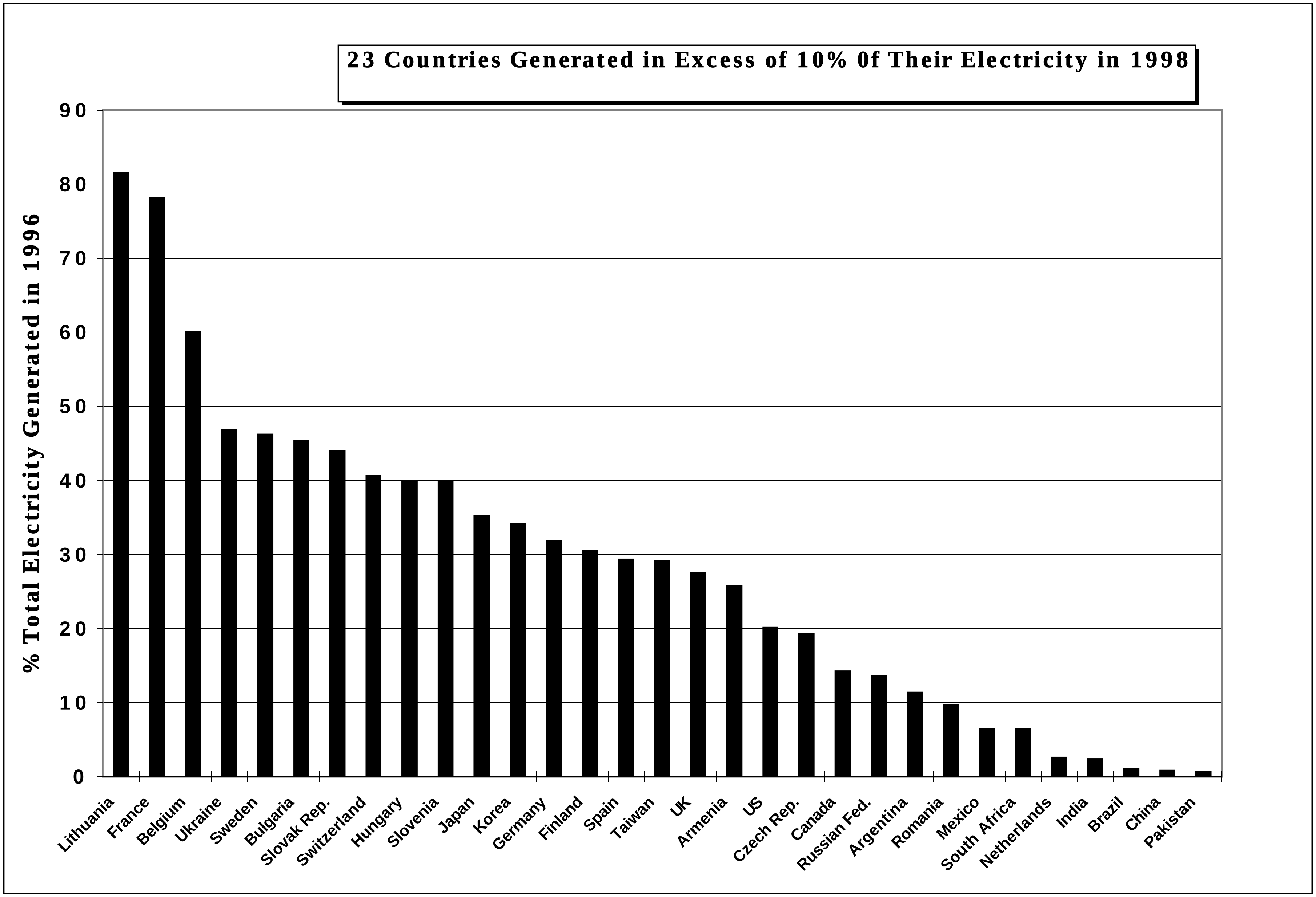

23 Countries Generated in Excess of 10% 0f Their Electricity in 1998
% Total Electricity Generated in 1996
0
10
20
30
40
50
60
70
80
90
Lithuania
France
Belgium
Ukraine
Sweden
Bulgaria
Slovak Rep.
Switzerland
Hungary
Slovenia
Japan
Korea
Germany
Finland
Spain
Taiwan
UK
Armenia
US
Czech Rep.
Canada
Russian Fed.
Argentina
Romania
Mexico
South Africa
Netherlands
India
Brazil
China
Pakistan

