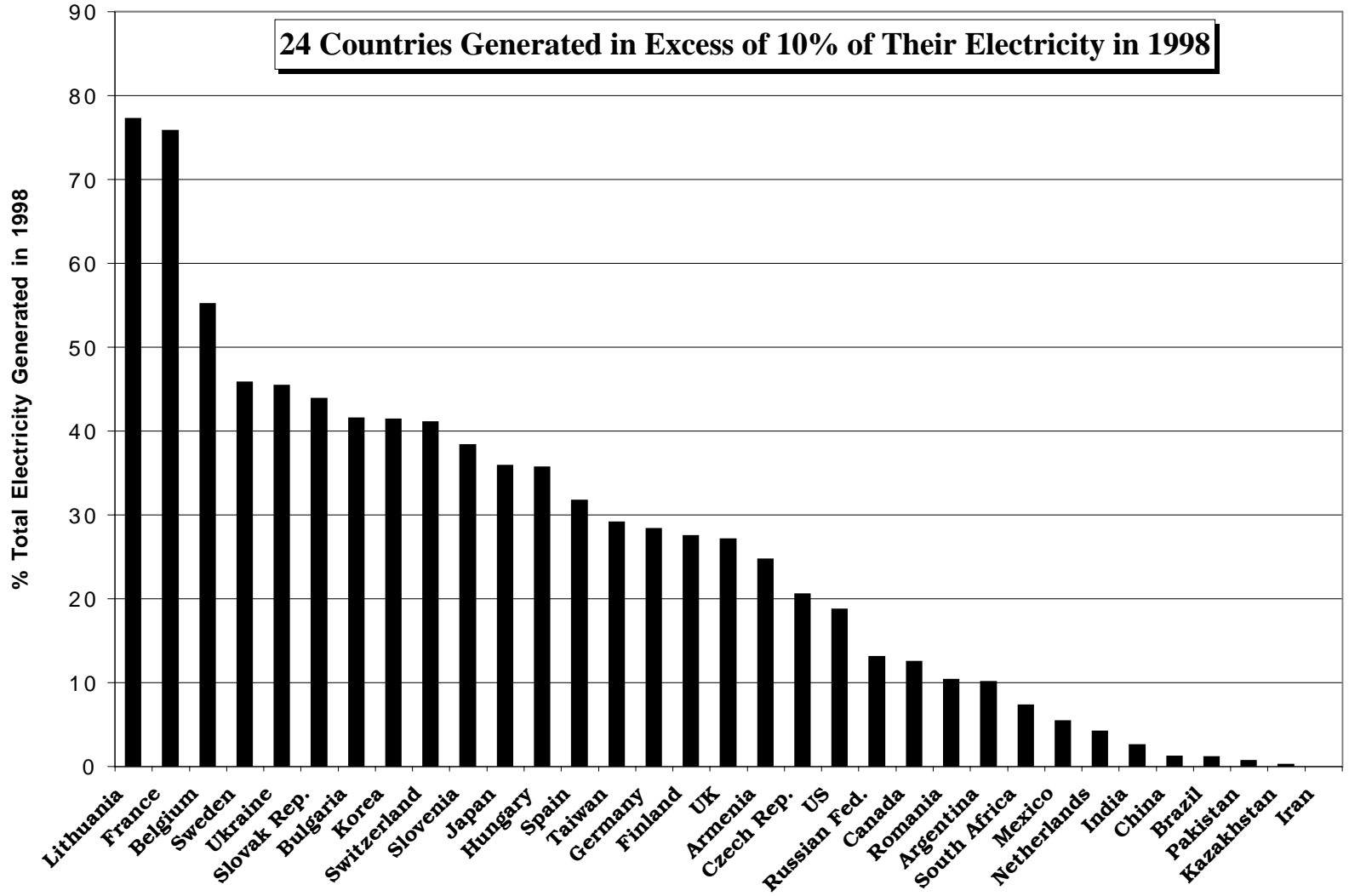


24 Countries Generated in Excess of 10% of Their Electricity in 1998



2-2 Nuclear Power

Nuclear Power Reactors in Operation and Under Construction, 1998											
		Reactors in Operation in 1998		Reactors Under Const. 1998		Nuclear Elect. Supplied in 1998				Nuclear Elect. Supplied in 1998	
Country	# of Units	Total MWe	# of Units	Total MWe	Billion kWhrs (1998)	% of Total	Country	Country	% of Total		
Lithuania	2	2,600	0	0	12.3	77.2	Lithuania	Lithuania	77		
France	58	64,330	1	1,516	368.4	75.8	France	France	76		
Belgium	7	5,836	0	0	43.9	55.2	Belgium	Belgium	55		
Sweden	12	10,438	0	0	70.0	45.8	Sweden	Sweden	46		
Slovak Rep.	5	2,200	1	440	11.4	43.8	Slovak Rep.	Ukraine	45		
Switzerland	5	3,279	0	0	24.4	41.1	Switzerland	Slovak Rep.	44		
Ukraine	14	12,808	2	2,000	70.6	45.4	Ukraine	Bulgaria	42		
Bulgaria	6	3,760	0	0	15.5	41.5	Bulgaria	Korea	41		
Hungary	4	1,840	0	0	13.1	35.6	Hungary	Switzerland	41		
Slovenia	1	652	0	0	4.8	38.3	Slovenia	Slovenia	38		
Armenia	1	408	0	0	1.4	24.7	Armenia	Japan	36		
Korea	14	12,089	6	5,750	85.2	41.4	Korea	Hungary	36		
Japan	53	45,362	2	1,925	306.9	35.9	Japan	Spain	32		
Spain	9	7,400	0	0	56.7	31.7	Spain	Taiwan	29		
Germany	19	22,069	0	0	145.2	28.3	Germany	Germany	28		
Taiwan	6	5,144	2	2,700	35.3	28.8	Taiwan	Finland	27		
Finland	4	2,650	0	0	21.0	27.4	Finland	UK	27		
UK	35	14,208	0	0	91.1	27.1	UK	Armenia	25		
US	104	101,733	0	0	673.7	18.7	US	Czech Rep.	21		
Czech Rep.	4	1,752	2	1,962	12.4	20.5	Czech Rep.	US	19		
Canada	14	10,915	0	0	67.5	12.4	Canada	Russian Fed.	13		
Russian Fed.	29	21,242	1	706	95.4	13.1	Russian Fed.	Canada	12		
Argentina	2	1,005	1	745	6.9	10.0	Argentina	Romania	10		
South Africa	2	1,930	0	0	13.6	7.3	South Africa	Argentina	10		
Mexico	2	1,329	0	0	8.8	5.4	Mexico	South Africa	7		
Netherlands	1	481	0	0	3.6	4.1	Netherlands	Mexico	5		
India	10	1,840	6	1,880	10.2	2.5	India	Netherlands	4		
Romania	1	706	1	706	4.9	10.4	Romania	India	3		
China	3	2,268	6	4,600	13.5	1.2	China	China	1		
Brazil	1	657	1	309	3.3	1.1	Brazil	Brazil	1		
Pakistan	1	137	1	325	0.3	0.7	Pakistan	Pakistan	1		
Kazakhstan	1	150	0	0	0.1	0.2	Kazakhstan	Kazakhstan	0		
Iran	0	0	2	2,111	0.0	0.0	Iran	Iran	0		
Total	430	363,218	35	27,675	2,291						

