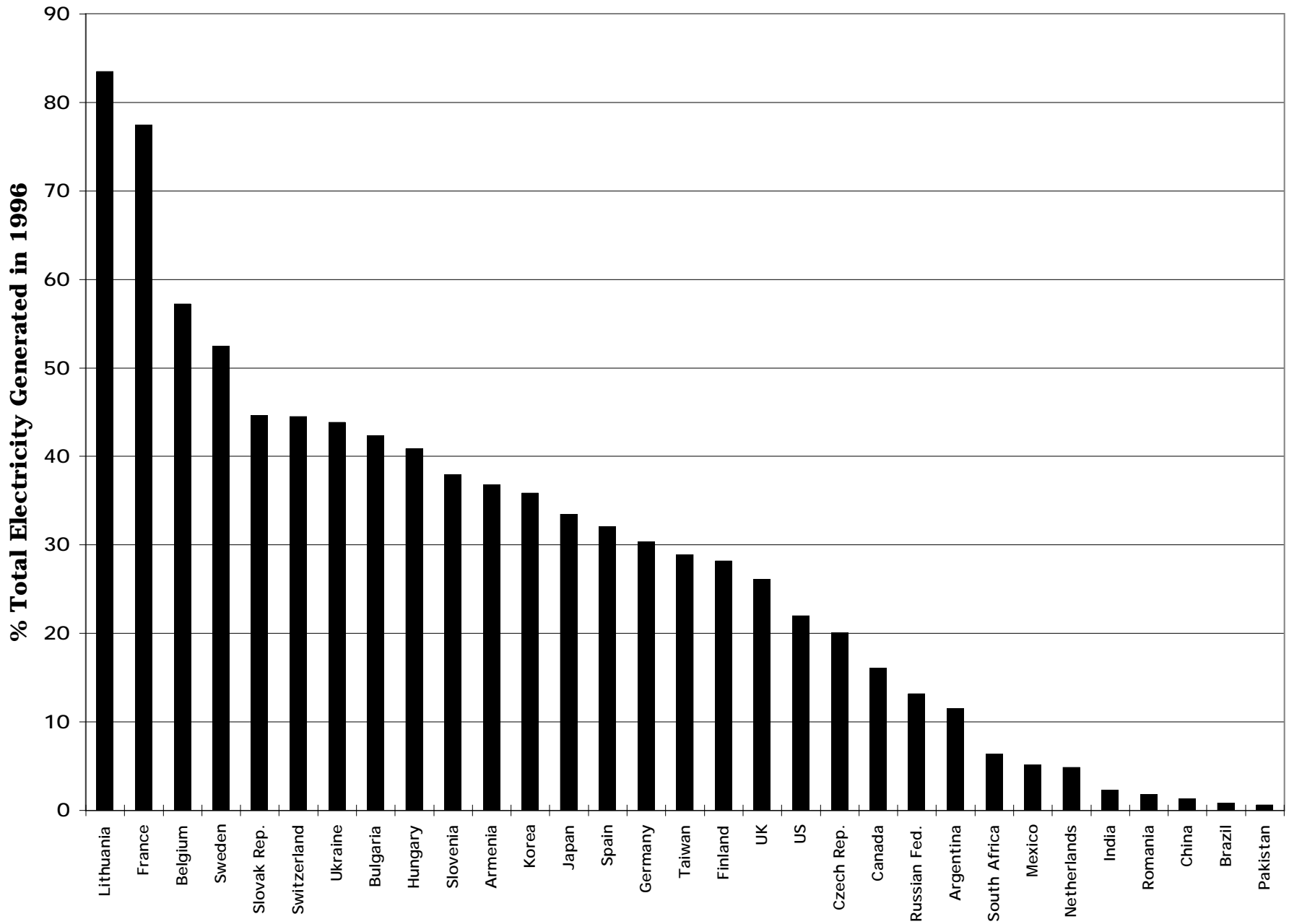


23 Countries Generated in Excess of 10% Of Their Electricity in 1996



Nuclear Power Reactors in Operation and Under Construction, 12/30/96										
		Reactors in Operation in 12/96		Reactors Under Const. 12/96		Nuclear Elect. Supplied in 1996		Nuclear Elect. Supplied in 1996		
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	83	
France	57	59,948	3	4,355	378.2	77.4	France	France	77	
Belgium	7	5,712	0	0	41.4	57.2	Belgium	Belgium	57	
Sweden	12	10,040	0	0	71.4	52.4	Sweden	Sweden	52	
Slovak Rep.	4	1,632	4	1,552	11.3	44.5	Slovak Rep.	Slovak Rep.	45	
Switzerland	5	3,077	0	0	23.7	44.5	Switzerland	Switzerland	44	
Ukraine	16	13,765	4	3,800	79.6	43.8	Ukraine	Ukraine	44	
Bulgaria	6	3,538	0	0	18.1	42.2	Bulgaria	Bulgaria	42	
Hungary	4	1,729	0	0	14.2	40.8	Hungary	Hungary	41	
Slovenia	1	632	0	0	4.4	37.9	Slovenia	Slovenia	38	
Armenia	1	376	0	0	2.1	36.7	Armenia	Armenia	37	
Korea	11	9,120	5	3,870	70.3	35.8	Korea	Korea	36	
Japan	53	42,369	2	2,111	287.0	33.4	Japan	Japan	33	
Spain	9	7,207	0	0	53.8	32.0	Spain	Spain	32	
Germany	20	22,282	0	0	152.8	30.3	Germany	Germany	30	
Taiwan	6	4,884	0	0	35.3	28.8	Taiwan	Taiwan	29	
Finland	4	2,355	0	0	18.7	28.1	Finland	Finland	28	
UK	35	12,928	0	0	85.5	26.0	UK	UK	26	
US	110	100,685	1	1,165	674.8	21.9	US	US	22	
Czech Rep.	4	1,648	2	1,824	12.9	20.0	Czech Rep.	Czech Rep.	20	
Canada	21	14,902	0	0	87.5	16.0	Canada	Canada	16	
Russian Fed.	29	19,843	4	3,375	108.8	13.1	Russian Fed.	Russian Fed.	13	
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	South Africa	6	
Mexico	2	1,308	0	0	7.1	5.1	Mexico	Mexico	5	
Netherlands	2	504	0	0	3.9	4.8	Netherlands	Netherlands	5	
India	10	1,695	4	808	7.4	2.2	India	India	2	
Romania	1	650	1	650	0.9	1.8	Romania	Romania	2	
China	3	2,167	2	1,200	13.6	1.3	China	China	1	
Brazil	1	626	1	1,245	2.3	0.7	Brazil	Brazil	1	
Pakistan	1	125	1	300	0.3	0.6	Pakistan	Pakistan	1	
Kazakhstan	1	70	0	0	0.1	0.2	Kazakhstan	Kazakhstan	0	
Iran	0	0	2	2,146	0.0	0.0	Iran	Iran	0	
Total	442	350,964	37	29,093	2,299					

