pdf/uranium_101/Cameco_-_Corporation_Report_on_GHG_Emissions_nov_2010.pdf

Why Nuclear Power

“DeathPrint” of Various Energy Sources

Energy Source	Mortality Rate (deaths/TkWhr)	Comments
Coal global average	170,000	50% global electricity
Coal China	280,000	75% China's electricity
Coal U.S.	15,000	44% U.S. electricity
Oil	36,000	36% of energy, 8% of electricity
Natural Gas	4,000	20% global electricity
Biofuel/Biomass	24,000	21% global energy
Solar (rooftop)	440	< 1% global electricity
Wind	150	≈ 1% global electricity
Hydro global average	1,400	15% global electricity
Nuclear global average	90	17% global electricity w/Chern&Fukush

Source: <http://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid>

Why Nuclear Power

Life Expectancy of Fossil Fuels

Fossil Fuel	Reserves	Consumption	Year	Life Time (years)	CO ₂ Emissions (tonnes)
Natural Gas	$1.90 \times 10^{14} \text{ m}^3$	$3.37 \times 10^{12} \text{ m}^3$	2011	56	6.75×10^9
Oil	$1.47 \times 10^{12} \text{ bbl}$	$2.87 \times 10^{10} \text{ bbl}$	2011	51	1.14×10^{10}
Coal	$8.60 \times 10^{11} \text{ ton}$	$6.64 \times 10^9 \text{ ton}$	2008	129	1.44×10^{10}

Source: US Energy Information Administration
<http://www.eia.gov>

Reactors Under Construction World Wide

Reactor Type	Reactor Type Description	Number of Reactors	Total (MW _e)
BWR	Boiling Light-Water-Cooled and Moderated Reactor.	4	5,250
FBR	Fast Breeder Reactor.	2	1,259
HTGR	High-Temperature Gas-Cooled Reactor.	1	200
LWGR	Light-Water-Cooled, Graphite-Moderated Reactor.	1	915
PHWR	Pressurized Heavy-Water-Moderated and Cooled Reactor (CANDU)	5	3,212
PWR	Pressurized Light-Water-Moderated and Cooled Reactor.	56	55,995
Total		69	66,831

Sources: International Atomic Energy Agency PRIS database <http://www.iaea.org/programmes/a2/index.html>

Nuclear Fission

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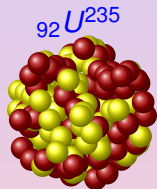
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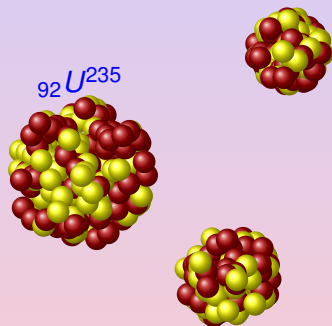
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 - Neutron induced fission.

