## APPENDIX-C
## The Free-Radical Fallacy about Ionizing Radiation: Demonstration that a Popular Comparison Is Senseless

Part 1. Does "Just Living" Hurt DNA More Seriously Than Ionizing Radiation?
Part 2. The Relative Frequency of DNA Damage-Events
Part 3. Reality-Check for the "Same-Nature" Assumption
Part 4. The Unique Power of Ionizing Radiation

Free radicals are highly reactive molecules possessing an unpaired electron. In cells, such radicals can do injury (for instance, oxidative damage) to proteins and other molecules --- including injury to the DNA molecules which encode the human genes.

### • Part 1. Does "Just Living" Hurt DNA More Seriously than Ionizing Radiation?

1a • In some peer-review journals and various interviews in the media, what we call the Free-Radical Fallacy has been employed in order to belittle the health menace of low-dose xrays, gamma rays, and beta particles (low-LET ionizing radiation). We will demonstrate the nature of the fallacy in Part 3, below.

1b • There is no doubt that routine metabolic chemistry in each cell produces, every hour, legions of free-radicals and consequent DNA damage-events in the process of "just living." And there is no doubt that exposure, to a small dose of low-LET ionizing radiation, adds relatively a very small number of DNA damage-events to irradiated cells.

1c • In 1990, Dr. Daniel Billen of the Oak Ridge Associated Universities proposed: "It would seem reasonable to conclude that, due to common oxidizing radicals, many of the qualitative changes in DNA are quite similar for radiation-induced or spontaneous DNA damage" (Billen 1990, p.243). Having assumed a qualitative equivalence, Billen concentrated on comparing the NUMBER of DNA damage-events per cell caused by natural intrinsic processes ("just living") versus the much lower number caused by small doses of low-LET ionizing radiation. And this type of comparison has become a refrain which is frequently incorporated, these days, into attempts to calm concerns about medical radiation and nuclear pollution.

1d • Part 3 demonstrates why such comparisons are fatally flawed and senseless. In short, a reality-check demonstrates that the nature of DNA damage from ionizing radiation and the nature of DNA damage from intrinsic processes cannot possibly be qualitatively equivalent.

### • Part 2. The Relative Frequency of DNA Damage-Events

2a • Billen (1990, p.242) cites various mainstream sources for two estimates: (1) "Approximately 10,000 measurable DNA modification events occur per hour in each mammalian cell due to intrinsic causes," and (2) "About 100 (or fewer) measurable DNA alterations occur per centi-Gray of low-LET radiation per mammalian cell." These two values are made comparable in Part 2d, below.

2b • The goodness of both estimates, above, will surely improve a great deal with future methods of measurement, but neither Billen's presentation nor refutation of its key assumption depends on precision in these two values.

2c • Billen states his conclusion (p.242): "Therefore, every HOUR, human and other mammalian cells undergo at least 50-100 times as much spontaneous or natural DNA damage as would result from exposure to 1 centi-Gray of ionizing radiation." Centi-Gray and "rad" are two names for the same amount of radiation exposure. How much is one rad of exposure?

2d • On the average, it takes about 10 years for a person to accumulate one rad of whole-body exposure from natural background radiation. So Billen's numbers mean that the ratio of damage-events PER UNIT OF TIME (per hour, or per day, or per year) may be as large as 8.8 million

endogenous damage-events for each damage-event due to natural background radiation. A very large difference ... but is it meaningful?

2e • The estimates presented by Billen of "DNA modifications" and "DNA alterations" are estimated numbers PRIOR to repair-work by the cell. Here (and elsewhere in the literature), the term "damage-events" is preferred, to signal that the event is not necessarily an unrepairable PERMANENT mutation of the DNA.

2f • Billen's arithmetic is correct, but a reality-check is needed for his assumption that the nature of DNA damage-events is the same from routine cellular metabolism and from ionizing radiation.

**• Part 3. Reality-Check for the "Same-Nature" Assumption**

3a • According to Billen (2a), a rad (centi-Gray) causes about 100 or fewer measurable DNA damage-events per cell.

3b • According to Billen (2b), the number of comparable damage-events from intrinsic causes per cell, every HOUR, is 50 to 100 times higher, which means 5,000 to 10,000 damage-events every hour from intrinsic causes, per cell. (Bruce Ames 1995, p.5259, provides an estimate per DAY, not per hour: "The number of oxidative hits to DNA per cell per day is estimated to be about 100,000 in the rat and roughly ten times fewer in the human." We will include this estimate in Point 3e.)