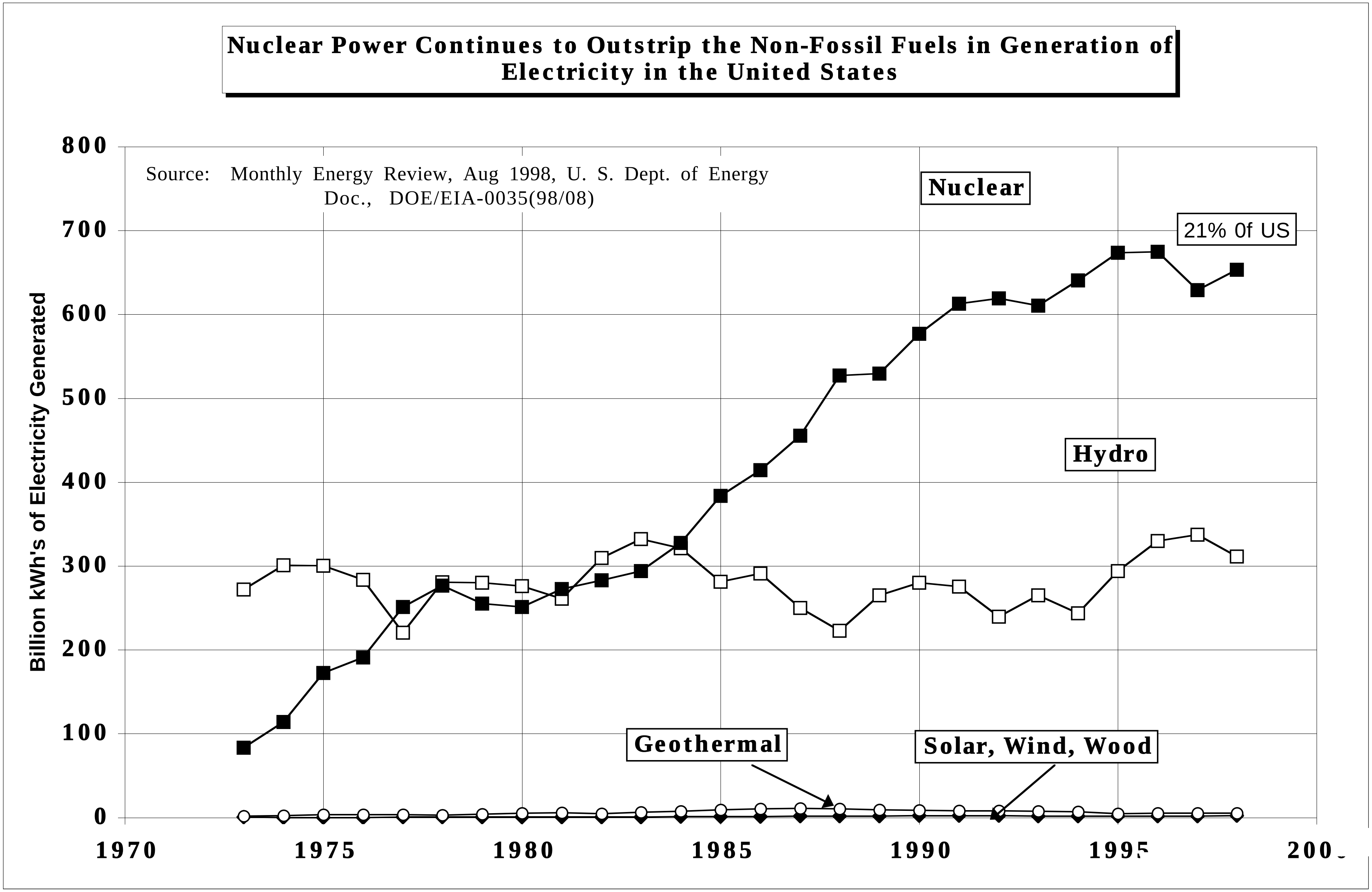
Nuclear Power Reactors in Operation and Under Construction, 3/98									
	Reactors in Operation in 3/98		***Reactors Under Const. 3/98***		***Nuclear Elect. Supplied in 1996***			***Nuclear Elect. Supplied in 3/98***	
Country	# of Units	Total MWe	# of Units	Total MWe	Billion kWhrs (1996)	% of Total	Country	Country	% of Total
Lithuania	2	2,370	0	0	12.7	83.4	Lithuania	Lithuania	82
France	59	62,853	1	1,450	378.2	77.4	France	France	78
Belgium	7	5,712	0	0	41.4	57.2	Belgium	Belgium	60
Sweden	12	10,040	0	0	71.4	52.4	Sweden	Ukraine	47
Slovak Rep.	4	1,632	4	1,552	11.3	44.5	Slovak Rep.	Sweden	46
Switzerland	5	3,079	0	0	23.7	44.5	Switzerland	Bulgaria	45
Ukraine	16	13,765	4	3,800	79.6	43.8	Ukraine	Slovak Rep.	44
Bulgaria	6	3,538	0	0	18.1	42.2	Bulgaria	Switzerland	41
Hungary	4	1,729	0	0	14.2	40.8	Hungary	Hungary	40
Slovenia	1	632	0	0	4.4	37.9	Slovenia	Slovenia	40
Armenia	1	376	0	0	2.1	36.7	Armenia	Japan	35
Korea	12	9,770	6	5,120	70.3	35.8	Korea	Korea	34
Japan	54	43,850	1	796	287.0	33.4	Japan	Germany	32
Spain	9	7,320	0	0	53.8	32.0	Spain	Finland	30
Germany	20	22,282	0	0	152.8	30.3	Germany	Spain	29
Taiwan	6	4,884	0	0	35.3	28.8	Taiwan	Taiwan	29
