Solution to EXAM-5 (Closed Book) 14:30; May 19, 2004

Problem-1 (10): Briefly explain the effects of radiation on DNA molecules.

(Solution)

The effects of radiation on DNA molecules are briefly summarized as follows:

- direct effects in the form of **single-strand or double-strand breaks**,
- a variety of **recombinatorial changes and cross-links**,
- alteration in sugar and base fractions, and
- base substitutions, deletions, etc.

Problem-2 (10 points): Explain the deterministic and stochastic effects of radiation exposure.

(Solution)

- **Deterministic effects** are those for which the severity of the effects varies with dose, result from high dose exposure and for them there is a threshold. The deterministic effects of various tissues summarized in ICRP-60 are:

DETERMINISTIC EFFECTS	single brief exposure	fractionated annual dose rate
testes - temporary sterility - permanent sterility	 0.15 Sv 3.5 - 6.0 Sv	 0.4 Sv/yr 2.0 Sv/yr
ovaries - sterility 3 Gy for 40-yr old; menopause 3 Gy for 20-yr old: temporary amenorrhea	2.5 - 6.0 Sv	> 0.2 Sv/yr
lens - detectable opacities - visual impairment (cataract)	 0.5 - 2.4 Sv 5.0 Sv	 0.1 Sv/yr > 0.15 Sv/yr
bone marrow - depression of hematopoiesis	 0.5 Sv	 > 0.4 Sv/yr
skin - erythema and dry desquamation - moist desquamation - tissue necrosis	3-5 Gy (symptoms after 3 weeks) 20 Gy (blistering after 4 weeks) 50 Gy (local cell deaths in the epidermal and dermal layers after 3 weeks)	
fetus - reduction in IQ - severe mental retardation	 30 IQ points per Sv 4.0×10^{-2} per Sv	

- **stochastic effects** are defined as the "probabilistic effects of low dose radiations without threshold which express themselves long after the exposure and include increased risk of cancer and hereditary disorders." Stochastic effects could be expressed in "risk factor." The overall risk factor for carcinogenesis effects (fatal cancer) is: 4.0×10^{-2} / Sv. And the risk factor for adverse hereditary effects is: 1.0×10^{-2} / Sv. And the risk factor of each organ is summarized as follows:

STOCHASTIC EFFECTS (ICRP-60)		
organs or tissue, T	risk factor, Sv^{-1}	biological effects
gonads	1.0×10^{-2}	severe genetic effects
red bone marrow	0.6×10^{-2}	leukemia
colon	0.6×10^{-2}	fatal cancer

lung	0.6×10^{-2}	fatal cancer
stomach	0.6×10^{-2}	fatal cancer
bladder	0.25×10^{-2}	fatal cancer
breast	0.25×10^{-2}	fatal cancer
liver	0.25×10^{-2}	fatal cancer
bladder	0.25×10^{-2}	fatal cancer
oesophagus	0.25×10^{-2}	fatal cancer
thyroid	0.25×10^{-2}	fatal cancer
skin	0.05×10^{-2}	fatal cancer
bone surfaces	0.05×10^{-2}	osteosarcoma
remainder*	0.25×10^{-2}	fatal cancer

* remainder organs = adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, uterus

Problem-3 (20 points): Explain the working mechanisms of the DNA Damage-Control Biosystem using the free radicals produced by metabolized oxygen.

(Solution)

Two to three percent of all metabolized oxygen is converted to free radicals, which are 10^{10} free radicals/cell/d, of which about 10^{8} surround DNA. The DNA alterations are largely prevented by ***antioxidants*** that scavenge approximately 99% of these free radicals. The resultant 10^{6} DNA alterations/cell/d are further reduced by ***enzymatic repair*** to about 10^{2} mis/unrepaired DNA alterations. Apoptosis, differentiation, necrosis, and the immune system remove about 99% of these mis/unrepaired DNA alterations so that an average of about 1 mutation/cell/d accumulates during a lifetime of a stem cell. This is the remarkably efficient biosystem which prevents precocious aging and malignancy.

