

From: Dennis Nelson
Sent: Friday, October 30, 2015 5:31 PM
To: Hanlon, Edward <Hanlon.Edward@epa.gov>
Subject: Re: Teleconference Registration

Dear Mr. Hanlon,

Please see the attached written comments for posting to the teleconference website. The file is in Microsoft Word format. If you need a different format please let me know. Thank you,

Dennis Nelson

Essay on Radiation “Dose?”

From the time of the discovery of X-rays by Wilhelm Conrad Röntgen in 1896 and the discovery of radioactivity by Antoine Henri Becquerel that same year, there has been a temptation to treat ionizing radiation in its interaction with biological systems just like any other chemical or photochemical reaction. Biochemical reactions, which modulate physiological processes in the human body, are often regulated by pharmacological agents (drugs) and can also be subject to the deleterious effects of noxious chemicals (toxins). Photochemical reactions use photon energy to initiate inorganic reactions such as those occurring in photographic emulsions in photography. Biochemical reactions can also involve photochemistry such as the use of visible light by plants to fix atmospheric CO₂ into organic molecules as occurs in photosynthesis. All of these are strictly chemical processes and obey the rules governing chemical reactions. This is because those reactions are driven by chemical concentrations of reactants and products and the photon energies are low.

The interaction of ionizing radiation (particles and photons) with biological systems is completely different, however, because the energetics of these reactions are all wrong. These interactions are not driven by chemical concentrations of reactants but rather by ionization damage in cells or groups of cells. It is unfortunate that such comparisons have been made between chemical and radiological toxicity, because it only causes confusion in interpreting the effects of ionizing radiation on biological organisms. The photon and particle energies in the case of ionizing radiation are so much greater than those operative in biochemistry and photochemistry that there is no direct parallel between them.

This confusion has led to the completely inappropriate application of the concept of “dose” to ionizing radiation in an attempt to assign risk estimates to exposure levels and to suggest threshold levels below which there is no effect. While thresholds do apply to chemical reactions such as those operating in pharmacology and toxicology, they do not apply to ionizing radiation interactions with biological systems. Thresholds apply in toxicology where the reactions are targeted to specific biochemical pathways and are modulated by reactant concentrations, chemical kinetics, activation energy and reaction equilibrium constants. Ionizing radiation typically has too high an energy from even a single nuclear disintegration to fit correctly into this scheme and so confusion arises when one tries to explain radiation damage in terms of dose. As

an example, a photon of visible light has an energy of about 2 eV. This energy level is about as high as can be accepted in photochemical reactions which can legitimately be described in terms of dose. Ultraviolet photons have energies between 3 and 24 eV, and these can cause some indiscriminate tissue damage, and induce melanin production in the skin, but they are not very penetrating. These UV photon-tissue interactions are also largely chemically mediated but there may be some ionization at the higher energies.

Ionizing radiation such as the beta particle from tritium has an energy of 5,000 eV, an alpha particle from plutonium has an energy of 5,000,000 eV and gamma and X-ray photons have packet energies from the low thousands to tens of millions of electron-volts. Energies of this magnitude cause massive indiscriminate, random damage to cells and cell components and are not targeted to a specific biochemical pathway at all. While some of this damage may be repaired and severely impaired cells may be cleared through immune processes and apoptosis, not all damage can be efficiently and accurately detected and repaired by the body. Because ionizing radiation causes a track of destruction in tissue, repair may not occur using cellular clones of the same tissue type but could rather involve clones of fibrous tissue which stitch together the wound much as damage caused by a physical injury is repaired with scar tissue.

Damage to a quiescent pluripotential stem-cell may lie hidden for years until that stem-cell is recruited into the dividing cell pool and the damage becomes expressed. Thus, latent cancers can lie dormant for decades until the damaged precursor cell begins a new differentiated tissue cell line after it is stimulated to divide. The hidden radiation damage to quiescent stem-cells also has the long term effect of limiting the ability of an organism to respond to stress and repair tissue damage, since the number of stem-cells in an organism is finite. Radiation exposure uses up prematurely the reserve stem-cells, which are present from birth and provide for lifetime tissue maintenance and repair. This explains why a non-specific life shortening effect has been observed in animal experiments involving external whole body irradiation. Stem cells can lead to millions of new cells through clonal expansion so radiation damage or destruction of stem cells can have far reaching and serious consequences. Clonal expansion of cells is also limited, however, because each time a cell divides a telomere at the end of each chromosome is shortened by one unit. This serves to limit cell division to a fixed number of progeny cells and prevents cells from dividing uncontrollably. Telomeres are repeat DNA segments on the ends of chromosomes which are shortened by one unit in every cell division. Some cells express an enzyme telomerase which can lengthen telomeres but this is uncommon and is often associated with cancer cells.