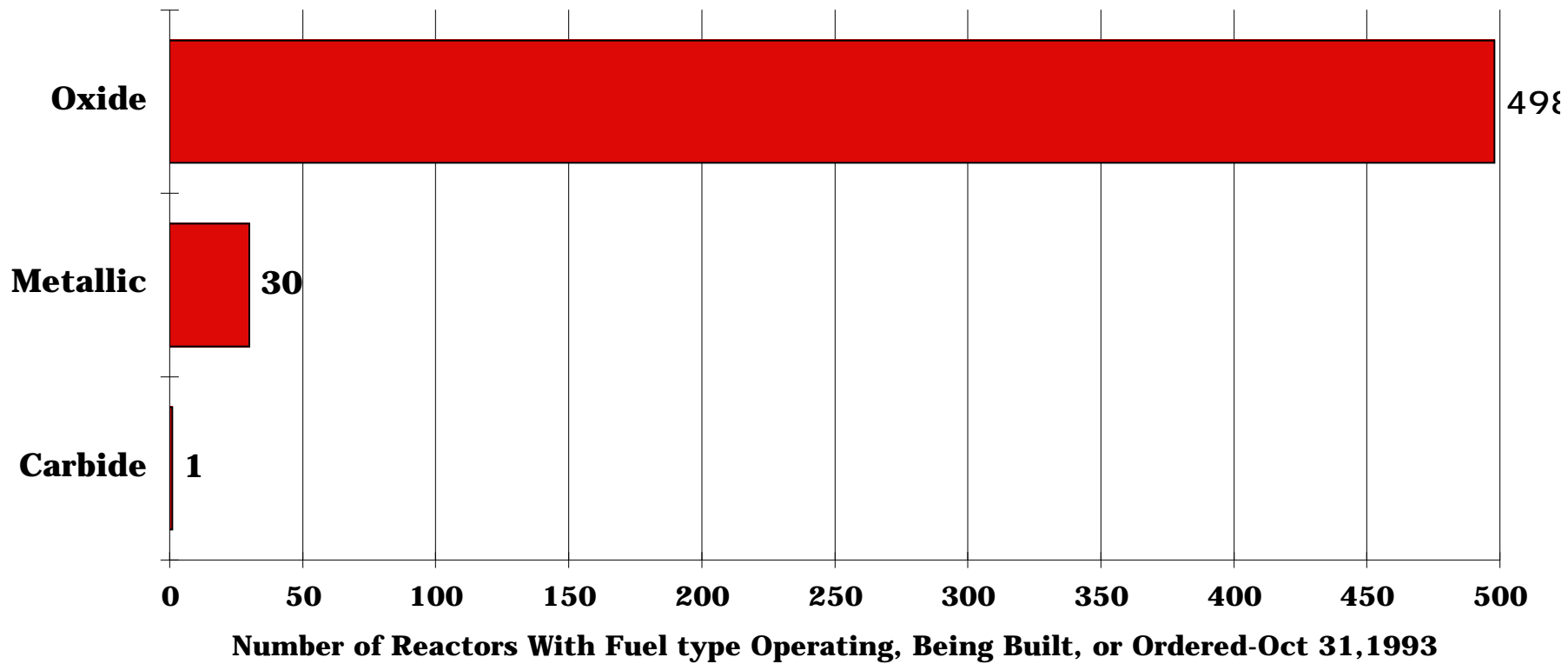
Worldwide Fission Power Reactor Status- Dec. 31, 1996

	Operating	Under Construction	Total
# of Reactors	442	36	478
Capacity-MW_e	350,964	27,928	378,892
Experience Reactor-Years	8,135	-	8,135
Research Reactors	323 (1991)	-	323 (1991)

