Spring Semester, 2011
Energy Engineering
에너지공학

Energy from fission

Ref. ch.8

Nuclear energy

Uranium (atomic number = 92): three isotopes → mass number 234, 235, 238 (^{234}U, ^{235}U, ^{238}U)

Nuclear reaction: fragmentation by splitting of the nuclei of atoms

energy, $W = mc^2$

e.g. 1 atomic mass unit (1.66×10^{-27} kg) → $W = 1.66 \times 10^{-27} \times (3 \times 10^8)^2$ J = 14.94×10^{-11} J = 4.147×10^{-17} kWh = 931 MeV

Nuclear fission: fragmented with neutrons(중성자)

<u>^{235}U fission</u>

^{235}U + neutron → ^{92}Kr + ^{141}Ba + 3neutron + gamma ray

Mass difference (235 – (92 + 141)) release energy

1 kg ^{235}U → 8×10^{13} J

Ref. Energy Studies

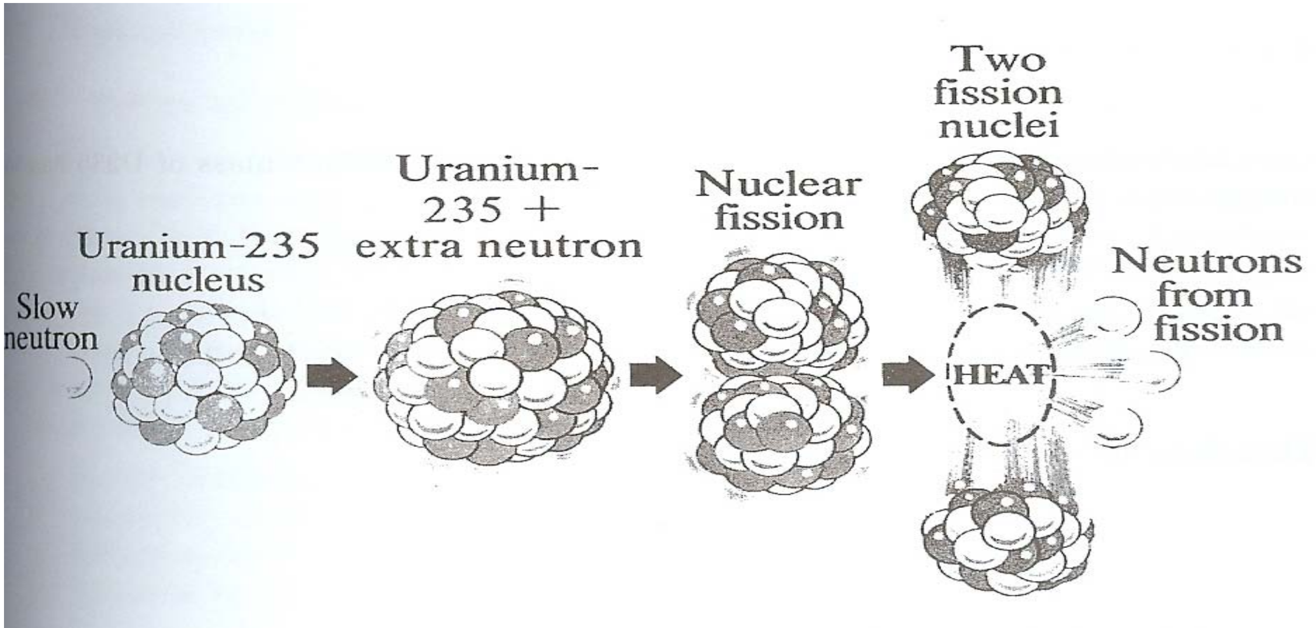
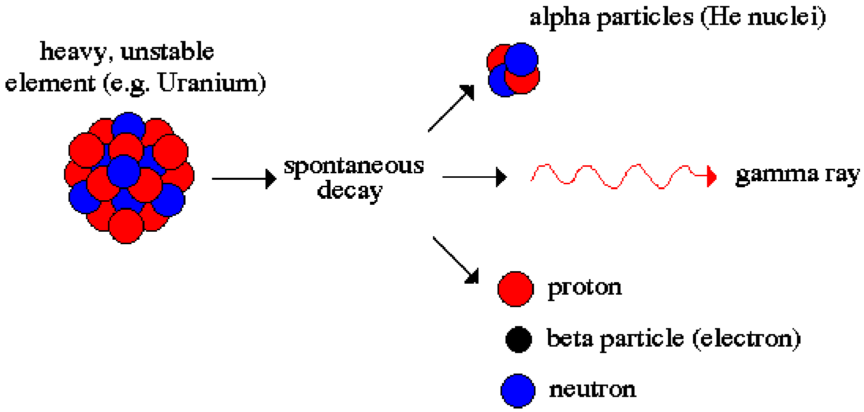


Fig. 8.1. Uranium fission [1] (reproduced by permission of AEA Technology plc).

Nuclear radiation:
alpha (α, helium nucleus, ^{4}He (atomic number 2))
beta(β, electron or positron)
Gamma (γ)-ray

Radioactivity



Units of radioactivity

The unit of activity is the **becquerel** (**Bq**)
One Bq is defined as one transformation (or decay) per second

GBq (gigabecquerel, 1 x 10^9 decays per second) or TBq (terabecquerel, 1 x 10^{12} decays per second) are commonly used

Another unit of radioactivity is the **curie, Ci**

1 Ci = the activity of any radionuclide decaying with a disintegration rate of 3.7×10^{10} Bq

Units of radiation

-”radiation-absorbed dose”(rad): 1 rad = 10^{-2} J/kg

-Gray (Gy) = 100 rads

-Roentgen (R): amount of X or γ radiation, 1 R = 2.58 x 10^{-4} C/kg

-”Roentgen equivalent man”(rem): amount of radiation that produces biological effect on human tissue, 1 sievert (Sv) = 100 rems

-The International Commission on Radiological Protection: max. radiation dose = 0.5 rem (or 5 mSv)/year

-No risk below 100 mSv/year

참고: 일본 후쿠시마 원자력발전소 방사능 유출

일본 후쿠시마 제1원자력발전소 1~4호기 폭발로 인한 방사능 누출이 심각해지면서 방사선 피폭 선량별 인체에 미치는 영향과 대응법에 관심이 쏠린다. 원자력법 시행령의 '방사선량 한도'에 따르면 일반인들은 자연 방사선과 의료방사선 선량을 제외하고, 연간 내부와 외부 피폭의 합계가 1미리 시버트(mSv: 방사선량 단위) 이상을 넘지 못하도록 제한하고 있다. 원자력 발전소 등 특수직 종사자들은 연간 최대 50밀리시버트(5년간 총 100밀리시버트)를 넘지 않도록 규정하고 있다.

