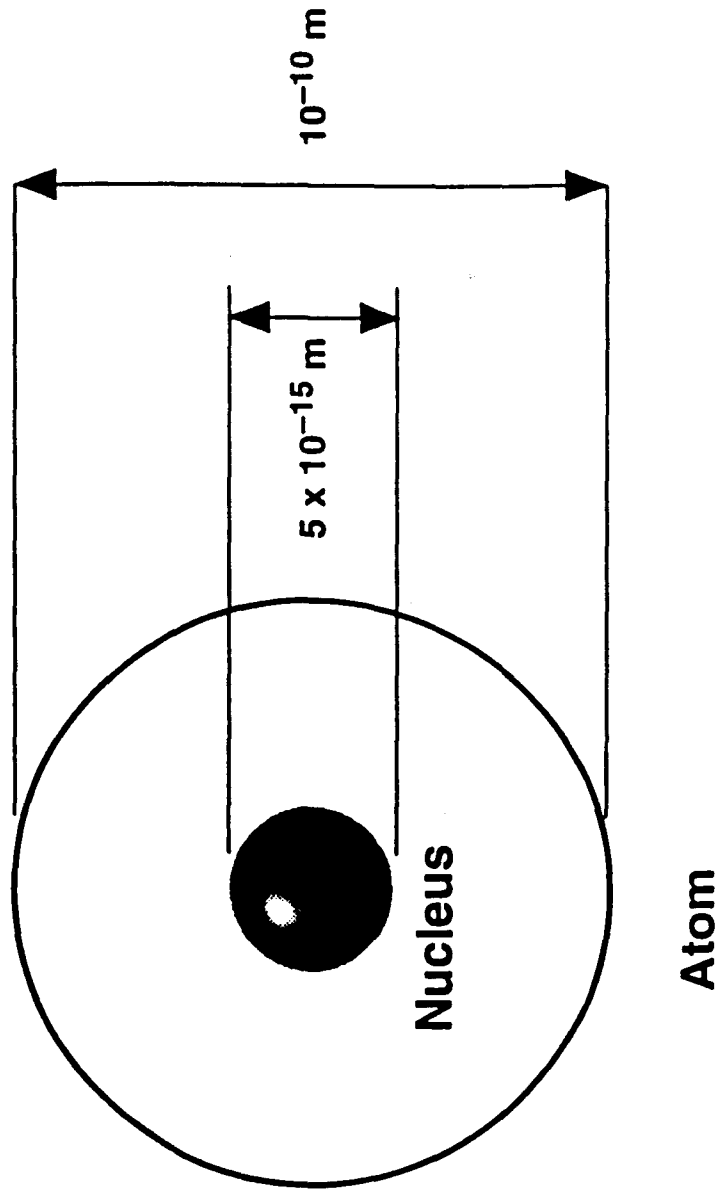


SECTION A

INTRODUCTION
TO
NUCLEAR REACTORS

Atom and Nucleus



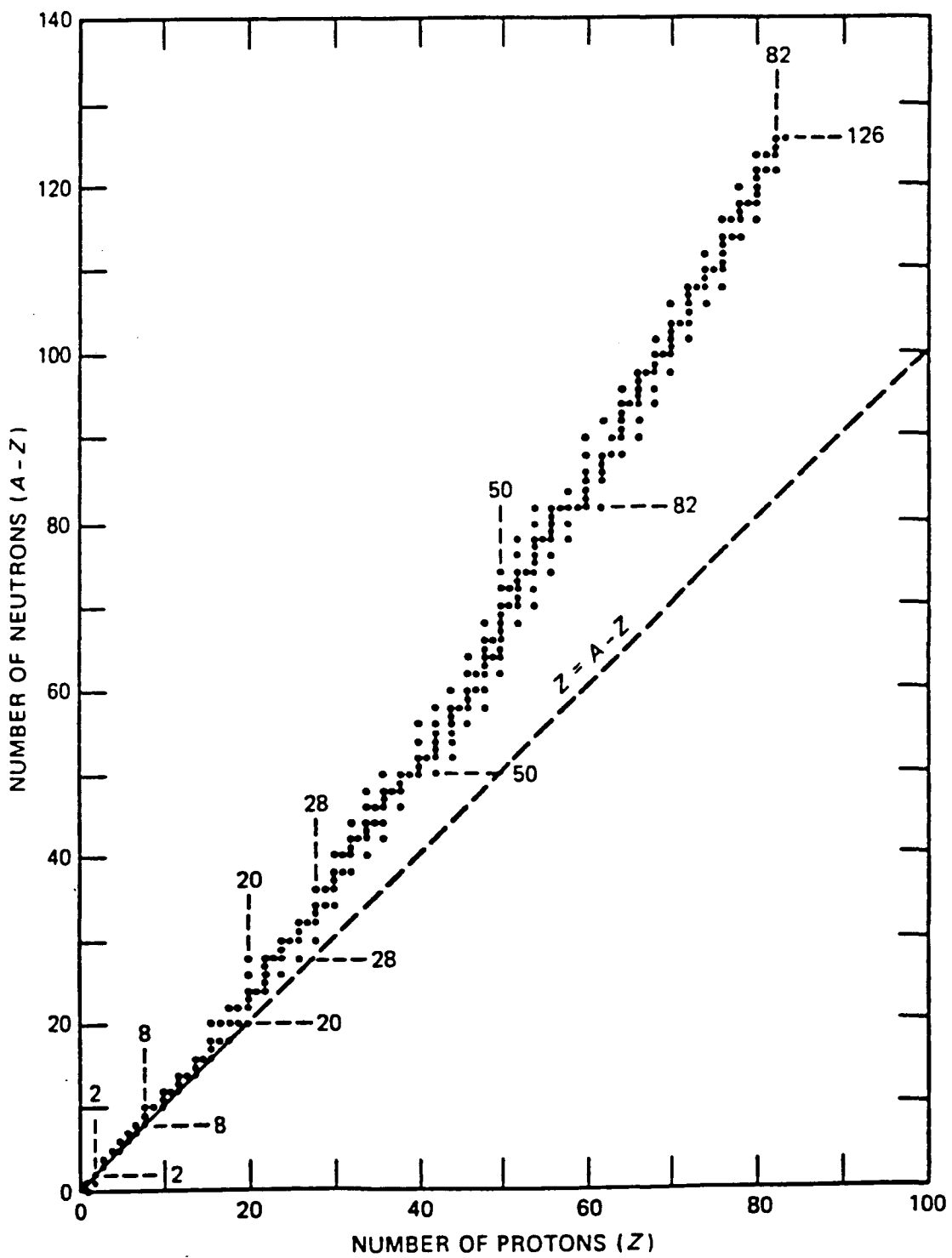
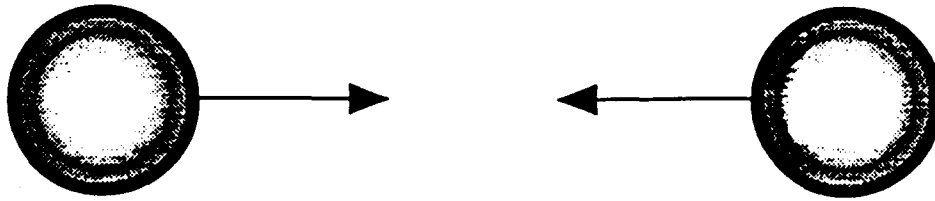
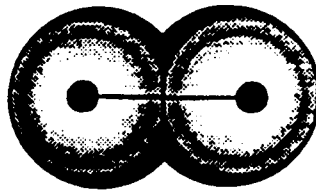


Fig. 1.2. Numbers of neutrons and protons in stable nuclei. (The short dashed lines indicate magic numbers of neutrons and protons.)