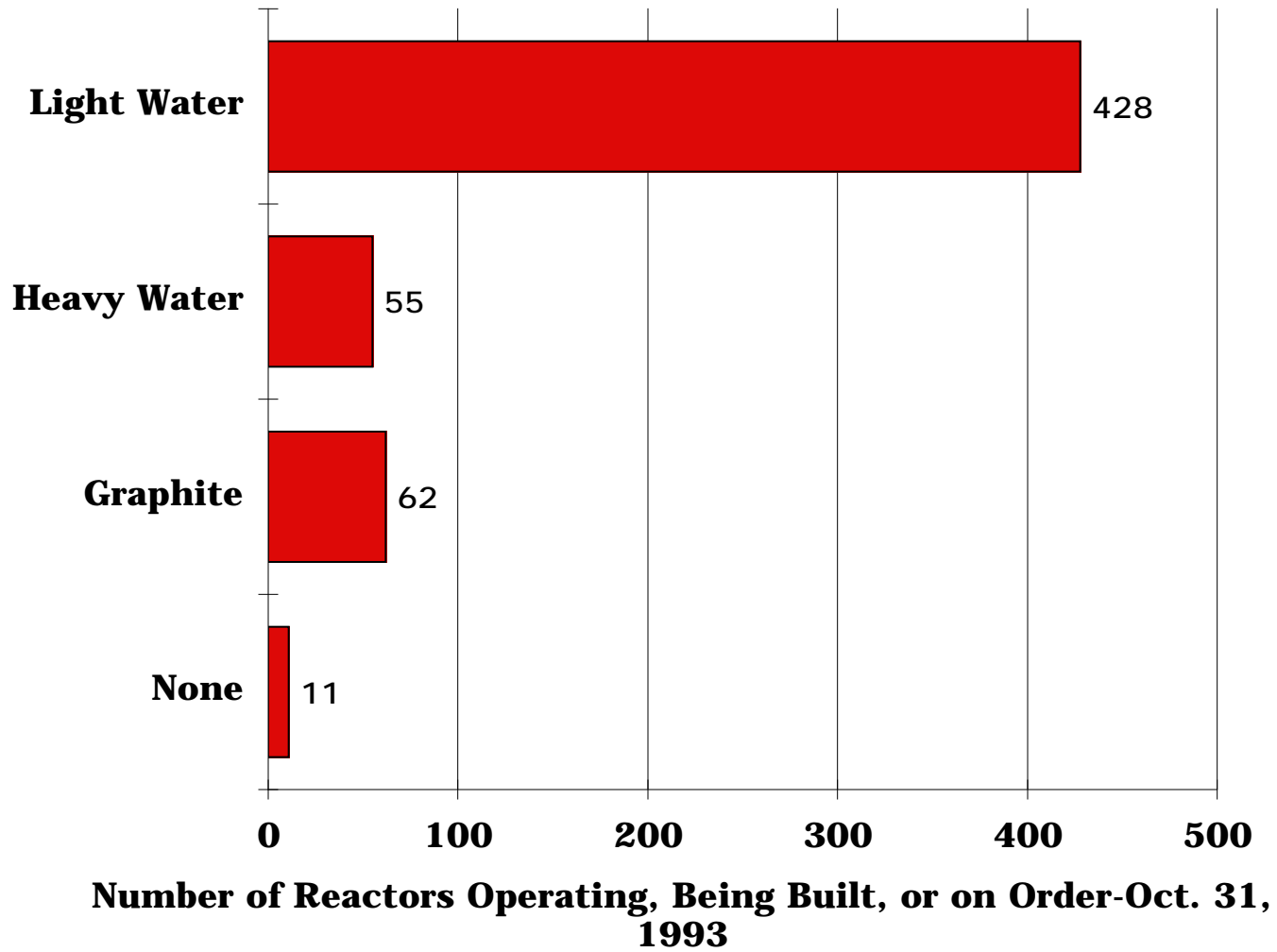
**Frequency of new nuclear power plant
connections to the grid around the world.**

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

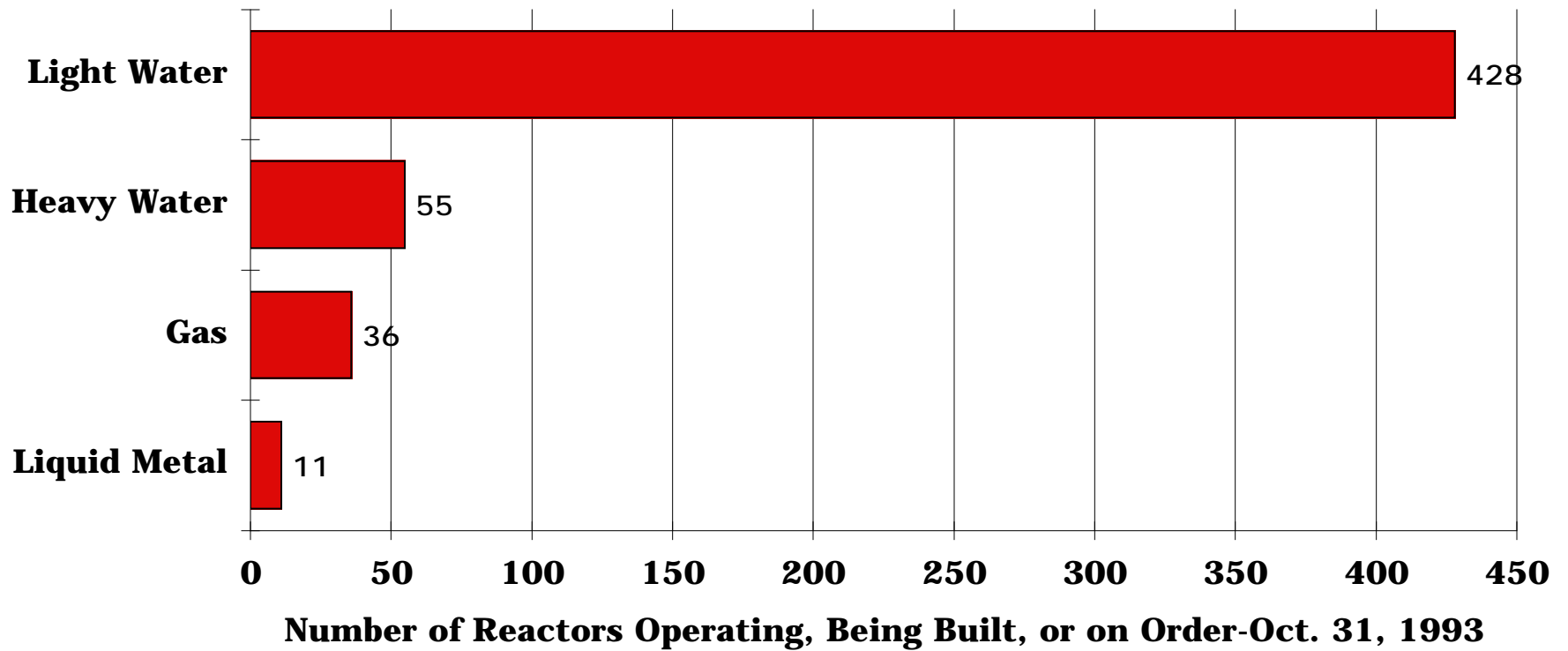
Over 90% of the Fuel in Fission Reactors is in the Form of an Oxide