source: Nuclear Engineering International, World Nuclear Industry Handbook 1999

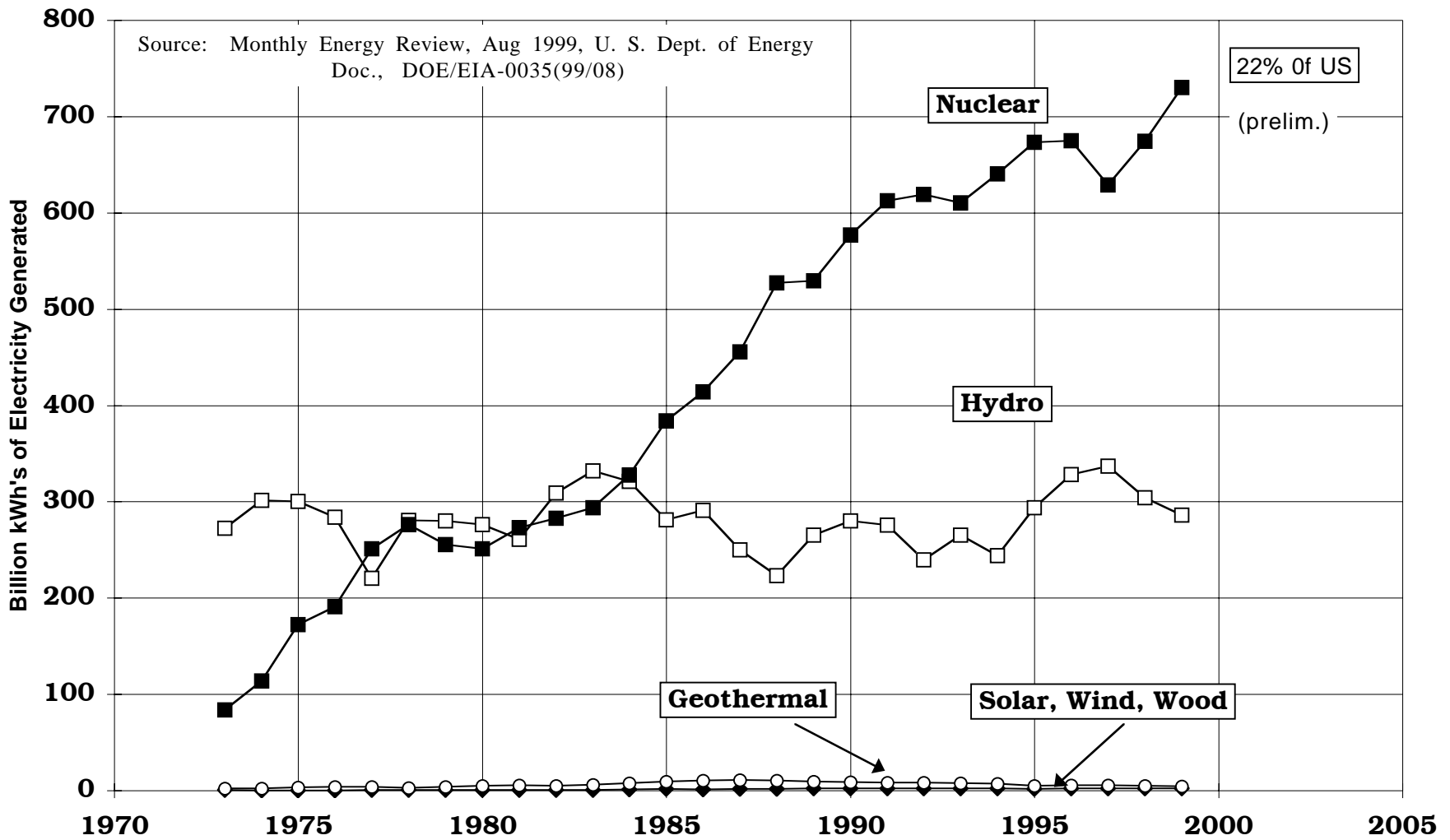
Worldwide Fission Power Reactor Status-December 31, 1998

	Operating	Under Construction	Total
# of Reactors	430	35	475
Capacity-MW_e	363,218	27,675	400,893
Experience Reactor-Years	9,010	-	9,010
Research Reactors	323 (1991)	-	323 (1991)