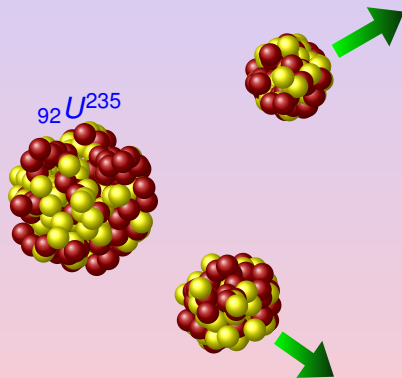
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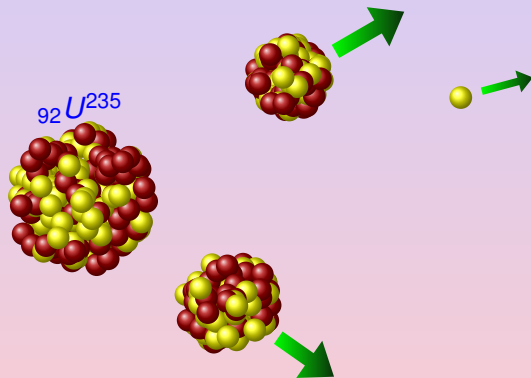
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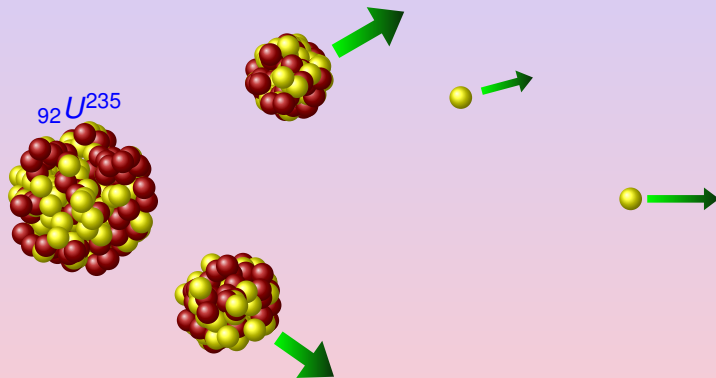
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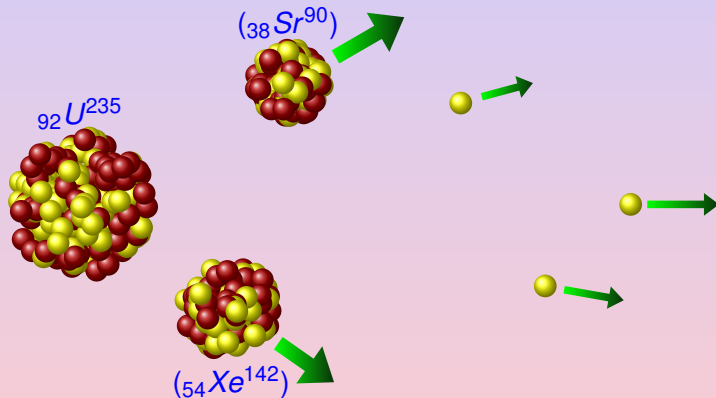
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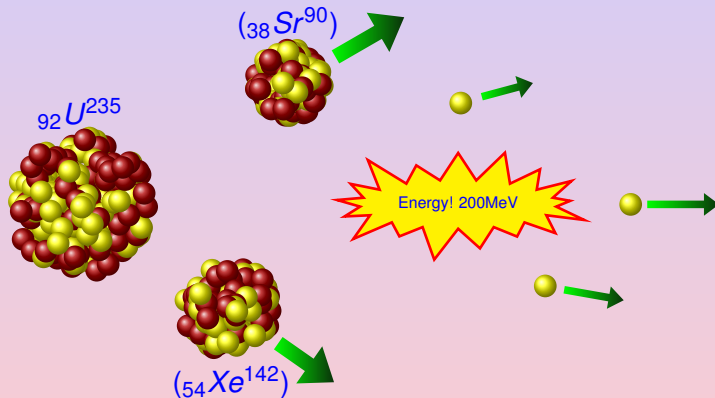