Binding Energy

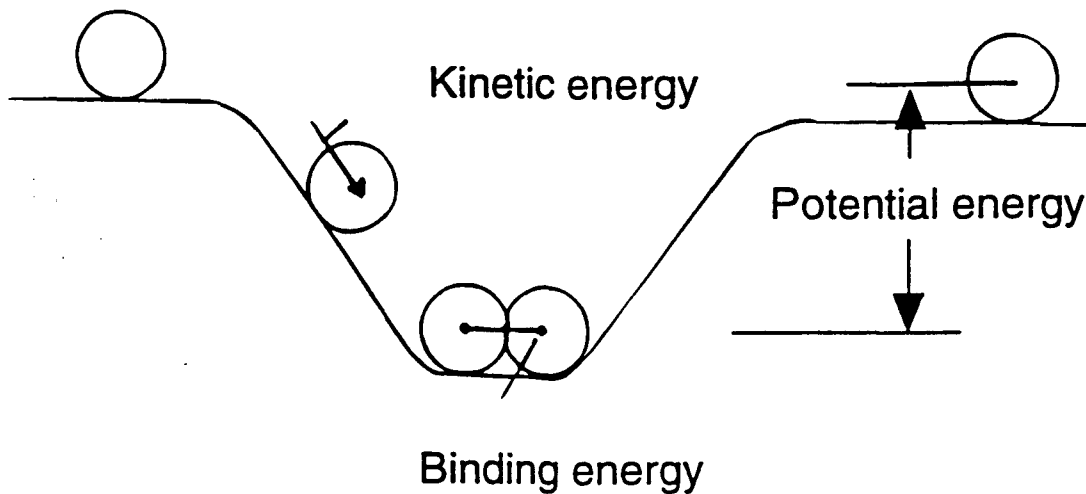


Force of attraction between nucleons



Work done by force = Binding energy (MeV)

Analogy with potential and kinetic energy



Binding Energy Per Nucleon

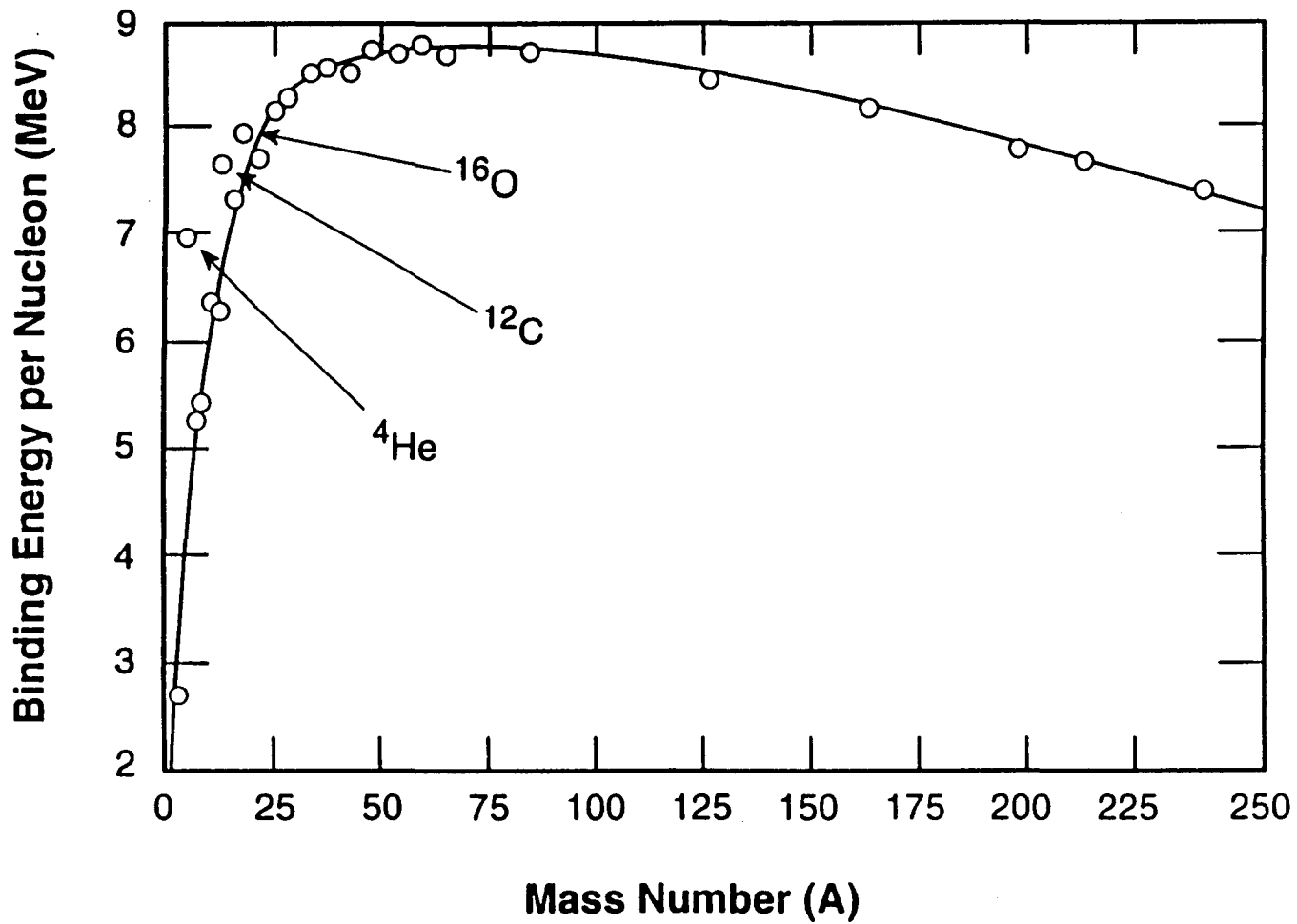
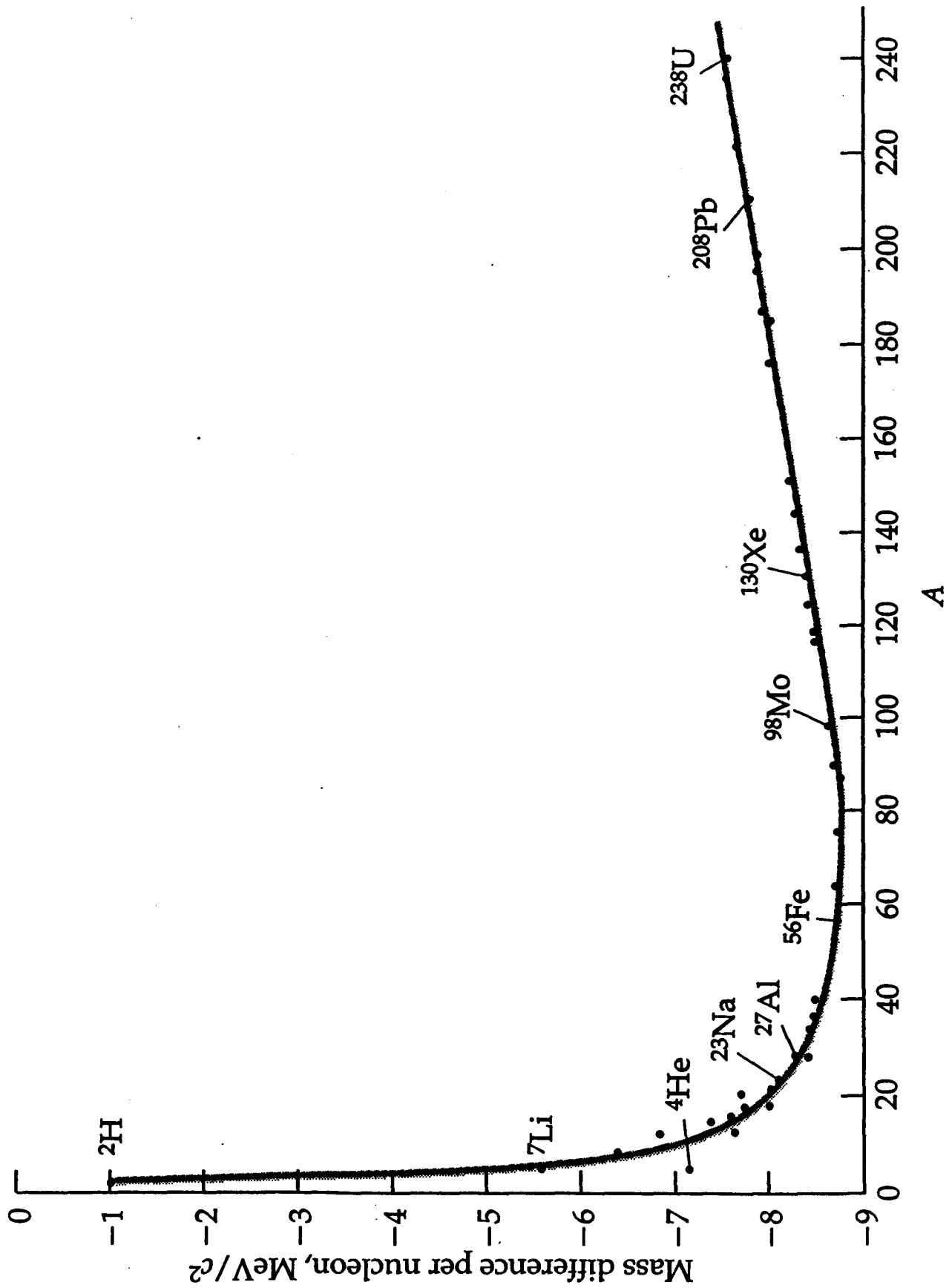
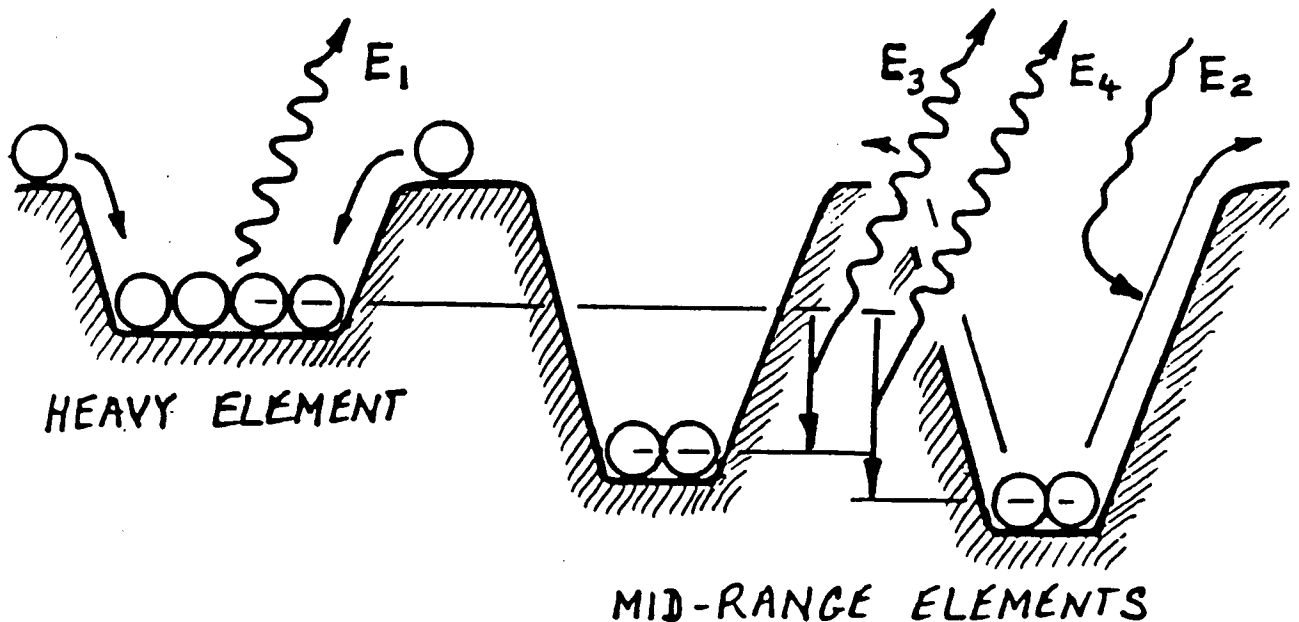