Finland	4	2,455	0	0	18.7	28.1	Finland	UK	28
UK	35	12,928	0	0	85.5	26.0	UK	Armenia	26
US	107	99,188	0	0	674.8	21.9	US	US	20
Czech Rep.	4	1,648	2	1,824	12.9	20.0	Czech Rep.	Czech Rep.	19
Canada	16	11,994	0	0	87.5	16.0	Canada	Canada	14
Russian Fed.	29	19,843	4	3,375	108.8	13.1	Russian Fed.	Russian Fed.	14
Argentina	2	935	1	692	6.9	11.4	Argentina	Argentina	11
South Africa	2	1,842	0	0	11.8	6.3	South Africa	Romania	10
Mexico	2	1,308	0	0	7.1	5.1	Mexico	Mexico	7
Netherlands	1	449	0	0	3.9	4.8	Netherlands	South Africa	7
India	10	1,695	4	808	7.4	2.2	India	Netherlands	3
Romania	1	650	1	650	0.9	1.8	Romania	India	2
China	3	2,167	4	3,090	13.6	1.3	China	Brazil	1
Brazil	1	626	1	1,245	2.3	0.7	Brazil	China	1
Pakistan	1	125	1	300	0.3	0.6	Pakistan	Pakistan	1
Kazakhstan	1	70	0	0	0.1	0.2	Kazakhstan	Kazakhstan	1
Iran	0	0	2	2,111	0.0	0.0	Iran	Iran	0
Total	437	351,755	36	26,813	2,299				

Worldwide Fission Power Reactor Status-March 31, 1998

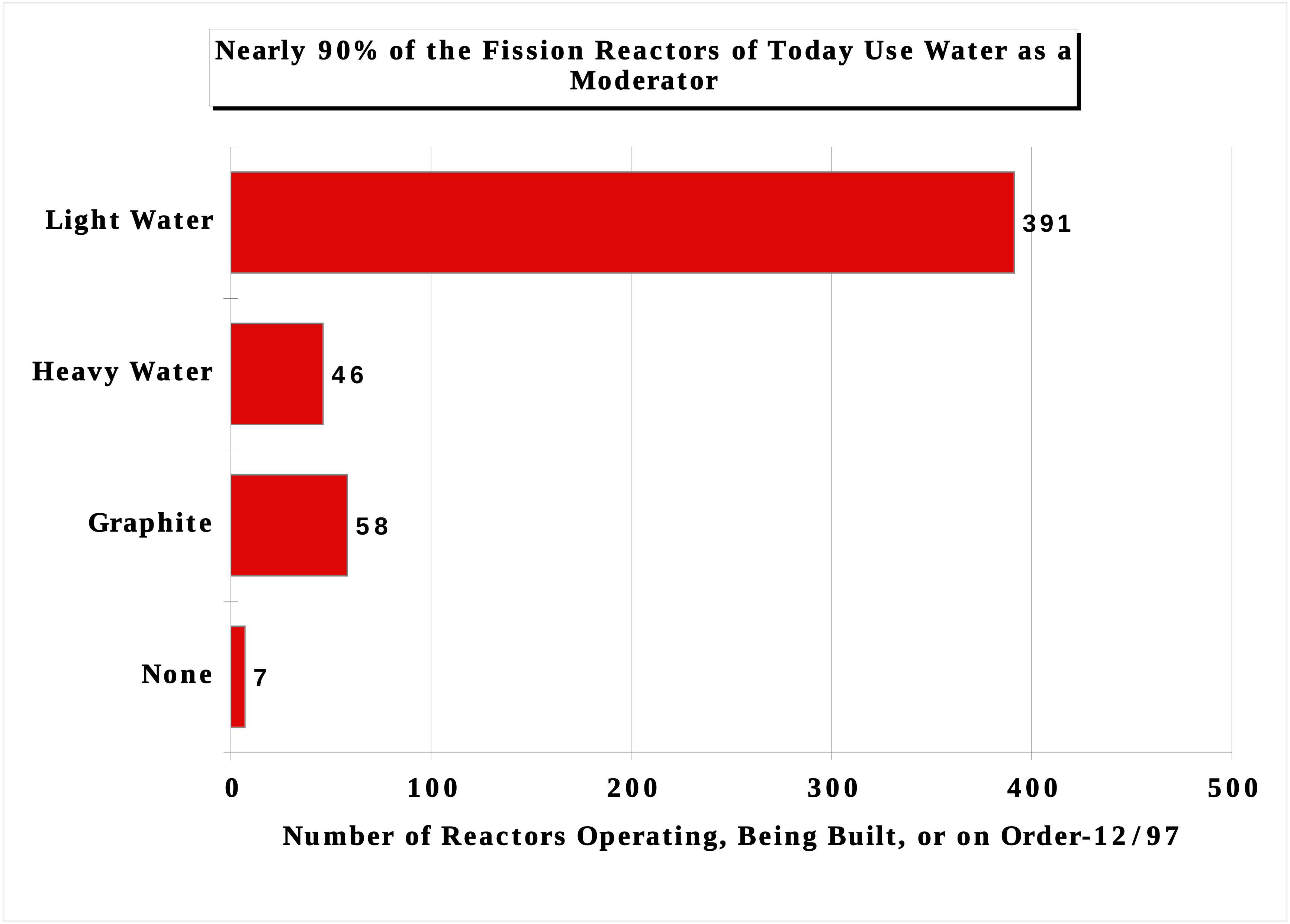
	Operating	Under Construction	Total
# of Reactors	437	36	478
Capacity-MW_e	351,795	26,813	378,608
Experience Reactor-Years	8,570	-	8,135
Research Reactors	323 (1991)	-	323 (1991)

