University of Pittsburgh

# ME/ENGR 2100 Fundamentals of Nuclear Engineering

## Radiation Protection:

## Radiation Damage in Biological Systems

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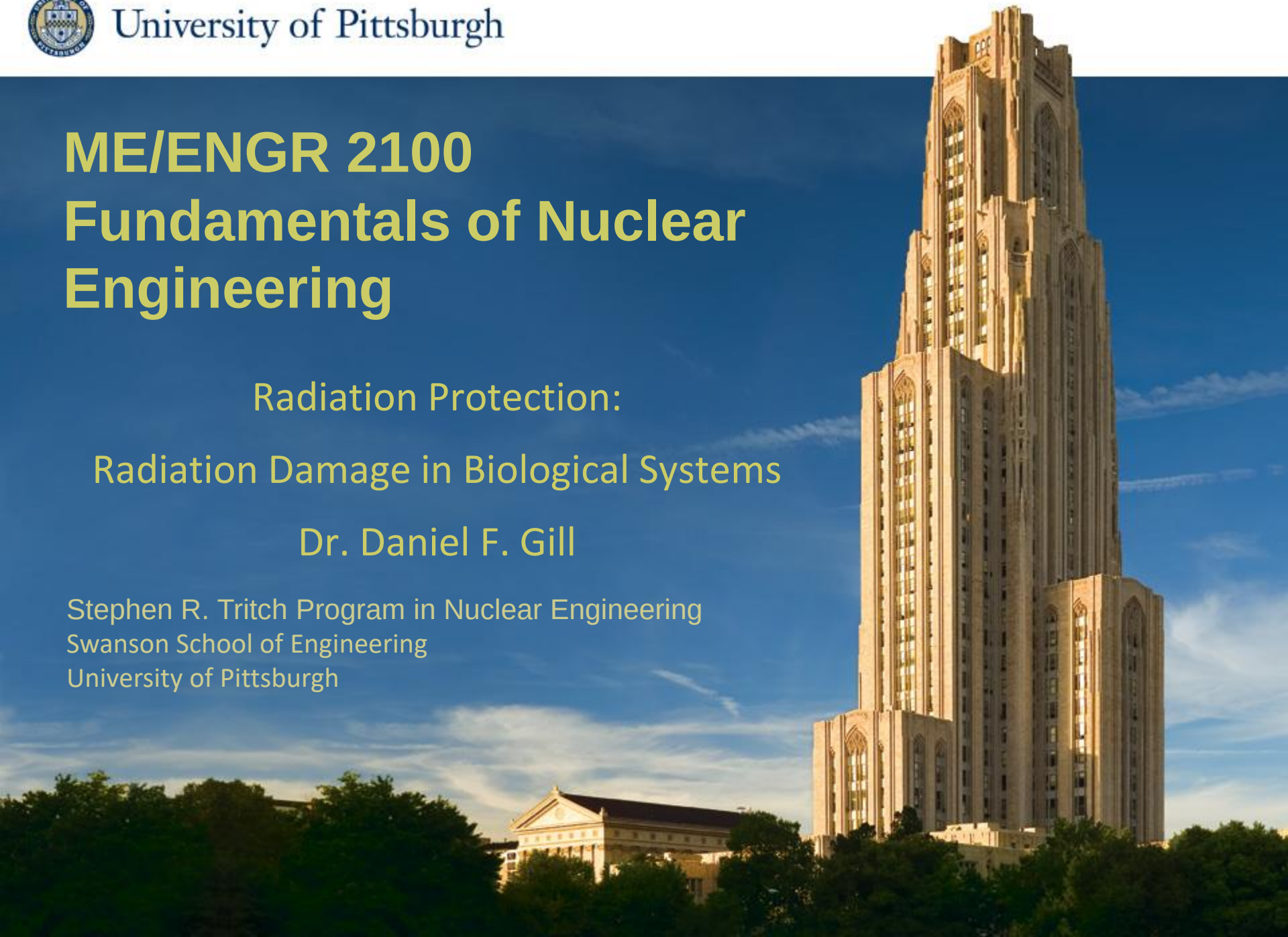

# Relevant Reading Assignments

- Chapter 9 of "Introduction to Nuclear Engineering," Lamarsh and Baratta, 3rd edition, Prentice-Hall (2001)
- Chapter 3 of "Nuclear Engineering: Theory and Technology of Commercial Nuclear Power," Knief, 2nd edition, American Nuclear Society (1992, reprint by ANS 2008)

# Learning Objectives

- Describe radiation damage effects in biological systems

- Define LD50/30. State the value of LD50/30 for whole-body radiation to humans.

# Describe radiation damage effects in biological systems

# Basis

- An animal is an organized collection of organs, held together by connective tissue, whose functions are coordinated by a nervous system.
  - Cells are the basic building blocks of life
  - Adult humans have approximately $7 \times 10^{13}$ total cells of 210 different types

# Cell Functions

- All cells perform basic tasks:
  - Metabolism: Cells break down complex nutrient molecules to release energy.
  - Reproduction: Cells reproduce by division.
  - Protein synthesis: Protein molecules take part in all biochemical processes in the cell. The cell builds proteins required to perform its specialized tasks of the cell.
- Every cell contains specialized "organelles," which are responsible for performing these tasks.