Fig. 1.4



BINDING ENERGY



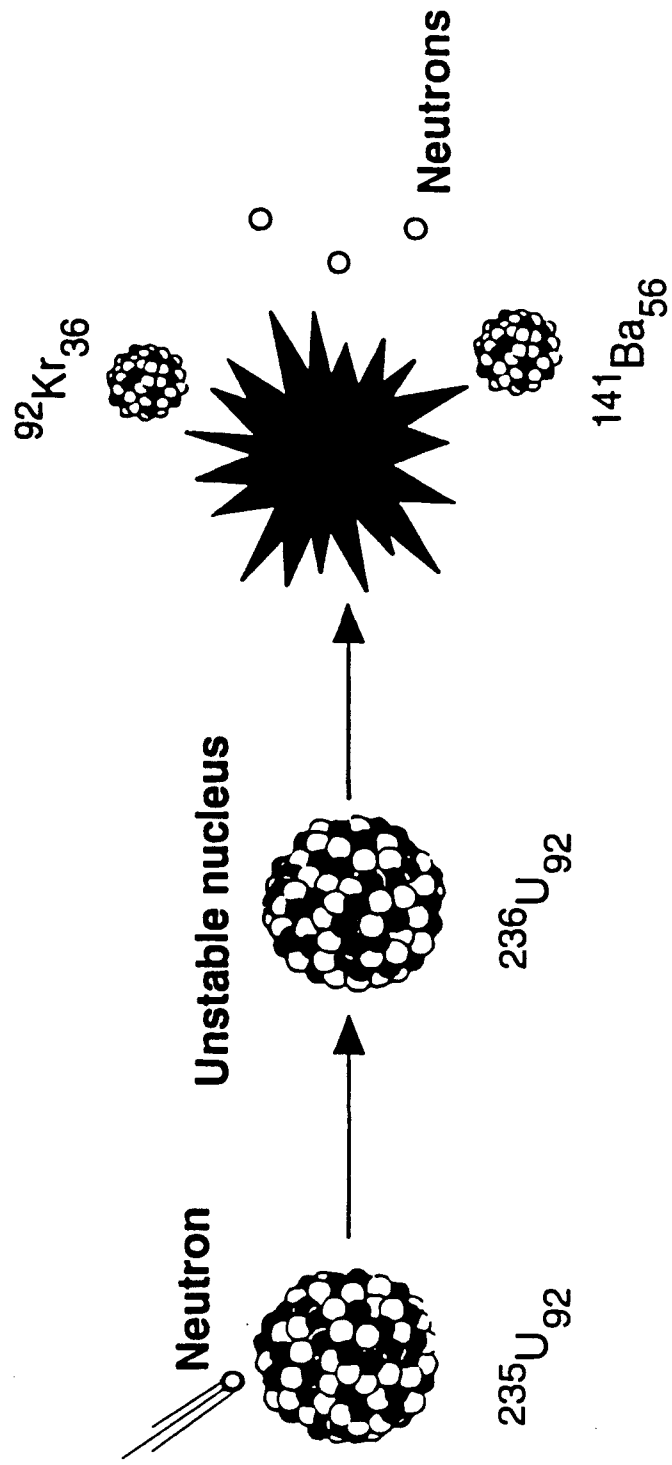
BINDING ENERGY CAN BE VIEWED IN TWO WAYS :

- ENERGY E_1 , GIVEN OFF WHEN NUCLEONS COMBINE
- ENERGY E_2 REQUIRED TO SEPARATE NUCLEONS

VERY HEAVY ELEMENTS HAVE LESS BINDING ENERGY THAN MID-RANGE ELEMENTS AS ILLUSTRATED,

WHEN A HEAVY ELEMENT FISSIONS TO BECOME TWO MID-RANGE ELEMENTS THE SURPLUS OF ENERGY E_3 AND E_4 IS GIVEN OFF.

