G R A D I E N T
TRENDS
Risk Science & Application

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Radiation Risk Assessment

By Marc Nascarella, Ph.D. and David Merrill, M.S.

A basic understanding of radiation risk assessment can help us keep in perspective the risks from a variety of natural and man-made conditions.

Understanding human health risks from radioactivity helps us appreciate the relative importance of radiation use in medicine (*e.g.*, computerized tomography, x-rays), of radiation resulting from background (*e.g.*, uranium in rocks, radon, cosmic rays), and from energy generation (nuclear power, radionuclides in coal).

Some forms of radiation are hazardous because of their ability to ionize matter, that is, to disrupt or break the chemical bonds that hold matter together. The two main forms of ionizing radiation are derived from high-energy subatomic particles and high-energy electromagnetic waves. The first type includes fast-moving helium nuclei (alpha [α] particles), electrons or positrons (beta [β] particles), and neutrons. This type of ionizing radiation generally results from the decay of radioactive elements. For example, uranium decays to thorium by releasing an α-particle. The second type of ionizing radiation is high-energy electromagnetic waves, which are X-rays and gamma [γ] rays.

> ***...the EPA's allowable lifetime incremental cancer risk level...is about 40,000 times more stringent than the LNT-predicted lifetime risk of developing cancer due to our exposure to natural background sources of radiation...***

The different types of radiation vary in their energy levels, and hence in their ability to damage biological systems. For example, α-particles ionize matter intensely, yet quickly lose their energy, and can be attenuated by a piece of paper. β-particles ionize matter less intensely, and can be attenuated by thin sheets of metal or plastic. X-rays have the lowest rate of ionization, but can only be attenuated or shielded by dense material, such as lead. The less energetic portions of the

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I N S I D E

Letter to our Readers

January 2010

Dear Colleague,

In this issue, we discuss the impact of radiation exposure on human health. Whether our exposure comes from naturally occurring elements in granite kitchen counters, CT scans, or cell phone use, there are a number of theories, studies, and conjectures about how radiation may affect our lives.

Gradient contributors to this issue include Dr. Marc Nascarella, a toxicologist at Gradient; Mr. David Merrill, M.S., a Gradient Principal; Dr. Peter Valberg, a Gradient Principal and toxicologist; and Dr. Lisa Bailey, a Gradient toxicologist. Joining us with a guest editorial is Dr. Dade Moeller, Professor of Environmental Health, *Emeritus*, at the Harvard School of Public Health, who discusses key factors and anxieties regarding Yucca Mountain.

We hope that this issue of *Trends* provides helpful insight on this controversial topic and gives you a clear perspective on how to separate fact from fiction.

Yours truly,

Teresa S. Bowers

Teresa S. Bowers, Ph.D.

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Radiation Risk Assessment

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electromagnetic spectrum, including radio waves, microwaves, and visible light, while considered radiation, do not have the ability to ionize matter.

In addition to man-made sources of radiation, radioactive elements occur naturally in the environment, often referred to as "naturally occurring radioactive material" (NORM), and are a major source of our exposure to radiation. Examples of NORM from minerals in the earth's crust include uranium, potassium-40, polonium, thorium, radium, and radon. Tritium and carbon-14 are examples of NORM produced in the atmosphere by cosmic rays. Elements that are not typically recognized as "radioactive" may have particular isotopes that are radioactive. For example, most carbon atoms are not radioactive, but carbon-14 is a radioactive isotope of carbon. Radon, a radioactive gas that is emitted to the air from decay of radium atoms in the soil, is a significant contributor (37%) to our background ionizing radiation exposure (NCRP, 2009).

There are three major dose-response models that are used to predict biological damage that may result from exposure to ionizing radiation. The "linear no-threshold" (LNT) theory postulates a linear increase in a response, such as carcinogenesis, and any concomitant increase in the dose of ionizing radiation (BEIR, 2006). Under the LNT theory, any exposure to radiation is presumed to cause biological harm. An alternative model, the "threshold" model, holds that damage (*e.g.*, cancer) occurs only at levels above a defined "threshold" dose of radiation. A third model is the hormetic dose-response (Calabrese and Baldwin, 2000), characterized as a "U-shaped" dose-response that shows opposite responses at low *vs.* high doses. In terms of radiation risk, this usually means that while high doses are damaging (similar to the previous two models), low level exposures may actually be beneficial. Currently, both the Nuclear Regulatory Commission (NRC) and the U.S. EPA have adopted the LNT dose-response model for assessing the health risk of ionizing radiation exposure.