3c • It follows from Billen that per DAY, the DNA damage-events per cell from endogenous causes are either:

( 5,000 events/hr) x (24 hr/day) = 120,000 events/day, or:
(10,000 events/hr) x (24 hr/day) = 240,000 events/day ... in each cell.

3d • And something else follows from Billen's assumption that there is no important difference between the endogenous and the radiation-induced damage-events. If correct, then the DNA-based consequences from a radiation dose which delivers 120,000 or 240,000 damage-events each day, per cell, should be the same as from 120,000 or 240,000 such events per cell each day, from endogenous sources.

3e • The whole-body radiation dose per day required (by Billen's numbers) to deliver 120,000 to 240,000 such DNA damage-events per cell, each day, would be either:

(120,000 events) x (1 rad/100 events) = 1,200 rads, or:
(240,000 events) x (1 rad/100 events) = 2,400 rads. And:

If we substitute Ames' figure (from Point 3b), we would calculate (10,000 events) x (1 rad/100 events) = 100 whole-body rads per day to deliver DNA damage equivalent to daily damage from intrinsic causes.

Bottom Line of the Reality-Check

3f • If there were equivalence between DNA damage from normal, intrinsic processes and DNA damage from ionizing radiation, then whole-body doses of 100 rads to 2,400 rads per day EVERY day would be easily tolerated. Instead, such doses are promptly LETHAL.

3g • For half the humans exposed, promptly-lethal doses are estimated by the radiation community at 300 or 400 whole-body internal-organ rads accumulated in one week or less (NCRP 1989-b, p.70, p.73).

3h • There is an additional observation worth noting. Unrepaired and misrepaired chromosomal (DNA) injuries are widely accepted as a cause of Cancer. The background rate of clinical Cancer is estimated (largely on the basis of the Atomic-Bomb Study) to be doubled by extra radiation doses of a few hundred whole-body rads of non-xray exposure. Suppose (for illustrative purposes) that 300 whole-body rads were required in order to double the background rate of clinical Cancer. According to Billen (2a), 300 rads of low-LET radiation would cause about 30,000 or fewer DNA damage-events per cell. But 30,000 damage-events per cell would be far exceeded by intrinsic processes in a single

day (Billen, 3c) or in ten days (Ames: 10,000 per day * ten days). If DNA damage from intrinsic causes and from low-LET ionizing radiation were equivalent, it is hard to see how anyone could escape having MULTIPLE clinical Cancers from intrinsic processes.

3i • From these two reality-based observations (acute lethal doses and doubling-doses for radiation-induced Cancer), we have demonstrated that the nature of damage caused by ionizing radiation CANNOT POSSIBLY BE THE SAME as it is from normal metabolic processes and oxidative damage. Without an equivalence, the Billen argument and its variations collapse. The Free-Radical Refrain is a Free-Radical Fallacy.

## • Part 4. The Unique Power of Ionizing Radiation

4a • The difference between free-radical damage from routine metabolism and from ionizing radiation almost surely lies in REPAIRABILITY. If DNA damage is perfectly repaired by a cell, such damage has no health consequences. It is inconsequential. The consequences arise only from injuries which are non-repairable or mis-repaired.

4b • The demonstration in Part 3 supports other evidence (and vice versa) that ionizing radiation can induce the special kinds of complex DNA damage which CANNOT BE PERFECTLY REPAIRED. A leading figure in this research is John F. Ward; see Reference List.

4c • The power of ionizing radiation to induce the complex injuries is not in dispute. Billen himself appears to acknowledge it, but then to ignore it (Billen 1991, p.388).

4d • The power of ionizing radiation to induce particularly complex and unrepairable genetic injuries is surely related to a UNIQUE PROPERTY of this agent. Ionizing radiation instantly unloads biologically abnormal amounts of energy at random in an irradiated cell. Biochemical reactions in a cell generally involve net energy-transfers in the ballpark of 10 electron-volts and below. By contrast, Ward reports (1988, p.103) that the average energy-deposit from low-LET ionizing radiation is thought to be about 60 electron-volts, all within an area having a diameter of only 4 nanometers. (The diameter of the DNA double-helix is 2 nanometers). In other words, ionizing radiation produces violent energy-transfers of a type simply absent in a cell's natural biochemistry.

4e • Because of its unique property, ionizing radiation is a unique menace to our DNA and chromosomes. This fact deserves wide recognition, as mankind learns that FAR more health problems are mutation-based than anyone could prove 15 years ago.

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