Fission Process



NUCLEAR REACTOR ENGINEERING

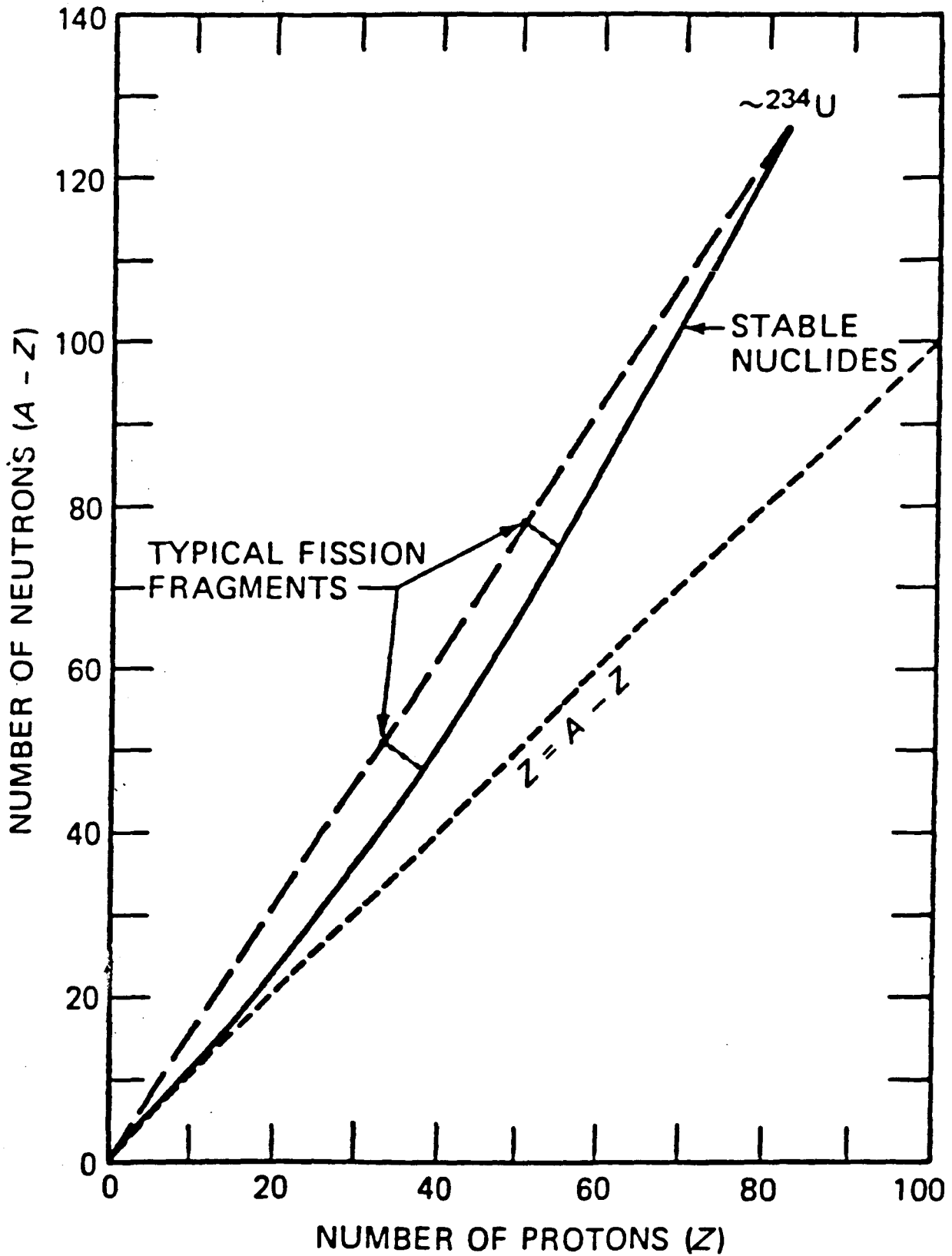
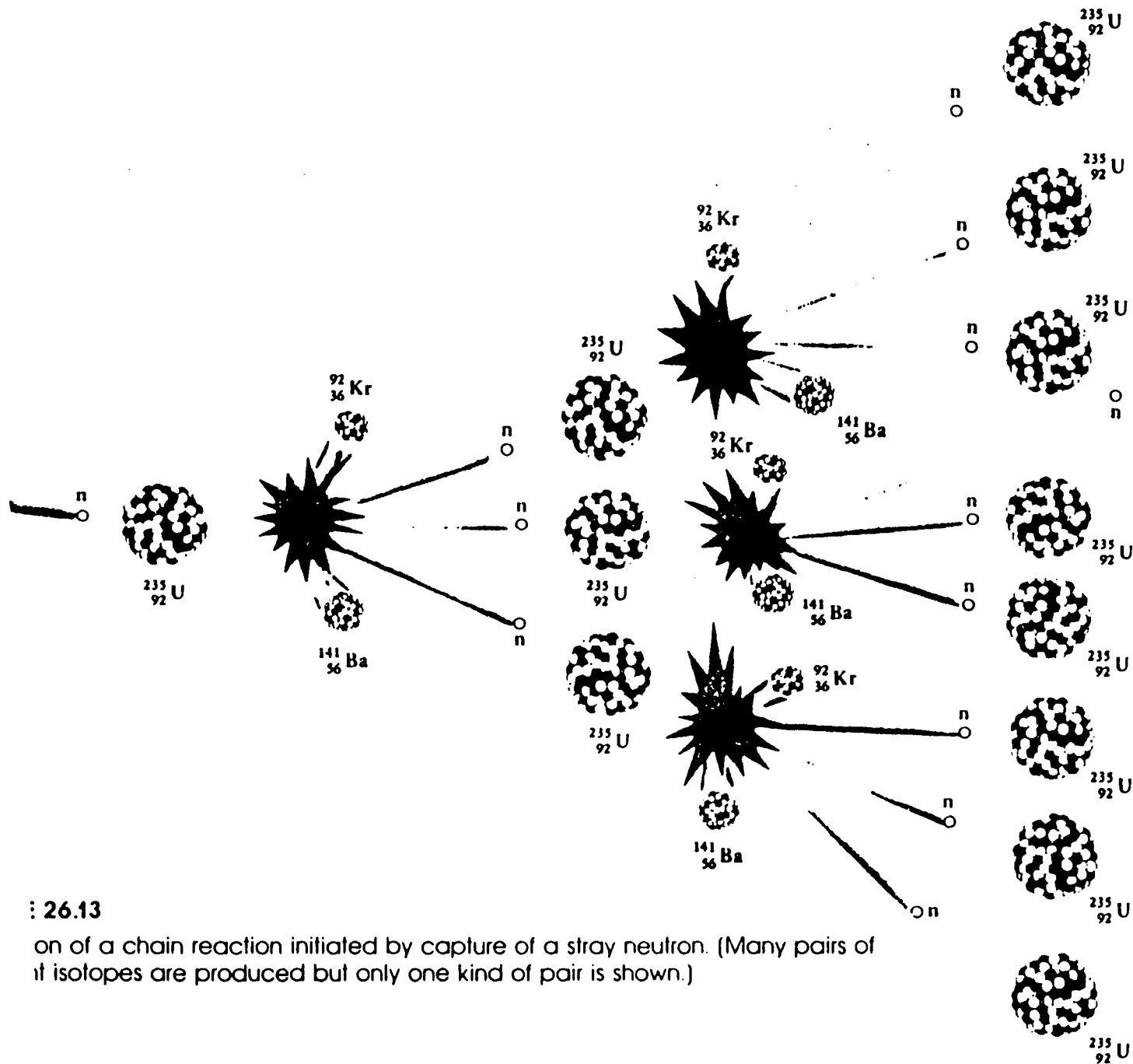


Fig. 2.29. Instability of fission fragments.



26.13

on of a chain reaction initiated by capture of a stray neutron. (Many pairs of fission products are produced but only one kind of pair is shown.)

Avogadro's Number

$$N_A = 6.022 \times 10^{23}$$

Number of atoms or nuclei in a given sample

$$N = \frac{N_A}{A} \times \text{MASS (g)}$$

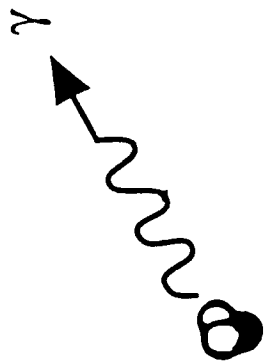
Example: Atoms in 1kg of U-235

$$\begin{aligned} N &= \frac{6.022 \times 10^{23}}{235} \times 1000 \\ &= 25.62 \times 10^{23} \text{ atoms} \end{aligned}$$

Example: 1kg of U-235 consumed in one day

$$\begin{aligned} N &= \frac{6.022 \times 10^{23}}{235} \times 1000 \text{ fission/day} \\ &= 25.62 \times 10^{23} \text{ atoms} / (24 \times 3600) \text{ Fissions/s} \\ &= 0.0002965 \times 10^{23} \times 200 \text{ MeV/s} \\ &= 0.05932 \times 10^{23} \times 1.6022 \times 10^{-13} \text{ J/s} \\ &= 0.09504 \times 10^{10} \text{ W} \\ &= 950 \times 10^6 \text{ W} \\ &= 950 \text{ MW} \end{aligned}$$