While both the EPA and the NRC are responsible for protection of human health from radiation exposure, they use different exposure assessment methodologies. NRC evaluates radiation exposures in terms of allowable doses in a single year, while EPA establishes their allowable exposure levels in terms of lifetime incremental cancer risks. The allowable levels of exposure also vary dramatically among the two agencies. For example, external radiation from cesium-137 (a radionuclide common in nuclear fission reactors) at 0.25 Sv/year is acceptable for NRC-licensed facilities, but equates to an incremental lifetime cancer risk of about 4 in 10,000, or roughly 400 times greater than the allowable level used by EPA to evaluate environmental cleanups. Perhaps most interesting is that the EPA's allowable lifetime incremental cancer risk level (*i.e.*, 1 in 1 million) is about 40,000 times more stringent than the LNT-predicted lifetime risk of developing cancer due to our exposure to natural background sources of radiation (*i.e.*, 4%) (BEIR, 2006).

Once we understand that not all radiation risks are created equal, we can have a more enlightened perspective on the potential radiation risks all around us, and on how we can best manage them in our daily lives.

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Glossary

Activity – Radioactive decay as measured in **Curies** (3.7×10^{10} disintegrations/sec) or **Becquerels** (1 disintegration/sec).

Alpha (α) Particles – Positively charged particles (helium nuclei with 2 positive charges) ejected from the nucleus of an atom during radioactive decay. Larger than β particles.

Beta (β) Particles – Negatively (electrons) or positively (positrons) charged particles emitted from the nucleus of an atom.

Gamma (γ) Radiation – High-energy, short wavelength, electromagnetic radiation frequently accompanying radioactive decay *via* α- and β-emissions. Includes X-rays.

Radiation Absorbed Dose (rad) – Amount of ionizing radiation energy deposited in water, tissue, air, *etc.* 1 rad = 100 ergs/gram.

Roentgen Equivalent Man (rem) – Dose equivalent of ionizing radiation deposited in human tissue. rem = rad × QF (quality factor); QF ≈ 1 for beta, gamma radiation, QF ≈ 20 for alpha and neutron radiation.

Gray (Gy) – Unit of absorbed dose, 1 Gy = 1 Joule/kilogram = 100 rad.

Sievert (Sv) – Unit for dose equivalent. 1 Sv = 1 Joule/kilogram = 100 rem. 1 Sv = 1 Gy × QF.

Source: http://www.nrc.gov/reading-rm/basic-ref/glossary.html

References:

BEIR Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. 2006. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. National Academies Press. 406p.

Calabrese, E.J. and L.A. Baldwin. 2000. Radiation hormesis: its historical foundations as a biological hypothesis. *Human & Experimental Toxicology* 19(1):41-75 DOI: 10.1191/096032700678815602.

National Council on Radiation Protection and Measurements (NCRP). 2009. Ionizing Radiation Exposure of the Population of the United States. NCRP Report No. 160. 387p.

Cell Phone Radio Waves are not X-Rays

By Peter Valberg, Ph.D.

Scientific evidence suggests that we should not get hung up over the potential cancer risks from cell phones.

There is significant, albeit unwarranted, controversy around the question of whether cell phones can cause brain cancer. Epidemiology studies of cell phone users report occasional positive associations, but laboratory studies and mechanistic understanding undermine the idea that cell phone radio frequency (RF) waves can induce cancer in living cells.

> ***…our knowledge of physics and chemistry tells us that RF photons from cell phones just don't have enough energy to affect biological processes in an adverse way.***

The mechanism by which cell phones have been accused of causing cancer is *via* the absorption of some of the RF waves passing between cell phones and base stations, which can lead to the generation of a small amount of heat. RF waves are generated by many sources, *e.g.*, radio and TV stations, cell phones, and microwave ovens. High levels of RF energy can heat materials; this is the fundamental principle by which microwave ovens work. However, the RF levels from cell phone technology are vastly lower than those in a microwave oven. Additionally, cell phone heating effects are vastly lower than the heat we absorb from sunshine, fireplaces, space heaters, and hot showers, not to mention saunas and steam rooms. In fact, exercising over a few minutes contributes far more heat to our bodies than being glued to a cell phone for hours.