일반인들은 우주방사선 등 자연상태에서 연간 2.4밀리시버트의 방사선에 평균적으로 노출돼 있다. 치료를 목적으로 한 의료 방사선의 경우 흉부엑스레이 1회 촬영에 0.1~0.3밀리시버트, 위 엑스레이는 5~19밀리시버트, CT촬영은 8~10밀리 시버트가 조사된다.

고지대일수록 자연방사선에 노출되는 정도가 심해 연간 평균 2.4밀리시버트인 일반지역과 달리 브라질과 같은 고지대의 경우 연간 10밀리시버트의 자연방사선이 관측되고 있다. 항공기 여행의 경우도 평지보다 방사선량이 많은데 서울에서 유럽으로 여행시 1회에 0.07미리시버트의 방사능에 노출된다.

일본 현지 언론에 따르면 15일 오전 후쿠시마 제1원전 정문 앞 방사선량이 1시간당 8217μSv (8217마이크로시버트=8.217밀리시버트) 검출됐다. 보통 방사선량률은 일반지역에서 시간당 100~300 나노 시버트(Sv/s)가 측정되고 있으며, 최근 조사된 우리나라 울릉도의 경우 시간당 129나노 시버트로 조사됐다. 일본 원전 폭발에 따른 방사선 누출 정도(8.2밀리 시버트)는 자연 상태에서의 시간당 방사선량의 수만배에 달하는 수치다.

하지만 국내에선 방사능 유출량의 기준으로 시간당 방사선량을 나타내는 방사선량률이 시간당 10밀리 시버트(mSv/s)를 넘어야 '방사선 재난'을 선포하는데 일본은 현재 이 기준을 밑도는 수준이다. 또 1회의 CT 촬영시 발생하는 순간 방사능 규모와 유사한 수준이다.

피폭량은 방사선의 세기와 시간의 곱으로 나타나므로 최대한 노출시간을 줄이는 것이 중요하다. 거리는 멀어질수록 피해가 줄어든다.... (머니투데이)

상황별 방사능 노출정도와 증상

	노출정도	증상
일반허용치	1mSv	없음
자연상태	2.4mSv	없음
비행기여행시(유럽기준)	0.07mSv	없음
흉부x-선촬영	0.1~0.3mSv	없음
컴퓨터단층촬영(CT)	8~10mSv	없음
고지대(브라질)	10mSv	없음
울릉도	129nSv	없음
일본 후쿠시마 원전 인근	8.217mSv	없음

<용어설명>시버트(Sv)
방사선량의 단위로 줄/킬로그램(J/kg)에 대한 고유명칭이다. 이 단위를 사용하기 전에는 렘(rem)을 사용하였으며, 1Sv는 100렘과 같다. 1시버트가 1000밀리시버트, 1밀리시버트가 1000마이크로시버트이다.

유해한 수준의 피폭량과 인체증상

0.5Sv	외적증상없지만 10명 중 1~2명 백혈구 감소
1~10Sv	조혈기 장애 일어나 피폭 2~3주 후부터 백혈구감소증과 혈소판감소증, 골수발육 부전 발생. 4~6주후 감염과 출혈로 사망 가능
10~15Sv	소화기 장애 발생. 피폭 2~3일후부터 복통, 발열, 설사증상. 2주 후 장염과 쇼크로 사망
50Sv 이상	중추신경장애로 오심 · 구토 일어나며 몇시간 후 뇌부종으로 사망

*단위:1Sv=1000mSv, 1mSv=1000μSv, 1μSv=1000nSv

일본 후쿠시마 제1 원전 작업자 3명 피폭, 2명은 긴급 병원行
피폭 정도는 약 170-180 밀리시베르트 정도이며... (2011년 3월 24일)

출처: 머니투데이 (2011년 3월 15일자)

Nuclear power (including on order & planned):

USA: 104 (98015 MW), S. Korea: 30 (20 operating) (27970 MW),
France: 59 (63203 MW), Japan: 68 (62589 MW),
world: 519 (467 operating) (425,790 MW)

Uranium resources

Table 8.4. Estimated recoverable resources of uranium [13] (tonnes U_3O_8, % of world).

Australia	889 000	27%
Kazakhstan	558 000	17%
Canada	511 000	15%
South Africa	354 000	11%
Namibia	256 000	8%
Brazil	232 000	8%
Russian Fed.	157 000	5%
USA	125 000	4%
Uzbekistan	125 000	4%
World Total	**3 340 000**	

Reasonably Assured Resources plus Estimated Additional Resources - category I, to US$ 80/kg U, from *Uranium: Resources, Production and Demand 1999*, OECD NEA & IAEA, July 2000.
Brazil, Kazakhstan and Russian Figures above are 75% of in situ totals.

Plutonium

Artificial radioactive isotope (^{239}Pu): produced from ^{238}U in ^{235}U fission
(cf. natural uranium: 0.7% fissionable ^{235}U, 99.3% ^{238}U)