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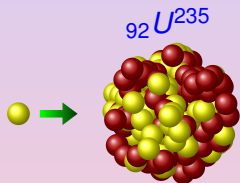
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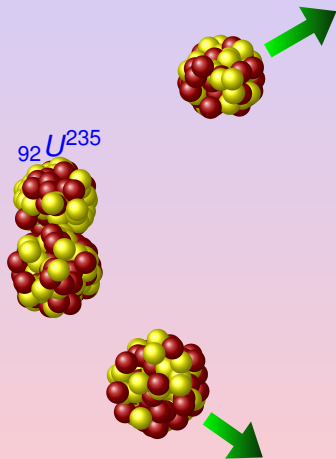
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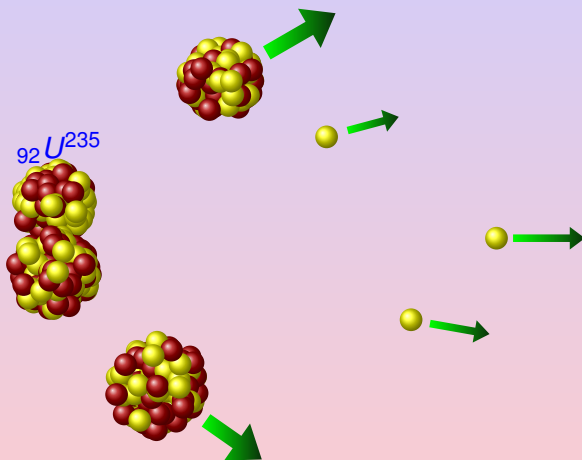
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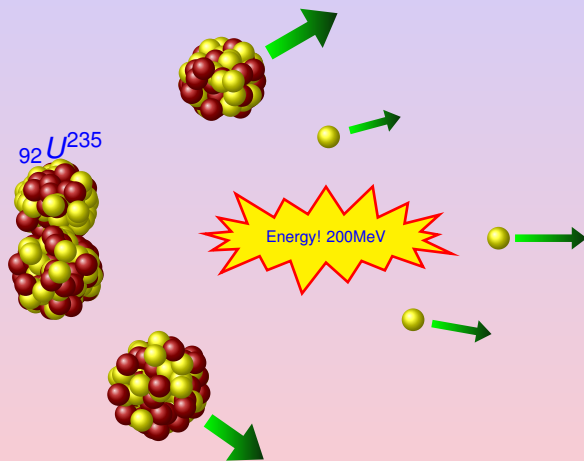
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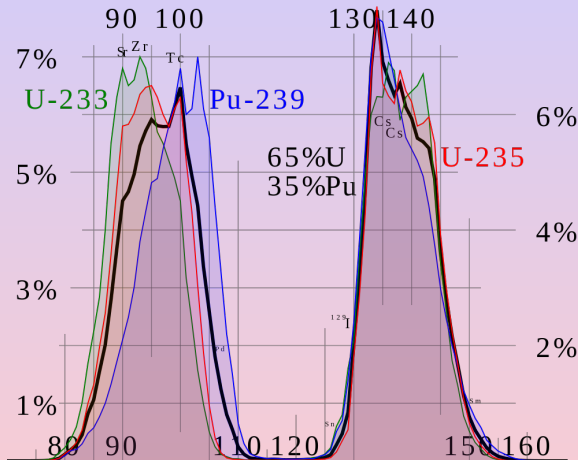