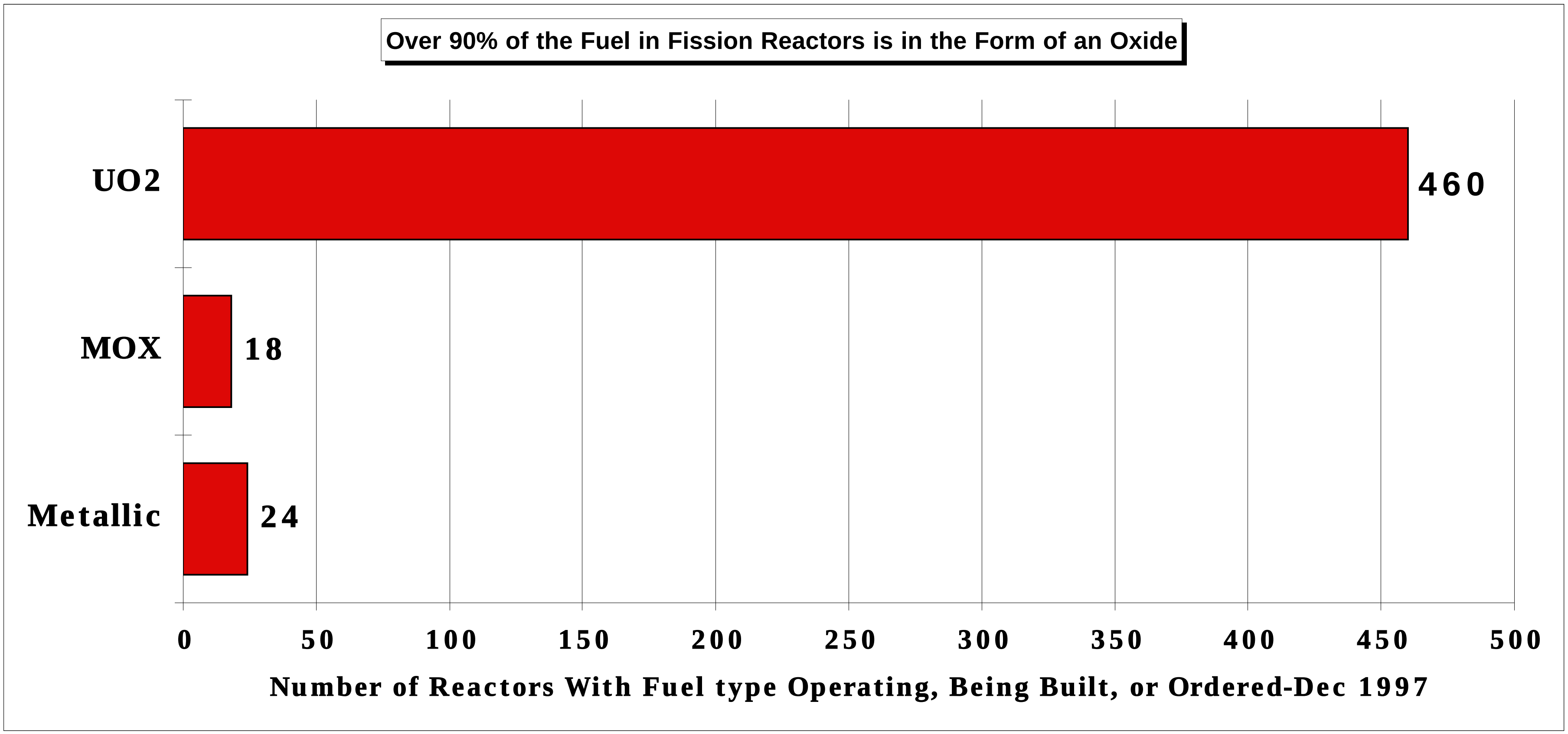
Frequency of new nuclear power plant connections to the grid around the world.

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



Nuclear Power Continues to Outstrip the Non-Fossil Fuels in Generation of Electricity in the United States
Source: Monthly Energy Review, Aug 1998, U. S. Dept. of Energy Doc., DOE/EIA-0035(98/08)
Nuclear
21% 0f US
Hydro
Geothermal
Solar, Wind, Wood
Billion kWh's of Electricity Generated
800
700
600
500
400
300
200
100
0
1970
1975
1980
1985
1990
1995


Nearly 90% of the Fission Reactors of Today Use Water as a Moderator
Light Water
391
Heavy Water
46
Graphite
58
None
7
0
100
200
300
400
500
Number of Reactors Operating, Being Built, or on Order-12/97



Over 90% of the Fuel in Fission Reactors is in the Form of an Oxide
UO2
460
MOX
18
Metallic
24
0
50
100
150
200
250
300
350
400
450
500
Number of Reactors With Fuel type Operating, Being Built, or Ordered-Dec 1997