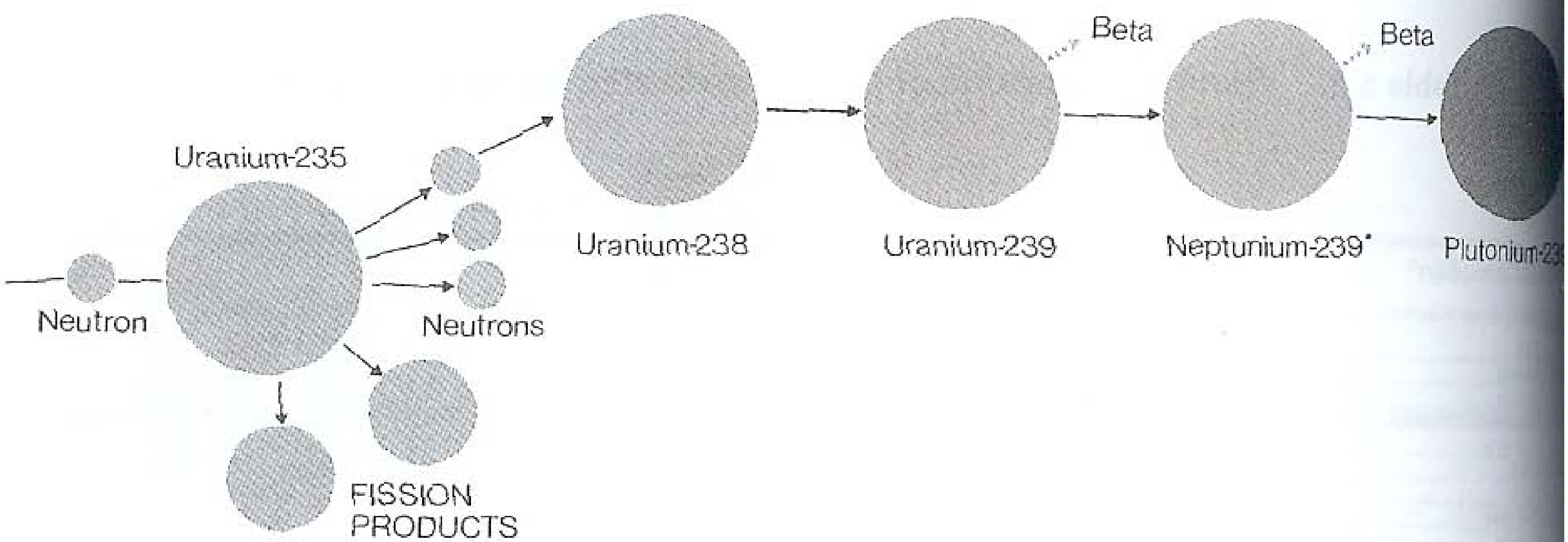


Fig. 8.7. The formation of plutonium [16] (reproduced by permission of AEA Technology plc)

Textbook

Introduction

- Nuclear bomb/waste vs. carbon-free energy

- Two form of nuclear energy
(i) fission: reaction used in atomic bomb
(ii) fusion: energy source in stars

- Mostly **uranium(U)** for fuel in ission reactors
Main producers: Canada, Australia
Energy: 1 ton U ~ 20,000 ton coal
U is as common as tin or zinc
Granite contains 4 ppm U, sea (~0.003 ppm, 총 4000 Mton)
USA: 3.3 Mt reserve at $130/kg + ~10.7 Mt

1. Binding energy and stability of nuclei

Nucleus: attraction force between protons & neutrons(nucleons). Its mass is less than the sum of its constituents → total binding energy BE = ΔMc^2 (Einstein's relation)

e.g.: carbon (C) : two isotopes, ^{12}C & ^{13}C, ^{14}C (unstable)

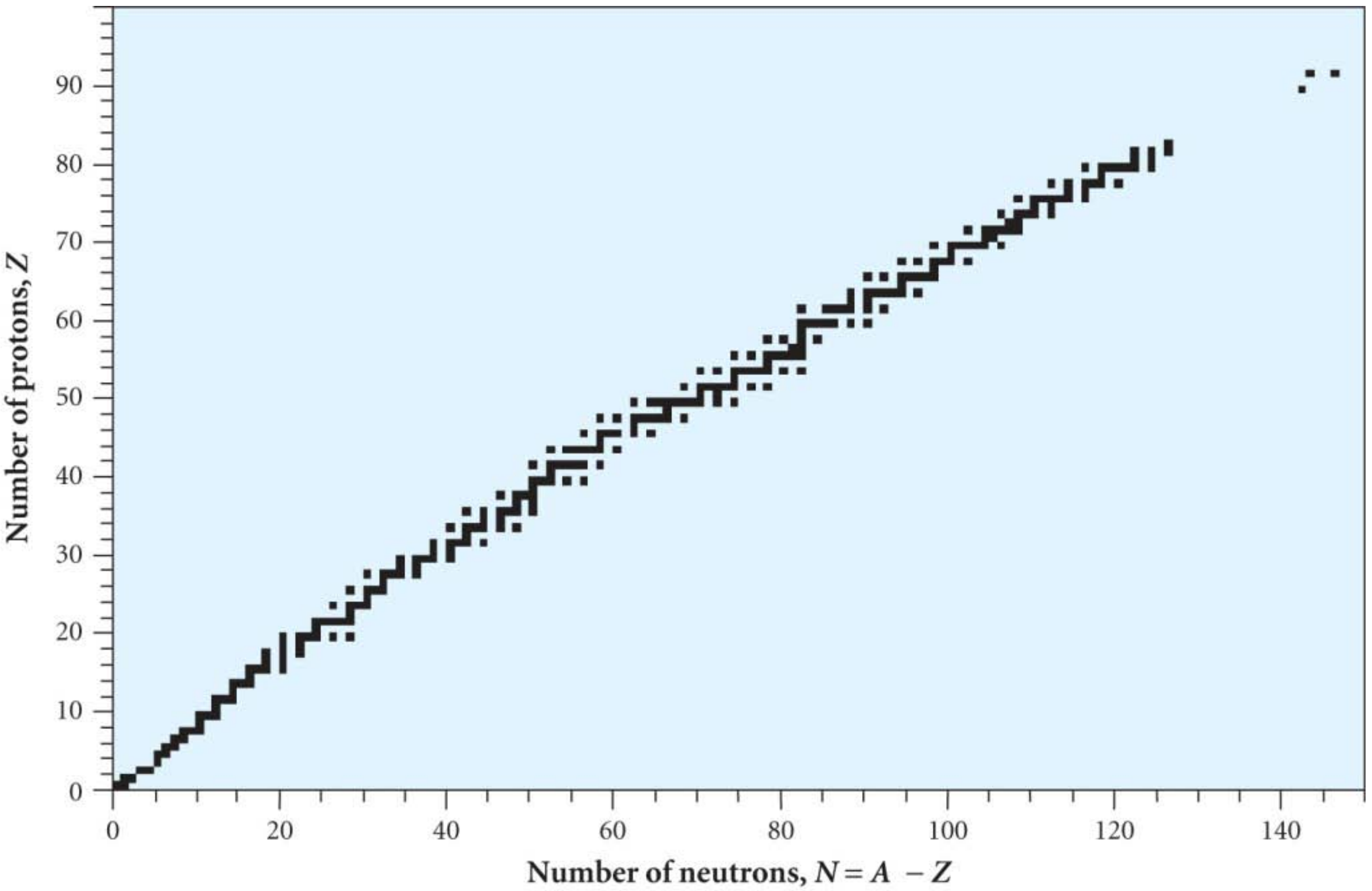
$^{14}C \rightarrow {}^{14}N + e^-$(electron) + ν (anti-neutrino)

^{14}C: unstable due to 6 protons & 8 neutrons (cf. ^{14}N: 7 protons & 7 neutrons)

Half-life of this beta decay: 5730 yrs → $^{14}C/^{12}C$ ratio is used in "radiocarbon dating"