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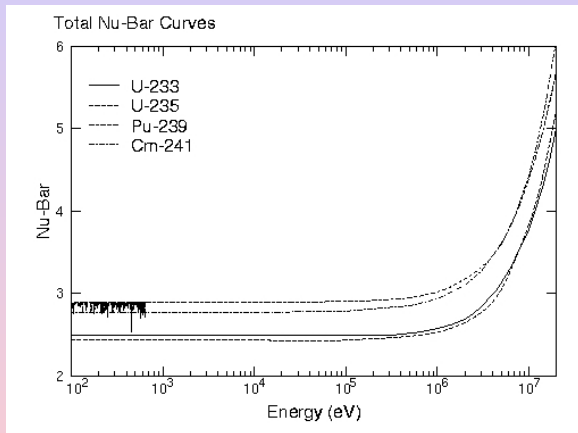


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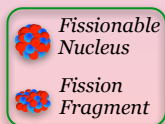


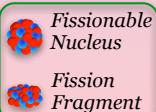
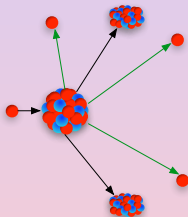


Source: http://en.wikipedia.org/wiki/Nuclear_fission_product

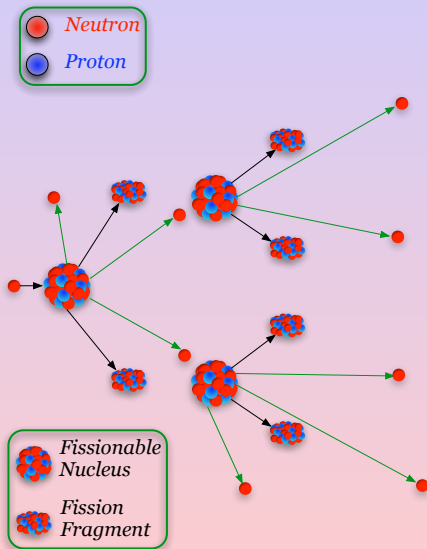


Source: <http://t2.lanl.gov/endf/intro22.html>

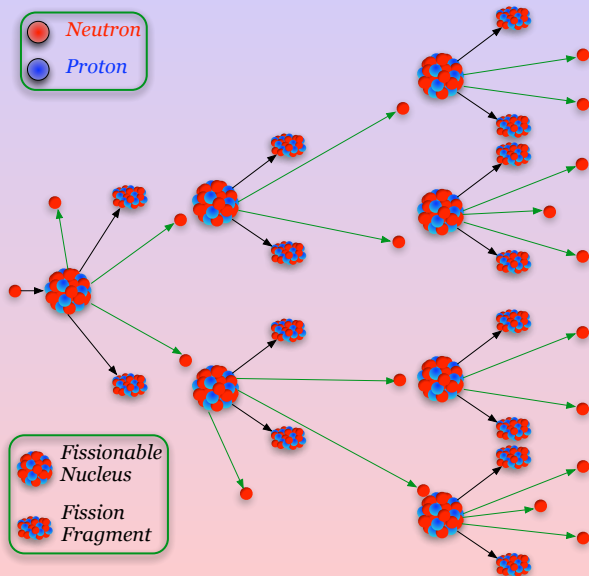




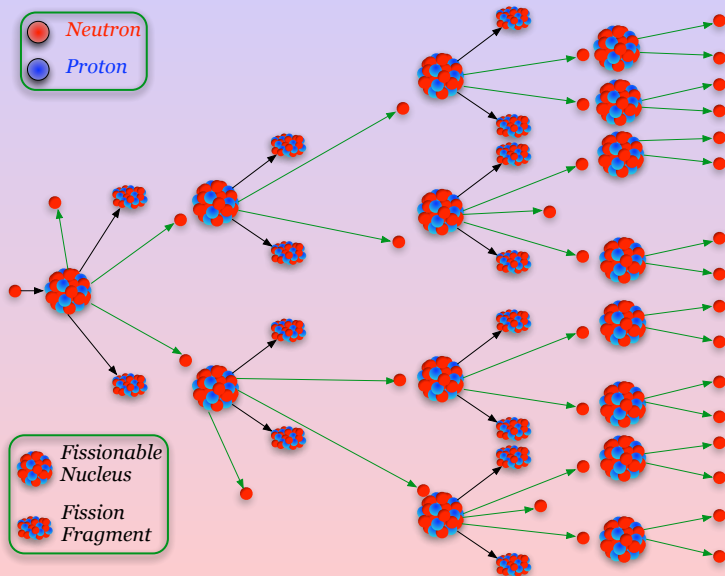
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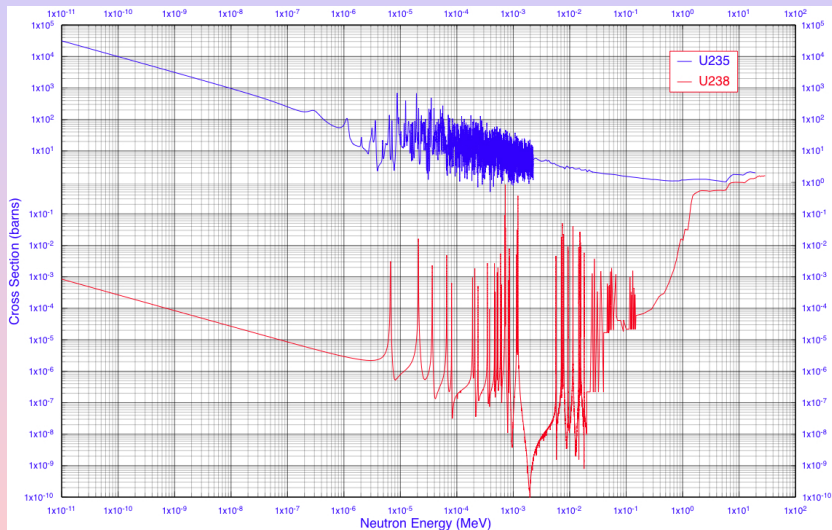
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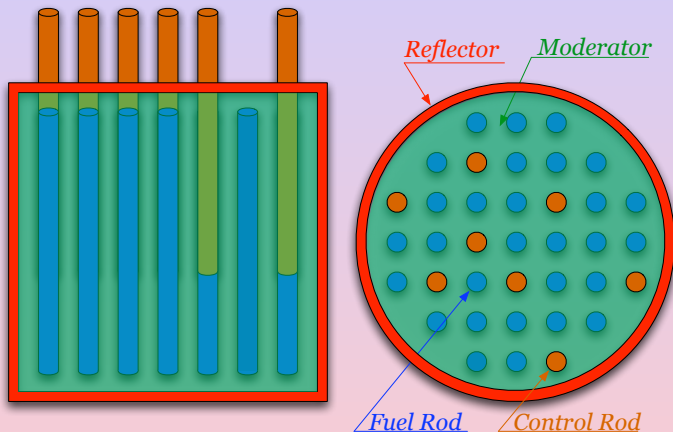