Every cell is 70% to 90% water

# Cell Damage

- Ionization can disrupt any of the three major functions of cells:
  - Metabolism
    - Cell cannot produce the energy that it needs and dies.
  - Protein synthesis
    - Cell cannot create protein needed for cell survival. -or-
    - Cell cannot create protein required for its specialized task; cell is alive but useless.
  - Reproduction
    - Cell cannot reproduce or reproduces incorrectly.

# Cell Damage

- Many ionizations within a single cell typically results in enough damage to disrupt metabolism or protein synthesis and immediately kill the cell.
- For radiation damage, this requires a lot of energy to be deposited within a single cell:
  - Direct radiation damage
    - High LET charged particles ionize biological molecules directly.
  - Indirect radiation damage
    - High-energy γ and X-Rays produce strongly oxidizing free-radicals by radiolysis. The free radicals then travel through the cell destroying molecules. Because cells are mostly water, indirect damage due to radiolysis of water is the most common mechanism.

# Radiation chemistry and toxicity

- Most of the body is water
- Most of the ionizing radiation interactions result in energy absorbed in water and the production of highly reactive free radicals.

$$H_2O \underbrace{\rightarrow}_{ionized} H_2O^+ + e^-$$

$$H_2O^+ \rightarrow H^+ + OH \;\&\; H_2O + e^- \rightarrow H_2O^- \rightarrow H + OH^-$$

$$High\ LET\ (e.g., \alpha's)$$

$$OH + OH \rightarrow H_2O_2 \;\&\; H + H \rightarrow H_2$$

If there is excess $O_2$

$$H + O_2 \rightarrow HO_2 \Rightarrow HO_2 + H \rightarrow H_2O_2$$

- The hydrogen peroxide is a powerful oxidizing agent that affects other cells not directly damaged by radiation.

# Radiation Interaction time scales

- Radiation's interaction with aqueous systems
  - Physical – creation of the ions, $10^{-15}$ seconds
  - Prechemical – free radicals before they react, $10^{-12}$ seconds
  - Early Chemical – reactions take place, $10^{-6}$ seconds
  - Late Chemical – further product yields

- In approx. 1 millionth of second the toxic products are formed.

# Radiation Dose in living tissue

- Chronic Dose
  - Dose delivered over an extended period of time.
- Acute Dose
  - Dose delivered over a short period of time.
  - An acute dose is generally more damaging than a chronic dose of the same size, because the body's repair mechanisms have less opportunity to act.
  - https://www.remm.nlm.gov/ars_timephases1.htm

# Short-Term Radiation Effects

- Immediate Effects (hours to days)
  - Skin reddening, inflammation
  - Immune suppression
  - Sterility
  - Blood chemistry changes
  - Loss of hair
  - Gastrointestinal syndromes
  - Central nervous system syndromes

# Long-Term Radiation Effects

- Long term effects (months to years)
  - Cancer / leukemia
  - Cataracts
  - Genetic defects
  - Blood disorders
  - Lifespan shortening
- Scientific consensus on high dose effects.
- Lack of consensus on low dose effects.

# Define LD50/30. State the value of LD50/30 for whole-body radiation to humans

# Definition of "LD 50/30"

- LD 50/30 is the dose of radiation expected to cause death to 50 percent of an exposed population within 30 days (**LD 50/30**). (USNRC)

# Radiation Dose Effects

| Equiv Dose Sv (Rem) | Symptoms | Lethality |
|---|---|---|
| 0.05-0.2 (5-20) | None | 0% |
| 0.2-0.5 (20-50) | No external. Temporary reduction in red blood count | 0% |
| 0.5-1 (50-100) | Mild radiation sickness | 0% |
| 1-2 (100-200) | Nausea and vomiting. Immune system depressed | LD10/30 |
| 2-3 (200-300) | Nausea and vomiting. Loss of hair, loss of white blood cells. | LD35/30 |
| 3-4 (300-400) | Uncontrollable hemorrhaging | LD50/30 |
| 4-6 (400-600) | Widespread internal bleeding. Near shutdown of immune system | LD60/30 |
| 6-10 (600-1000) | Complete destruction of bone marrow. Widespread damage to organs | LD100/14 |
| 10-50 (1000-5000) | Direct damage to central nervous system. Direct burning damage to skin. | LD100/7 |
| >50 (>5000) | Increased severity of symptoms listed above | LD100/2 |

No detectable response <0.25 Sv (25 rem)

Human LD 50/30 ≈4.5 Sv (450 rem)

Selected data from Wikipedia: "Radiation poisoning", 8-26-2007, GDFL

*Symptoms are cumulative to maximum equivalent dose received.

† LD xx/yy gives the percentage of fatalities (xx%) within yy days, without medical attention.