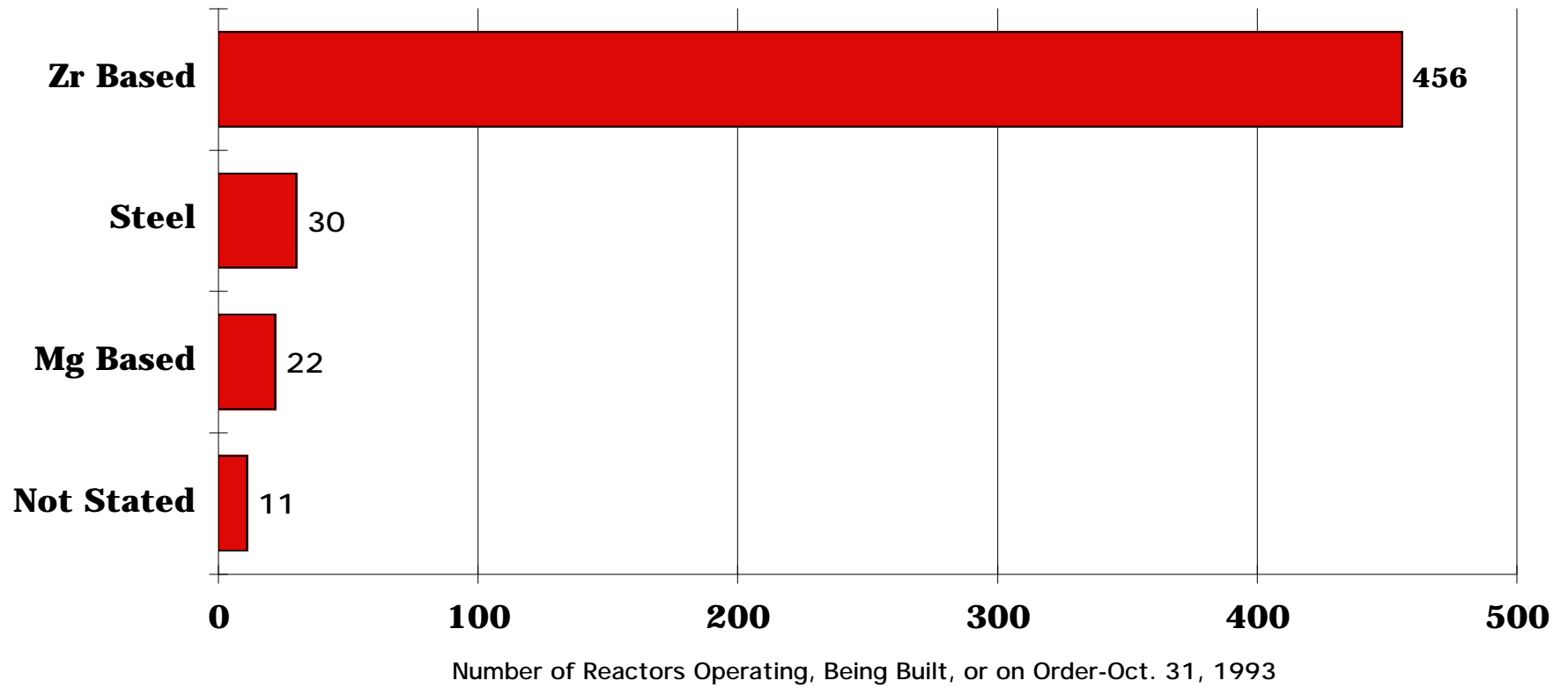
**Nearly 90% of the Fission Reactors of Today Use Water
as a Moderator**