Radiative Capture



Elastic Collision

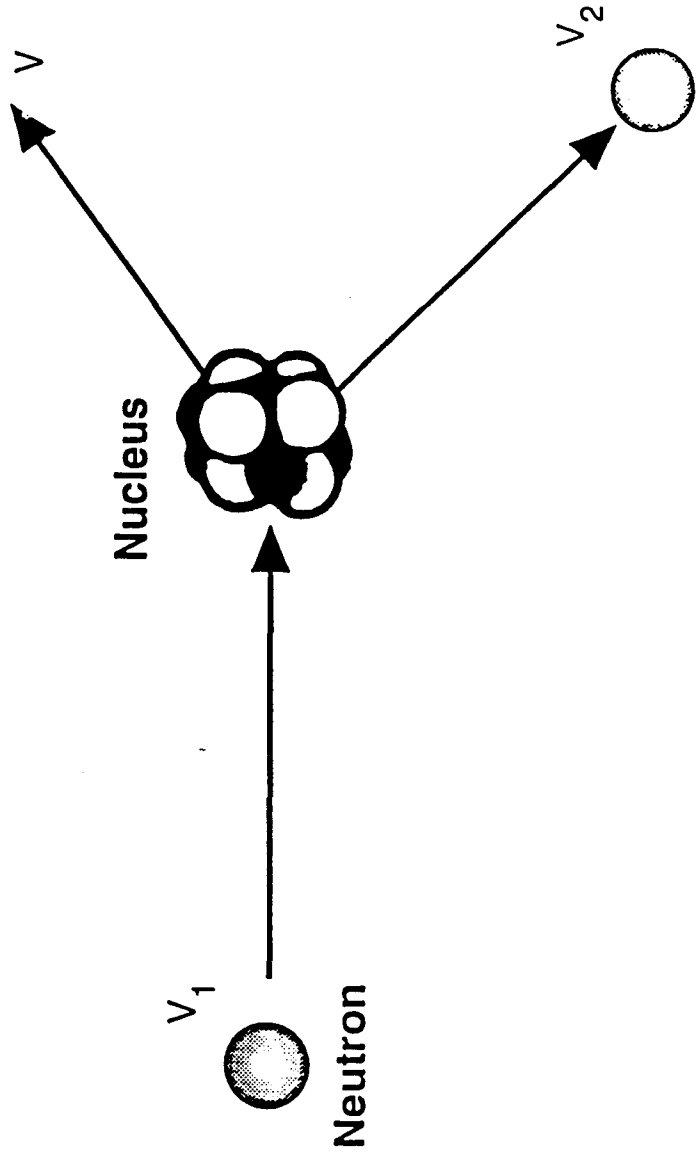
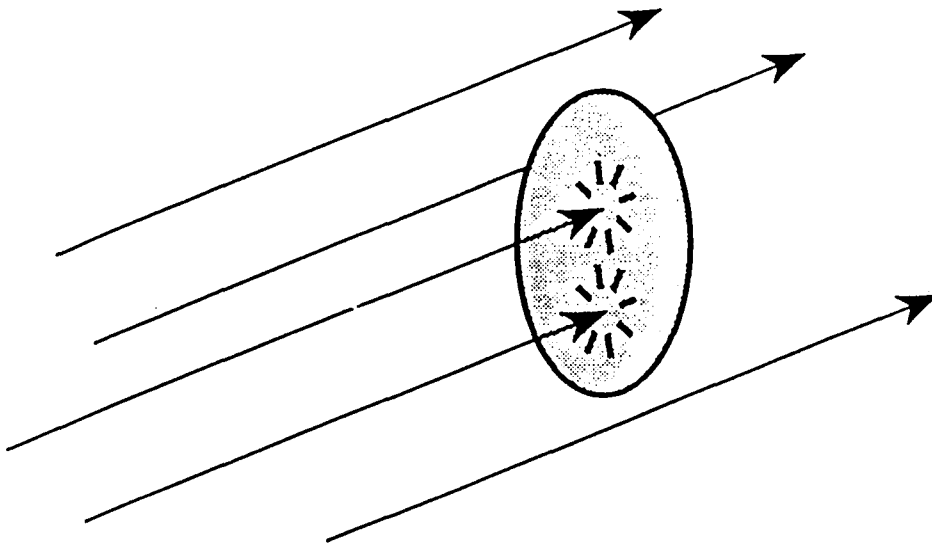
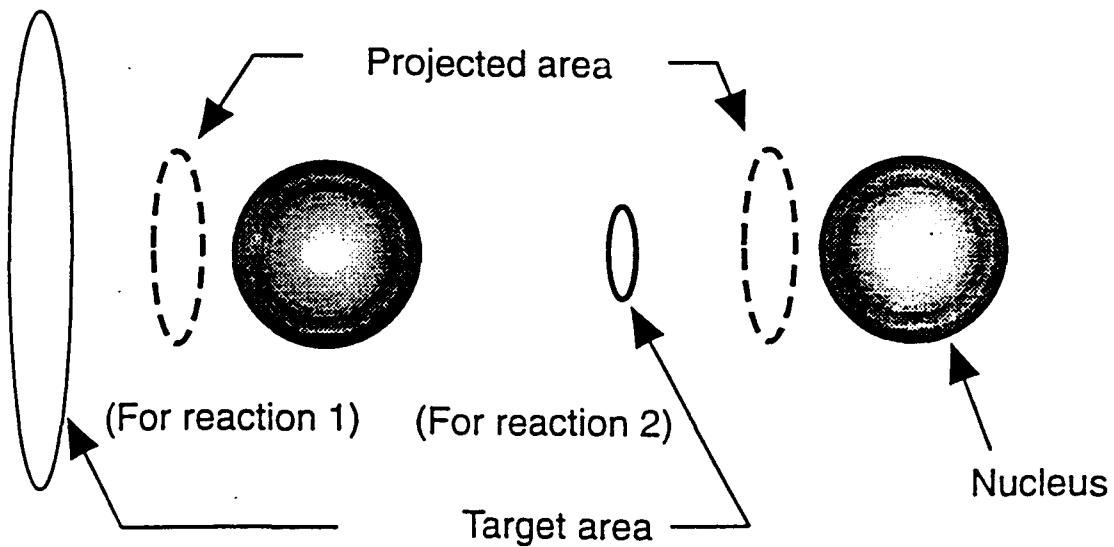


Fig. 2.1

Target Areas



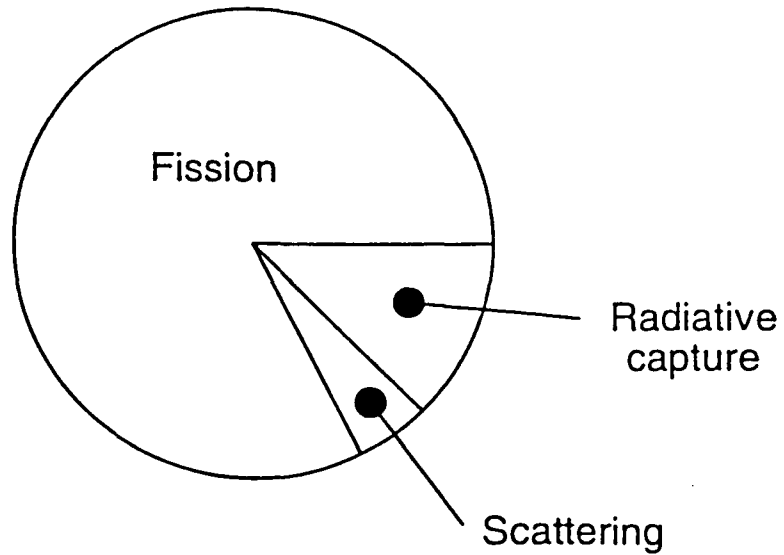
Target area may be smaller or larger than projected (physical) area of nucleus



Target areas are different for different nuclear reactions

Pie Diagram for Cross-Sections of U-235 and Nat-U

U-235



Nat-U

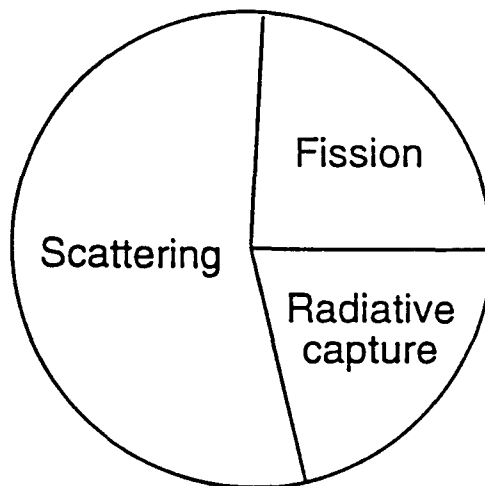
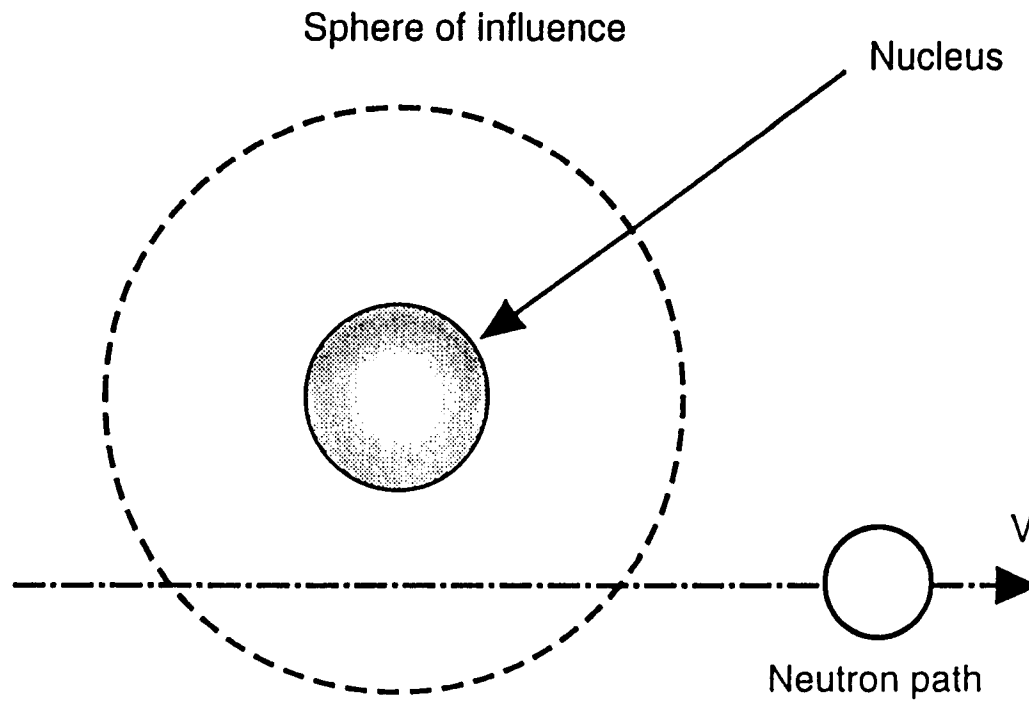


