

A list of books for further reading

- M. Gowing, *Britain and Atomic Energy, 1939-1945*, Macmillan, 1964.
- M. Gowing, *Independence and Deterrence—Britain and Atomic Energy, 1945-1952*, Macmillan 1974.
- R. F. Pocock, *Nuclear Power: Its Development in the United Kingdom*, Unwin Brothers and the Institution of Nuclear Engineers, 1977.
- R. Williams, *The Nuclear Power Decisions*, Croom Helm Ltd., 1980.
- G. Greenhalgh, *The Necessity for Nuclear Power*, Graham & Trotman, 1980.
- 'Nuclear Power and the Environment', Sixth Report of the Royal Commission on Environmental Pollution, Cmnd 6618, 1976.
- D. R. Poulter (ed.), *The Design of Gas Cooled Graphite Moderated Reactors*, Oxford University Press, 1963.
- A. F. Henry, *Nuclear Reactor Analysis*, M.I.T. Press, Cambridge, Mass., 1975.
- A. M. Judd, *Fast Breeder Reactors*, Pergamon Press, 1980.
- J. R. Lamash, *Nuclear Reactor Theory*, Addison-Wesley, 1966.
- J. Lewins, *Nuclear Reactor Kinetics and Control*, Pergamon Press, 1978.
- R. L. Murray, *Nuclear Energy* (2nd Edition), Pergamon Press, 1980.
- T. J. Connolly, *Fundamentals of Nuclear Engineering*, Wiley, 1978.
- S. Glasstone and A. Sesonske, *Nuclear Reactor Engineering*, Van Nostrand Reinhold Company, 1981.
- S. Rippon, *Nuclear Energy*, Heinemann, 1984.
- 'Nuclear Energy: a professional assessment', Watt Committee on Energy, Report No. 13, 1984.
- W. Marshall (ed.), *Nuclear Power Technology* (3 vols), Clarendon Press, 1984.
- E. E. Pochin, *Nuclear Radiation: Risks and Benefits*, Oxford University Press, 1983.
- E. Addinall and H. Ellington, *Nuclear Power in Perspective*, Kogan Page, 1982.
- 'Chernobyl — A Technical Appraisal', British Nuclear Energy Society, Thomas Telford, 1987.
- 'Advances in Power Station Construction', Central Electricity Generating Board, Barnwood, Pergamon, 1986.
- F. R. Farmer (ed.), *Nuclear Reactor Safety*, Academic Press, 1977.
- J. F. Flagg (ed.), *Chemical Processing of Reactor Fuels*, Academic Press, 1961.
- J. H. Fremlin, *Power Production — What Are The Risks?*, Oxford University Press, 1987.
- N. J. McCormick, *Reliability and Risk Analysis — Methods and Nuclear Power Applications*, Academic Press, 1981.
- L. E. J. Roberts, *Nuclear Power and Public Responsibility*, Cambridge University Press, 1984.
- J. R. Thomson, *Engineering Safety Assessment — an Introduction*, Longman, 1987.

Constants and conversion factors

Avogadro's number	6.023×10^{26} atoms/kilogram atom (molecules/ kilogram mole)
Boltzmann's constant	1.38×10^{-23} joule/Kelvin
Speed of light	2.998×10^8 metres/second
Proton mass	1.007 277 unified atomic mass units
Neutron mass	1.008 665 unified atomic mass units
Electron mass	0.000 549 unified atomic mass units
Electron charge	4.8×10^{-10} electrostatic unit
Energy:	or 1.602×10^{-19} coulomb
Mass:	1 MeV = 10^6 eV = 1.602×10^{-13} J = 1.602×10^{-6} erg
Mass-Energy:	1 u = 1.6604×10^{-27} kg
Power:	1 W = 931 MeV
Burnup:	1 MWd = 8.64×10^{10} J
Cross-section:	1 barn = 10^{-24} cm ²
Radioactivity:	1 becquerel = 1 disintegration/second
Radiation absorbed dose:	1 curie = 3.7×10^{10} disintegrations/second
Radiation dose equivalent:	1 gray = 1 J/kg
	1 sievert = 1 J/kg

Cross-sections and other data for materials used in nuclear engineering

Fuels	Density	σ_a	σ_r	σ_a	ν	η
	g/cm ³	barns	barns	barns		
Natural uranium	18.9	3.4	4.2	8.3	—	1.32
²³⁵ U	18.7	101	579	10	2.42	2.07
²³⁸ U	18.9	2.72	0	8.3	—	—
²³⁹ Pu	19.6	266	742	9.6	2.93	2.12

Moderators	Density	σ_a	σ_r	ξ	\bar{D}	L^2	$L(\bar{\nu})$
	g/cm ³	barns	barns		cm	cm ²	cm ³
Water	H ₂ O 1.0	0.66	~50	0.920	0.16	8.1	27
Heavy water	D ₂ O 1.1	0.001	10.6	0.509	0.87	30 000	131
Graphite	C 1.6	0.0045	4.7	0.158	0.84	2650	368
Beryllium	Be 1.85	0.0092	6.1	0.209	0.50	480	102

Structural, control and other materials	Density	σ_a	σ_r
	g/cm ³	barns	barns
Boron	2.3	759	4
Nitrogen	gas	1.85	10
Oxygen	gas	0.0002	3.8
Sodium	0.97	0.53	4
Magnesium	1.74	0.063	4
Aluminium	2.7	0.232	1.4
Sulphur	2.07	0.52	1.1
Iron	7.87	2.56	11
Zirconium	6.8	0.182	8

Notes: Cross-sections for capture and fission are 2200 m/s values. Scattering cross-sections are values for thermal neutrons and are in general (with the exception of H₂O and D₂O) constant at thermal energy.

The capture cross-sections of graphite and heavy water (and hence also their diffusion lengths) are very sensitive to impurities. The value of σ_a given for graphite is for commercial reactor grade graphite which has minor impurities. The value of σ_a given for D₂O is for pure material.

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