Coolant Attributes For Fission Reactors

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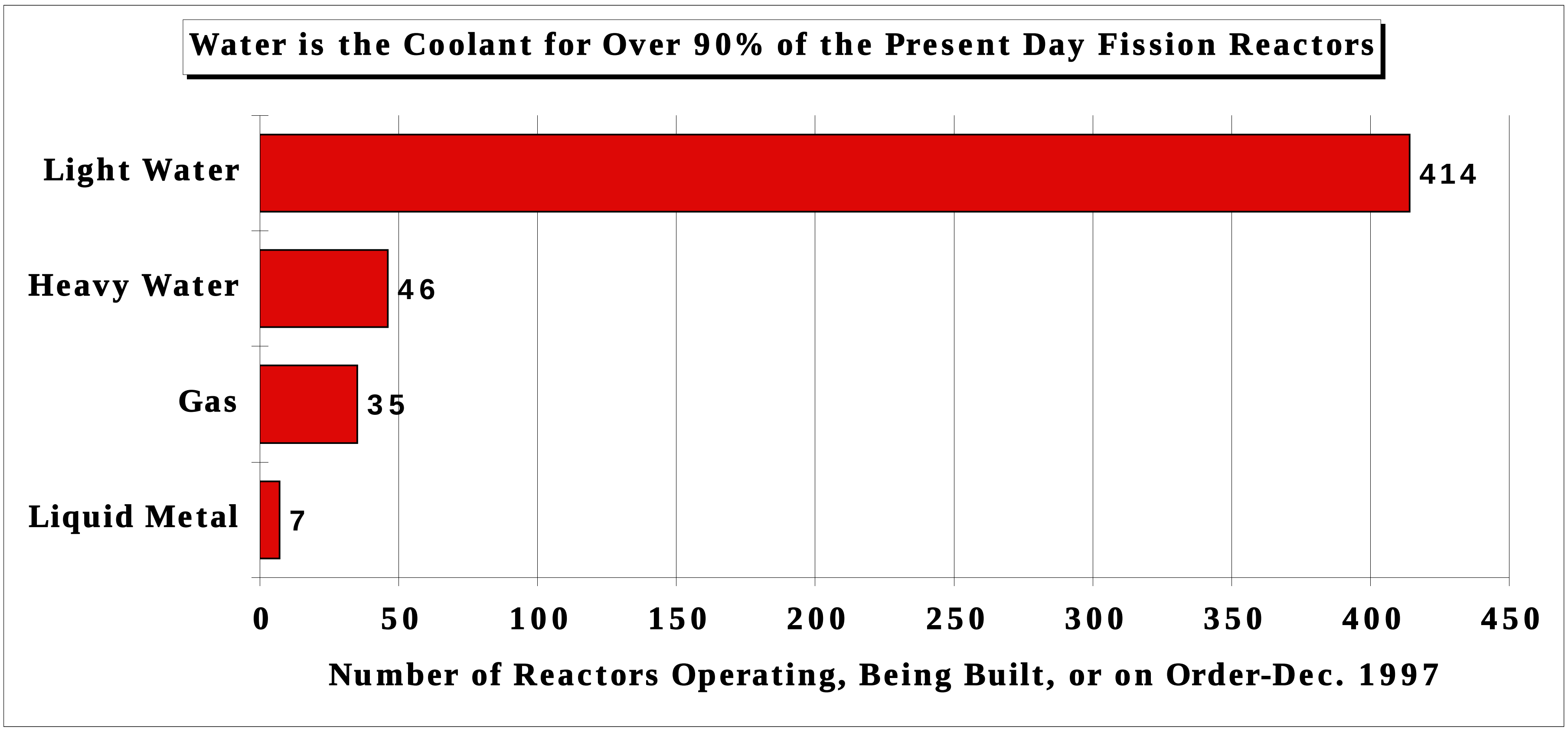
1.) High thermal conductivity

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
Light Water
414
Heavy Water
46
Gas
35
Liquid Metal
7
0
50
100
150
200
250
300
350
400
450
Number of Reactors Operating, Being Built, or on Order-Dec. 1997

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

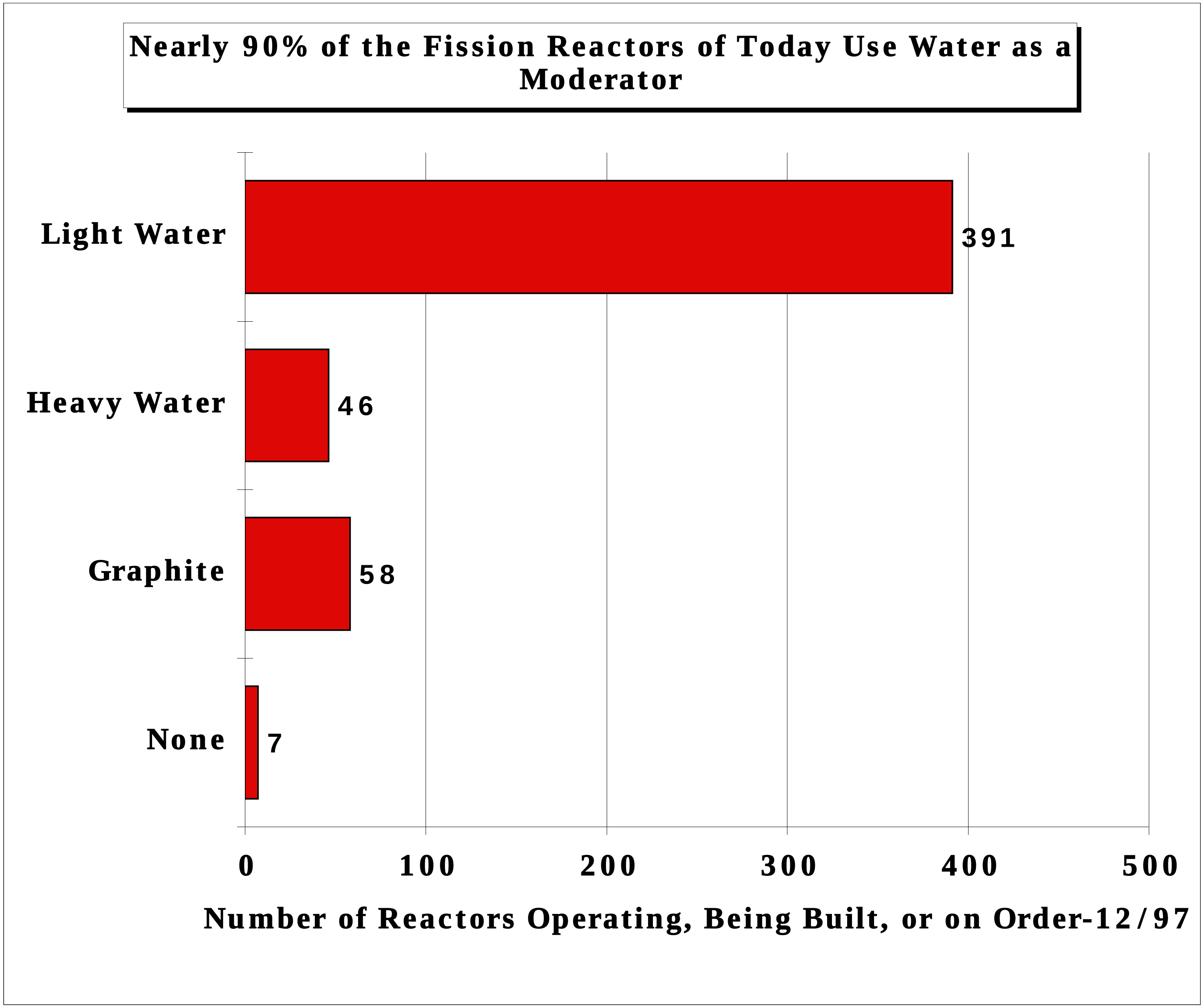
$$\xi = 1 + \frac{(A-1)^2}{2A} \ln \frac{A-1}{A+1}$$