Fig. 3.2

Radiative Capture



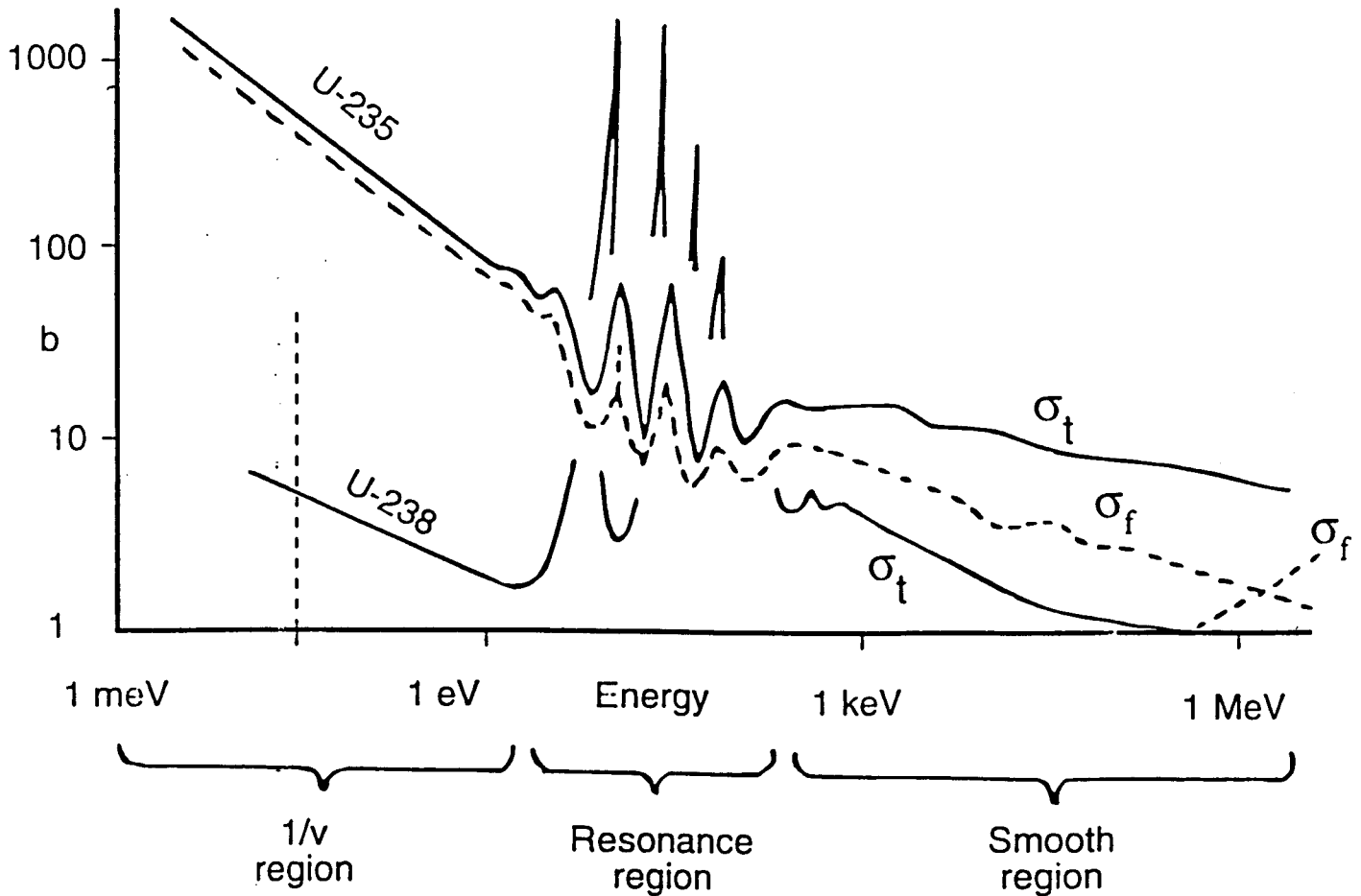
Time spent in sphere of influence

$$t \propto \frac{1}{v}$$

If probability of capture \propto time

$$\sigma_a \propto \frac{1}{v}$$

Fission Characteristics



Interactions of importance

$$\left. \begin{array}{l} \sigma_s = \text{Scattering} \\ \sigma_\gamma = \text{Radiative capture} \\ \sigma_f = \text{Fission} \end{array} \right\} \sigma_a = \text{Absorption}$$

