22.01 Fall 2015, Quiz #3 (Final)

December 24, 2015

Complete all the assigned problems, and show all intermediate work. Partial credit *will* be given generously for showing the correct approach, even if you can't solve the problem. Make sure to write whatever you can, to show what you really know. Define any variables which you don't know and keep cranking. HINT: Read all questions before starting, to help you budget your time.

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1 Conceptual Questions (10 Points Each)

1.1 Mechanistically explain five ways in which irradiation prevents the early spoilage of food, and/or the spread of harmful agricultural pests.

1.2 Suggest three reasonable ways (lead underpants are ***not*** an option) in which airlines could help flight attendants and pilots incur less radiation dose per unit of flight time. Mention why you choose each one, and state which sources/forms of radiation you are mitigating.

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1.3 **Studies still disagree on whether second-hand smoke is actually dangerous. Explain from a radiological point of view why you think it is/isn't (choose a side), and set up an equation to estimate the increase in equivalent dose from living with a smoker.**

1.4 **Set up, but do not solve, an expression for the equivalent dose rate in $\frac{Sieverts}{second}$ for a person standing at a distance D from a point source of gamma activity A_γ. Define any variables you need to complete the expression.**

1.5 Rank the following types of cells in order of increasing radiation sensitivity, based on your knowledge of acute radiation effects: Bone marrow cells, cerebral neurons, endometrial (blood vessel liner) cells, hair follicle cells, intestinal cells in villi.

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1.6 Qualitatively and mechanistically explain the observed trend (below) in G-values as a function of chemical species and particle energy, using your knowledge of charged particle creation, diffusion, and stopping power:

Table 13.3 *G* Values (Number per 100 eV) for Various Species in Water at 0.28 μs for Electrons at Several Energies

Species	Electron Energy (eV)							
	100	200	500	750	1000	5000	10,000	20,000
OH	1.17	0.72	0.46	0.39	0.39	0.74	1.05	1.10
H_3O^+	4.97	5.01	4.88	4.97	4.86	5.03	5.19	5.13
e^-_{aq}	1.87	1.44	0.82	0.71	0.62	0.89	1.18	1.13
H	2.52	2.12	1.96	1.91	1.96	1.93	1.90	1.99
H_2	0.74	0.86	0.99	0.95	0.93	0.84	0.81	0.80
H_2O_2	1.84	2.04	2.04	2.00	1.97	1.86	1.81	1.80
Fe^{3+}	17.9	15.5	12.7	12.3	12.6	12.9	13.9	14.1

Table 13.4 *G* Values (Number per 100 eV) for Various Species at 10^{-7} s for Protons of Several Energies and for Alpha Particles of the Same Velocities

Species Type	Protons (MeV)				Alpha Particles (MeV)			
	1	2	5	10	4	8	20	40
OH	1.05	1.44	2.00	2.49	0.35	0.66	1.15	1.54
H_3O^+	3.53	3.70	3.90	4.11	3.29	3.41	3.55	3.70
e^-_{aq}	0.19	0.40	0.83	1.19	0.02	0.08	0.25	0.46
H	1.37	1.53	1.66	1.81	0.79	1.03	1.33	1.57
H_2	1.22	1.13	1.02	0.93	1.41	1.32	1.19	1.10
H_2O_2	1.48	1.37	1.27	1.18	1.64	1.54	1.41	1.33
Fe^{3+}	8.69	9.97	12.01	13.86	6.07	7.06	8.72	10.31

2 Analytical Questions (20 Points Each)

2.1 **Set up, but do not solve, a complete set of equations to calculate the added risk of long-term radiation effects (cancer, mutations) for a person standing and permanently living within 1 km of an atomic bomb detonation delivering a 1 MeV neutron flux of Φ_n and a 1 MeV gamma flux of Φ_γ. Consider all possible sources of elevated radiation exposure that would result from being in close proximity to an atomic bomb blast, and how they would become incorporated in the human body. Define any symbols you need to represent quantities which you do not know: Numbers aren't important here, concepts are!**

2.2 **Set up, but do not solve, a complete set of equations to determine the acute, equivalent dose to which a person was exposed by taking time-dependent measurements of their white blood cell count. Graph what this function would look like for any general case starting at the time of acute radiation exposure, and point out the major features, slopes, or other parameters of this graph. (HINT: Also graph the concentration of cells which produce white blood cells, and think back to our discussion of isotope production & decay)**

Useful Equations, Figures, and Tables Not in the Yip Book

$$\frac{\lambda^2}{6\tau} = D$$

$$\Omega = \frac{Area}{r^2} \ (for\, a\, point\, source)$$

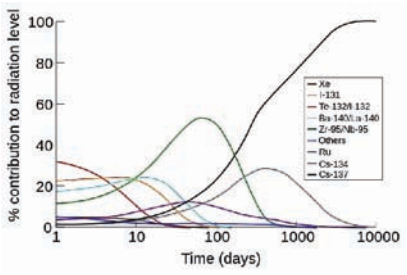


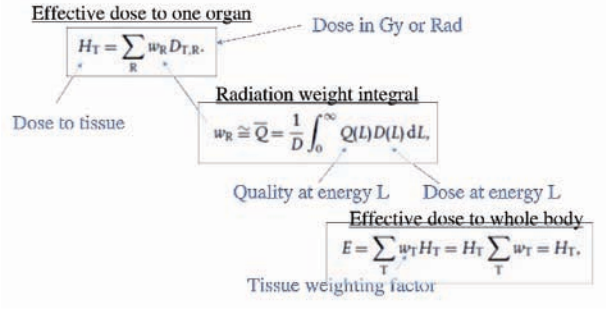
Table 12.2 Dependence of Quality Factor Q on LET as Currently Recommended by ICRP, NCRP, and ICRU

LET, L (keV μm^{-1} in Water)	Q
<10	1
10–100	$0.32L-2.2$
>100	$300/\sqrt{L}$

Table 9.1. Values of the quality factor for different radiations. Source: ICRP [1991]; NCRP [1993].

