Radiation:
How to Address the Confusion

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Preface

About the Author

Jill Anderson received her B.S. in nuclear, plasma, and radiological engineering specializing in radiation and medical instrumentation with a minor in biomolecular engineering from the University of Illinois in May, 2008. She is currently pursuing her M.S. at the University of Illinois in nuclear engineering and medical physics. On campus, Jill is involved with the University of Illinois student chapter of the American Nuclear Society, Society of Women in Engineering, university chorus, university band, and served as president of Alpha Omega Epsilon professional engineering sorority.

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Executive Summary

Public perception and understanding of radiation is a critical issue for the advancement and safety in nuclear technology. Throughout history, every living thing has been exposed to radiation. However, most individuals are neither informed about the natural and man-made sources of radiation in our world nor understand the importance of radiation. Radiation and its accompanying technology are used in medicine, academia, industry, food safety, security, and power generation. Given the prevalence of its natural occurrence and broad human use, we, as a society, need to understand radiation's benefits and risks. An ill-informed public can not only create problems for advancements in technology but also fuel mass terror and avoidance of life saving procedures.

The accuracy and adequacy of public education is severely lacking. While education is a broad topic, the issue of radiation can be addressed in a series of small steps. These policy steps include,

- Increased education in K-12 through academic, regulatory, and industry involvement.
- Unified efforts by industry and the regulating bodies to present accurate, honest, consistent, and up-to-date information that includes the benefits and the risks of radiation applications.

The many uses of radioactive materials and applications will continue to develop and change. Whether one is for or against some of the uses of radioactive material, the need for the public to be properly informed about radiation and nuclear technology is important for the support of both public safety and the ability to implement appropriate public policy.

Table of Contents

I. Introduction

Throughout history, every living thing has been exposed to radiation. We use radiation for medical procedures, food and public safety, in academia and industry, and finally, to generate power. However, most individuals are neither informed about the natural and man-made sources of radiation in our world nor understand the actual risks. To add to the confusion, there are different regulating bodies, each with different standards for different situations. This public lack of familiarity has negative consequences regarding technological advancements as well as safety. The purpose of this paper is to address these concerns and offer policy solutions to clarify radiation.

Section II will discuss the background of radiation including its discovery, current uses, regulations, and current policy. Section III addresses the conflicts and concerns of radiation including nuclear power plants, perceptions, dose levels, and the effects of these concerns. In concluding, Section IV looks at the future of radiation and policy.

II. Background

Radiation occurs naturally all around us and in us. We encounter it every day through the water we drink, the food we eat, and the air we breathe.[1]

IIA. The nuclear reactor and the discovery of radiation

Through the ages, some events have dramatically altered the course of human history. One such world-changing event involved the field of nuclear technology. On December 2, 1942, the Italian-American physicist Enrico Fermi led a small team of scientists at the

[1] Eisenbud, M, Gesell, T. Environmental radioactivity from natural, industrial and military sources. 4 th ed. (Boston: Academic Press, Inc, 1997) 5.

University of Chicago in operating the world's first nuclear reactor.[2] Though primitive by today's technology standards, Fermi's CP-1 inaugurated the modern age of nuclear power. Fermi's milestone was built on the previous advances in x-rays and other forms of radiation by the likes of Wilhelm Roentgen, Henri Becquerel, Thomas Edison, and Marie Curie. This pioneering experiment by Fermi started a new technical era, one filled with the great hope that human beings might wisely harvest the energy within the atomic nucleus in a controlled manner. In addition to generating power, the reactor's core produced a large quantity of neutrons that could create many isotopes for applications in medicine, food safety, security, industry, basic research, environmental science, and space exploration.

IIB. Radiation dose units and sources

Radiation is energy emitted from an atom when it changes energy states. Ionizing radiation (when electrons are detached from the atom) will be the focus of this paper. For radiation protection work, a commonly used unit of dose measurement is called the rem, which has traditionally been used to express the effect of radiation on humans. Rem, however, is being replaced with the SI unit Sievert (Sv). One hundred rem is equal to one Sv and the Sievert is the preferred measure of radiation dose. The word dose is used to describe the amount of radiation absorbed, referring to the first uses for healing.[3]

Radiation is categorized by source. Primordial/terrestrial radiation is emitted from the rocks and soil (earth), cosmic radiation comes from space, and human enhanced radiation is found in a variety of sources. It has been estimated that individuals in the United States receive about 3.60 mSv each year from all of these sources.[4] Of this total, natural

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[2] Angelo, Joseph . Nuclear Technology. (Greenwood Press, 2004) 1.