While the biochemical processes occurring in pharmacology and toxicology largely operate at the atomic or molecular level the physical processes operative with radiation damage usually occur at the cellular or tissue level and are more akin to the physical, projectile damage to tissues or organs that occurs with bullet wounds. Because radiation effects are so large and indiscriminate, it makes no more sense to try to explain the biological effects of ionizing radiation in terms of dose than it does to try to describe the effects of flying bullets on a battlefield in terms of dose. Anyway the word dose comes from the Greek word “dosis” which means gift. Ionizing radiation is **not** a gift.

There are two dogmas often encountered in the fields of biological and environmental toxicology. They are: (1) “The Dose Makes the Poison;” and (2) “Dilution is the Solution to

Pollution.” While there is some truth in these dogmas, they are only applicable in the case of chemical toxicity not physical toxicity. Chemical toxicity only results when a measurable concentration of a toxin is exceeded. This is because the toxic reaction does not occur unless a high enough concentration of the toxin is present to exceed the activation energy of the toxic reaction. Thus, there is a threshold concentration (toxic dose) below which no biological effect is observed. It follows that if one were able to dilute an environmental toxin below this concentration limit there will be no measurable deleterious effects. The corollary is that there is also a threshold therapeutic dose below which a drug will have no beneficial effect. Chemical concentrations are extremely large in terms of total atoms or molecules. Because Avogadro’s number is so large (6.023×10^{23} molecules per mole (gram molecular weight)) chemical reaction concentrations are typically very large in terms of total reacting units. Dilution can, therefore, reduce the concentration of the toxin molecules below the reaction level (activation energy) where they are no longer toxic. This is **not** the case with ionizing radiation.

Radiation damage does **not** fit into this scheme because a single nuclear disintegration or high energy photon contains enough energy to interact with cells or sub-cellular organelles and completely disrupt their cellular architecture and biochemical processes. Dilution does not effect this process because there is no chemical activation energy and no concentration threshold for toxicity. While dilution may reduce the number of target cells hit or destroyed it does not eliminate all damage. The question becomes how many damaged or compromised cells can the body safely tolerate and how does the cumulative destruction of cells affect ones health and lifespan? In the Old West bullet wounds were sometimes referred to euphemistically as “lead poisoning.” This is because the bullets were usually made of lead. Lead poisoning can also refer to ingestion of soluble lead compounds such as lead acetate in concentrations sufficient to cause chemical toxicity. These two modes of injury have the same name and involve the same element but refer to entirely different processes one physical and one chemical. Both can lead to injury and death, however, by entirely different mechanisms.

Many nuclear industry apologists make no effort to understand the nature of ionizing radiation effects on biological organisms. They compare exposure to various sources of man-made radiation to the natural background radiation (NBR) with no suggestion that NBR can also create risk. Their tacit assumption is that since some radiation is “natural” it must be harmless and by inference other man-made radiation of the same magnitude must also be harmless. In fact, all radiation exposures are harmful as well as additive and there is no, scientifically proven, safe threshold level of exposure. NBR may also be responsible for our defined life span as a species since it causes the body to progressively use up its stores of inborn repair capacity. When all the repair cells are gone the person dies.

The Nuclear Regulatory Commission (NRC) speaks repeatedly of radiation dose, but in reality one does not measure a dose of radiation at all but rather the total amount of damage caused by a given amount of exposure and how it may be repaired. What actually needs to be researched and documented is the efficiency and fidelity of biological repair following radiation damage. This is not an easy quantity to measure and it differs for every single individual. It depends on the location of the damaged cells, which sub-cellular organelles are affected such as the mitochondria, the ribosomes, the nuclei, or even the cellular scaffolding such as the actin molecules. Damage to the mitochondrion is particularly problematic since it can destroy its

architecture and release molecules normally active in the electron transport chain, which when bound in proper sequence in the mitochondrial architecture are key elements on the step-wise oxidation of glucose and acetate. This step-wise cascade is coupled to the formation of multiple high energy molecules such as ATP which are very important in cellular energetics. When released from their proper position in the electron chain from oxygen to water, they can act as free radical generators within the cell. This can result in a severe oxidative stress load on the cell and explains why radiation is known to potentiate oxygen toxicity.

Any reference to radiation “dose” should therefore be viewed with suspicion and any attempt to predict radiation risk based on a hypothetical “dose” level should also be rejected. Thus, in the case of radiation toxicity and environmental contamination, “The Dose does **NOT** Make the Poison,” and “Dilution is **NOT** the Solution to Pollution.”

Dennis Nelson, Ph.D

For additional information I invite the members of the Radiation Advisory Board to visit the SERV website at: www.serv.org.