

## Table of Contents

### **SECTION 1 BASIC RADIATION PHYSICS**

<b>A. Atomic and Nuclear Structure</b> .....	Phy-3
1. Basic Atom .....	Phy-3
2. Protons and Neutrons (Nucleons).....	Phy-3
3. Electrons.....	Phy-3
4. Atomic Number and Atomic Mass Number .....	Phy-4
5. Nomenclature.....	Phy-4
6. Nuclides, Isotopes, Isobars .....	Phy-5
7. Energy Units .....	Phy-5
<b>B. Radioactive Decay</b> .....	Phy-6
1. General .....	Phy-6
2. Stability and Instability .....	Phy-6
3. Rate of Decay .....	Phy-7
a. Decay Constant .....	Phy-7
b. Half-Life ( $t_{1/2}$ ).....	Phy-7
c. Activity.....	Phy-8
d. Exponential Decay .....	Phy-9
4. Types of Radiation .....	Phy-10
a. Subatomic Particles.....	Phy-10
b. X-rays and Gamma Rays .....	Phy-11
5. Types of Radioactive Decay .....	Phy-11
a. Alpha ( $\alpha$ ) Decay .....	Phy-11
b. Beta ( $\beta^-$ ) Decay .....	Phy-12
c. Electron Capture (EC).....	Phy-13
d. Positron ( $\beta^+$ ) Emission.....	Phy-14
e. Internal Conversion .....	Phy-15
f. Internal Transition.....	Phy-15
6. Decay Schemes and Energy Levels.....	Phy-16

a.	I-131 Decay Diagram (Beta Decay Example) .....	Phy-16
b.	Zn-65 Decay Diagram (Electron Capture .....	Phy-18
c.	Ra-226 Decay Diagram (Alpha Decay Example) .....	Phy-19
<b>C.</b>	<b>Interaction of Radiation with Matter</b> .....	<b>Phy-20</b>
1.	Ionizing and Nonionizing Radiations .....	Phy-20
2.	Consequences of Interactions (Ionization and Excitation) .....	Phy-20
a.	Ionization .....	Phy-20
b.	Excitation .....	Phy-20
3.	Charged Particle Interactions .....	Phy-21
a.	Beta Particles .....	Phy-21
b.	Bremsstrahlung .....	Phy-22
c.	Annihilation .....	Phy-23
d.	Alpha Particles .....	Phy-23
4.	Electromagnetic Radiation Interactions .....	Phy-24
a.	Gamma and X-rays, General .....	Phy-24
b.	Photoelectric Effect .....	Phy-24
c.	Compton Scattering .....	Phy-25
d.	Pair Production .....	Phy-25
<b>D.</b>	<b>Time, Distance and Shielding</b> .....	<b>Phy-26</b>
1.	Time .....	Phy-26
2.	Distance (Inverse Square Law) .....	Phy-26
3.	Shielding .....	Phy-28
a.	Charged Particle Attenuation .....	Phy-28
b.	X-ray and Gamma Ray Attenuation .....	Phy-30
<b>E.</b>	<b>Basic Dose Quantities and Units</b> .....	<b>Phy-33</b>
1.	Historical Overview .....	Phy-33
2.	International System (SI) Versus Traditional Units .....	Phy-33
3.	Exposure .....	Phy-33
4.	Absorbed Dose .....	Phy-34
5.	Quality Factor (Q) .....	Phy-35

6.	Dose Equivalent .....	Phy-35
7.	Rate Units .....	Phy-36
8.	Predicting Radiation Levels .....	Phy-37
a.	Estimation of Gamma Exposure: Specific Gamma Ray Constant ( $\Gamma$ ) .....	Phy-37
b.	Estimating Beta Dose Rates .....	Phy-39
<b>F.</b>	<b>Internal Radiation Dose</b> .....	Phy-42
1.	Uptake .....	Phy-42
2.	Interorgan Transfer .....	Phy-43
3.	Residence Time .....	Phy-43
4.	Energy Deposition .....	Phy-43
<b>G.</b>	<b>Annual Limits on Intake (ALI)</b> .....	Phy-43
<b>H.</b>	<b>Annual Dose Limits</b> .....	Phy-44
1.	Occupational Dose Limits for Adult Workers .....	Phy-44
a.	Total Effective Dose Equivalent (“Whole Body”) .....	Phy-44
b.	Lens of the Eye .....	Phy-44
c.	Skin and Extremity Dose .....	Phy-44
d.	Other Organs .....	Phy-44
2.	Occupational Dose Limits for Minors .....	Phy-44
3.	Dose to an Embryo/Fetus of an Occupationally Exposed Person .....	Phy-44
4.	Dose Limits for Individual Members of the Public .....	Phy-45
<b>I.</b>	<b>Natural Background and Average Population Doses</b> .....	Phy-45
1.	Cosmic Radiation .....	Phy-45
2.	Terrestrial Radiation .....	Phy-45
3.	Internally Deposited Radionuclides .....	Phy-46
4.	Natural Background Radiation Dose Equivalent .....	Phy-46
5.	Medical Radiations .....	Phy-46
6.	Miscellaneous Dose .....	Phy-47
7.	Total Average Population Doses .....	Phy-47
	<b>Abbreviations and Symbols</b> .....	Phy-49

