Human Response to Ionizing Radiation

Radiation is everywhere and it plays many roles integral to the existence of life. Indeed, life may never have emerged on this planet if not for the influence of particular types of radiation from celestial clouds, the birth places of stars (Browne, 1998). However, radiation can be, and has been demonstrated to be, dangerous to biological systems, but this danger has been observed only for high doses of radiation. The effect of relatively low doses of radiation on biological systems continues to be a point of scientific contention. Some scientists believe that mild exposure to radiation has no negative health effects; others argue that it is actually beneficial.

Ionizing radiation (hereafter referred to as radiation) is "radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized" (World Health Organization, 2010). When these electrons are removed, the most serious effect, in the context of biological damage, is the disruption of chemical bonds. That is, molecules essential to life, like proteins and DNA, can be broken which can cause a variety of undesirable effects, most notably cancer. A low level of radiation is present throughout the environment--in the air, in the soil, in food, in man-made structures, and in all living things (World Health Organization, 2010). Exposure from these sources is called "background."

There was a time when radiation was generally believed to be physiologically and mentally beneficial. In the early 1900s, devices were sold that deliberately increased the user's radiation exposure (Davidson, 2006). For example, many devices were developed for the purpose of increasing the radioactivity of drinking water. These devices involved either the storage of drinking water in ceramic vessels lined with radioactive material, or the submersion of radioactive materials in the water. Other similar products ranged from radium containing toothpaste to radon vitamins to radium bath salts, even radioactive refrigerator deodorizers (Oak Ridge Associated Universities, 1998). Furthermore, the words "radium" and "radon" were used as brand names for countless products that were not radioactive, a use analogous to that of "gold" and "platinum" for products which contain neither element (Davidson, 2006). Collectively, these products claimed to cure every ailment from depression to arthritis to tooth decay, even cancer (Oak Ridge Associated Universities, 1998).

However, as scientists began to study radiation more extensively, they began to suspect, ever more concretely, that in large doses, radiation was damaging to biological systems (Davidson, 2006). These suspicions were soon dramatically confirmed. On August 6 and August 9, 1945, the United States detonated two atomic weapons over the Japanese cities of Hiroshima and Nagasaki (U.S. Department of Energy Office of History & Heritage Resources, 2003). In addition to obliterating both cities and killing approximately 140,000 people, the bombs spread radiation across vast areas of Japan, exposing countless civilians and animals. Radiation-induced cancer caused an unknown number of additional deaths for years following each of these events (Veracity, 2006).

Since the nuclear bombing of Hiroshima and Nagasaki an ever-darkening cloud of nuclear paranoia has enveloped the general public (Davidson, 2006, 12:40). On April 26, 1986, this paranoia was exacerbated by the Chernobyl nuclear catastrophe in the Ukrainian Soviet Socialist Republic (then part of the Soviet Union). This event, like the bombing of Japan 41 years earlier, spread radiation across large tracks of Eastern Europe and the Western parts of the Soviet Union (Davidson, 2006, 28:02). Today, there are few words that evoke more fear than "radiation." This irrational fear has been fostered by the media and popular culture, yet it is not based on scientific evidence (Davidson, 2006, 19:07).

Besides their destructive consequences, the atomic bombing of Japan and the Chernobyl nuclear disaster offered scientists their only two opportunities to study cases of widespread public exposure to high levels of radiation. By calculating the relative doses of radiation received by various populations, and by tracking changes in the prevalence of cancer, scientists were able to derive a relationship between radiation dose and increased chance of developing cancer. This model is represented by a linear function relating the dose of radiation received (in milisieverts*) and the percent increase in the likelihood of getting cancer (Davidson, 2006, 15:29).

* The sievert "relates the absorbed dose in human tissue to the effective biological damage of the radiation" (Radiation Information Network, 2010). The quality factor, a quantity denoting the efficiency with which the radiation transmits energy, represents the radiation source. For example, a medical x-ray has a quality factor of 1. The absorbed dose is the average amount of energy absorbed in the form of radiation throughout the body (Radiation Information Network, 2010).