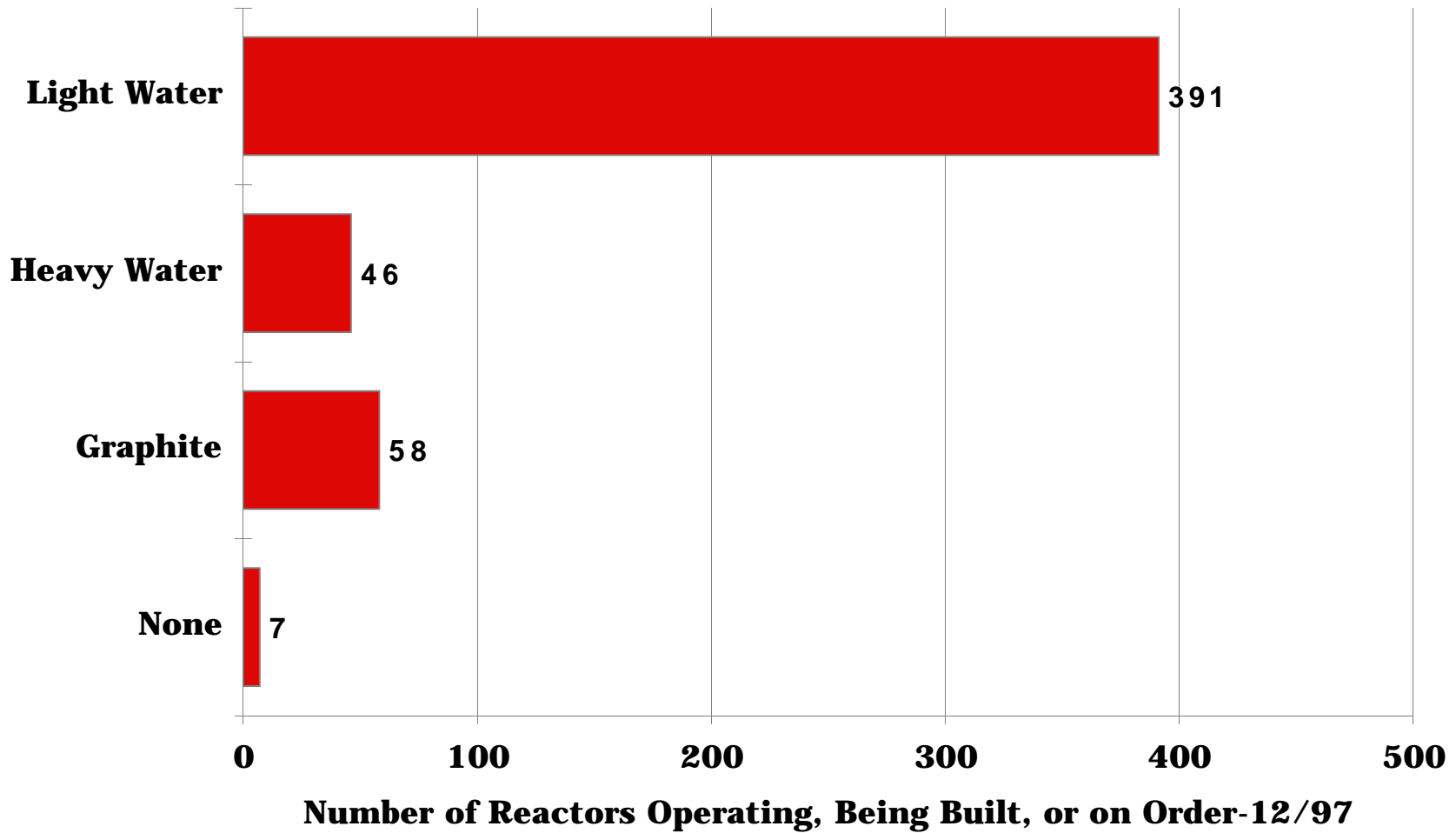
**Frequency of new nuclear power plant
connections to the grid around the world.**

1986	1 every 2.2 weeks
1987	1 every 2.5 weeks
1988	1 every 3.5 weeks
1989	1 every 5.5 weeks
1990	1 every 13 weeks
1991	1 every 8.7 weeks
1992	1 every 10.4 weeks
1993	1 every 8.7 weeks
1994	1 every 7.4 weeks
1995	1 every 13 weeks
1996	1 every 10.4 weeks
1997	1 every 13 weeks
1998	1 every 13 weeks

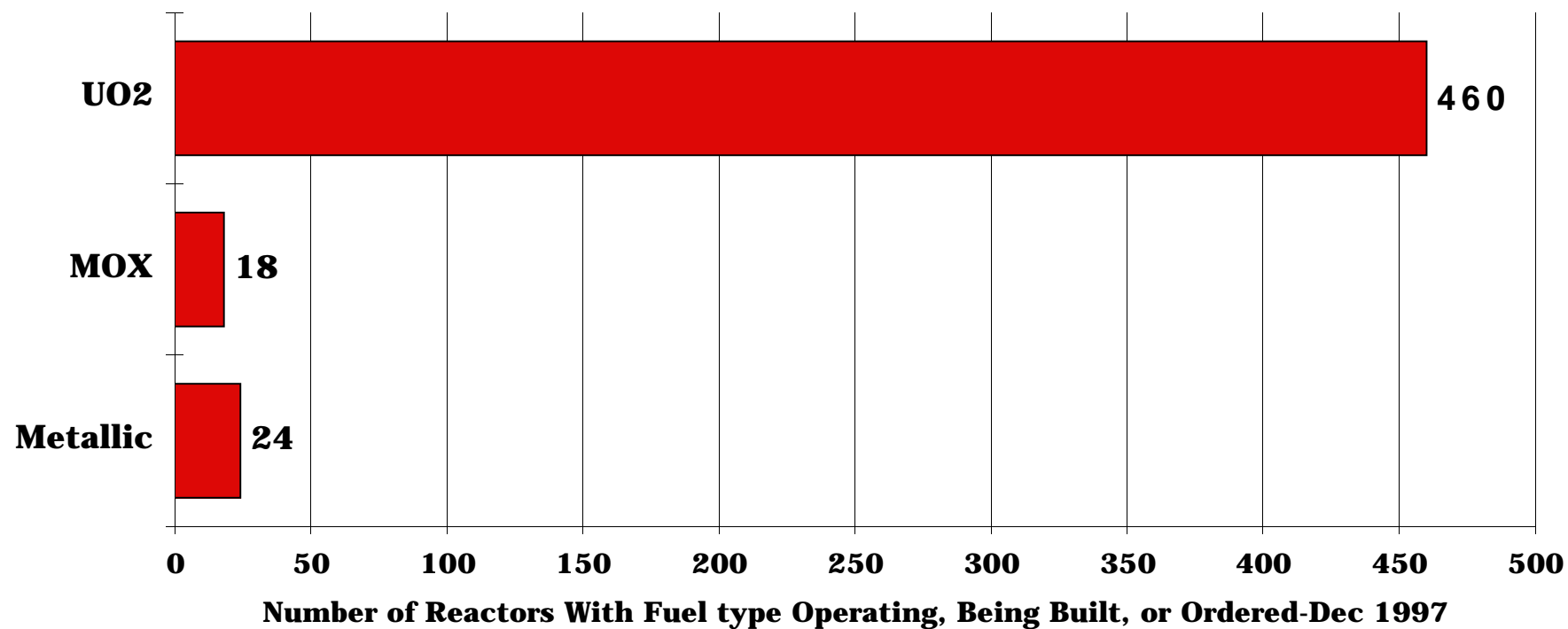
Nuclear Power Continues to Outstrip the Non-Fossil Fuels in Generation of Electricity in the United States