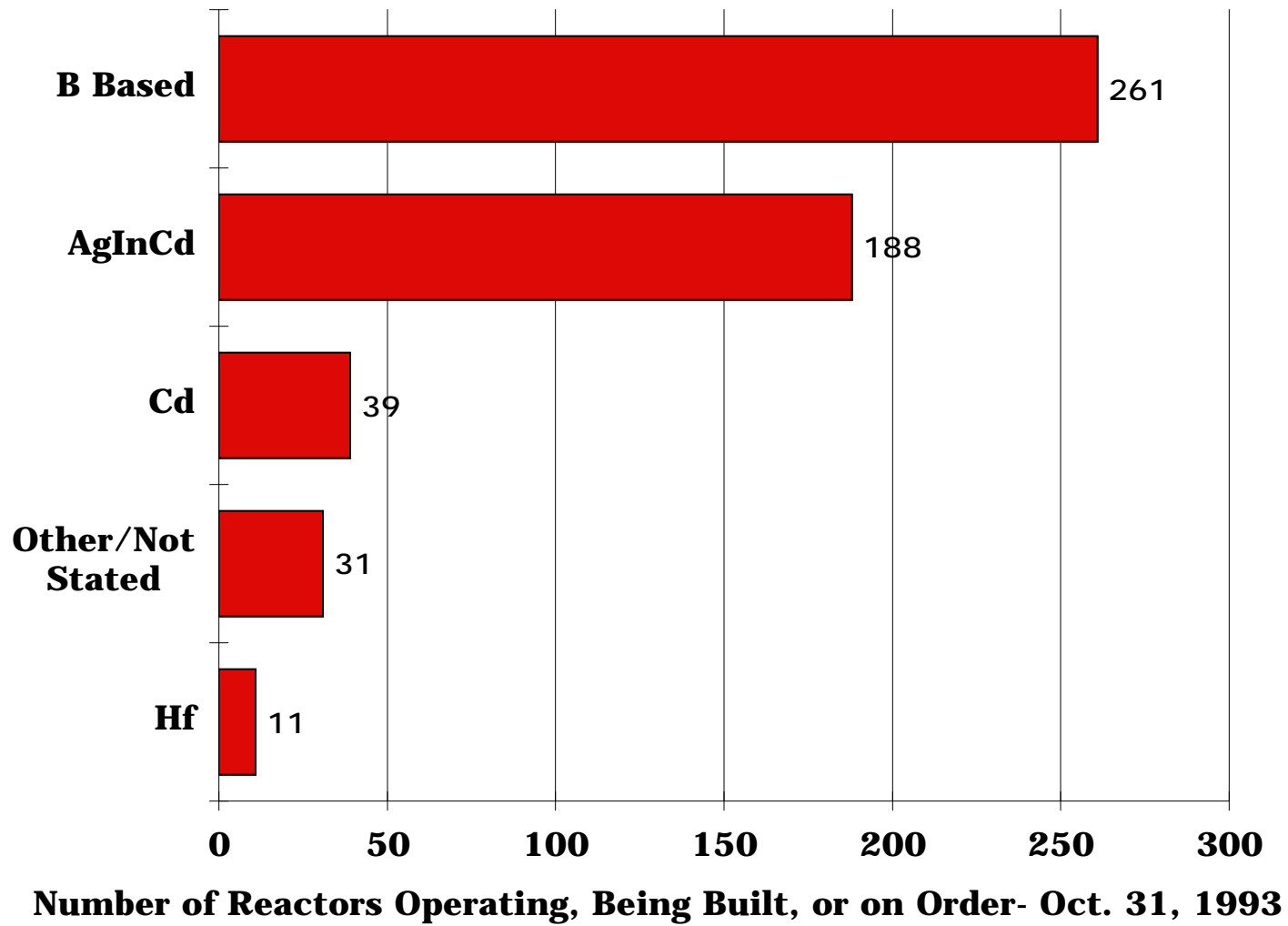
Water is the Coolant for Over 90% of the Present Day Fission Reactors



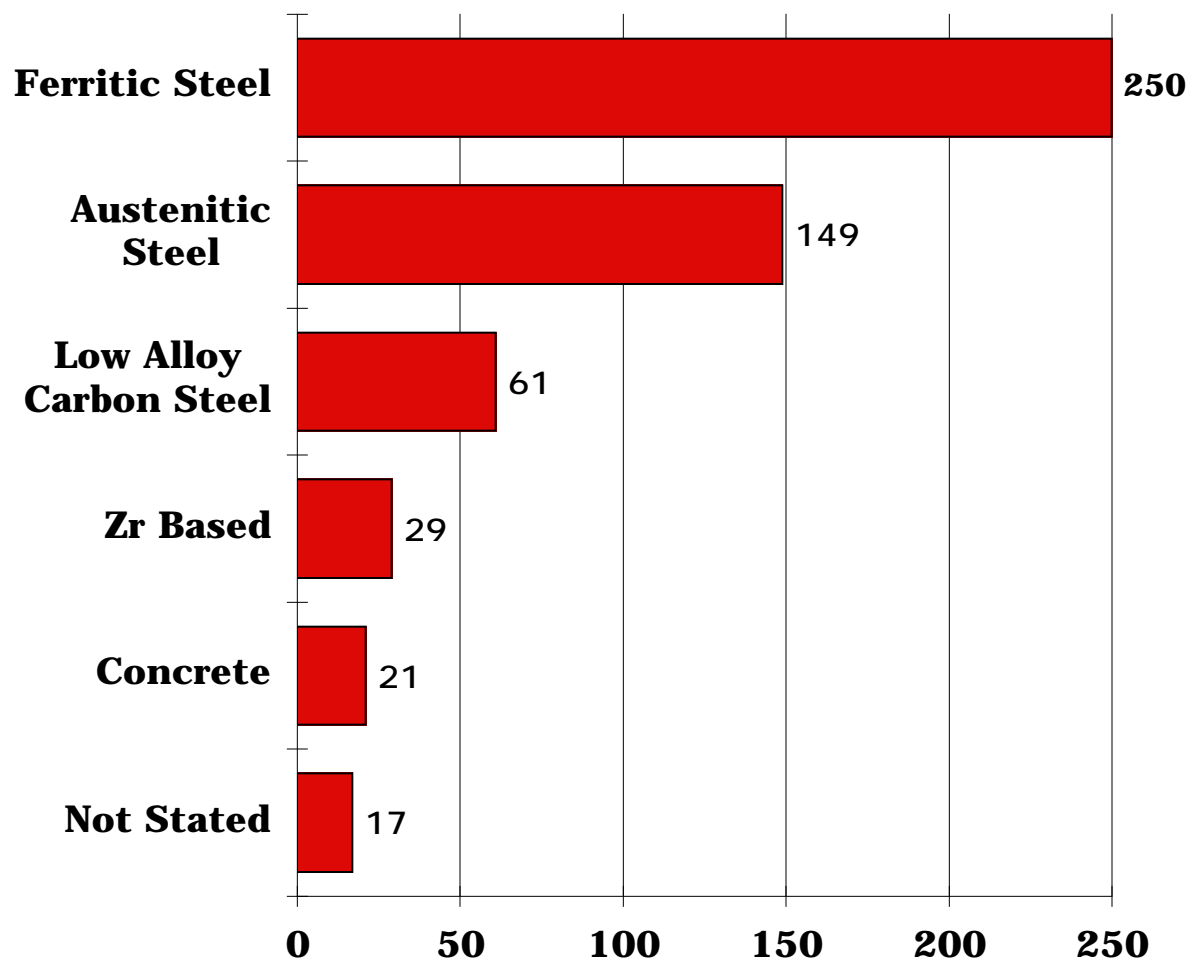
Nearly 90% of Today's Fission Reactors Used Zr Based Cladding Materials



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



Number of Reactors Operating, Being Built, or on Order- Oct. 31, 1993

Coolant Attributes For Fission Reactors

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

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
H ₂ O	1.53	72.	
D ₂ O	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.	