<b>Glossary</b> .....	Phy-51
<b>Energy Units</b> .....	Phy-56
<b>Radiological Units</b> .....	Phy-57
<b>Hazard Information for Common Radionuclides</b> .....	Phy-58
Hydrogen-3.....	Phy-58
Carbon-14.....	Phy-59
Sulfur-35 .....	Phy-60
Phosphorus-32 .....	Phy-61
Iodine-125 .....	Phy-62
Iodine-131 .....	Phy-63
<b>Appendix 1</b> .....	Phy-65
Figure 1: Chart of Stable Nuclides.....	Phy-67
Figure 2: Average and Maximum Beta Energy by Radionuclides.....	Phy-68
Figure 3: Decay Schemes .....	Phy-73
Hydrogen-3	
Carbon-14	
Oxygen-15.....	Phy-73
Fluorine-18	
Sodium-24.....	Phy-74
Phosphorus-32	
Phosphorus-33	
Sulfur-35.....	Phy-75
Calcium-45	
Chromium-51	
Iron-55 .....	Phy-76
Cobalt-60	
Copper-64.....	Phy-77
Zinc-65	
Strontium-90	
Yttrium-90 .....	Phy-78

Molybdenum-99 and Technicium-99m	
Indium-111 .....	Phy-79
Iodine-125	
Iodine-131	
Cesium-137 .....	Phy-80
Thallium-201	
Radium-226 .....	Phy-81
Figure 4: Radioactive Decay, Semi-Log Plot.....	Phy-82
Figure 5: Half Value Layer vs Photon Energy.....	Phy-84
Figure 6: Mass Attenuation Coefficients.....	Phy-86
Figure 7: Gamma Radiation Levels.....	Phy-88
Figure 8: Specific Gamma Ray Constants for Monoenergetic Photons .	Phy-89
Figure 9: Exposure Rate from Gamma Emitters.....	Phy-90
Figure 10: Beta Dose Rate from Surface Contamination.....	Phy-91
Figure 11: Beta Emitters .....	Phy-92
Figure 12: Penetration Ability of Beta Radiation.....	Phy-94
Figure 13: Annual Limits on Intake (ALI) for Occupational Exposures .	Phy-95
Figure 14: Radiation Exposure from Consumer Products and Miscellaneous Sources .....	Phy-97

## **SECTION 2 BIOLOGICAL EFFECTS OF IONIZING RADIATION**

<b>A. Introduction .....</b>	<b>Bio 3</b>
<b>B. Sequential Pattern of Biological Effects.....</b>	<b>Bio 3</b>
1. Latent Period .....	Bio-3
2. Period of Demonstrable Effects on Cells and Tissues.....	Bio-3
3. Recovery Period .....	Bio-4
<b>C. Determinants of Biological Effects .....</b>	<b>Bio 4</b>
1. The Dose Response Curve .....	Bio-4
2. Rate of Absorption .....	Bio-5

3.	Area Exposed .....	Bio-5
4.	Variation in Species and Individual Sensitivity .....	Bio-5
5.	Variation in Cell Sensitivity .....	Bio-6
<b>D.</b>	<b>Short Term Effects</b> .....	Bio 6
1.	Stages in the Acute Radiation Syndrome.....	Bio-6
a.	Prodrome .....	Bio-6
b.	Latent Stage .....	Bio-6
c.	Manifest Illness Stage .....	Bio-7
d.	Recovery or Death .....	Bio-7
2.	Relation of Dose to Type of Acute Radiation Syndrome.....	Bio-7
3.	Summary.....	Bio-8
<b>E.</b>	<b>Long Term Effects</b> .....	Bio 9
1.	Introduction .....	Bio-9
2.	Carcinogenic Effects .....	Bio-10
a.	Possible Carcinogenic Mechanisms.....	Bio-10
b.	Human Evidence for Radiation Carcinogenesis .....	Bio-11
c.	Significance of Human Studies on Radiation Carcinogenesis .....	Bio-15
3.	Embryological Effects.....	Bio-16
a.	Embryological Effect vs Stage of Pregnancy .....	Bio-16
b.	Human Evidence for Embryological Effects .....	Bio-17
c.	The Problem of Unsuspected Pregnancy .....	Bio-17
4.	Cataractogenic Effects.....	Bio-17
5.	Life Span Shortening.....	Bio-18
a.	Mechanisms.....	Bio-18
b.	Human Evidence .....	Bio-18
6.	Genetic Effects.....	Bio-19
a.	Background.....	Bio-19
b.	Observing Mutations .....	Bio-20
c.	Animal Evidence of Genetic Effects .....	Bio-22
d.	Human Evidence of Genetic Effects.....	Bio-22
e.	Health Significance of Genetic Mutations .....	Bio-23