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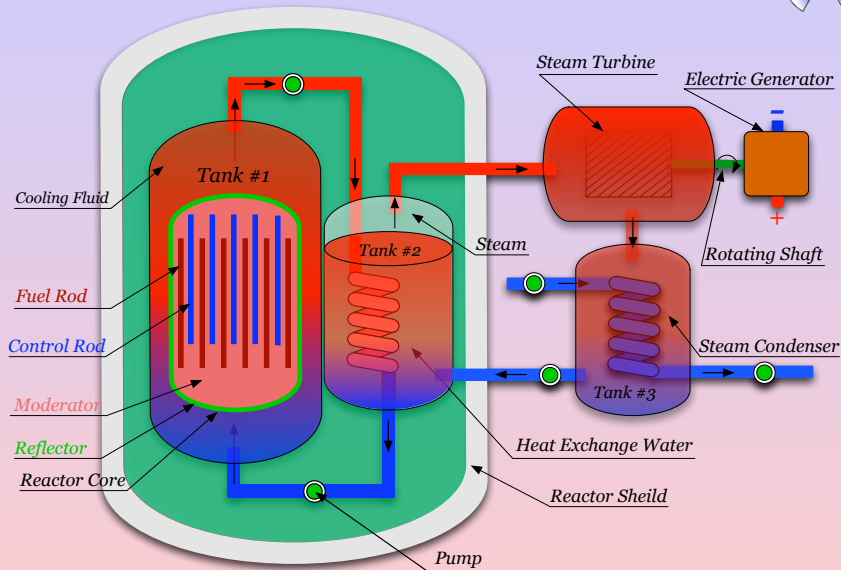


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 - Accumulated Pu opens the door for weapons proliferation.

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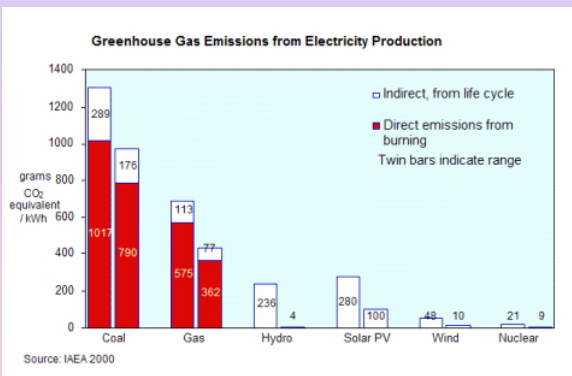
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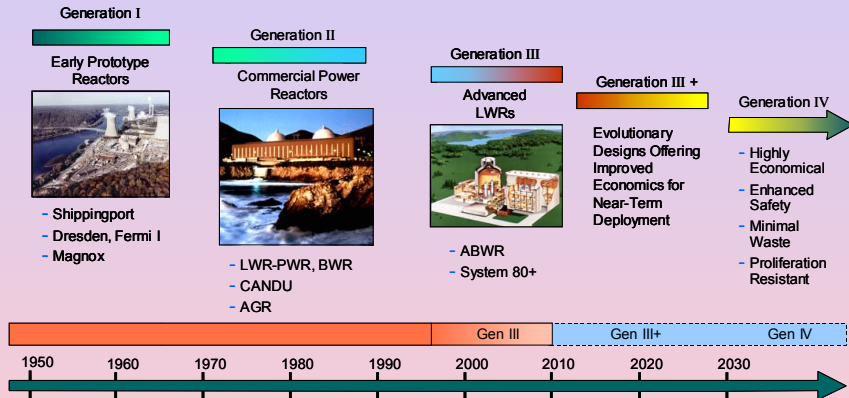
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 - Requires active safety, very little passive safety features.
 - Susceptible to Core meltdown in the event of coolant loss. Due to heat from radioactive decay of fission fragments.





