

## Basic Science: Ionizing Radiation

Various forms of radiation are always present virtually anywhere on earth, often in forms such as infrared radiation (heat), radio waves, microwaves, and visible light. One very specific type of radiation is relevant to this project: ionizing radiation. This term refers to the forms of radiation that are able to create ions by direct or indirect means (Glossary of Nuclear Science Terms, 2004, I section, para. 3).

There are three main types of ionizing radiation: alpha, beta, and gamma. There is also a fourth type, x-radiation, which is very similar to gamma radiation. Alpha radiation comprises two protons and two neutrons (a helium-4 nucleus), and typically does not penetrate deeply into exposed materials. It does not pose a serious threat to most organisms unless it is taken into the organism itself (Glossary of Nuclear Science Terms, 2004, A section, para. 1). Beta radiation is composed of a single electron of either positive or negative charge. It penetrates more deeply than alpha radiation and is typically considered more dangerous to living organisms (Glossary of Nuclear Science Terms, 2004, B section, para. 2). Gamma radiation is the most deeply penetrating of the three common forms of radiation. Unlike the other two forms, it is massless. It is actually a form of high energy electromagnetic radiation. Gamma radiation and x-radiation are virtually identical once emitted. The only difference between the two is how each is generated (Moeller, 2001, A section, para. 1).

All of these forms of ionizing radiation can cause damage when interacting with cells. On a basic level, there are four different effects the radiation could have on the cell. The first is that it could have no observable effect on the cell whatsoever – the cell continues to function normally. The second is that the cell sustains some damage, but is able to repair itself before reproducing, whereas in the third scenario, the cell is damaged and is not able to repair itself before reproducing. The final possibility is that the cell is damaged to the

point that it dies (MODULE 2 - The Basics of Radiation and Radiation Health Effects, 2004, Radiation Health Effects: How Radiation Causes Harm section, para. 1-4).

While there are many levels of radiation damage to cells, there are also several mechanisms by which that damage can occur. Ionizing radiation imparts energy to molecules, causing them to become charged. These changes in charge can cause chemical bonds within molecules to break and can also cause the formation of chemical bonds between previously separate molecules. This can lead to the detrimental linking of macromolecules or damage to the molecules that are critical to the internal control of the cell (Open Source Radiation Safety Training Module3: Biological Effects, 2007).

#### Ionizing Radiation in Relation to Biological Systems

It is common knowledge that radiation, specifically ionizing radiation, has an effect on living organisms. The linear no-threshold model of radiation damage is summarized by the belief that any level of radiation is harmful. However, there is also the hormetic model, which states that in accordance with the linear no-threshold model, high doses of radiation are harmful to living organisms, but also states that low doses of ionizing radiation may in fact be beneficial to the health of an organism.

Currently, the most prevalent model is the linear no-threshold model (LNT), developed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 1958. This model assumes a linear correlation between the amount of ionizing radiation an organism is exposed to and the amount of damage done to it. This model was achieved by collecting data for damage inflicted by high doses of ionizing radiation and extrapolating to determine the effects of low dose ionizing radiation. This theory also states that any level of exposure to ionizing radiation is harmful to an organism because any level of radiation will produce a biological response (Mortazavi, n.d., Hormesis and LNT Model, para. 2-4).

Various studies have led to the proposal of a new model centering around the concept of radiation hormesis. Hormesis in general is the concept that a substance that is harmful in large quantities can have a beneficial or stimulatory effect in small amounts. Applied to ionizing radiation, this implies that large doses are harmful, but smaller doses may have a stimulatory effect on organism (Mortazavi, n.d., Hormesis at a Glance section, para. 1). This phenomenon has been observed in many situations, in laboratories and in nature, as will be discussed later in the paper.