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

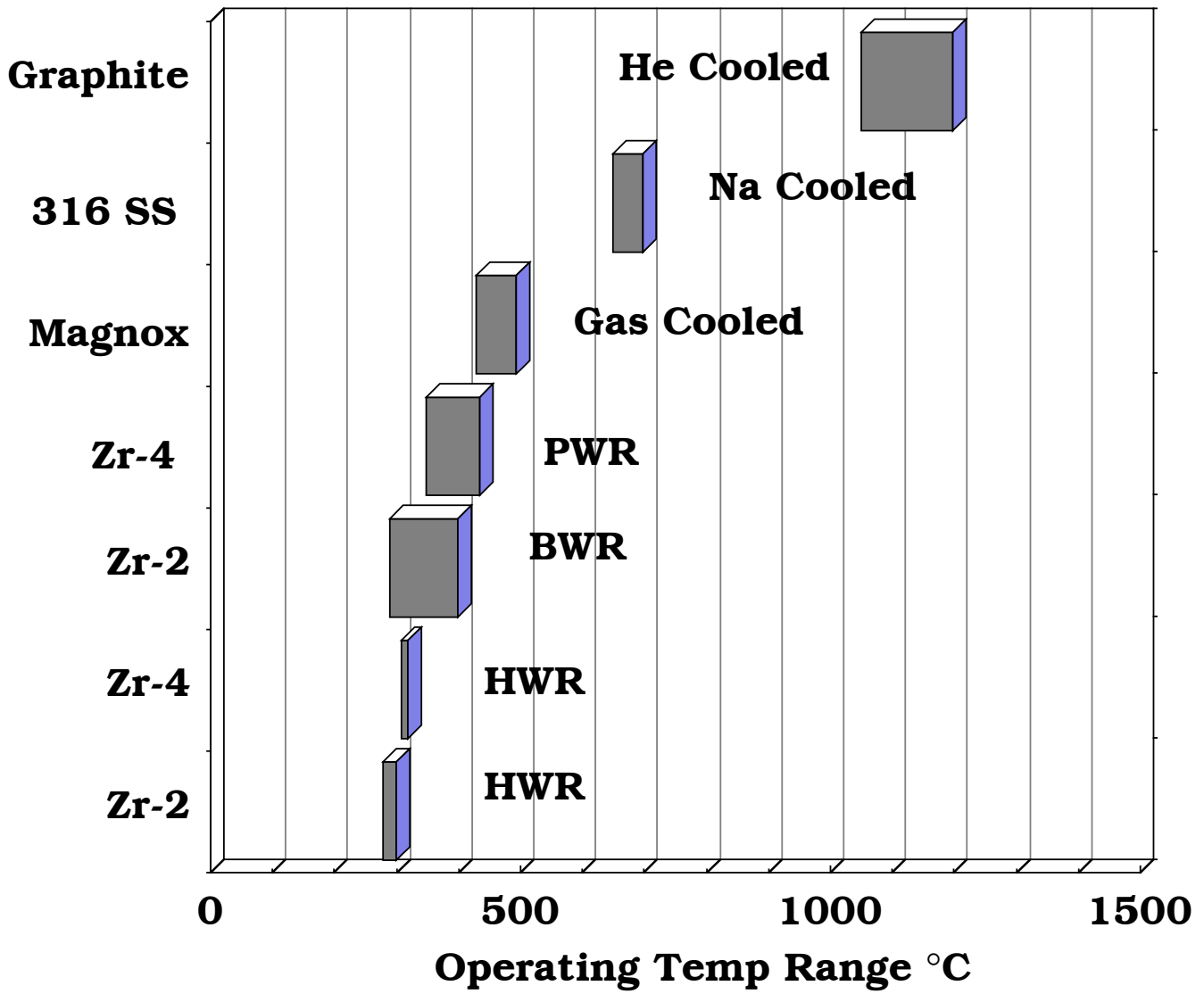
Fuel Must Be Protected From the Coolant and the Coolant Must Be Protected From the Fuel