Nearly 90% of the Fission Reactors of Today Use Water as a Moderator



Over 90% of the Fuel in Fission Reactors is in the Form of an Oxide

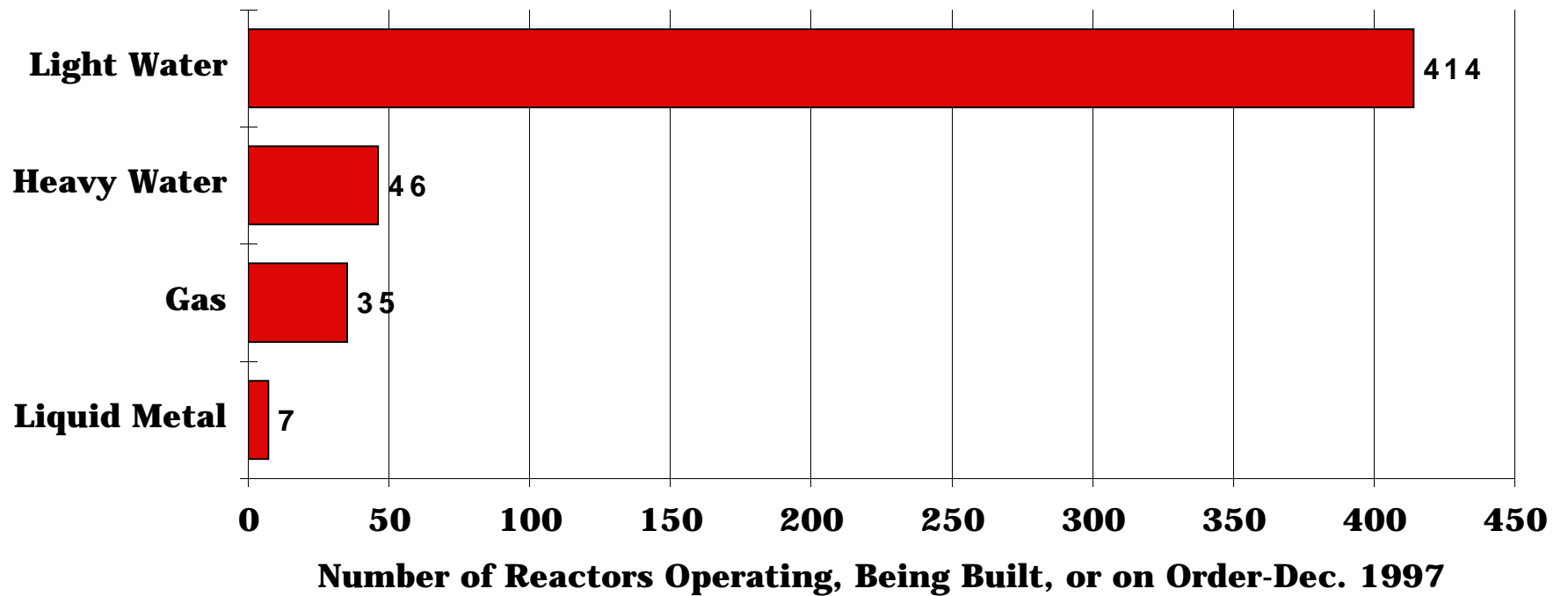


Coolant Attributes For Fission Reactors

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- 1.) High thermal
conductivity**
- 2.) High C_p**
- 3.) Stability
(Irradiation, Temp.)**
- 4.) Low induced
radioactivity**
- 5.) Low corrosiveness**

Water is the Coolant for Over 90% of the Present Day Fission Reactors



Attributes of Moderator Materials

- 1.) **High scattering cross section**
- 2.) **Low absorption cross section**
- 3.) **High $\xi = \ln(E_1/E_2)$ energy loss/collision**

$$\xi = 1 + \frac{(A - 1)^2}{2A} \ln \frac{A - 1}{A + 1}$$

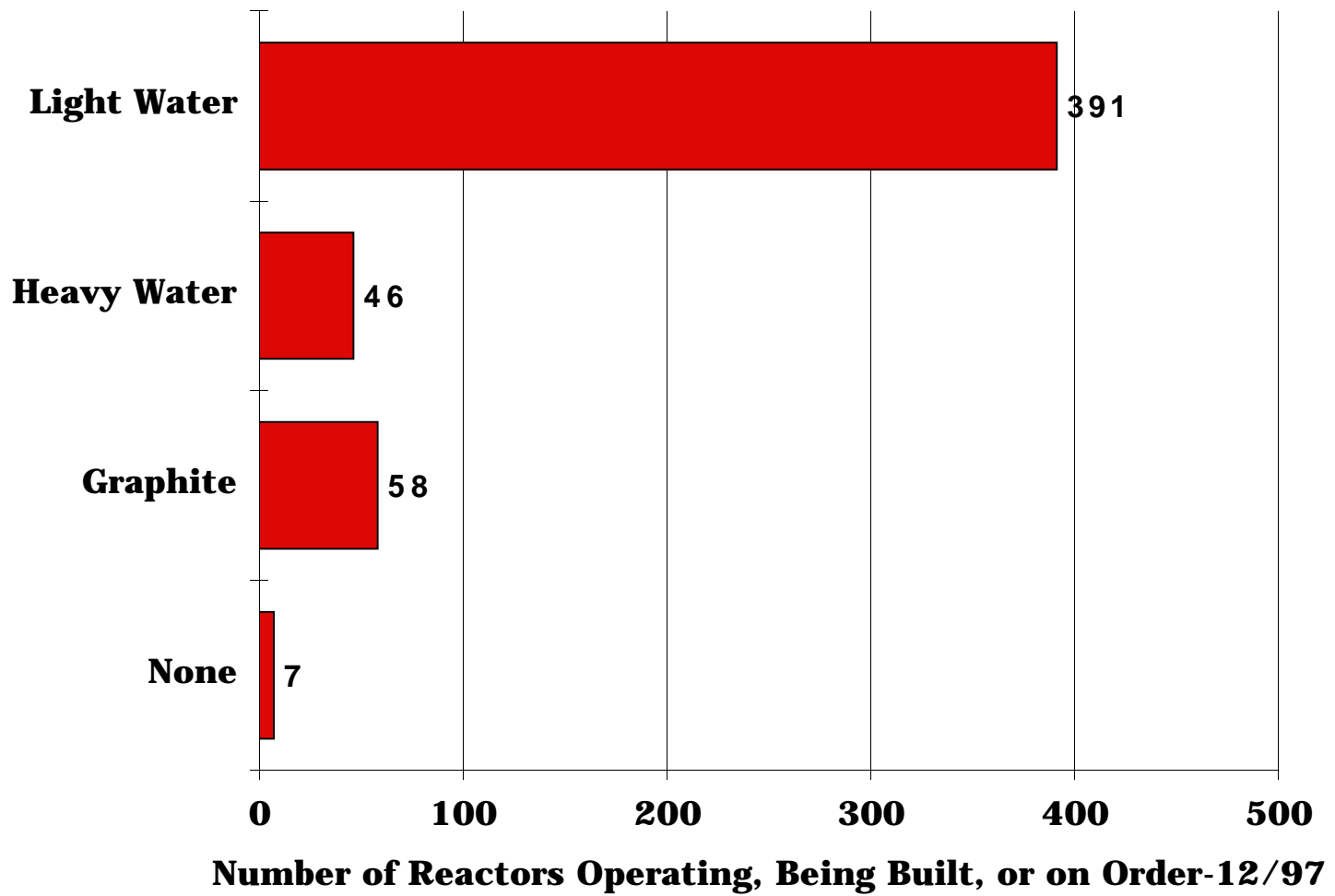
$$\xi \approx \frac{2}{A + \frac{2}{3}} \text{ for } A > 2$$

$$\text{Slowing Down Power} = \text{SDP} = \xi N \sigma_s = \sum_s \xi$$

$$\text{Moderating Ratio} = \text{MR} = \frac{\sum_s \xi}{\sum_a}$$

Moderator	SDP, cm⁻¹	Mod Ratio	Comments
H₂O	1.53	72.	
D₂O	0.37	12,000.	≈ 100 \$/kg
He (STP)	0.000016	83.	low ρ
Be	0.176	159.	≈ 200 \$/kg
C	0.64	170.	
ZrH_{1.79}	0.8	56.	