$$\text{Capture/fission ratio: } \alpha = \sigma_\gamma / \sigma_f$$

$$\text{Probability of fission: } p = \sigma_f / \sigma_a$$

Elastic Collision

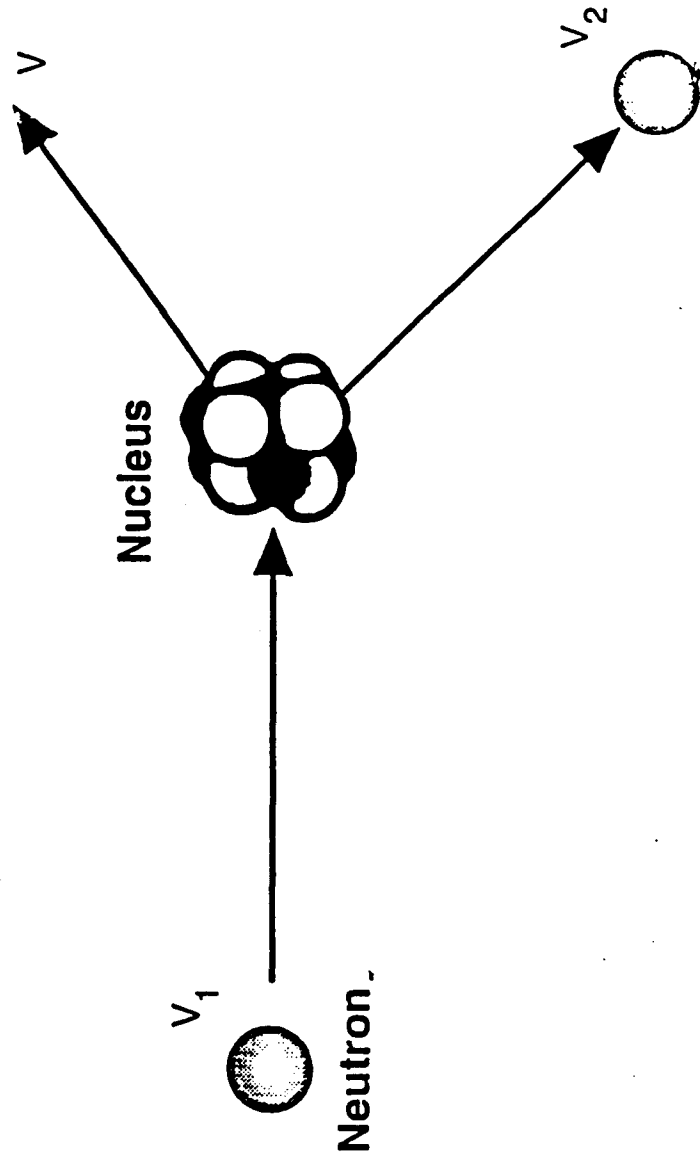
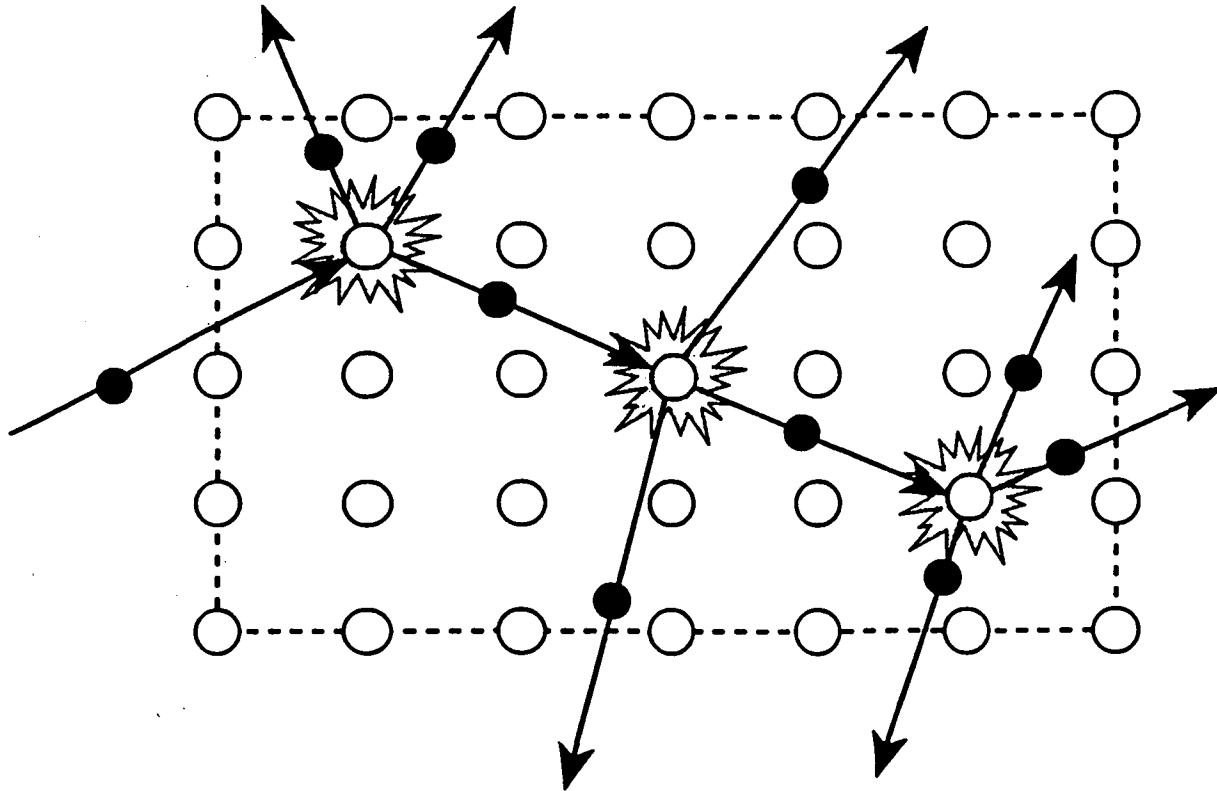


Fig. 2.1

Average Number of Elastic Collisions to Thermalize Fission Neutrons in Various Materials

H	18
D (Deuterium)	25
H ₂ O (Light water)	20
D ₂ O (Heavy water)	36
C-12 (Graphite)	115
U-238	2172

Fission Chain Reaction



Path of a Neutron from Birth to Absorption

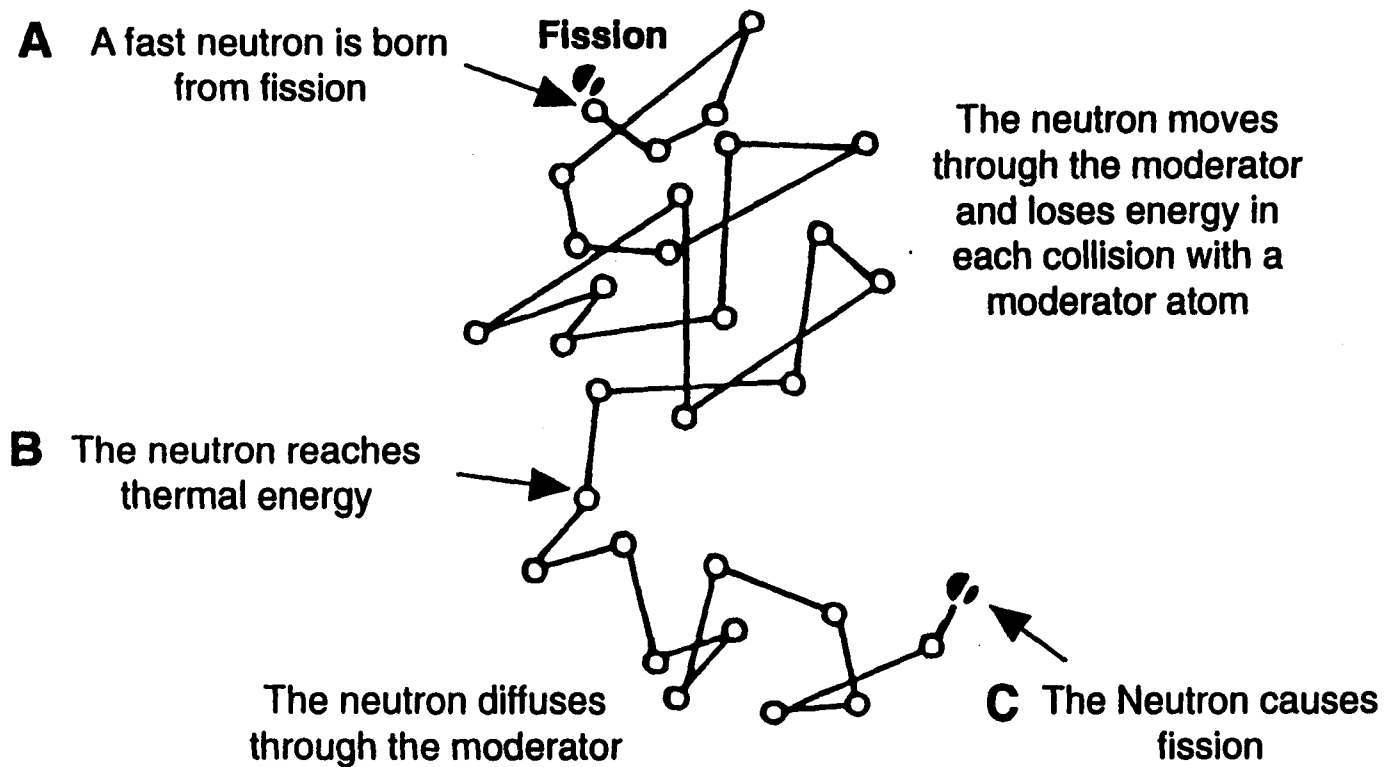
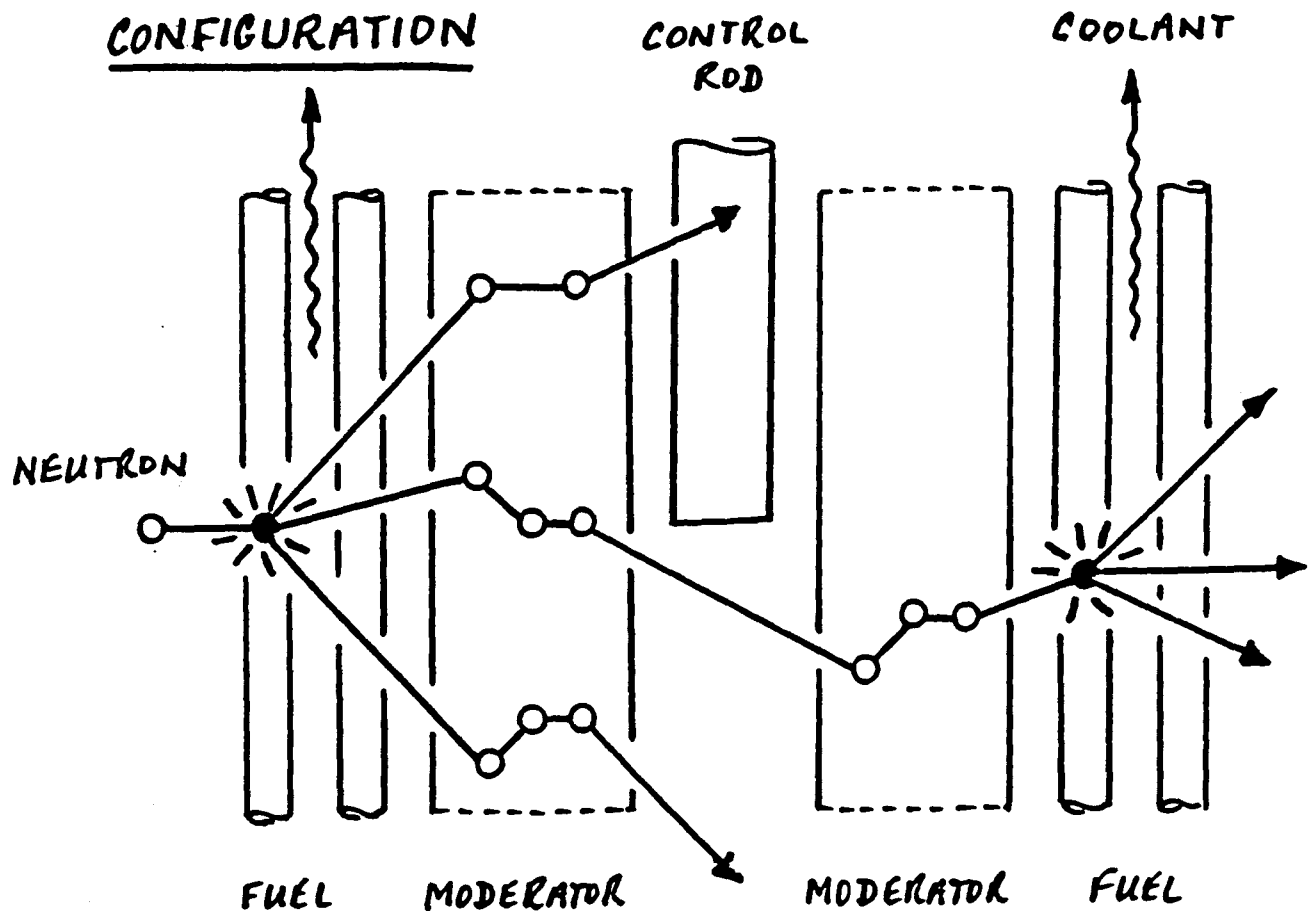