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**

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**

Attributes of Shield Material

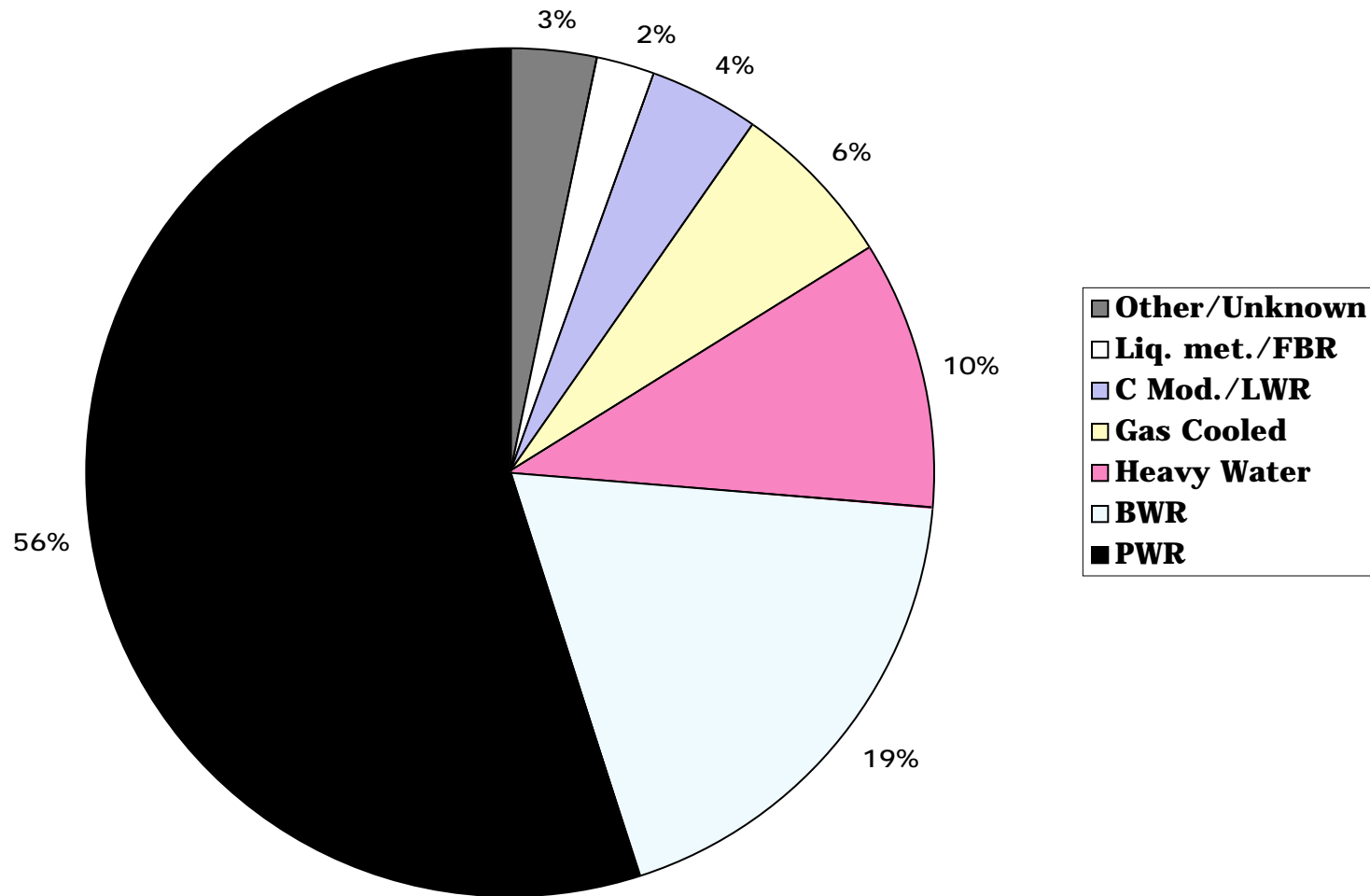
- 1.) Good moderating material
- 2.) Good neutron absorber
- 3.) High density to attenuate gamma rays

=====

Possible Shield materials

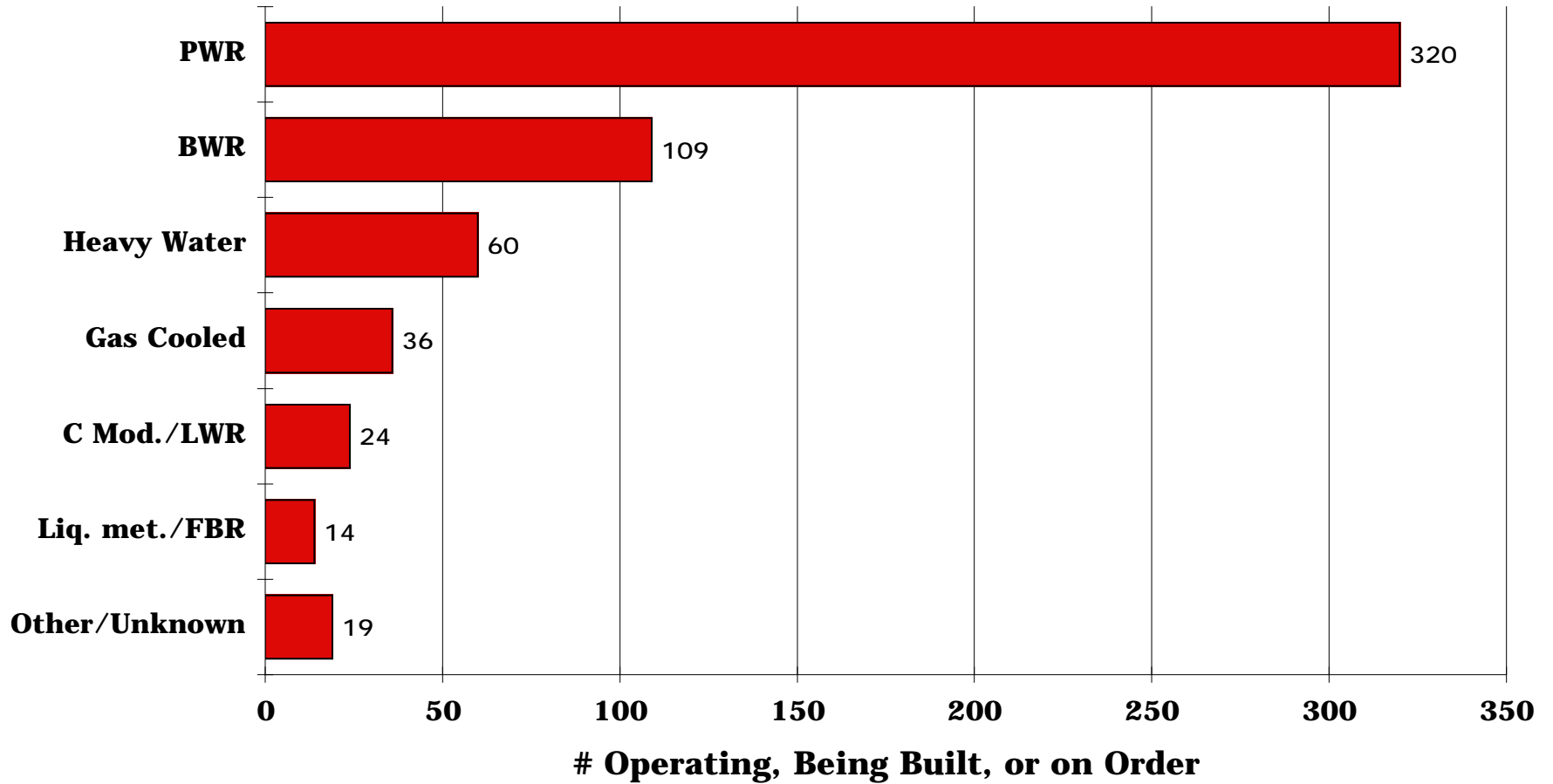
- A.) Amalgams
- B.) Cements & concretes with special aggregates
- C.) Ceramics and cermets
- D.) Glasses and fused salts
- E.) Metal ores
- F.) Metal alloys and sintered powders
- G.) Organics such as plastics, metal esters, metal loaded resins, elastomers, and silicones
- H.) Silica and other gels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