Nearly 90% of the Fission Reactors of Today Use Water as a Moderator



General Characteristics of Fission Reactor Designs

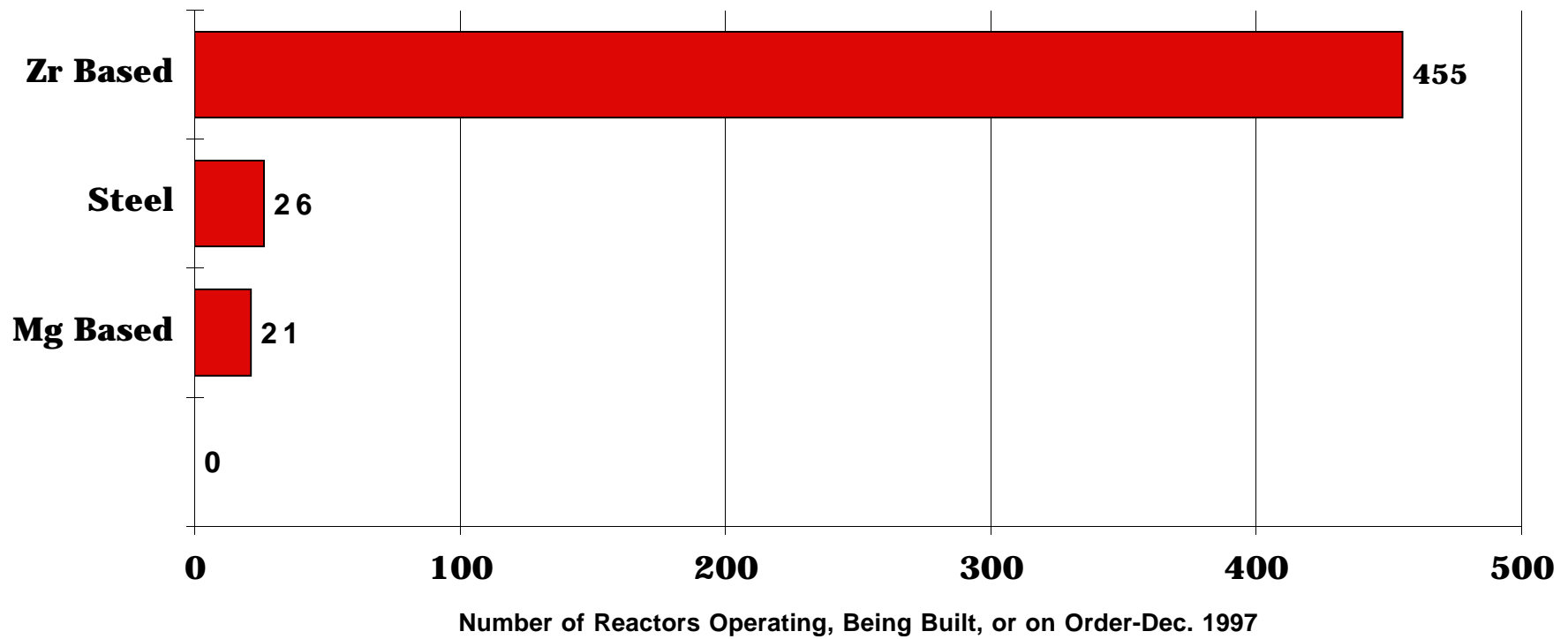
Type	Fuel (% ²³⁵U)	Moderator	Coolant (atm)	Steam Generator
PWR	UO ₂ (3.2)	H ₂ O	H ₂ O (160)	Separate Circuit
BWR	UO ₂ (3.2)	H ₂ O	H ₂ O (70)	Direct
CANDU	UO ₂ (0.711)	D ₂ O	D ₂ O (90)	Separate Circuit
Magnox	U (0.711)	Graphite	CO ₂ (20)	Separate Circuit
AGR	UO ₂ (2.3)	Graphite	CO ₂ (40)	Separate Circuit
RBMK	UO ₂ (2.0-2.4)	Graphite	H ₂ O (70)	Direct
LMFBR	UO ₂ -PuO ₂ (15% ²³⁹ Pu)	None	Na (≈1)	Separate Circuit

Fuel Must Be Protected From the Coolant and the Coolant Must Be Protected From the Fuel