The mechanism by which radiation hormesis may occur is not entirely understood. One theory is that the effect is caused by proteins produced to repair the damage to DNA (deoxyribonucleic acid) by the radiation (radiation is a macromolecule and can be damaged as discussed above). Another theory is that radiation stimulates the health of complex organisms by stimulating the immune systems (Mortazavi, n.d., The Mechanism of Hormetic Phenomena section, para. 1-3). However, while there is a large body of evidence supporting the existence of radiation hormesis, no one theory of how it works had gained precedence.

#### Incidence of Radiation Hormesis in Microorganisms

Several studies have been conducted that deal with the effect of low doses of ionizing radiation on single cellular organism, such as protozoans. T.D. Luckey conducted an experiment in which *Tetrahymena pyriformis* (a species of protozoan) were isolated from background radiation (exposed to levels of ionizing radiation lower than normal), and separately exposed specimens of the same species of increased levels of ionizing radiation (Luckey, T. D., 1986, p. 215, para. 1). A decrease in reproduction rate was observed in the specimens shielded from background radiation, and an increase in reproduction rate was observed in the specimens exposed to increased levels. Both of these results correspond to the predictions of the hormetic model.

A similar experiment was conducted with a species of bacterium, *Escherichia coli*. Separate cultures of bacteria were irradiated with either UVc radiation or proton beams. The organisms were then cultivated in Petri dishes, and the number of colonies formed was determined (Jaqueline Kappke et al., 2005, Results and Discussion section, para.3). Using this data, survival curves were created to show the relationship between exposure and survival fraction. While no hormetic pattern was seen in the bacteria exposed to UVc radiation, a survival peak consistent with hormetic theory predications was observed in the bacteria exposed to proton radiation.

#### Basic Science: Bacteria

The domain Bacteria is one of the three domains of life now recognized, the other two being Archaea and Eukarya. It is composed of a number of diverse species of single-celled organisms that are capable of living in an equally diverse number of habitats. While the members of this domain are all microscopic, they have a tremendous impact on the world.

There are several key defining characteristics the organisms in this domain. It is first important to note that organism in domain Bacteria are very similar to those in domain Archeae, the primary difference being habitat and environmental tolerance. In comparison to domain Eukarya, and bacteria are generally simpler morphologically. With this decreased complexity comes a decrease in size. The maximum of bacteria is ten percent the maximum size of eukaryotes. Perhaps the most important characteristic of bacteria as relates to radiation is method of DNA storage. Bacteria do not contain their DNA in a membrane-bound nucleus as do eukaryotes. In place of this bacteria have an unbounded nucleoid region in which the DNA is stored. Cellular processes involving DNA are likewise much simpler in bacteria. It is possible that this different method of DNA storage and usage could cause bacteria to respond differently to radiation than the eukaryotes typically tested in past studies of radiation hormesis.

## Research Plan

There are two competing theories that describe how ionizing radiation dosage affects biological systems: the linear no-threshold model and the hormetic model. Both theories predict that high doses of ionizing radiation are harmful, but the linear no-threshold theory predicts that radiation is harmful even at low doses, whereas the hormetic model predicts that these low levels of radiation may in fact be beneficial. Most investigations in this area have focused on mammals or eukaryotes. One measure of cell health is reproduction rate. How do low doses of ionizing radiation affect the reproduction rate of a prokaryote?

If the linear no-threshold theory applies to the selected species of prokaryote, higher radiation doses should result in decreased reproduction rates, and the lowest doses should result in the highest rates. However, if the hormetic model applies, then there should be a peak in reproduction rate somewhere between the highest dose and the lowest dose.

A stock culture of a specific species of prokaryote will be acquired from a biological supply house. This culture will be used to start a number of smaller cultures in nutrient broth. Approximately 20-30 radiation dose settings will be selected. At each setting, three cultures will be irradiated. Each of these samples will be cultured in a new vial. The reproduction rate of the bacteria will be measured by a series of readings taken with a spectrophotometer or a similar device. Three control cultures will be exposed to all the same condition but will not be irradiated. At the conclusion of the recording period, a sample from each radiation setting will be observed under a light microscope for any visible morphological alterations.

## Literature Cited

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