Radiation	QF
X, γ, $\beta^{\pm}$, (all energies)	1
Neutrons < 10 keV	5
10–100 keV	10
0.1–2 MeV	20
2– 20 MeV	10
> 20 MeV	5
Protons (> 2 MeV) [ICRP]	5
Protons (> 2 MeV) [NCRP]	2
Alpha particles	20

Tissue or Organ	w_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01



Useful Figures and Tables Not in the Yip Book

Table 1 – Signs and symptoms of prodromal phase.[4]

Signs and symptoms	Mild (1–2 Gy)	Moderate (2–4 Gy)	Severe (4–6 Gy)	Very severe (6–8 Gy)	Lethal (>8 Gy)
Vomiting					
Onset	≥2 h after exposure	1–2 h after exposure	<1 h after exposure	<30 min after exposure	<10 min after exposure
% of incidence	10–50	70–90	100	100	100
Diarrhea	None	None	Mild	Heavy	Heavy
Onset			3–8 h	1–3 h	Within min
% of incidence			<10	>10	100
Headache	Slight	Mild	Moderate	Severe	Severe
Onset			4–24 h	3–4 h	1–2 h
% of incidence			50	80	80–90
Consciousness	Unaffected	Unaffected	Unaffected	May be altered	Unconsciousnes s/min
Onset					
% of incidence					100 at >50 Gy
Body temperature	Normal	Increased	Fever	High fever	High fever
Onset		1–3 h	1–2 h	<1 h	<1 h
% of incidence		10–80	80–100	100	100

Table 2 – Signs and symptoms of latent phase.[4]

Signs and symptoms	Mild (1–2 Gy)	Moderate (2–4 Gy)	Severe (4–6 Gy)	Very severe (6–8 Gy)	Lethal (>8 Gy)
Latency period	21–35 days	18–28 days	8–18 days	≤7 days	None
Lymphocytes G/L (days 3–6)	0.8–1.5	0.5–0.8	0.3–0.5	0.1–0.3	0.0–0.1
Granulocytes G/L	>2.0	1.5–2.0	1.0–1.5	≤0.5	≤0.1
Diarrhea	None	None	Rare	Appears on days 6–9	Appears on days 4–5
Depilation	None	Moderate, beginning on day 15 or later	Moderate, beginning on day 11–21	Complete earlier than day 11	Complete earlier than day 10

Table 3 – Signs and symptoms of critical phase.[4]

Signs and symptoms	Mild (1–2 Gy)	Moderate (2–4 Gy)	Severe (4–6 Gy)	Very severe (6–8 Gy)	Lethal (>8 Gy)
Onset of symptoms	>30 days	18–28 days	8–18 days	<7 days	<3 days
Clinical manifestations	Fatigue, weakness	Fever, infections, weakness, depilation	High fever, infections, bleeding, depilation	High fever, diarrhea, vomiting, dizziness, desorientation, hypotension	High fever, diarrhea, unconsciousness
Lymphocytes G/L (days 3–6)	0.8–1.5	0.5–0.8	0.3–0.5	0.1–0.3	0.0–0.1
Platelets G/L	60–100	30–60	25–35	15–25	<20
% of incidence	10–25	25–40	40–80	60–80	80–100
Lethality	0%	0–50%	20–70%	50–100%	100%
Onset time		6–8 week	4–8 week	1–2 week	1–2 week

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Table 4 – The time course and severity of clinical signs and symptoms.

Absorbed dose level	Prodromal phase	Latent phase	Manifest illness	Final phase
0.5–1.5 Gy	Absence of symptoms or nausea and vomiting for 1 day	1 day–several weeks	No symptoms or weakness, nausea and vomiting, temporary hair loss	Recovery
1.5–4 Gy	Nausea, vomiting, fatigue, weakness, diarrhea for up to two days	1–3 weeks	Hematopoietic syndrome (HS): leucopenia and trombocitopenia, hair loss	Recovery possible with supportive care
4–6 Gy	Nausea, vomiting, weakness, diarrhea for up to two days	<1–3 weeks	HS: bleeding, immunosuppression and sepsis, permanent hair loss	Death without supportive care
6–15 Gy	Severe nausea and vomiting, diarrhea in shorter period of time	Several days	HS + gastrointestinal syndrome: diarrhea, bleeding, fluid loss and electrolyte imbalance	Variable with supportive care
>15 Gy	Immediate severe nausea and vomiting	Non-existent	Neurovascular syndrome	Death within 48 h

Modified from Ref. 5.

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