Attributes of Cladding

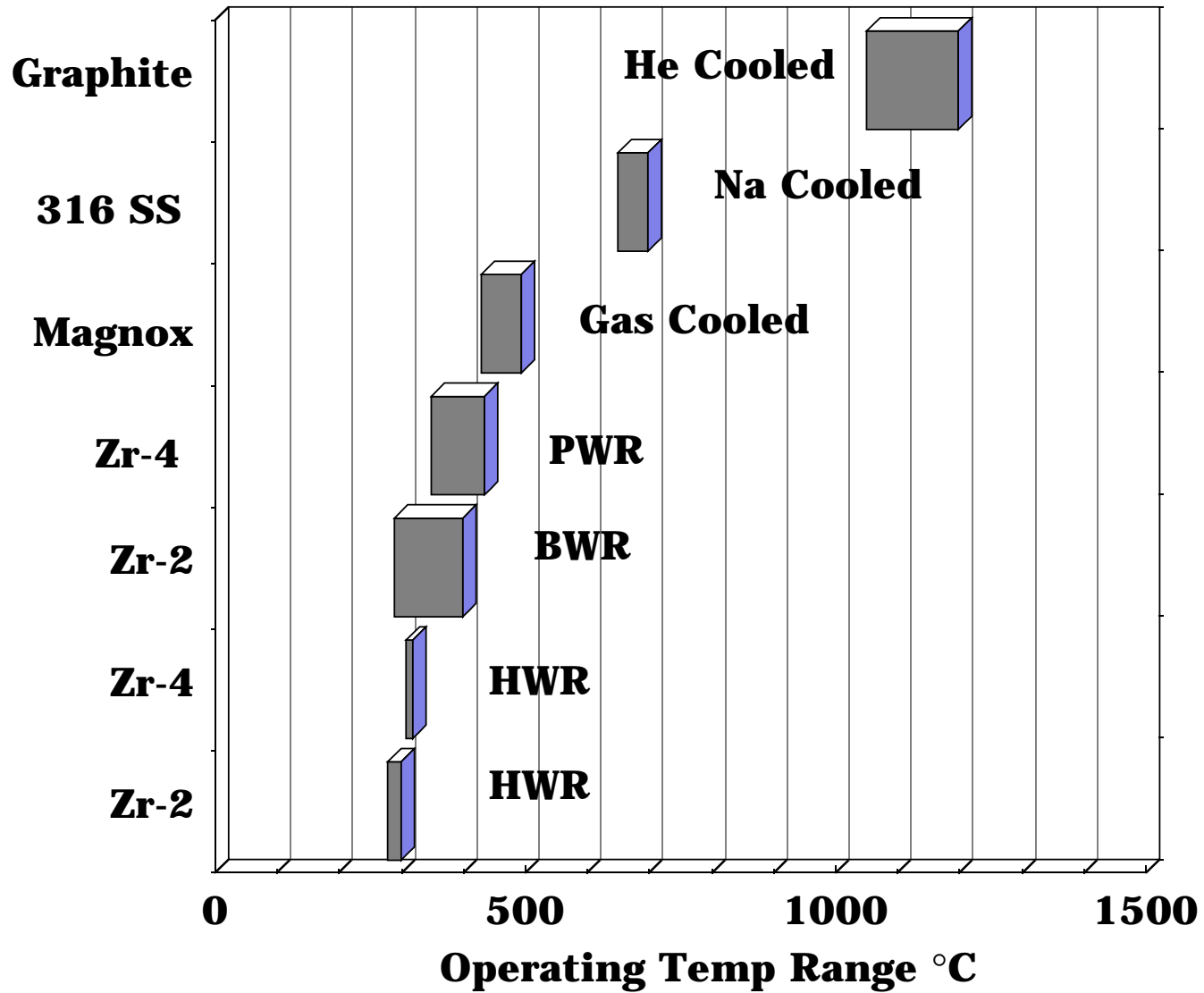
- 1.) Adequate σ_y at high T & during irradiation**
- 2.) Resist corrosion**
- 3.) Dimensionally stable**
- 4.) Predictable Mechanical Properties**
- 5.) High thermal conductivity**
- 6.) Good neutronic properties**
- 7.) Easy to fabricate and install**
- 8.) Easy to reprocess**
- 9.) Low Cost**
- 10.) Low demand on scarce resources**

Nearly 90% of Today's Fission Reactors Used Zr Based Cladding Materials



Summary of Fission Reactor Operating Temperatures			
Cladding Material	T_{max}, °C	Coolant	T_{out} °C
<u>Fast Reactors</u>			
316 SS	650-700	Na	500-550
<u>HWR</u>			
Zircaloy-2	280-300	D₂O	260-310
Zircaloy-4	310-330	D₂O	260-310
<u>Graphite</u>			
Magnox	430-495	CO₂	350-400
Mg-Zr	465-510	CO₂	350-400
Graphite	1050-1200	He	750-850
Austenite	625-640	He	750-850
<u>BWR</u>			
Zircaloy-2	290-400	H₂O	280-290
<u>PWR</u>			
Zircaloy-4	350-435	H₂O	310-330

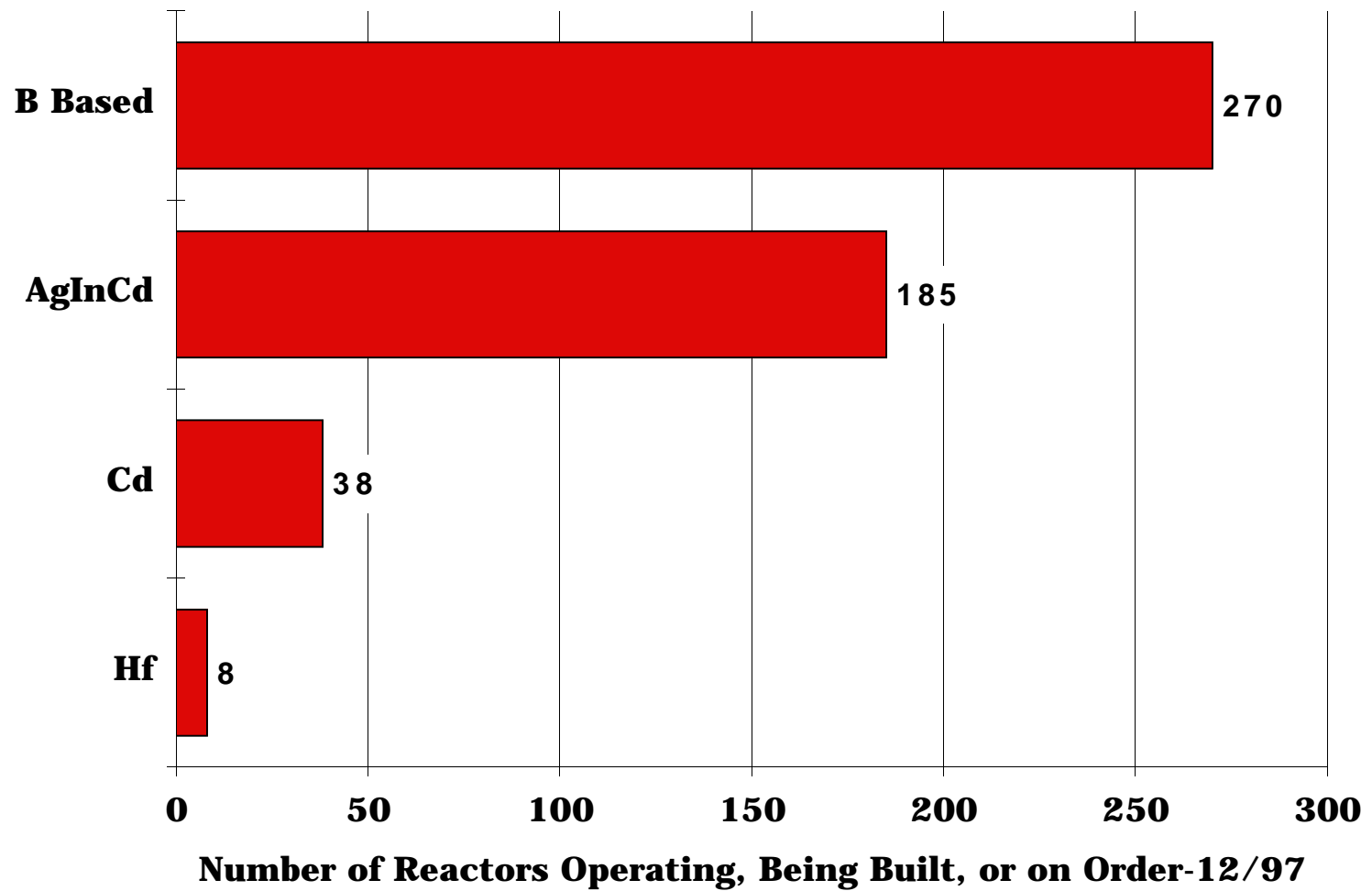
Operating Temperature Range for Cladding Material for Fission Reactors