The number of metabolic events occurring daily in each cell of the body is summarized as given in the table below:

Free radicals converted by metabolized oxygen	10^{10}
Free radicals created near DNA	10^{8}
DNA alterations	10^{6}
Un/misrepaired alterations	10^{2}
Mutations: persistent un/misrepaired	10^{0}

Problem-4 (10 points): What are the objectives of radiation protection suggested in ICRP Publication 26?

(Solution)

1) adopt no practice unless produces a net positive profit (**justification of practice**)
2) prevent detrimental deterministic effects of radiation (**limits of exposure**)
3) keep the probability of stochastic effects ALARA (**optimization of protection**)

Problem-5 (20 points): What is the annual acceptable risk for workers? Derive the annual effective dose equivalent limit to radiation workers set forth in ICRP Publication 60.

(Solution)

ICRP-60(1990) Recommendations are as follows:

	workers	public
annual acceptable risk	8×10^{-4} / year	5×10^{-5} / year
radiation risk factor	4×10^{-2} / Sv	5×10^{-2} / Sv
effective dose-equivalent limit		
- averaged over 5 years	20 mSv / year	1 mSv / year
- annual maximum	50 mSv / year	-
tissue dose equivalents		
- lens	150 mSv / year	15 mSv / year
- skin	500 mSv / year	50 mSv / year
- hands and feet	500 mSv / year	-

Problem-6 (10 points): Explain ALI and DAC.

(Solution)

ALI (annual limit of intake, Bq per year) is defined as the "annual limit of intake by ingestion and inhalation which is derived from the annual dose limit for workers." ALI is computed based on ICRP-26 recommendations.

DAC (Derived Air Concentration, Bq/m^3) is defined as the "radioactivity concentration of each radionuclide in air which results in ALI when an occupational worker breathes for 1 working year (2000 hours = 50 weeks x 40 working hours per week)."

$$\int C(t)B(t)dt \le ALI \quad (Bq) \qquad (5\text{-}8.1)$$

where,

$C(t)$ = concentration in air, Bq/m^3

$B(t)$ = breathing rate m^3/min

$$\therefore \text{DAC} = \text{ALI} / (2000 \times 60 \times 0.02) = \frac{ALI}{2.4x10^3} \quad \text{Bq/m}^3 \qquad (5\text{-}$$

where, 2000 x 60 = (50 weeks) (40 hours/week) (60 min/hour)

0.02 m^3/min=breathing rate under light activity (twice for heavy)

Problem-7 (20 points): The dose limits recommended for workers in ICRP-26 are: 1) effective dose equivalent of 5 rem / year for stochastic effects, and any organ dose of 50 rem / year for non-stochastic (or deterministic) effects.

(Solution)

Based upon ICRP-26 recommendations, compute ALI of Pu-239 for inhalation of the solubility class Y-unsoluble.

Data for Pu-239 for inhalation of the solubility class Y-unsoluble:

target organ	tissue weight factor*	$H_{50,T}$ per unit intake (Sv/Bq)**
lungs	0.12	3.2×10^{-4}
bone marrow (red)	0.12	7.6×10^{-5}
bone surfaces	0.03	9.5×10^{-4}
liver	0.06	2.1×10^{-4}

* ICRP-26 data ** ICRP-30 data

$$\sum_T W_T \cdot H_{50,T} = (0.12)(3.2\times10^{-4}) : \text{for lungs}$$

$$+ (0.12)(7.6\times10^{-5}): \text{for red bone marrow}$$

$$+ (0.03)(9.5\times10^{-4}): \text{for bone surfaces}$$

$$+ (0.06)(2.1\times10^{-4}): \text{for liver}$$

$$= 8.9\times10^{-5} \text{ Sv/Bq}$$

Hence, with the limits recommended in ICRP-26,

1) to meet the limit on effective dose equivalent (5 rem / year):

ALI (stochastic) = (0.05 Sv/yr) / (8.9×10^{-5} Sv/Bq) = 5.6×10^{2} Bq/yr

2) to meet the limit on organ dose (50 rem / year) - bone surfaces in this example

ALI (non-stochastic) = (0.5 Sv/yr) / (9.5×10^{-4} Sv/Bq) = 5.3×10^{2} Bq/yr

cf. ICRP-30 gives 5×10^{2} Bq/yr