<b>Suggested General References</b> .....	Bio-24
<b>Glossary</b> .....	Bio-25

## **SECTION 3 RADIATION PROTECTION PROCEDURES**

<b>A. Introduction</b> .....	Pro-3
1. Human Factors .....	Pro-3
2. Environmental Factors.....	Pro-3
3. Toxic Agents, such as radioactive Material	
<b>B. Organizational Plan for Radiation Protection</b> .....	Pro-3
<b>C. Radiation Lab Protection Procedures</b> .....	Pro-4
1. Laboratory Layout .....	Pro-4
2. Fumes Hoods.....	Pro-5
3. Protective Clothing .....	Pro-5
4. Storage Security.....	Pro-6
5. Waste Collection and Disposal.....	Pro-6
6. Records .....	Pro-6
7. Labeling.....	Pro-7
<b>D. Accident Anticipation</b> .....	Pro-7
1. Identification of An Accident.....	Pro-7
2. Habits That May Result in RAM Ingestion.....	Pro-7
a. Mouth Habits.....	Pro-7
b. Food, Drinks, and Smoking .....	Pro-8
c. Pipetting .....	Pro-8
3. Protective Measures .....	Pro-9
a. Planning Work.....	Pro-9
b. Knowledge of Radionuclides Being Used .....	Pro-9
c. Lab Procedures .....	Pro-9

<b>E. Surveys and Decontamination Procedures .....</b>	<b>Pro-9</b>
1. Routine Surveys.....	Pro-9
2. Decontamination of Equipment and Work Surfaces .....	Pro-10
3. Personnel Action in Event of Contamination .....	Pro-11
4. Bioassays.....	Pro-12
a. Tritium.....	Pro-12
b. Radioiodine.....	Pro-12
<b>F. Principles of Radiation Detection.....</b>	<b>Pro-13</b>
1. Methods Classified by Media in Which Ionization or Excitation Interactions Occur .....	Pro-13
a. Photographic Detection Media .....	Pro-13
b. Gas Media.....	Pro-13
c. Scintillation Media.....	Pro-14
d. Solid State Detector Media.....	Pro-14
2. Classifications of Instruments by Use.....	Pro-15
a. Personnel Dosimeters .....	Pro-15
b. Survey Instruments .....	Pro-16
<b>G. Mitigating External Radiation Hazards .....</b>	<b>Pro-17</b>
1. Time.....	Pro-17
2. Distance .....	Pro-17
3. Shielding .....	Pro-17
<b>H. Mitigating Internal Radiation Hazards .....</b>	<b>Pro-18</b>
1. Good Hygiene.....	Pro-18
2. Control of Contamination .....	Pro-18
3. Airborne Hazards .....	Pro-18
4. Protective Clothing.....	Pro-18
<b>Abbreviations .....</b>	<b>Pro-21</b>
<b>Glossary .....</b>	<b>Pro-23</b>
<b>Appendix 3.....</b>	<b>Pro-25</b>

Figure 1: Emergency Procedures (On Campus Use) .....	Pro-27
Figure 2: Emergency Procedures (Off Campus Use) .....	Pro-28
Figure 3: Radiation Safety Manual - Section 14, <i>Radioactive Waste</i> ....	Pro-29
Figure 4: Form 160 Radioactive Material Delivery and Usage Record .	Pro-44
Figure 5: Radiation Safety Manual - Section 13, <i>Laboratory Survey Procedures</i> .....	Pro-45
Figure 6: Radiation Detecting Devices .....	Pro-57

## **SECTION 4 RADIATION SAFETY RULES AND REGULATIONS**

<b>A. Historical Perspective</b> .....	RR-3
<b>B. Regulatory Organizations</b> .....	RR-3
1. National .....	RR-3
2. State .....	RR-4
3. University .....	RR-4
<b>C. Authorization Process for Users of Radioactive Material</b> ....	RR-4
1. Introduction .....	RR-4
2. Application Process .....	RR-5
3. Laboratory Certification .....	RR-5
4. Authorized Investigator's Responsibilities .....	RR-5
5. Radiation Worker Responsibilities and Rights .....	RR-6
<b>D. University Regulations</b> .....	RR-6
1. Inventory Control .....	RR-6
a. Purchasing of Radioactive Material .....	RR-6
b. Receipt of Radioactive Material .....	RR-7
c. Disposal of Radioactive Material .....	RR-8
d. Transfer of Radioactive Material .....	RR-8
2. Off Campus Shipment of Radioactive Material .....	RR-9

**Abbreviations** .....RR-10

**Appendix 4**.....RR-11

Figure 1: Radiation Protection – General Provisions,  
WAC 246-220-007, *Statement of Philosophy*.....RR-13