Source:

"A Technology Roadmap for Generation IV Nuclear Energy Systems"

U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum.

Generation IV Reactors

Generation IV Reactor Systems

System Description	Acronym
Gas-Cooled Fast Reactor System	GFR
Lead-Cooled Fast Reactor System	LFR
Molten Salt Reactor System	MSR
Sodium-Cooled Fast Reactor System	SFR
Supercritical-Water-Cooled Reactor System	SCWR
Very-High-Temperature Reactor System	VHTR

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- The fuel, which also doubled as coolant, was LiF-BeF₂-ZrF₄-UF₄ (65-29-5-1).

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 - A frozen plug can provide passive safety (more on that later).

DUAL FLUID REACTOR

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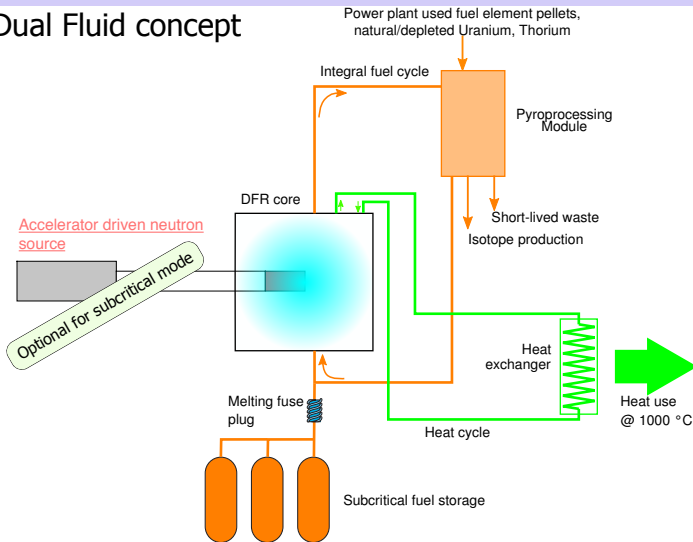
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 - **Doppler broadening of resonances increases the neutron capture cross-section.**

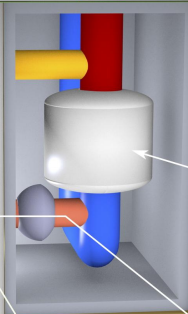
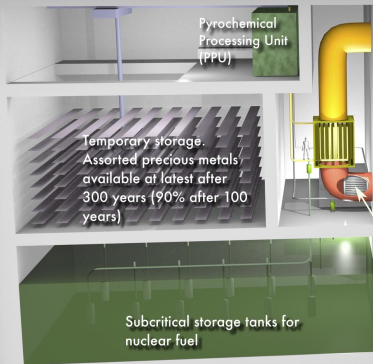
The Dual Fluid Reactor (DFR)