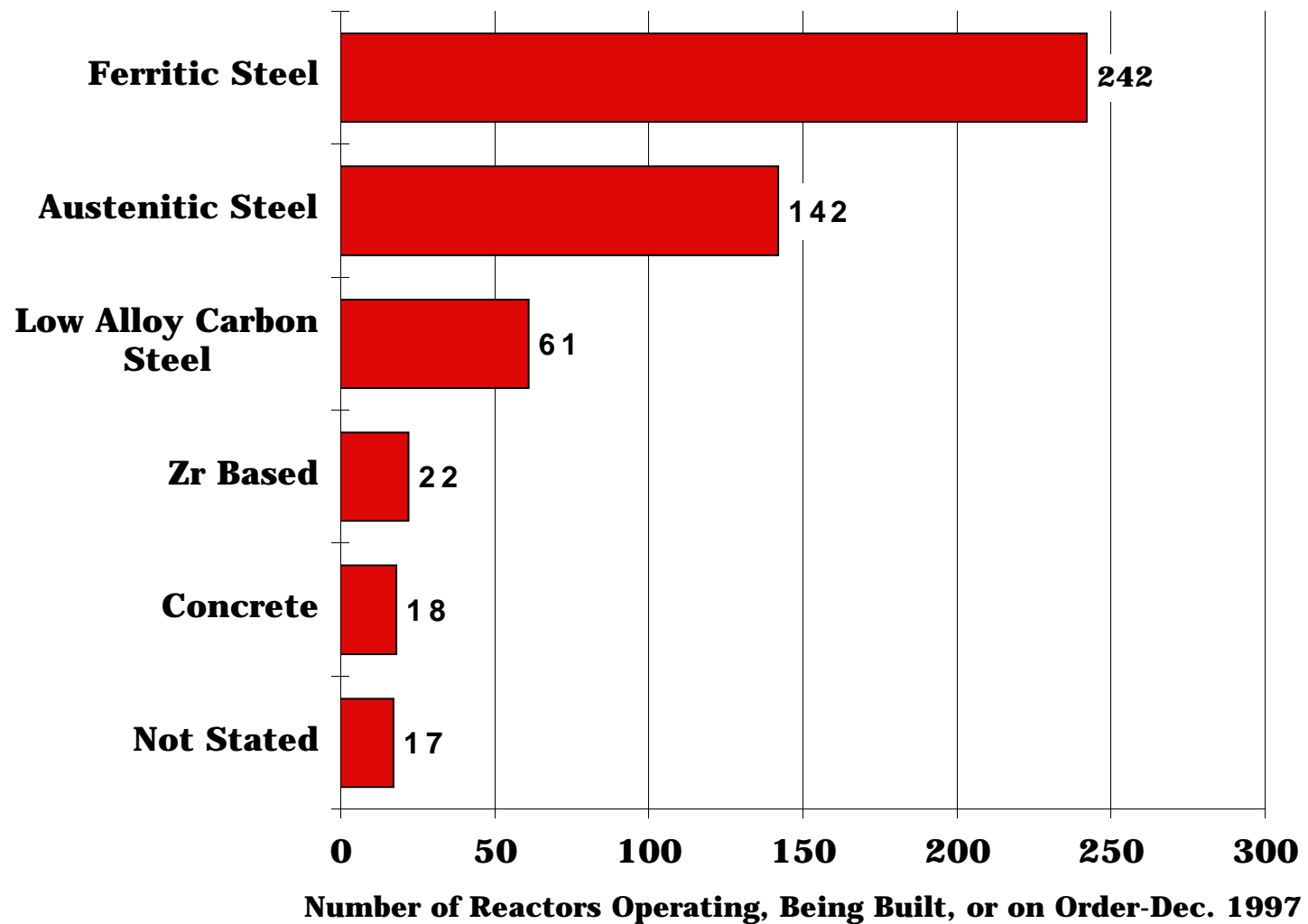
Attributes of Control Rod Materials

- 1.) High absorption cross section**
- 2.) Adequate strength for solid rods**
- 3.) Low mass to permit rapid movement**
- 4.) Corrosion resistance**
- 5.) Stability- Chemical and Dimensional**
- 6.) Low Cost**
- 7.) Good heat transfer capabilities**