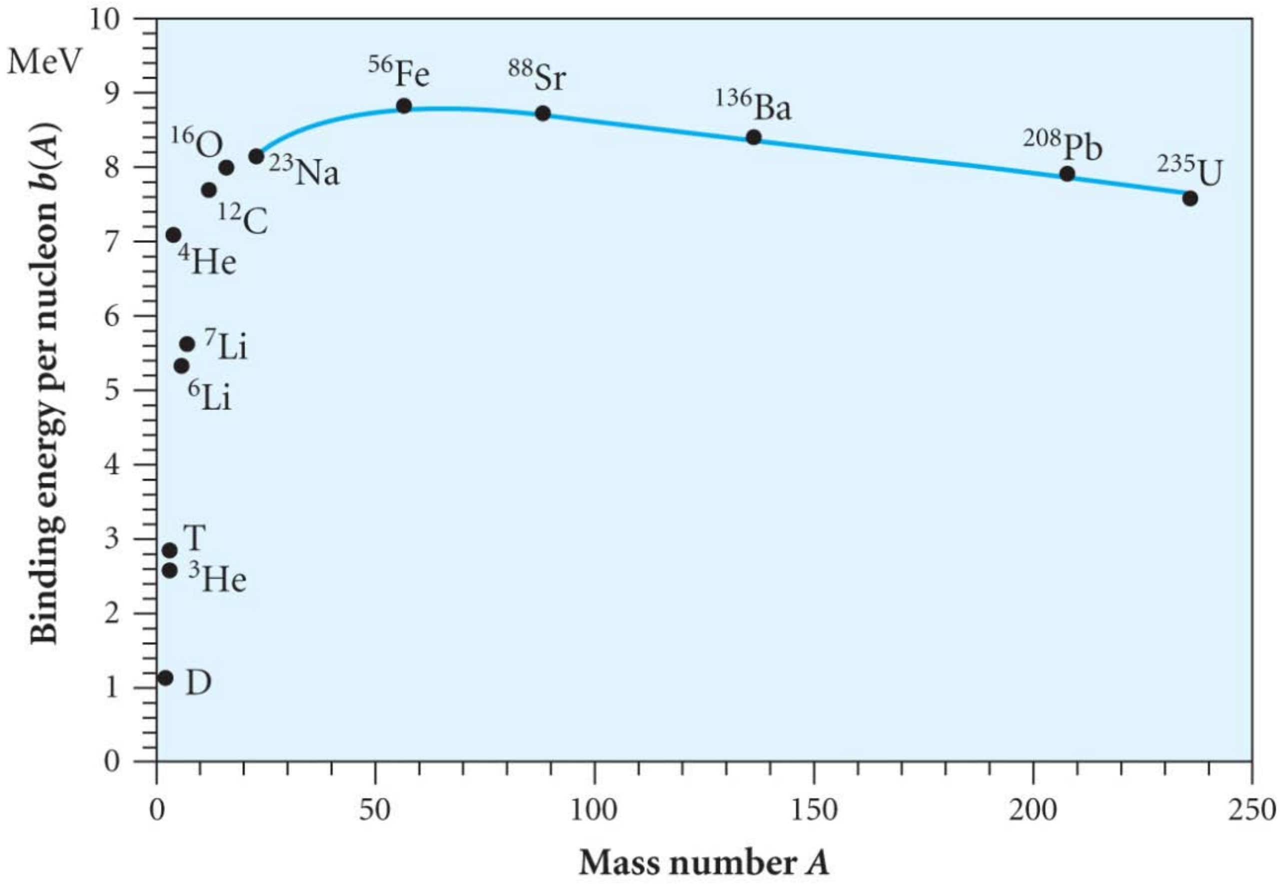
Beta decay can leave a nucleus in an excited state, that can decay to the ground state with the emission of γ-ray

Stable nuclei



Total binding energy is proportional to # of nucleons (A) → BE per nucleon,
BE/A = b(A) (approximately constant)

Above A ~ 12, roughly constant (maximum near iron (Fe (A ~ 60))
Heavy nuclei: neutrons > protons → b(a) decrease



If mass number A_1 splitting two nuclei with mass number A_2 & A_3, total energy release

$$E_R = A_2\{b(A_2) - b(A_1)\} + A_3\{b(A_3) - b(A_1)\}$$

----

e.g. 8.1

(cf. 50 million times more than chemical combustion rxn, $C + O_2 \rightarrow CO_2$ + 4.2 eV (=7 x 10-19 J). 1 ton ^{235}U ~ 2.3 million ton C)

Energy is also released in fusion(융합)

$$^{2}H + {}^{3}H \rightarrow {}^{4}He + n$$

b(A) for deutrium, tritium, helium: 1.1, 2.6, 7.1 eV → (4 x 7.1) – (2 x 1.1) – (3 x 2.6) ~ 18 MeV release