Perhaps, the argument goes, even though the RF from cell phones is so much lower than from other sources, the constant use of phones and the continuous RF waves around a base station lead to a larger effect. So, can multiple individual quanta of RF energy from cell phones cause cancer? An understanding of basic principles of physics and chemistry shows this claim is not plausible. Electromagnetic radiation, although "wave-like" in nature, behaves like "particles" when being absorbed or emitted by matter. That is, absorption and emission of electromagnetic waves occurs in discrete energy units, called photons, with energy content proportional to frequency. Photon energy is expressed in units of electron-volts (eV).

For RF photons to cause cancer, they would have to interact with biological molecules (or structures) in such a way as to change their chemistry, shape, charge, or energy in an irreversible way, and significantly enough to derail normal biological function and launch a disease process. The problem with this theory is that the RF photons just don't have enough energy to cause such chemical changes.

In contrast, x-rays are able to disrupt biological function, because each x-ray photon has sufficient energy to break many chemical bonds, which is why x-rays are called "ionizing" radiation. When x-rays break chemical bonds in a molecule such as DNA, and if the damage occurs at certain crucial locations, a normal cell can be changed into a cancer cell. The photons making up RF waves, as in cell phones, have about one billion-fold less energy than x-ray photons, and cannot break or disrupt chemical bonds (*i.e.*, RF radiation is "non-ionizing"). In fact, even the most prevalent source of electromagnetic energy in our environment, visible light, has far more energy per photon than RF waves.

The table compares the energies from RF photons associated with cell phones (about 0.000004 eV) to those of x-ray photons (about 4,000 eV). This billion-fold difference in photon energy is what differentiates potentially damaging x-rays from innocuous RF photons with respect to their damage-causing potential.

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Wavelength, Frequency, and Photon Energies for Different Parts of the Electromagnetic Spectrum

	NON-IONIZING				IONIZING	
	Cell Phones	**Microwaves and Radar**	**Radiant Heating, Infrared**	**Sunlight, Yellow Light**	**Medical X-Rays**	**Gamma Rays**
Wavelength	30 cm	3 mm	6,000 nm	600 nm	0.3 nm	0.0003 nm
Frequency	1 GHz	100 GHz	50 THz	500 THz	10^{18} Hz	10^{21} Hz
Energy	4 μeV	0.0004 eV	0.2 eV	2 eV	4,000 eV	4 MeV
Example	Cell phones	Police radar	Body heat	Vision	CT-scans	Cosmic rays
Biological Effect	RF heating currents			Photo chemistry	Molecular damage	

nm = nanometers = 10^{-9} meter; THz = terahertz = 10^{12} Hz; GHz = Gigahertz = 10^{9} Hz; 1 Hz = 1 cycle per second

Do Medical Monitoring Risks Outweigh Benefits?

By Lisa Bailey, Ph.D.

Increasing use of radiological diagnostic tools may be having the unintended consequence of subjecting some patients to unnecessary risks, with no attendant benefits.

According to a 2009 report by the National Council on Radiation Protection and Measurements (NCRP, 2009), the collective (*i.e.*, population sum) effective dose from ionizing radiation exposure from medical procedures in the U.S. increased seven-fold from the 1980s to 2006. Medical imaging procedures accounted for approximately 15% of the total ionizing radiation exposure of the U.S. population in the early 1980s, increasing to 48% in 2006, roughly equal to background ionizing radiation exposures (50%). One reason for the increase is growing use of computed tomography (CT).

…the typical ionizing radiation dose from one CT scan is…only slightly lower than the lowest doses received by Japanese atomic bomb survivors… who have experienced a detectable increase in radiation-related cancer mortality.

Medical imaging can play an important role in critical care, and for diseased individuals it can be much less invasive than alternative detection methods. For example, CT angiograms are much less invasive than coronary angiograms. Mammograms are another example of diagnostic medical imaging for which the evidence suggests the benefits outweigh the risks. However, a study conducted at the Massachusetts General Hospital showed that the frequency with which a CT scan yields the information needed to establish a diagnosis has dropped in the past 10 years; the data indicated that from 1995-2005 "approximately 35% of CT scans performed on children had no impact on their diagnosis" (NCRP, 2009). Therefore, there is rising concern that increased use of diagnostic CT scanning of individuals with no symptoms of disease provides little benefit. In fact, the FDA has stated that it "knows of no data demonstrating that whole body CT screening is effective in detecting any particular disease early enough for the disease to be managed, treated, or cured" (FDA, 2009).