Nearly Half of Present Day Fission Reactors Use Boron Based Control Rods



Nearly 90% of Present Day Fission Reactors Use Steel for the Pressure Vessels



Attributes of Shield Material

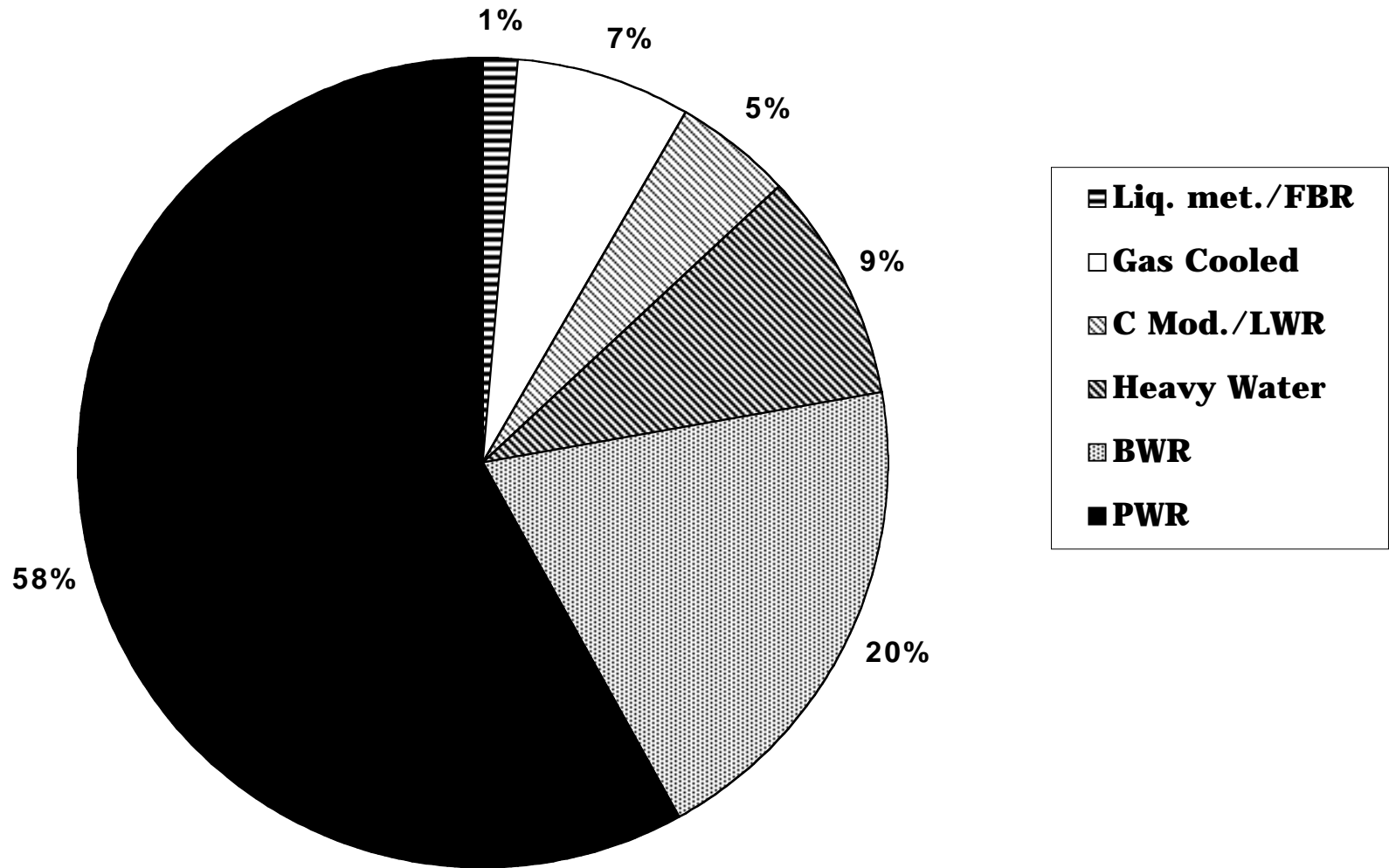
- 1.) **Good moderating material**
- 2.) **Good neutron absorber**
- 3.) **High density to attenuate gamma rays**

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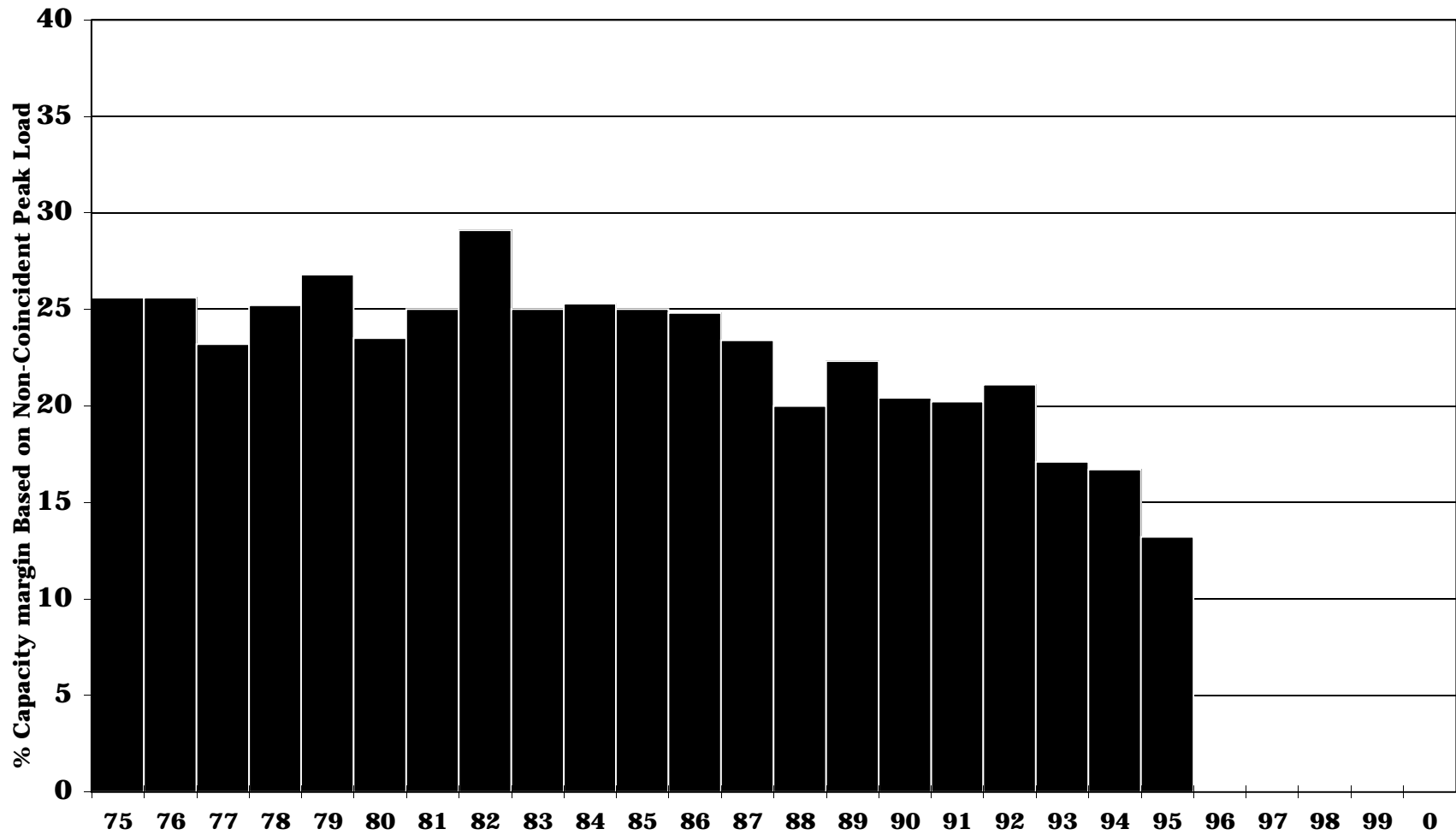
Possible Shield materials

- A.) **Amalgams**
- B.) **Cements & concretes with special aggregates**
- C.) **Ceramics and cermets**
- D.) **Glasses and fused salts**
- E.) **Metal ores**
- F.) **Metal alloys and sintered powders**
- G.) **Organics such as plastics, metal esters, metal loaded resins, elastomers, and silicones**
- H.) **Silica and other gels precipitated from B loaded solutions**

Over 90% of the Fission Power Reactors in the World are Cooled by Water



The U. S. Electric Utility Capacity Margin Has Fallen Below the Recommended 20% "Floor"



Source: EEI Statistical Yearbook-1995