For example, the model predicts that exposure to 500 milisievert (mSv) of radiation (about 200 times background radiation levels) will cause a 3% increase in the likelihood of a patient's developing cancer (Davidson, 2006, 15:35). This model, based on studies performed on thousands of individual cases, is the standard, in terms of both frequency of use and reliability, by which all high level radiation risks are estimated (Aubrecht, 2006, p. 2).

However, reliable data has only been obtained for doses in excess of 100 mSv (Davidson, 2006, 17:20). The assumption upon which all evaluation of low level radiation risk is based today is that the data extrapolates linearly to zero, an assumption that has several important consequences (Aubrecht, 2006). First, the model predicts that any dose of radiation, however small, increases the risk for cancer. Second, it allows standards for maximum radiation exposure to be legislated and the amount of shielding required to ensure that doses remain under this maximum to be easily calculated (Aubrecht, 2006, p. 1). Third, in the case of an event involving the release of large amounts of radiation, this model allows for the prediction of a death toll (Davidson, 2006, 18:10). This predictive mathematical model is called the Linear No-Threshold (LNT) model and, despite its ease of use from a theoretical standpoint, its ability to represent the biological response to radiation accurately elicits significant controversy in the scientific community.

In no other case is this controversy more vividly illustrated than in the aftermath of the Chernobyl nuclear disaster. The estimated death toll from Chernobyl was based on the LNT model, even though most of the population had received doses towards the unreliable low dose end of the function (Davidson, 2006, 20:37). Therefore, casualties were expected to number in the thousands (Davidson, 2006, 22:03). Even today, some organizations continue to use the theory of a direct correlation between radiation exposure and cancer-related deaths to estimate the death toll attributable to radiation released from the Chernobyl reactor. For example, Greenpeace (2006) blames Chernobyl for more than 200,000 deaths. However, these figures could not be farther from the truth. As of 2006, only 56 fatalities were directly attributable to radiation released from the accident at Chernobyl (Davidson, 2006, 26:23).

This gross difference in the predicted death toll and the actual number of deaths clearly illustrates that the LNT model is seriously flawed. Most of the scientific community opposed to the LNT model point a collective finger at the assumptions made at the low-dose end of the relationship (Aubrecht, 2006, p. 8). There are two scientifically feasible replacements for the linear no-threshold theory: a model incorporating a threshold of radiation exposure below which there would be no biological effect and a model in which low doses of radiation actually decrease the risk for developing cancer (Davidson, 2006). Several influential scientific organizations promote the adoption of one of these alternatives to the LNT model including: the Health Physics Society, the General Accountability Office, the American Nuclear Society, and the National Academy of Sciences (The Boeing Company, 2007, p. 2). However, many experts still believe that the LNT model is the best method for estimating radiation risk.

The first of these alternatives is fairly simple; it involves merely modifying the function such that below an exposure of about 100 mSv, the graph finishes as a curve instead of a line (Aubrecht, 2006, p. 9). This curve would be formulated to convey the theory that as the dosage increases from zero mSv to 100 mSv, the increase in risk for cancer would remain close to zero and then dramatically increase to meet the linear portion of the graph above 100 mSv (Davidson, 2006, 41:55).

In order to provide evidence supporting or denying this hypothesis, scientists study the background radiation exposure for various groups across the globe. Because background radiation levels vary with geographic location, scientists are able to compare groups of people living in different locations and the cancer prevalence within these groups (Davidson, 2006). In doing so, scientists are able draw conclusions about whether or not elevated levels of background radiation increase the prevalence of cancer. One particular group often studied today is airline crews (Davidson, 2006, 36:44). At high altitudes, the shielding offered by the earth's atmosphere is reduced and, therefore, background radiation increases (Davidson, 2006, 36:20). During a flight, airline crews are exposed to radiation levels as high as 100 times normal background (Bailey, 2000, p. 34). However, despite this relatively high dose, there is no consistent increase in cancer cases in airline crews versus civilians who spend little time flying (Davidson, 2006, 36:51).