There are several reasons for this increasing use, and possible overuse or misuse, of CT scanning. For example, since the costs of the instruments have dropped, they are becoming more available to and used by private practitioners who often feel pressured to conduct "defensive medicine" in order to avoid lawsuits. A 2008 study conducted by the Massachusetts Medical Society found that "28% of all CT scans were ordered for defensive reasons…and not motivated by medical need." In addition, given the increased use, there is an increased potential for instrument malfunction and human error that may lead to overexposure of individuals.

The increase in CT scanning is particularly concerning because the typical ionizing radiation dose from one CT scan is in the range of 1 to 10 millisieverts (mSv), which is only slightly lower than the lowest doses received by Japanese atomic bomb survivors (5 to 20 mSv), who have experienced a detectable increase in radiation-related cancer mortality (FDA, 2009). In addition to the cancer risks associated with CT scanning, there are potential health risks related to unnecessary follow-up due to invasive diagnostic procedures. It is clear that the risks of CT scanning likely outweigh the benefits for many individuals, particularly those who show no symptoms of disease. Many patients, health care providers, and others involved in making decisions about uses of medical imaging for medical monitoring programs are not fully informed about the potential risks. Therefore, education and outreach, as well as clear guidelines on use, are necessary to ensure that use of medical imaging provides a clear benefit with a relatively lower associated risk.

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Food and Drug Administration (FDA). 2009. Radiation-Emitting Products. Accessed at http://www.fda.gov/Radiation-EmittingProducts/default.htm.

Massachusetts Medical Society. 2008. Investigation of defensive medicine in Massachusetts. November. Accessed at http://www.massmed.org/defensivemedicine.

National Council on Radiation Protection and Measurements (NCRP). 2009. Ionizing Radiation Exposure of the Population of the United States. NCRP Report No. 160. 387p.

By The Way…

The most dangerous aspect of cell phones is using one while driving.

Source: Strayer D.L., F.A. Drews, and D.J. Crouch. 2006. A comparison of the cell phone driver and the drunk driver. *Human Factors* 48:381-91.

What's New at Gradient

Recent Awards and Appointments

Barbara D. Beck has been appointed to the Water, Science, and Technology Board of the National Research Council's Committee on Future Options for Management in the Nation's Subsurface Remediation Effort.

Barbara D. Beck received a Lifetime Achievement award in the industry sector at the 2009 Annual International Conference on Sediments, Soils, and Water.

Lorenz R. Rhomberg was awarded the Outstanding Risk Practitioner of the Year award by the Society for Risk Analysis at its Annual Meeting in Baltimore on December 8, 2009.

Julie E. Goodman is now an adjunct faculty member in the Department of Epidemiology at the Harvard School of Public Health.

David G. Dodge is now certified as a Diplomate of the American Board of Toxicology (DABT).

Christopher M. Long, **Ari S. Lewis**, and **Sonja S. Sax** received a 2009 World of Coal Ash Poster Award for Excellence in Coal Ash Research for their presentation "Evaluation of Potential Risks from Mercury *via* Inhalation of Indoor Air from Beneficial Use of Coal Combustion Products in Building Materials."

Upcoming Presentations

San Antonio, TX. January 27-29, 2010. A.B. Bittner and **K.D. Herman**. EPRI MGP Symposium. "How Much Tar is in the Mud? - Reducing Uncertainty in Characterizing the Distribution and Mass of DNAPL in Sediments."

Salt Lake City, UT. March 7-11, 2010. Society of Toxicology 49th Annual Meeting.

- **L.A. Beyer**, **L.R. Rhomberg**, **A.K. Hamade**, and **B.D. Beck**. "Evaluation of Recent Information on Carcinogenicity of Perchloroethylene (PCE) in Humans."
- **J.K. Chandalia**, **J.E. Goodman**, **S. Thakali**, and **M. Seeley**. "Meta-Analysis of Airway Hyper-Responsiveness in Asthmatics after Nitrogen Dioxide Exposure."
- **D.G. Dodge**, **J.E. Goodman**, and **B.D. Beck**. "Weight-of-Evidence Analysis of Hydroquinone and Leukemia."
- **A.S. Lewis**, **R.L. Mattuck**, B.Hensel, and K. Ladwig. "Population Risk from Arsenic Exposure in Communities Living Near Coal Combustion Waste Facilities."
- **M.A. Nascarella**, **A.S. Lewis**, and **B.D. Beck**. "Mode of Action Proposal for Oral Hexavalent Chromium Carcinogenesis."
- K. Rahmani, W.W. Neely, and **T.A. Lewandowski**. "Preliminary Evaluation of Potential Lead-Mercury Toxicological Interaction in an *in vitro* Model."
- **L.R. Rhomberg**. "Low-Dose Linearity from Interaction of Agents with Background Disease Causes. A Conversation on Statistical and Toxicological Principles."
- **M. Seeley**, **B.D. Beck**, and **P.J. Drivas**. "Blue soil at former MGP sites – is it a health hazard?"
- **S. Thakali**, **J.K. Chandalia**, **M. Seeley**, and **J.E. Goodman**. "Meta-Analysis of Nitrogen Dioxide Effects on Airway Hyper-Responsiveness in Asthmatics: Effects of the Types of Airway Challenge, Exposure Methods, and Activities During Exposure."