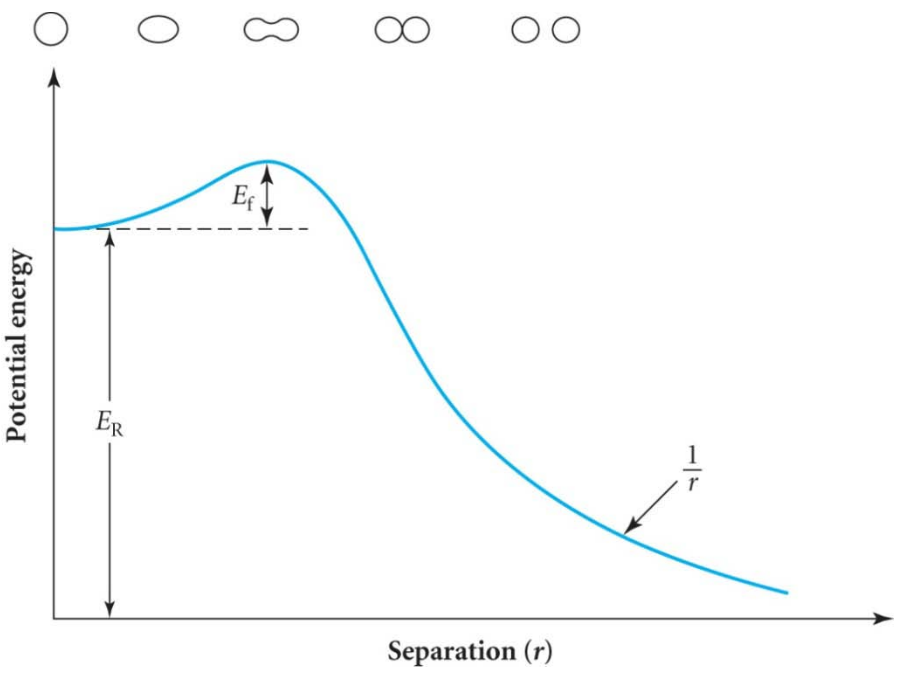
2. Fission

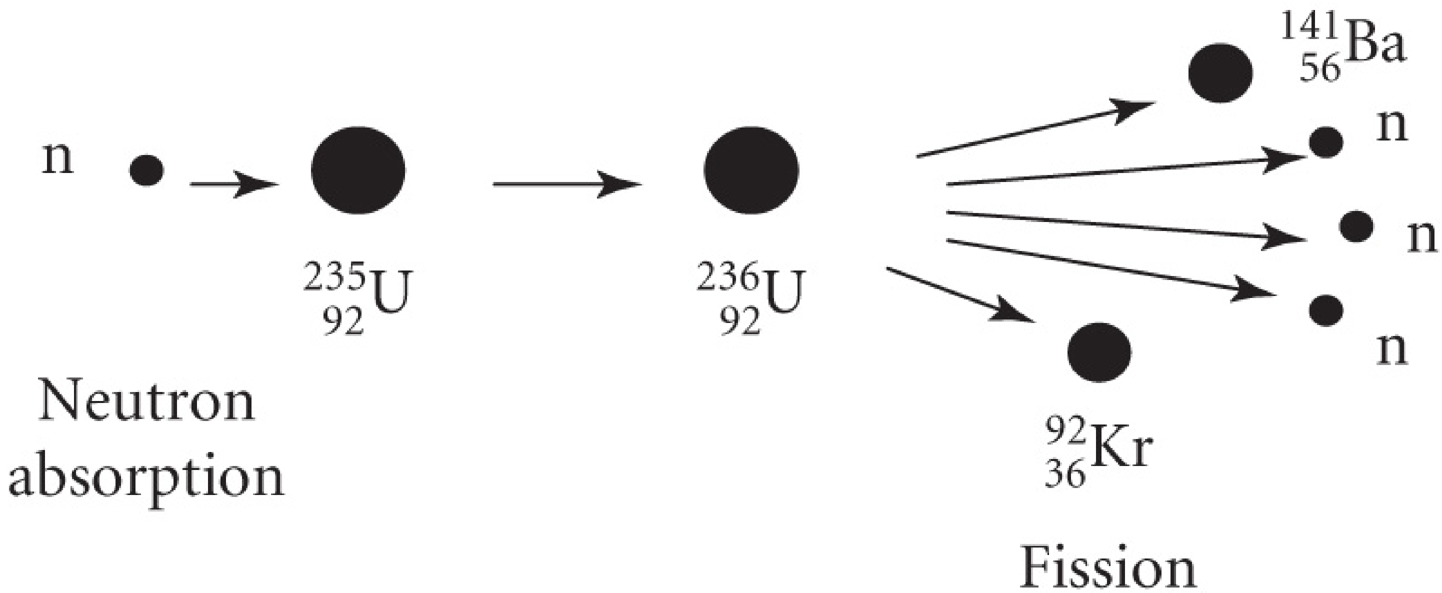
Spontaneous fission is rare due to fission barrier

2.1 Neutron-induced fission

Probability of fission↑ when nucleus captures a neutron

n + ^{235}U → ^{236}U* (excited state): above fission barrier: fission!!
(cf. n + ^{238}U → ^{239}U* (excited state): ~1 MeV below the top of barrier fission barrier)





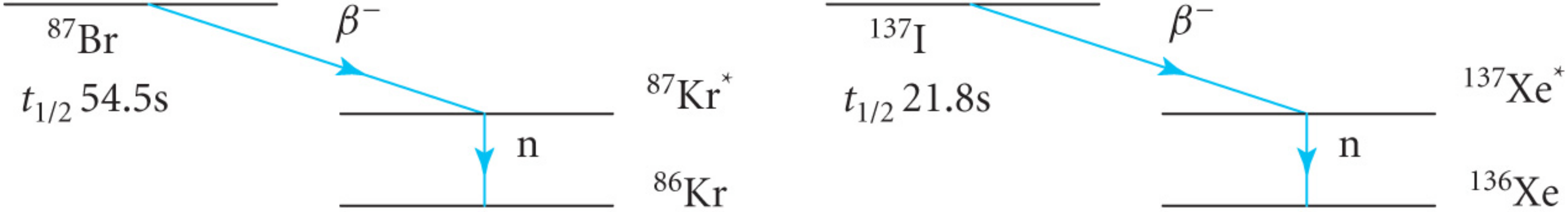
$$n + {}^{235}_{92}U \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n$$

2.2 Energy release in fission

Natural uranium: 0.7% ^{235}U, 99.3% ^{238}U: 1 ton U ~ 20,000 ton coal

Energy from fission: prompt release & delayed release (following the beta decay of the neutron-rich nuclei)

Beta-delayed neutron emission



e.g. 8.2

^{235}U

~2.4 neutrons are emitted in the neutron-induced fission: mean energy ~2 MeV

Emitted neutron: open up the possibility of chain reaction (fission of other nuclei)

0.65% neutrons are beta-delayed neutrons with a mean delay time of 13 sec

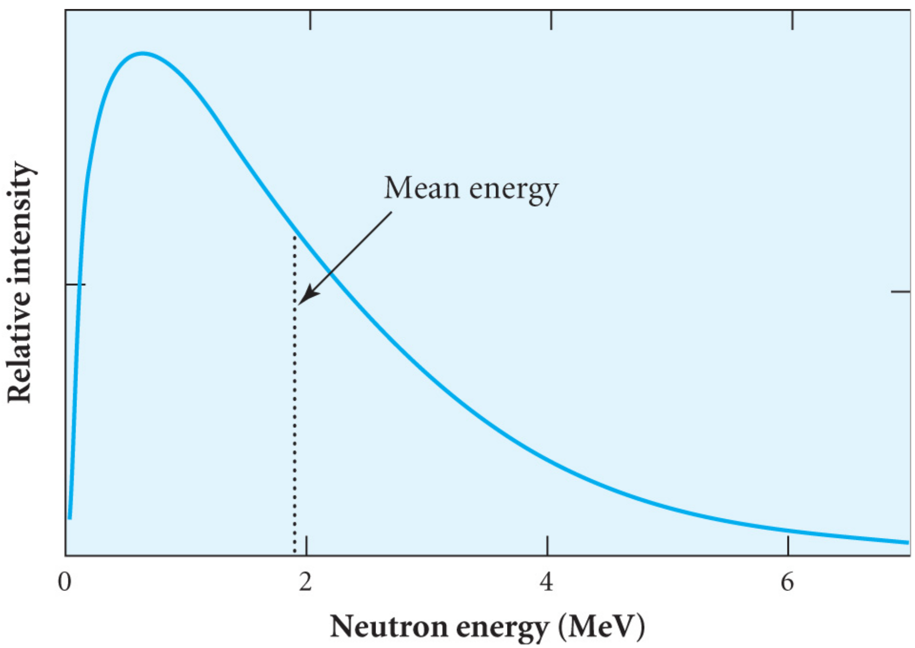


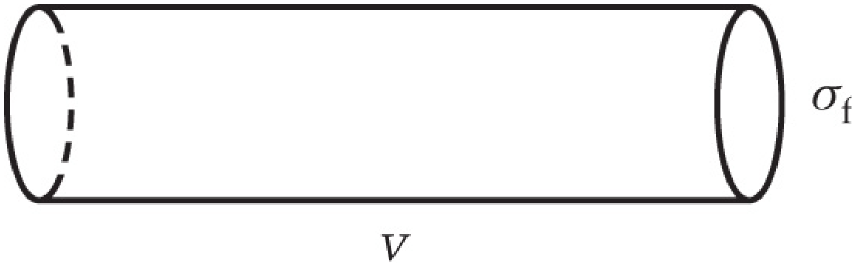
Table 8.1

2.3 Chain reactions

Neutron absorption: induced fission & captured
Probability of neutron-induced fission
Cross-section σ → unit, barns(b): 1 b = 10^{-28} m^2
Cross-section of uranium nucleus ~ 2b (실제로는 중성자가 파동의 성질을 가지므로 이보다 훨씬 크다)