The second alternative to the LNT model, the theory that low doses of radiation decrease the risk for cancer, is much more controversial. Some scientists have grown to suspect that not only are low doses of radiation not harmful, but they also may even be beneficial (Davidson, 2006, 38:44). This effect is termed "radiation hormesis" (Aubrecht, 2006, p. 9).

The first evidence supporting this theory was unearthed by American scientist Ronald Chesser in a study he conducted on the effects of radiation exposure on the wildlife around Chernobyl. Chesser traveled to the Chernobyl exclusion zone 1992 and collected animals from the region surrounding the remnants of the reactor (Davis, 2006). The collection of specimens with which Chesser returned to the U.S. included many animals that had lived the entire duration of their lives exposed to very high doses of radiation (Davidson, 2006, 33:46). The most radioactive species, the Bank Voles, were measured to be emitting between eight and 15 mSv per day, equivalent to 8,000 chest x-rays (Davidson, 2006, 31:55). Chesser and his research team expected to find significant genetic damage upon examining these specimens; however, after several repeated analyses, they came to the shocking conclusion that the rodents from Chernobyl displayed no more genetic damage than the rodents in their control group, which had not been exposed to radiation above normal background (Davidson, 2006, 34:12). However, it remained to be determined whether or not the same apparent resistance to radiation would be observed in humans.

The most compelling evidence supporting the radiation hormesis theory originates from Rāmsar, Iran. Here, background radiation levels range from 55 to 200 times normal background (Mortazavi, 2002). The average resident of this area is exposed to doses as high as 135 mSv per year which is 270% higher than the dose limits recommended by the Nuclear Regulatory Commission (NRC) for radiation workers and higher than anywhere in the Chernobyl exclusion zone (Mortazavi, 2002). In the late 1990s, a team of scientists traveled to Rāmsar to collect blood samples from the residents there and samples from residents of nearby cities with normal background radiation levels (Davidson, 2006, 37:00). The research team then exposed both sets of samples to a dose of 1,500 mSv (Davidson, 2006, 37:08). The blood taken from Rāmsarian residents suffered significantly less genetic damage than the blood from residents of areas with normal background radiation. These results indicate that the human body has mechanisms for adaptation to radiation exposure. For example, cells contain proteins and enzymes capable of detecting and repairing genetic damage (Mortazavi, 2002).

The mechanism for this apparent radio-adaptive response may be hidden within the genetic codes of both animals and humans. An emerging body of research done over the last two decades involving the damage inflicted on DNA by radiation suggests that low doses of radiation stimulate a specialized protein in human cells that repairs broken DNA strands (Aubrecht, 2006, p. 10). This protein, identified as the mediator of DNA damage checkpoint protein 1 (MDC1), once activated, acts as a biological defense mechanism against cancer (Aubrecht, 2006, p. 10). Ronald Chesser and Robert Baker of the Texas Tech University conducted extensive research into the activity of MDC1 in the animal samples recovered from Chernobyl (Davis, 2006). They found that in animals from areas with normal background radiation levels, the MDC1 displayed little activity, whereas in the animals from Chernobyl, a much greater level of activity was observed (Davidson, 2006, 39:40). Some researchers now believe that at low levels of radiation, below a threshold of about 100 mSv, the genetic damage inflicted is more than compensated for by the MDC1, and as a result, the net effect the radiation has on the likelihood of developing cancer is negative (Davidson, 2006, 40:00).

Even though strong evidence has been presented for all three models of the effects radiation has on humans, until even more research is done, a scientific consensus will likely not be reached about which model more accurately reflects reality. For now, as is the case with any scientific conflict, there are parties on each side of the argument. Today, the LNT model is used for almost all regulations dealing with radiation safety despite its obvious inaccuracy when applied to low doses. These inaccuracies tend to cause overestimations of risk which, for evaluating safety, is not necessarily a problem (Aubrecht, 2006). However, for the purposes of scientific understanding, the debate among proponents of the LNT, Threshold, and Radiation Hormesis models is ongoing.

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