The Dual Fluid Reactor

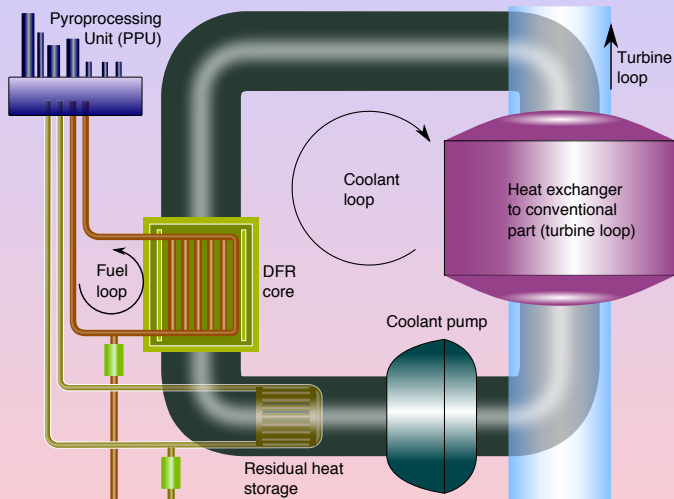
www.dual-fluid-reactor.org

<http://festkoerper-kernphysik.de>

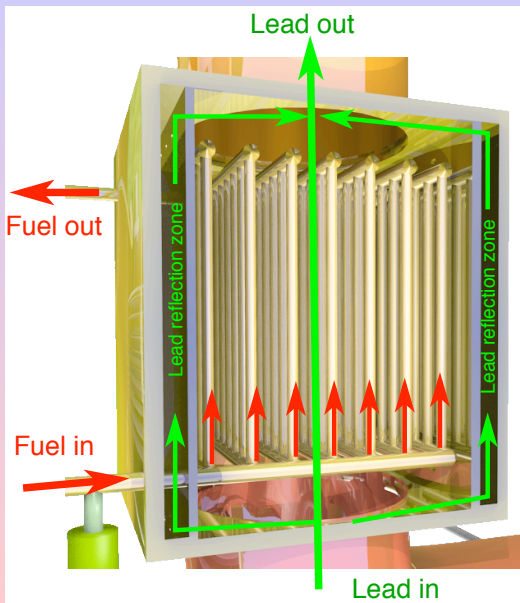


Residual heat deposited separately from the core

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- Th-U fuel cycle produces much less neutron yield than U-Pu cycle.

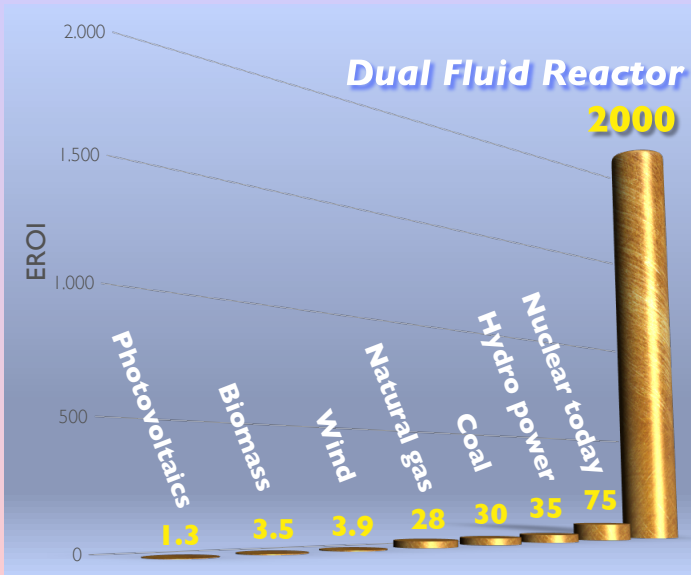
Energy input of the DFR

Item	Units or Total (1000 kg)	Energy Inventory (TJ/1000 kg)	Total Inventory (TJ)
Concrete containment for reactor, fission products and turbine building	21000	0.0014	30
High performance refractory metals and ceramics (PPU and core)	60	0.5	30
High temperature isolation material for PPU and core	100	0.1	10
Initial load, isotopically purified ^{37}Cl + fuel	25 + 60	2.5/0.4	50 + 25
Refractory metals and ceramics for the heat exchanger	180	0.5	90
Isolation and structural materials, heat exchanger	300	0.1	30
Unfabricated, low-alloyed metal for fission product encapsulation	3000	0.033	100
Structural materials (steel) for non-nuclear part	1000	0.02	20
Lead coolant	1200	0.036	45

continued..

Item	Energy input of the DFR		
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Turbines with generators	3	40	120
Mechanical engineering parts			150
Cooling tower (special concrete)	20000	0.003	60
Refueling, 1200 kg/a actinides over 50 years	≈ 60	0.4	≈ 25
^{37}Cl loss compensation	2	2.5	5
Maintenance, high-performance refractories+ isolation for 1 new core	30 + 50	0.5/0.1	20
Maintenance, 50% of other reactor parts, refractories+ isolation	90 + 175	0.5/0.1	62.5
Maintenance, 50% of mechanical engineering and turbines			135
Maintenance electricity, 2MW over 20 days/a and heating, 50×0.2 TJ			182.5
Sum			1190
Output over 50 years lifetime, ≈ 1500 MW net, ≈ 8300 full-load hours			2,250,000

The Dual Fluid Reactor (DFR)



Estimated Construction Costs (Million US\$)

Item	500 MW _e DFR	1500 MW _e DFR
Concrete containment for reactor, earthquake-proof	100	130
Reactor with primary circuit, features including a facility for pyrochemistry	250	300
Secondary gas loop	200	600
Gas turbine 500 MWe (3x), generator, transformer	200	500
Tertiary cooling system with cooling tower	140	250
Additional bunkers	140	200
Planning and building authority, contingency	140	200
Sum	1200	2200
Costs per installed power	2.4 US\$/W	1.5 US\$/W

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- The above estimates use a more expensive external cooling system. A different choice could reduce the costs by 10%.