Cross-section of neutron absorption: $\sigma_a = \sigma_c$(captured) + σ_f (induced fission)

Neutron speed through uranium (v), # of ^{235}U nuclei per unit volume (n_f)



Volume σ_f v swep out by neutron in 1 sec

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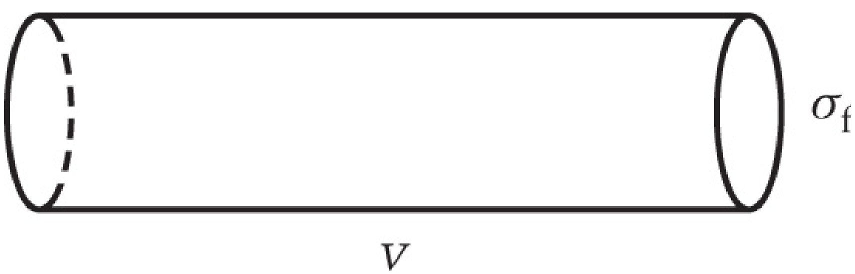
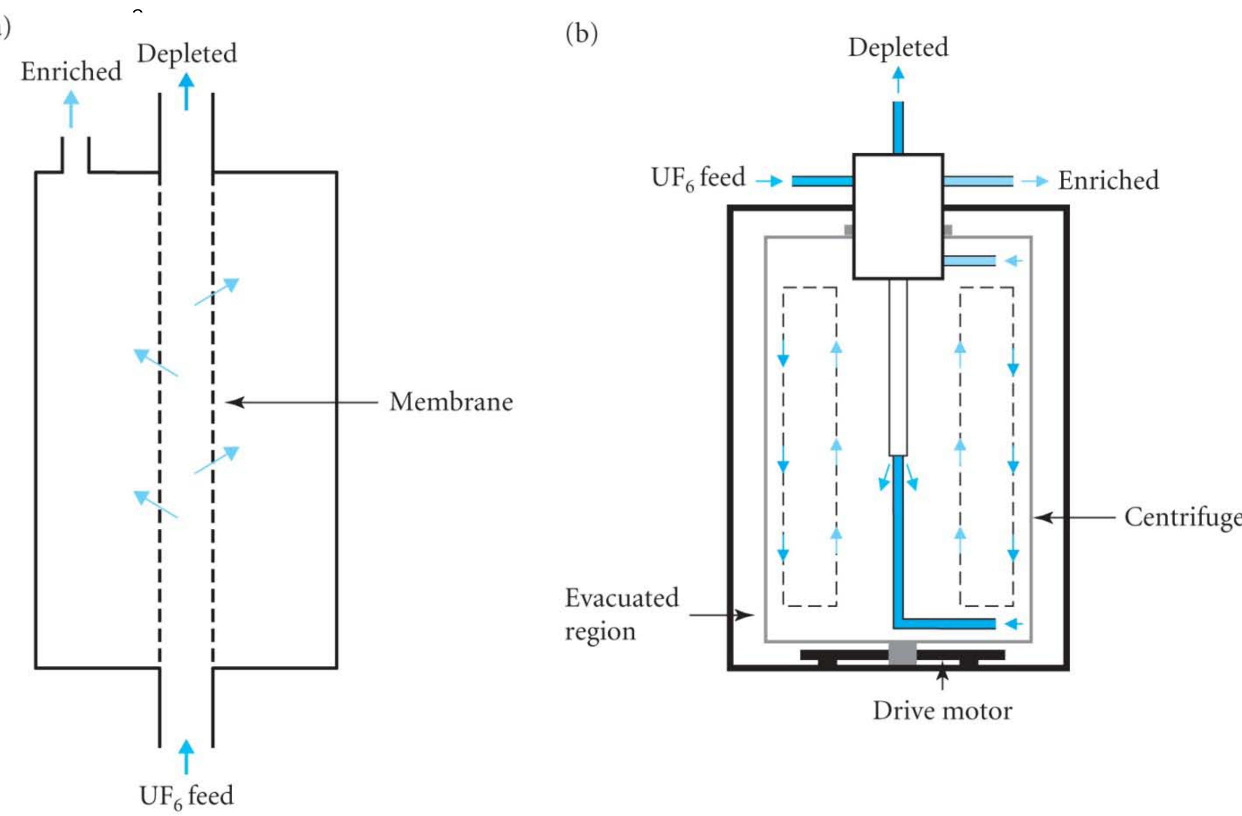


Volume σ_f v swep out by neutron in 1 sec

Basic knowledge of fluid mechanics for hydropower, wave power, and wind power

1. Basic physical properties of fluids

Density (ρ): mass per unit volume of a fluid. Kgm^{-3}. (ρ_{water} ~ 10^3 kgm^{-3} & ρ_{air} ~ 1.2 kgm^{-3} at



Pressure (p): forc ... 1 atmosphere ~

Viscosity: force p ... e relative moti ... direction.