Fig. 4.3

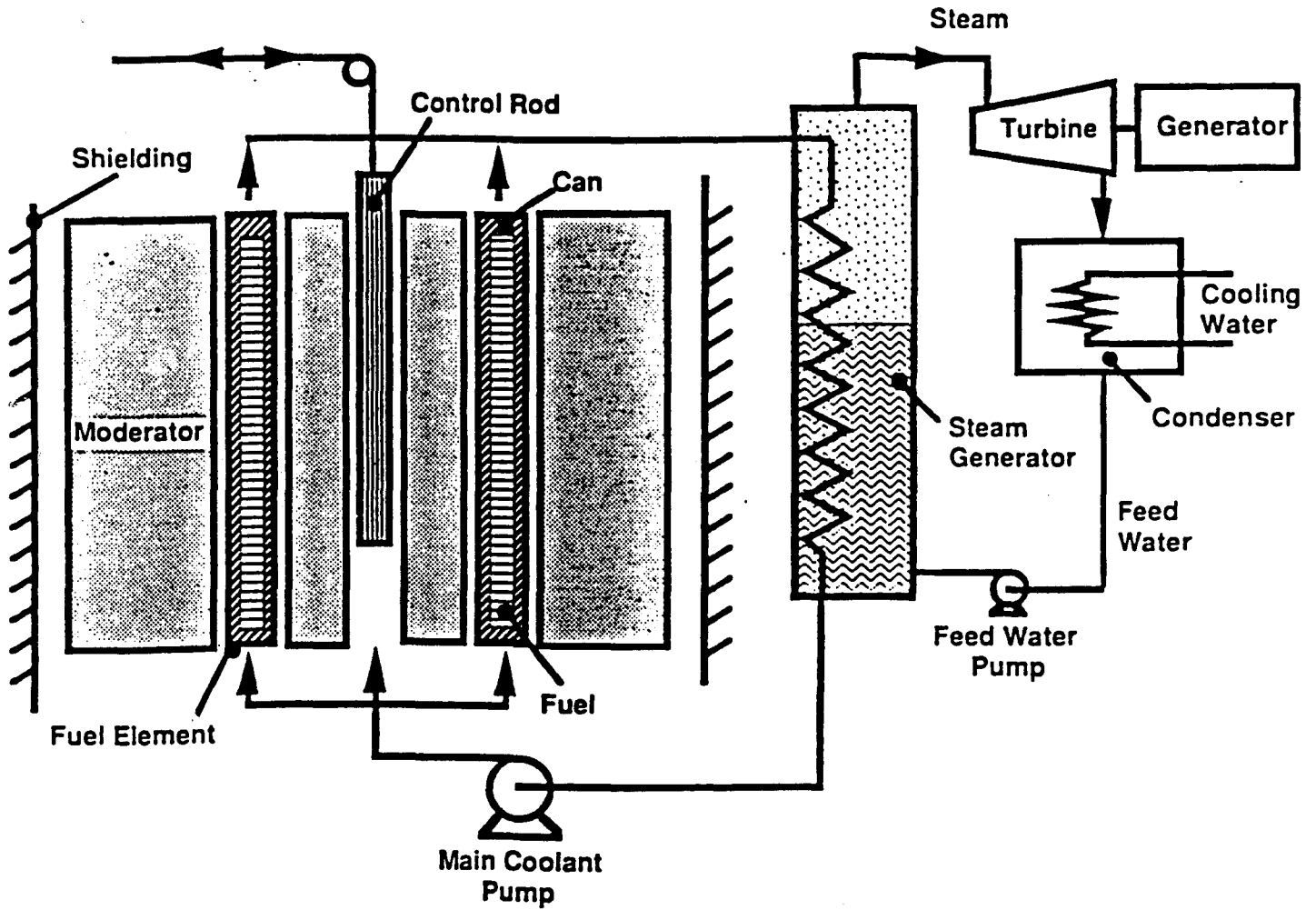
REACTOR PRINCIPLES

PRINCIPLES

- NEUTRON CHAIN REACTION
- CONTROL OF NEUTRONS
- MODERATION OF NEUTRONS
- REMOVAL OF ENERGY



BASIC REACTOR COMPONENTS



Definitions

Macroscopic cross-section

(Cross-section density in material)

$$\Sigma = N\sigma$$

$$\left(\frac{1}{\text{cm}} \right) \text{ or } \left(\text{cm}^{-1} \right)$$

N = Nuclei per unit volume

$$\left(\frac{\text{nuclei}}{\text{cm}^3} \right)$$

σ = Microscopic cross-section

$$\left(\text{cm}^2 \right)$$

Neutron flux

(Neutrons passing through given area per second)

$$\phi = n\nu$$

$$\left(\frac{\text{neutrons}}{\text{cm}^2 \text{ s}} \right)$$

n = Neutrons per unit volume

$$\left(\frac{\text{neutrons}}{\text{cm}^3} \right)$$

ν = Neutron velocity

$$\left(\frac{\text{cm}}{\text{s}} \right)$$

Reaction rate

(Reaction rate of neutrons with material)

$$R = \phi\Sigma$$

$$\left(\frac{\text{reactions}}{\text{cm}^3 \text{ s}} \right)$$

ϕ = Neutron flux

$$\left(\frac{\text{neutrons}}{\text{cm}^2 \text{ s}} \right)$$

Σ = Macroscopic cross-section

$$\left(\frac{1}{\text{cm}} \right)$$

Reactor Power

Neutron Flux

$$\phi = nv \text{ (neutrons/cm}^2\text{s)}$$

$$n = \text{Neutron density (neutrons/cm}^3\text{)}$$

$$v = \text{Neutron velocity (cm/s)}$$

Macroscopic cross-section

$$\Sigma_f = N\sigma_f \text{ (cm}^{-1}\text{)}$$

$$N = \text{Nuclei density (nuclei/cm}^3\text{)}$$

$$\sigma_f = \text{Microscopic cross-section (cm}^2\text{)}$$

Reactor power

$$P = \Sigma_f \phi V E_f \quad \frac{1}{\text{cm}} \times \frac{1}{\text{cm}^3\text{s}} \times \frac{\text{cm}^3}{1} \times \frac{\text{J}}{1}$$

$$v = \text{Volume of reactor (cm}^3\text{)}$$

$$E_f = \text{Energy release per fission (J)}$$