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

Slowing Down Power = SDP=$\xi N \sigma_s = \Sigma_s \xi$

Moderating Ratio =MR = $\dfrac{\Sigma_s \xi}{\Sigma_a}$

Moderator	SDP, cm^{-1}	Mod Ratio	Comments
H_2O	1.53	72.	
D_2O	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
Light Water
391
Heavy Water
46
Graphite
58
None
7
0
100
200
300
400
500
Number of Reactors Operating, Being Built, or on Order-12/97

General Characteristics of Fission Reactor Designs				
Type	**Fuel (% ^{235}U)**	**Moderator**	**Coolant (atm)**	**Steam Generator**
PWR	UO_2 (3.2)	H_2O	H_2O (160)	Separate Circuit
BWR	UO_2 (3.2)	H_2O	H_2O (70)	Direct
CANDU	UO_2 (0.711)	D_2O	D_2O (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_2O (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**

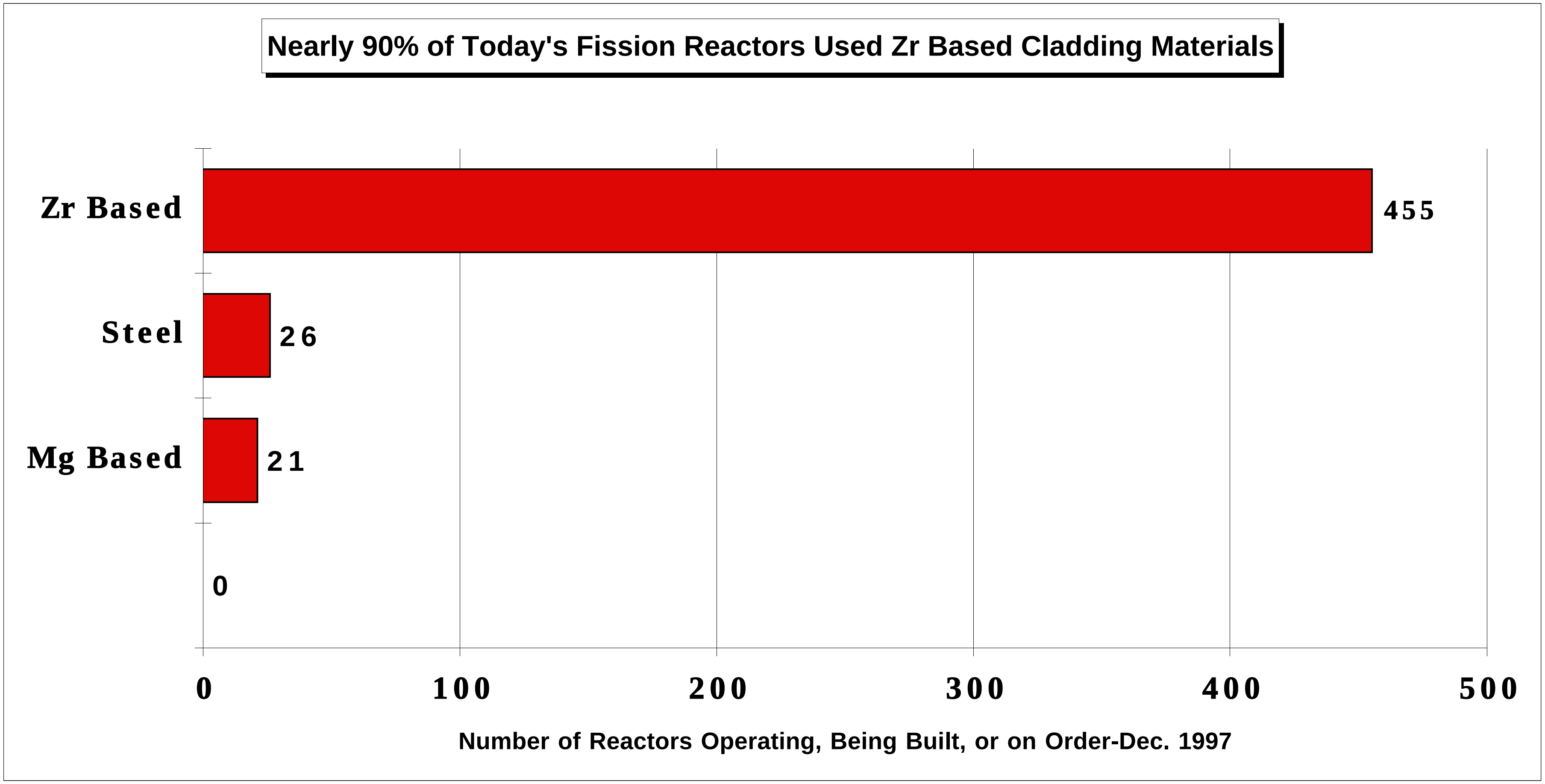
6.) **Good neutronic properties**

7.) **Easy to fabricate and install**

8.) **Easy to reprocess**

9.) **Low Cost**

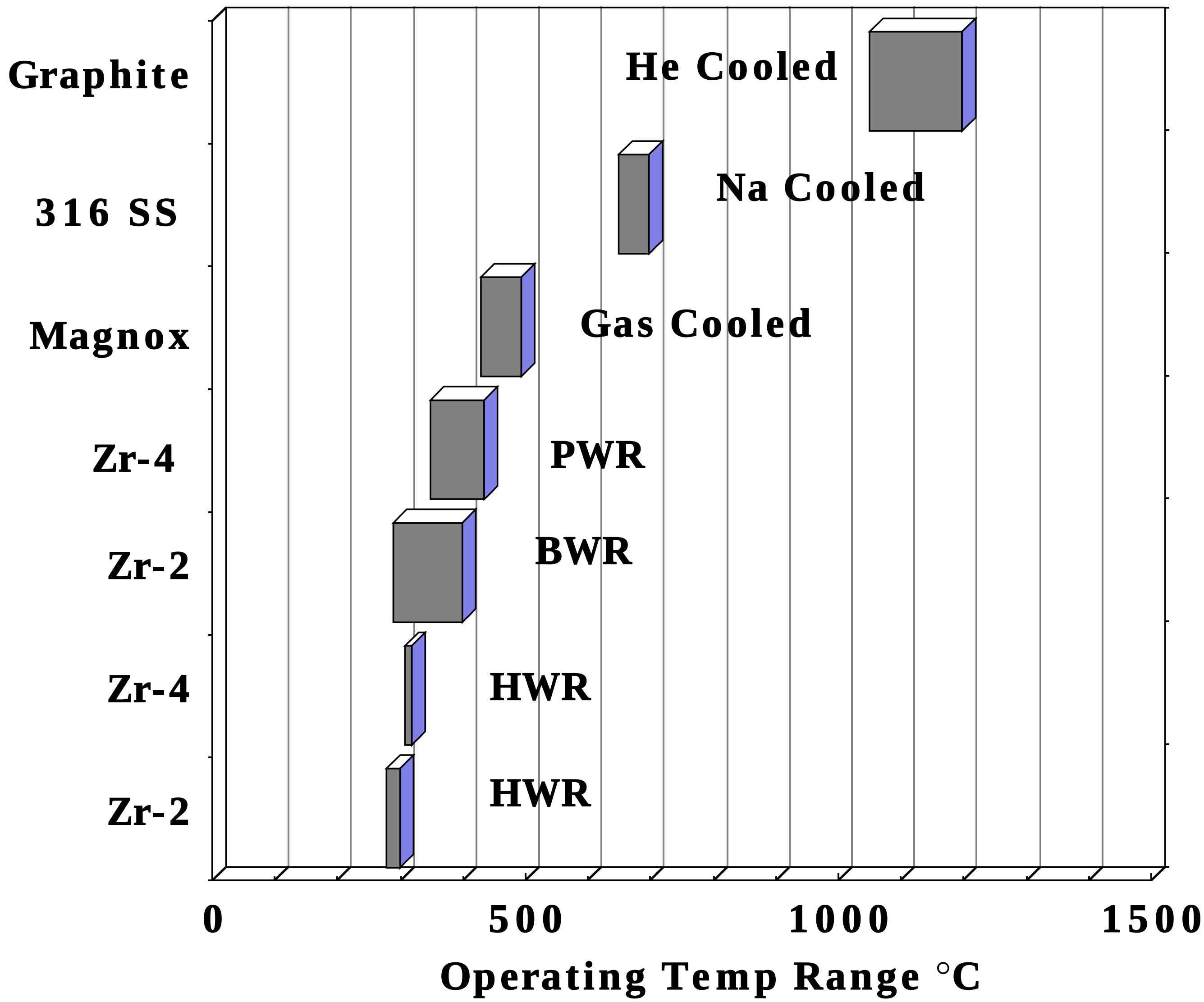
10.) **Low demand on scarce resources**



Nearly 90% of Today's Fission Reactors Used Zr Based Cladding Materials
Zr Based
455
Steel
26
Mg Based
21
0
0
100
200
300
400
500
Number of Reactors Operating, Being Built, or on Order-Dec. 1997

Summary of Fission Reactor Operating Temperatures			
Cladding Material	Tmax, °C	Coolant	Tout °C
Fast Reactors			
316 SS	650-700	Na	500-550
HWR			
Zircaloy-2	280-300	D_2O	260-310
Zircaloy-4	310-330	D2O	260-310
Graphite			
Magnox	430-495	CO_2	350-400
Mg-Zr	465-510	CO_2	350-400
Graphite	1050-1200	He	750-850
Austenite	625-640	He	750-850
BWR			
Zircaloy-2	290-400	H_2O	280-290
PWR			
Zircaloy-4	350-435	H_2O	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