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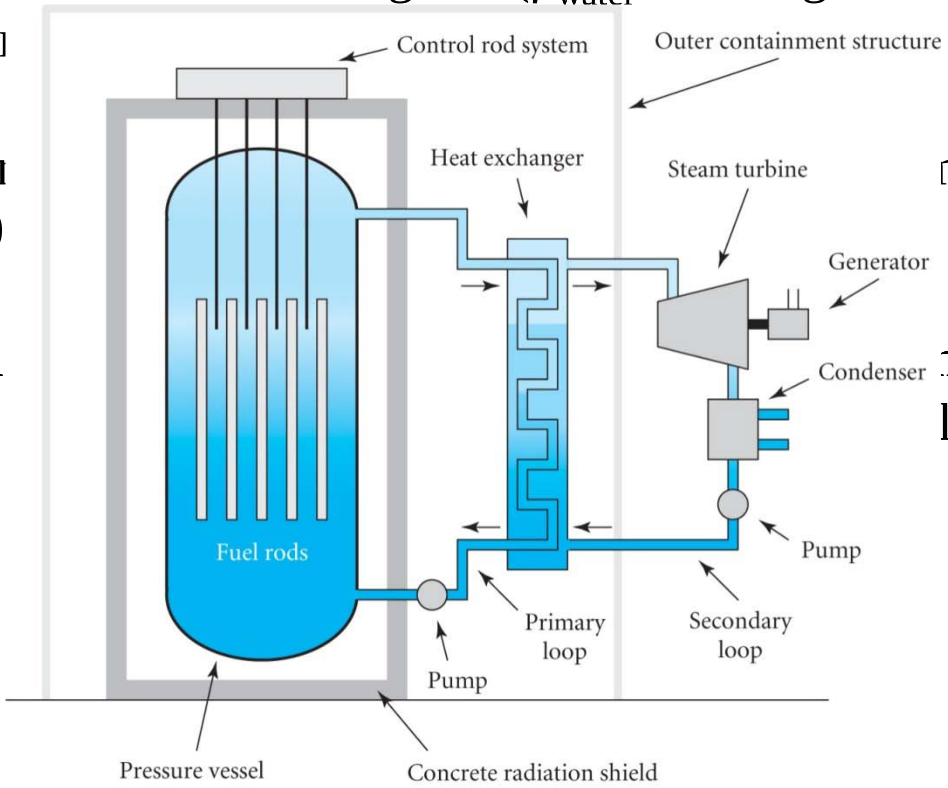

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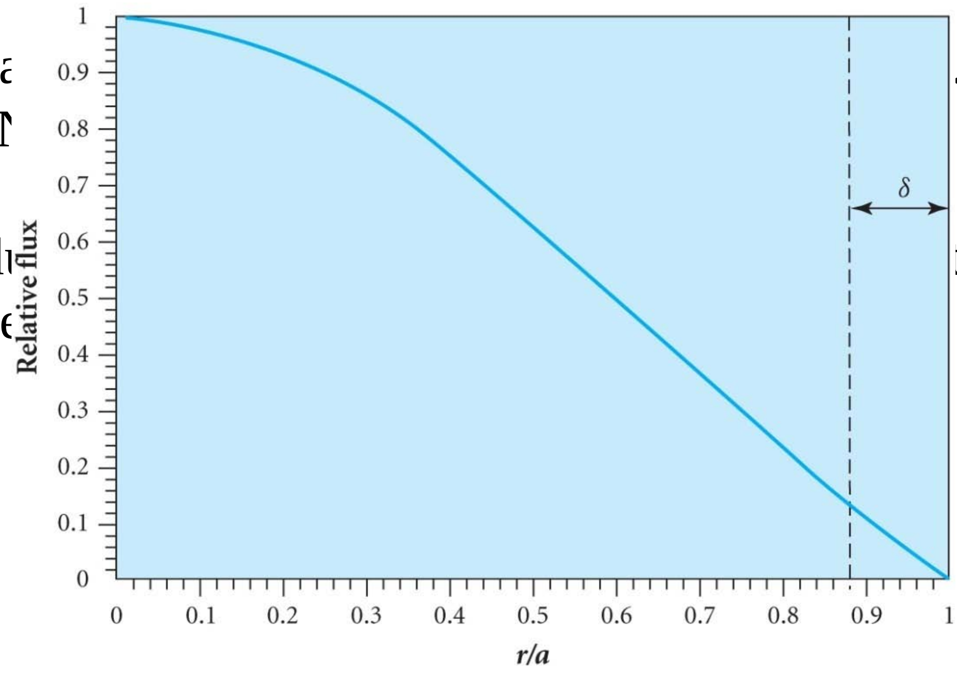

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Viscosity: force per unit area due to internal friction in a fluid arising from the relative motion between neighbouring elements in a fluid. Tangential direction.

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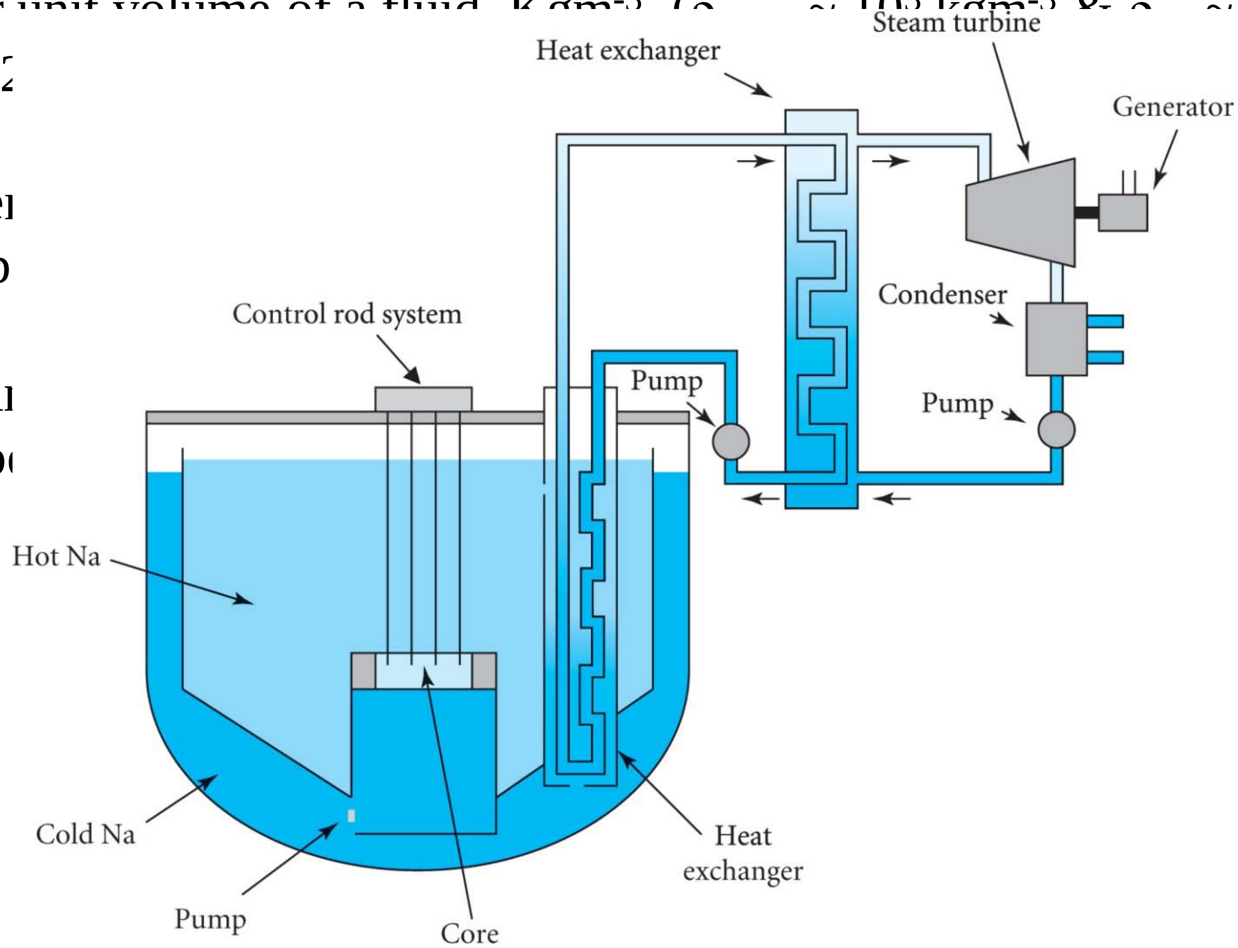