Over 85% of the Fission Power Reactors in the World are Cooled by Water

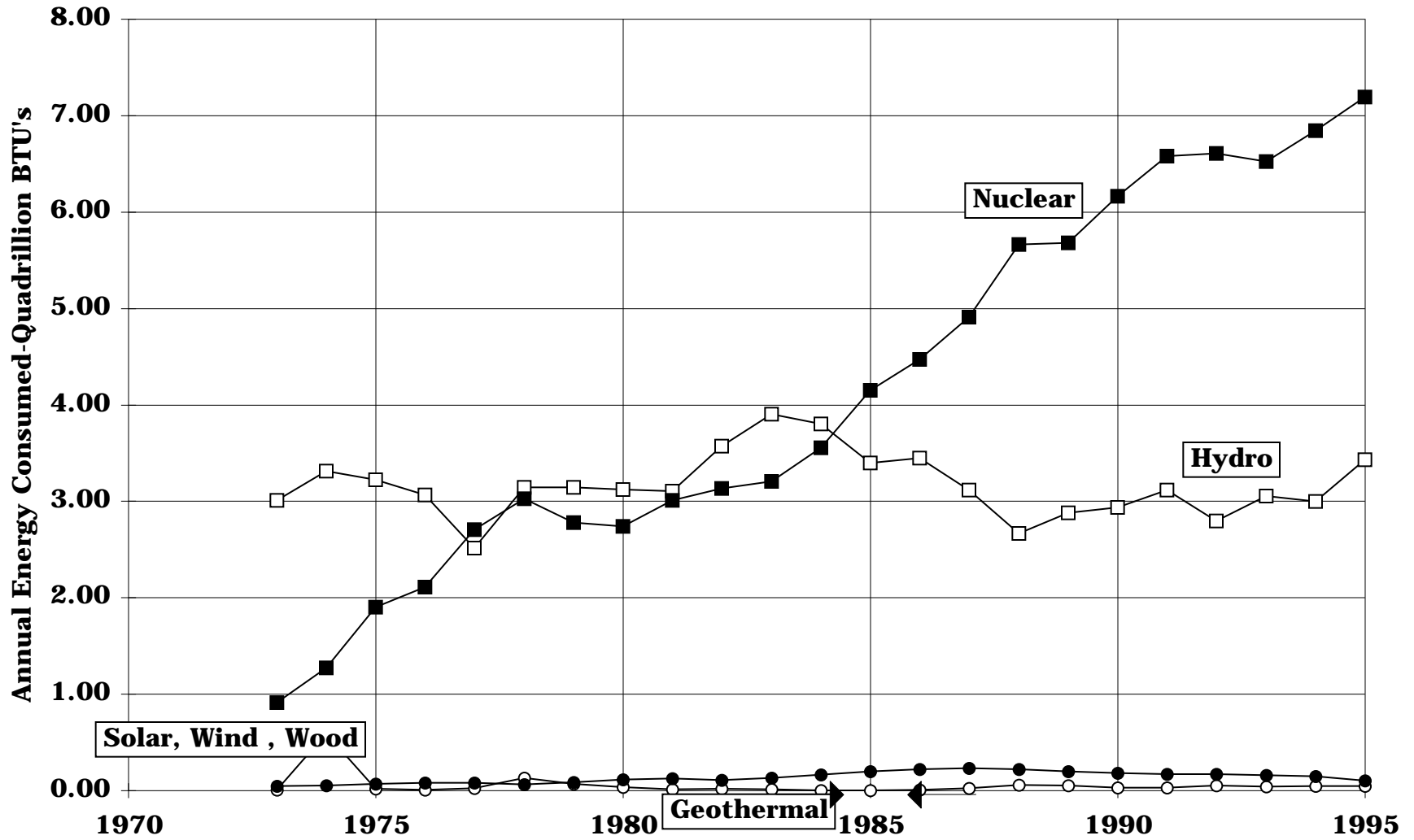


**Approximately 90% of the Fission Reactors Around the World Are Water Cooled-Oct.
31, 1993**

582 Total Reactors



The Nuclear Energy Consumed in the U. S. Continues to Outstrip That Provided by All Other Renewable Sources



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