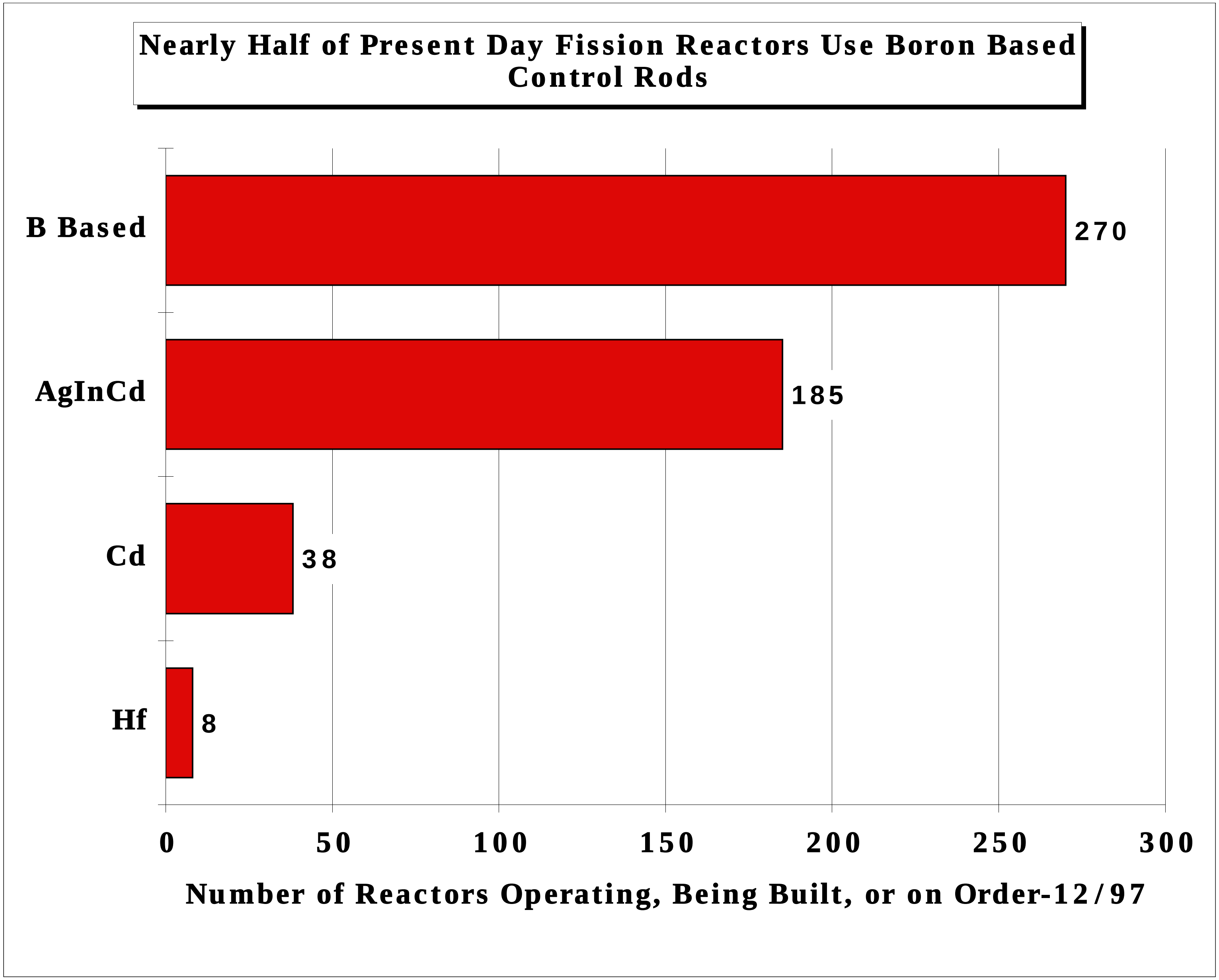
3.) Low mass to permit rapid movement

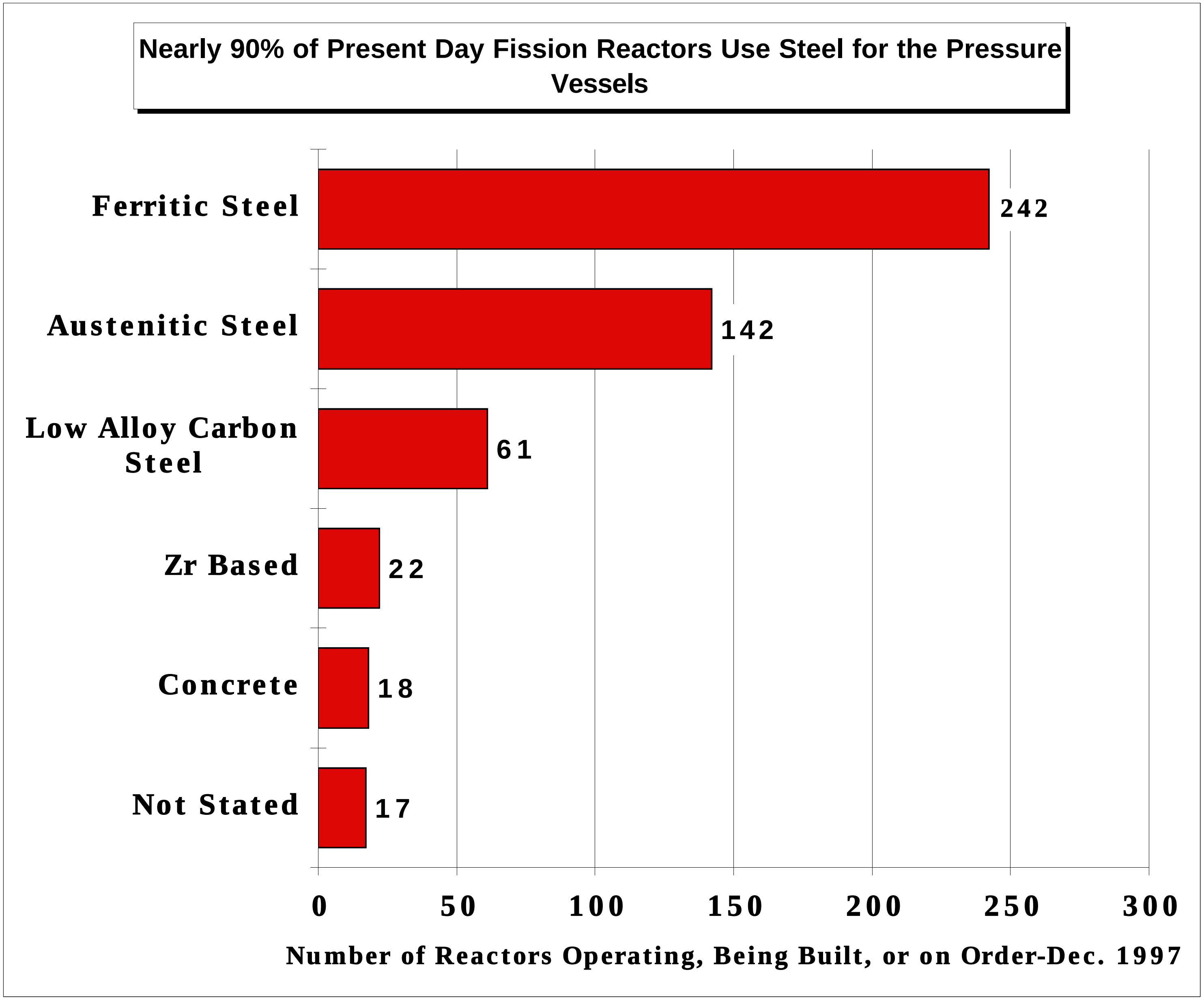
4.) Corrosion resistance

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
B Based
270
AgInCd
185
Cd
38
Hf
8
0
50
100
150
200
250
300
Number of Reactors Operating, Being Built, or on Order-12/97



Nearly 90% of Present Day Fission Reactors Use Steel for the Pressure Vessels
Ferritic Steel
242
Austenitic Steel
142
Low Alloy Carbon Steel
61
Zr Based
22
Concrete
18
Not Stated
17
0
50
100
150
200
250
300
Number of Reactors Operating, Being Built, or on Order-Dec. 1997