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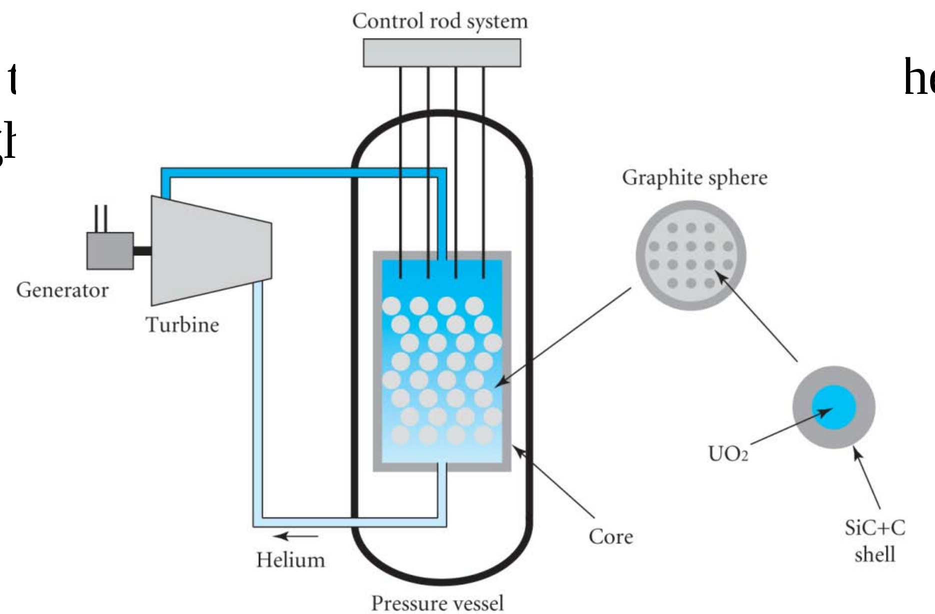

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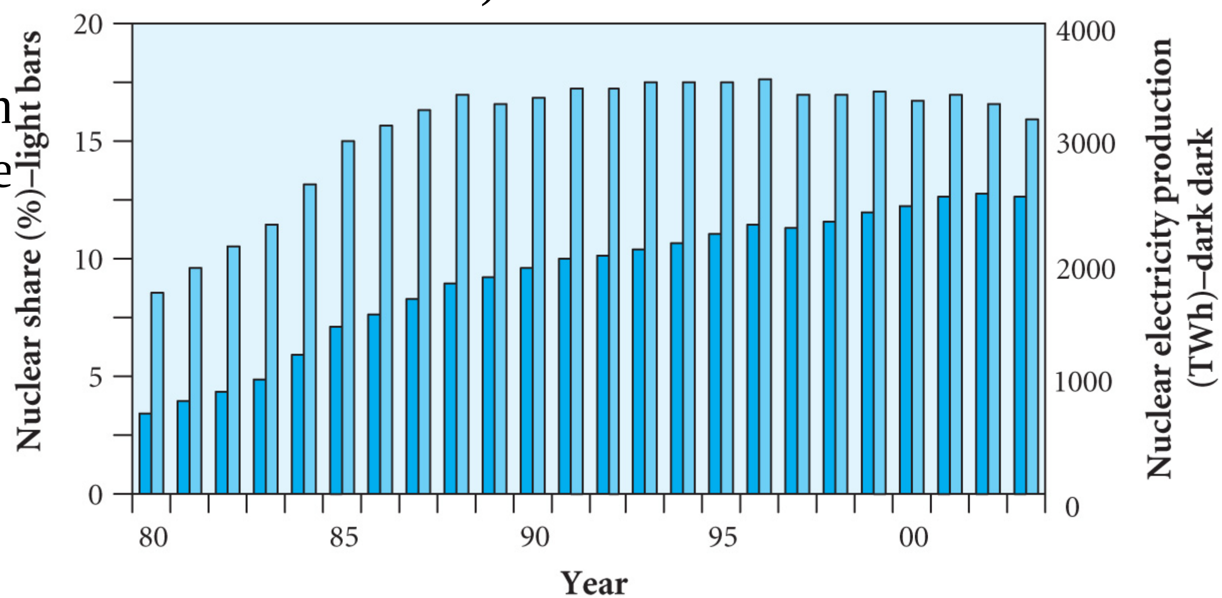

Basic knowledge of fluid mechanics for hydropower, wave power, and wind power

1. Basic physi

- Density (ρ): m … ρ_{air} ~ 1.2 kgm^{-3}
- Pressure (p): f … n^{-2}. (1 atmospher
- Viscosity: forc … n the relative m … l direction.

			OPERATING		BUILDING		PLANNED/PROPOSED	
	billion kWh	% electricity	No.		No.	MWe		
Belgium	45.3	56	7		0			—
Canada*	86.8	15	18		0			2
China	50.3	2.0	10		5			24
France	430.9	79	59		0			2
Germany	154.6	31	17		0			0
India	15.7	2.8	15		8			24
Japan	280.7	29	55		1			12
Korea RO (South)	139.3	45	20		0			8
Russia	137.3	16	31		4			9
Sweden	69.5	45	10		0			0
United Kingdom	75.2	20	23		0			0
USA	780.5	19	103		1			13
WORLD**	**2626**	**16**	**441**		**27**			**153**
	billion kWh	**% e**	**No.**	**MWe**	**No.**	**MWe**		**MWe**

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1. Basic physical properties of fluids

Density (ρ): mass per unit volume of a fluid. Kgm^{-3}. (ρ_{water} ~ 10^3 kgm^{-3} & ρ_{air} ~ 1.2 kgm^{-3} at T = 20 ℃ and p = 1 atm)

Pressure (p): force per unit area in a fluid (수직방향의 힘). Pascal or Nm^{-2}. (1 atmosphere ~ 1 bar = 10^5 Nm^{-2} = 10^5 Pa)

Viscosity: force per unit area due to internal friction in a fluid arising from the relative motion between neighbouring elements in a fluid. Tangential direction.

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