Operational Costs

Estimated Annual DFR Operating Costs (million US\$)

Item	500 MW _e	1500 MW _e
Operating personnel: 30 man-years (3 shifts 10/12 man-years each 130,000 US\$)	4	5
Operating supplies	1.5	2.5
Nuclear fuel: 500 kg (330 US\$ mining, 330 US\$ transport, 650 US\$ per kg waste management)	0.5	0.5
Maintenance, conventional section (2.5% building costs per annum)	9	25
Maintenance, nuclear and pyrochemical section (2% building costs per annum)	5.5	7
Reserve for dismantling (25% of the building cost of 1000/1900 million US\$)	5	9
Administration, safety	2.5	4
Sum	26	53

Electricity Costs

Estimated Total Costs OF Electricity Produced With DFR In US¢/kWh

Item	500 MW _e	1500 MW _e
Capital costs	0.60	0.35
Operating costs	0.65	0.45
Sum	1.25	0.80
DFR/PWR or Coal	0.30	0.20

Note1: PWR \equiv Pressurized Water Reactor, most commonly used reactor.

Note2: Cost of electricity produced by Coal fired power stations are close to those produced by PWRs.

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- Uses no water, so it can be build anywhere, including underground.

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DFR Is A Nuclear Reactor That:

- Has the **highest** Energy Returned On Energy Invested (EROEI) among all sources including all fossil fuels, all renewables, and current nuclear reactors.

ERoEI For Different Electricity Generating Technologies

Power plant technology	ERoEI
Run-of-the-river hydroelectricity	36
Black-coal fired power	29
Gas-steam power	28
Solar thermal (desert)	9
Wind power (german coast)	4
Photovoltaics (desert)	2.3
Pressurized water reactor	75
DFR (500 MWe)*	1000
DFR (1500 MWe)*	1800

*EROEI for DFR may increase by 25% if cyclone separator heat exchanger works.

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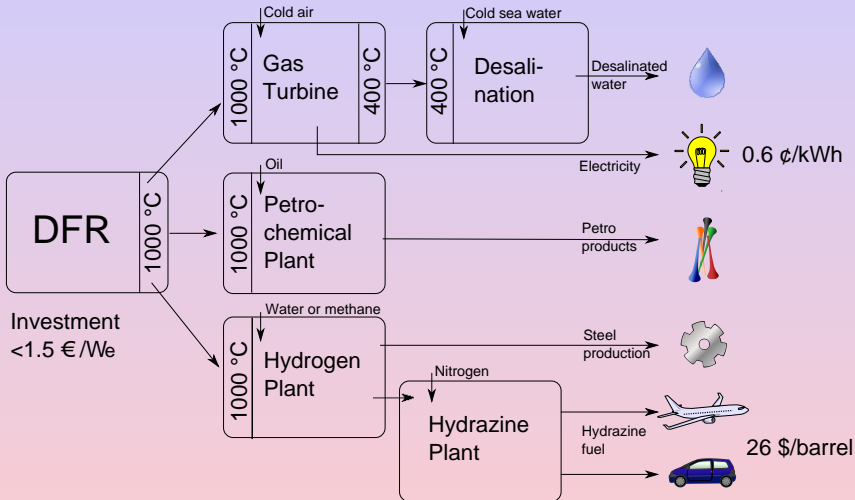
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- All these fuels are “organic fuels”, based on carbon and hydrogen. As a result, they all produce Carbon Dioxide as they burn.

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- Hydrazine has been used as rocket fuel in NASA's space program.
- It can be used in automotive combustion engines with proper additives, resulting in **Water Vapour** and **Nitrogen** as waste.
- Similarly, Silane burns to **Water Vapour** and **Silicon Nitride**, an inert compound.

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Synthetic Automotive Fuels

- In addition, Hydrazine and Silane have a wide range of industrial applications.

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Synthetic Automotive Fuels

- In addition, Hydrazine and Silane have a wide range of industrial applications.
- The hazardous properties and toxicity of these fuels are similar to Gasoline.

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