NUCLEAR

A SUPPLEMENTARY TEXT FOR INTRODUCTORY NUCLEAR ENGINEERING

[Editor's Note: This lecture material is supplementary to Course # 1.1, Nuclear Physics and Reactor Theory by Ian Cameron (Course 22106), Modules 1 to 7]

1997

R.A. CHAPLIN

UNIVERSITY OF NEW BRUNSWICK

REFERENCE TEXT

This text does not treat Nuclear Engineering in a rigorous manner and should be used in conjunction with an appropriate comprehensive textbook on Nuclear Engineering. The scope of this text follows the contents of the reference text book fairly closely to facilitate cross referencing and further reading.

Reference Text

INTRODUCTION TO NUCLEAR ENGINEERING

by

JOHN R.

LAMARSH

CORRESPONDENCE OF MATERIAL AS COVERED IN EACH SECTION & MODULE

1.1a Introduction to Nuclear Technology (Nuclear Theory I) -- UNB Course ChE 3804	1.1 Nuclear Physics & Reactor Theory (Course 22106)
Section 1 – Nuclear Physics	Module 1, Parts 1.3 to 1.7
Section 2 – Nuclear Interactions	Module 2, Parts 2.3 to 2.8 Module 3, Parts 3.3 to 3.9 Module 4, Parts 4.4 to 4.6
Section 3 – Neutron Diffusion	Not included
Section 4 – Reactor Theory	Module 5, Parts 5.3 to 5.6 Module 6, Parts 6.3 to 6.5
Section 5 – Reactor Kinetics	Not included

CONTENTS

NOMENCLATURE

CONSTANTS

CONSTANTS

Use the following constant values where applicable

Constant Values:
Density of Water $\rho = 1000\ kg/m^3$
Gravitational Acceleration $g = 9.81\ m/s^2$
Avogadros Number $N_A = 0.6022 \times 10^{24}$
Boltzmann Constant $k = 8.6170 \times 10^{-5}\ eV/°k$
Boltzmann Constant $k = 1.3806 \times 10^{-23} J/°k$

Conversion Factors:
1 barn = $10^{-24}\ cm^2$
1 curie = 3.7×10^{10} disintegrations/s
1 *amu* = 931 MeV
1 MeV = 1.6022×10^{-13} J

Reactor Kinetics:
Delayed neutron fraction $\beta = 0.0065$
Average neutron lifetime $\ell = 0.001$ s
Delayed neutron time constant $\lambda = 0.1\ s^{-1}$

If not given asume that the atomic (or molecular) mass (in amu) is equal to the atomic mass number A.

REFERENCE FORMULAE

Reaction Rate:

$$R = \phi\sigma N$$

Decay Activity:

$$\alpha = \lambda N$$

Build up Activity:

$$\alpha = R(1 - e^{-\lambda t})$$

Decay Equations:

$$dN / dt = - \lambda N$$

$$N_t = N_o e^{-\lambda t}$$

Build up - Decay Equations:

$$dN_x / dt = \phi\sigma_y N_y - \lambda_x N_x$$

$$N_x = N_{eqx} [1 - e^{-\lambda_x t}]$$

$$N_{eqx} = \phi \sigma_y N_y / \lambda_x$$

Burn up Equations:

$$dN / dT = - \phi \sigma N$$

$$N_t = N_o e^{-\sigma\phi t}$$

Build up - Burn Up Equations:

$$dN_x / dt = \phi \sigma_y N_y - \phi \sigma_x N_x$$

$$N_t = N_{eqx} [1 - e^{-\sigma_x \phi t}]$$

$$N_{eqx} = \sigma_y N_y / \sigma_x$$

NEUTRON DIFFUSION

$$J_x = - D\,(d\phi / dx)$$

$$D \approx \lambda_{tr} / 3$$

$$\Sigma_{tr} = \Sigma_s(1 - \mu)$$

$$\mu = 2 / 3A$$

$$L^2 = D / \Sigma_a$$

$$L^2 = r^2 / 6$$

$$\lambda_{tr} = 3D$$

$$\lambda_{tr} = 1 / \Sigma_{tr}$$

REACTOR THEORY

$$\nabla^2\phi + B^2\phi = 0$$

$$B^2 = (k_\infty - 1) / L^2$$

$$B^2 = (k_\infty - 1) / M^2T$$

$$M^2{}_T = L^2{}_T + \tau_T$$

$$\tau_T = D_1 / \Sigma_1$$

REACTOR KINETICS

Reactor Kinetics Equation:

$$P_t = P_o \left[\frac{\beta}{\beta - \Delta k} e^{\frac{\lambda \Delta k}{\beta - \Delta k} t} - \frac{\Delta k}{\beta - \Delta k} e^{-\frac{\beta - \Delta k}{\ell} t} \right]$$

Prompt Drop Approximation:

$$P_t = P_o \frac{\beta}{\beta - \Delta k} e^{\frac{\lambda \Delta k}{\beta - \Delta k} t}$$

Prompt Fission Neutron Equation:

$$P_t = P_o e^{\frac{\Delta k}{\ell} t}$$

Reactor Period Equations:

$$\tau = \frac{\ell}{\Delta k} \quad \text{(prompt neutrons only)}$$

$$\tau = \frac{\beta - \Delta k}{\lambda \Delta k} \quad \text{(with delayed neutrons)}$$

Subscritical Multiplication Factor:

$$S_\infty = \frac{S_o}{1 - k}$$

TABLE 6.2
Bucklings and fluxes for critical bare reactors

Geometry	Dimensions	Buckling	Flux	A	ϕ_{max}/ϕ_{av}
Infinite slab	Thickness a	$(\pi/a)^2$	$A \cos(\pi x/a)$	$1.57\ P/aE_R\Sigma_f$	1.57
Rectangular parallelepiped	a x b x c	$(\pi/a)^2 + (\pi/b)^2 + (\pi/c)^2$	$A \cos(\pi x/a) \cos(\pi y/b) \cos(\pi z/c)$	$3.87P/VE_R\Sigma_f$	3.88
Infinite cylinder	Radius R	$(2.405/R)^2$	$AJ_o(2.405r/R)$	$0.738P/R^2E_R\Sigma_f$	2.32
Finite cylinder	Radius R Height H	$(2.405/R)^2 + (\pi/H)^2$	$AJ_o(2.405r/R) \cos(\pi z/H)$	$3.63P/VE_R\Sigma_f$	3.64
Sphere	Radius R	$(\pi/R)^2$	$A\ 1/r \sin(\pi r/R)$	$P/4R^2E_R\Sigma_f$	3.29

Cross Section of Sphere $A = (\pi/4)\ D^2$

Volume of Sphere $V = (\pi/6)\ D^3$

Surface of Sphere $S = \pi D^2$