New Orleans, LA. March 18, 2010. B.D. Beck. DRI Toxic Torts and Environmental Law Seminar. "These Kids are Driving me Crazy: The Science of Sensitive Subpopulations."

San Diego, CA. March 22-26, 2010. P.A. Valberg and **C.M. Long**. American Association for Aerosol Research International Specialty Conference on Air Pollution and Health. "Do Brain Cancer Mortality Rates Correlate with Ambient-PM Levels or to Hazardous Air Pollutant Concentrations?"

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Cell Phone Radio Waves are not X-Rays

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In summary, RF safety guidelines protect us against thermal effects of RF with a large margin of safety, and our knowledge of physics and chemistry tells us that RF photons from cell phones just don't have enough energy to affect biological processes in an adverse way. In fact, our bodies constantly radiate energy in a higher frequency band, namely infrared (IR), as can be verified by a night-vision camera. If our bodies function happily in this bath of IR radiation, there is no reason to believe that photons of an even lower energy, RF, can damage biological systems.

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Guest Editorial: Yucca Mountain, a Repository of Risk, or Not?

By Dade W. Moeller, Ph.D.

Although the Yucca Mountain high-level nuclear-waste repository is often portrayed as a facility that will threaten humans and the environment, actual radiation exposure would be low-level, and in fact, benign.

Key factors that influence health risks due to the intake of radionuclides include their physical decay, biological clearance, environmental behavior and stability, relative intake of comparable stable elements, and the energy released and nature of their decay. Perhaps most important in understanding radionuclide risks are data from radiation epidemiology. If one weighs these radiological, biological and epidemiological considerations for the eight radionuclides potentially released from Yucca Mountain, conclusions on dose and risk are as follows:

…anxieties surrounding the Yucca Mountain repository far outstrip its projected impacts on human health…

1. Carbon-14: We daily consume about 300 g of stable carbon. Based on conservative estimates of the maximum possible intake of C-14 released from the repository, it will be diluted by a ratio of 25 trillion to 1. The dilution factor is so high, it is as if the person had consumed no C-14 at all and the upper-bound risk will be negligible.
2. Technetium-99: The radionuclide has a biological half-life of three days, and the nature of the receiving groundwater is such that it will be immediately precipitated once it leaves the repository. The potential for ingestion is nearly nil, and long-term accumulation is not an issue.
3. Iodine-129: This isotope has a physical half life of 15.7 years. The National Council on Radiation Protection has concluded that it "does not pose a meaningful threat of thyroid cancer." Because I-129 is so nearly stable, it actually blocks the thyroid (which weighs only 20 grams) from elevated uptake, and its activity, even when the thyroid is saturated, is nil. Epidemiological studies after massive iodine releases (Chernobyl accident) showed that thyroid cancer mortality rates were very low.
4. Radium-228: This material has a physical half-life of 5.75 years and will have decayed prior to the time it will be placed in the repository.
5. Radium-226: Studies of bone cancers in radium-dial painters have established a threshold that is considerably above the estimated upper-bound intakes from repository releases.
6. Plutonium-239: Evaluations of Pu-239 exposures during the past 50 years by Los Alamos National Laboratory showed it has a threshold for cancer induction far above estimated repository exposures.

7/8. Neptunium-237, Americium-241: It is anticipated that the International Commission on Radiological Protection will soon announce that it has concluded that these and all other α-emitting radionuclides have similar thresholds to that of Pu-239.

Hence, the anxieties surrounding the Yucca Mountain repository far outstrip its projected impacts on human health, as based on hypothetical, upper-bound dose estimates. The repository is far too important to the U.S. nuclear energy program to be impeded by inappropriate standards, exaggerated perceptions of risk, and ill-founded regulatory restrictions.

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In the next issue:

The Long Arm of REACH

Decision-Making: State vs. Federal Role

Implications of TSCA Reform

Guest Editorial: Is Science being Hijacked?

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