Attributes of Shield Material

1.) Good moderating material

2.) Good neutron absorber

3.) High density to attenuate gamma rays

=======================================

Possible Shield materials

A.) Amalgums

B.) Cements & concretes with special aggregates

C.) Ceramics and cermets

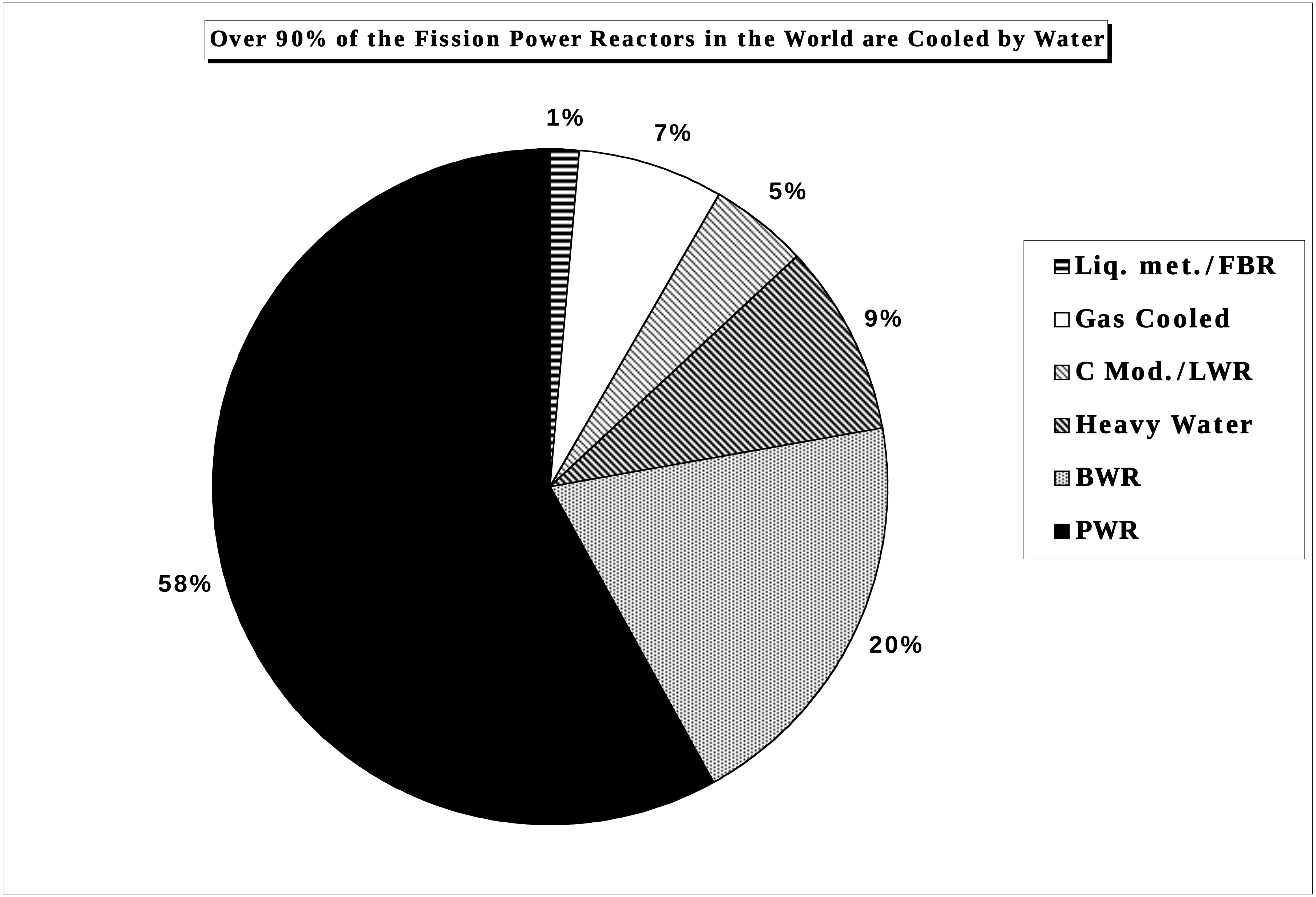
D.) Glasses and fused salts

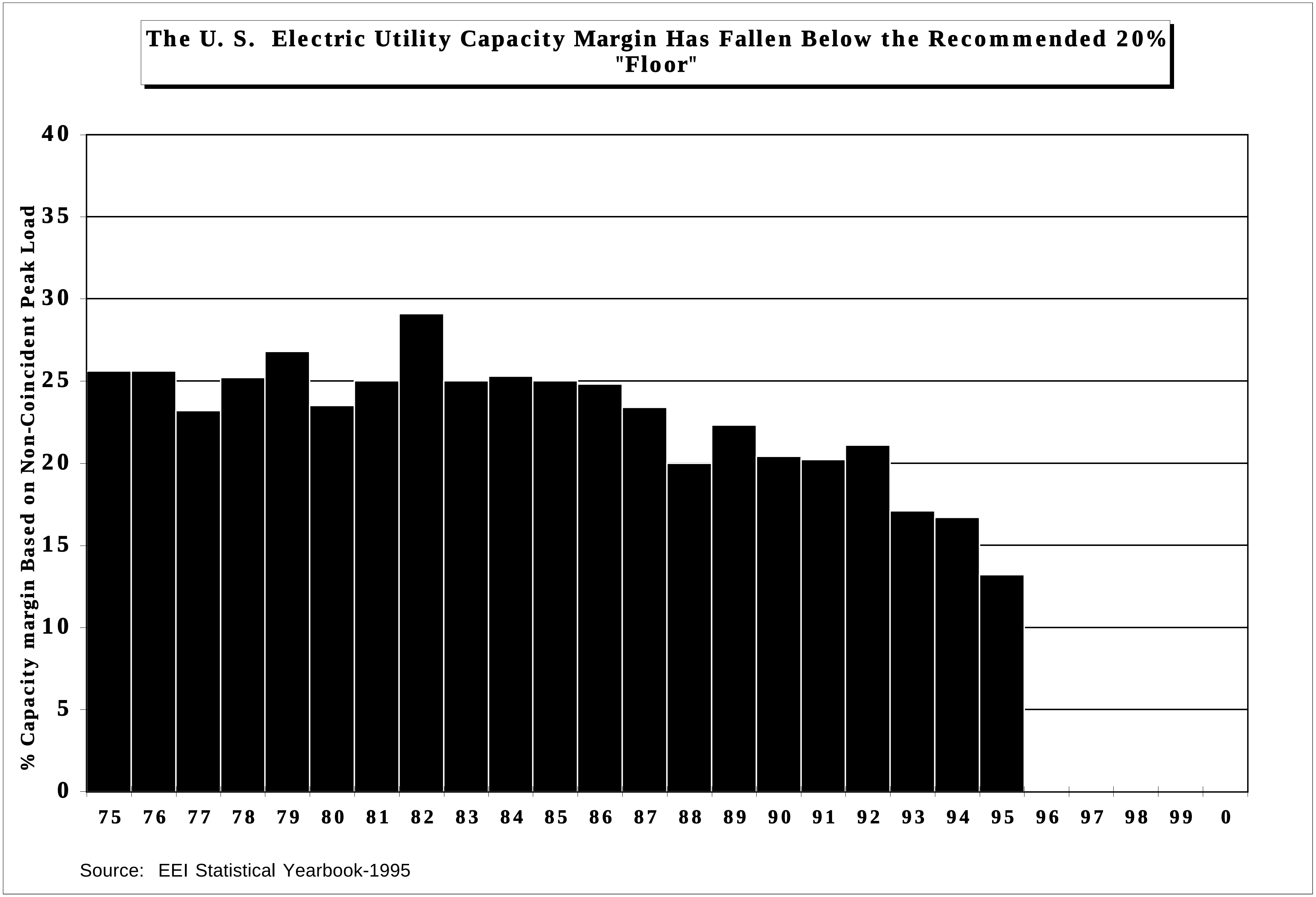
E.) Metal ores

F.) Metal alloys and sintered powers

G.) Organics such as plastics, metal esters, metal loaded resins, elastomers, and silicones

H.) Silica and other gels preciptated from B loaded solutions


Over 90% of the Fission Power Reactors in the World are Cooled by Water
1%
7%
5%
9%
20%
58%
Liq. met./FBR
Gas Cooled
C Mod./LWR
Heavy Water
BWR
PWR


The U. S. Electric Utility Capacity Margin Has Fallen Below the Recommended 20% "Floor"
% Capacity margin Based on Non-Coincident Peak Load
40
35
30
25
20
15
10
5
0
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 0
Source: EEI Statistical Yearbook-1995