[3] Rockwell, Theodore. Creating the New World: Stories & Images from the dawn of the atomic age. (Bloomington, 2003) 116.

sources of radiation account for about 82 percent, while man-made sources account for the remaining 18 percent.[4] Table 1 shows the estimated radiation dose per person based on the three above mentioned sources.

Table 1: Average Annual U.S. Estimated Radiation Dose Per Person[6]

Source	Average annual effective dose (mSv)
Radon from soil, rocks, building material and naturally occurring radionuclides in the air, water, plants, and our bodies	2.70
Cosmic radiation	.30
Human-enhanced sources	.60
Total	**3.60**

Figure 1 shows the sources of the radiation dose in more detail by percentage of total dose received. The radiation from the earth, in blue, is broken up into three categories, radon, soil, and internal radiation produced by our bodies. (Table A, illustrating the natural radiation in our food and water can be found in the appendix.) Also in blue is cosmic radiation. Human-enhanced radiation is illustrated in yellow and is broken up into other (nuclear power plant emissions and fallout from past atomic bomb detonations[4]), consumer products, nuclear medicine, and medical x-rays. It can be noted that the largest dose of radiation we receive is from naturally occurring sources, primarily radon. Soil contains naturally occurring uranium that eventually decays to radon gas.

[4] National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987.

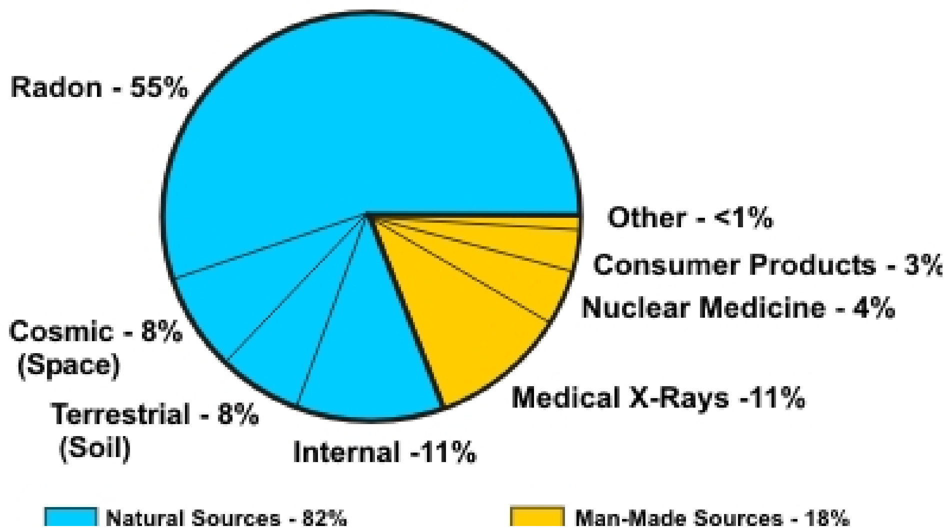

Figure 1: Sources of Radiation Exposure in the United States[4]

IIC. Medical uses of radiation

A wide array of nuclear radiation and materials are used in various medical professions to diagnose, monitor, and treat an assortment of metabolic processes and medical conditions in humans.[5] These medical uses are under the general heading of radiology and include not only procedures where radiation is administered from the outside of the body but also those in which a radioactive substance is placed into the body (nuclear medicine).

IIC1. External radiation: x-rays

The x-ray detects bone fractures; it is the best known external radiation procedure. Other diagnostic procedures utilizing the principles of x-rays include mammography, computerized tomography (including CAT scans to look at internal organs), PET scans, and cardiology (where x-ray pictures are taken of the heart). PET stands for positron-

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[5] Hall, EJ, Giaccia, AJ. Radiobiology for the radiologist. 6 th ed. (New York: Lippincott Williams & Wilkins, 2006) 23.

emission tomography, and it is a specialized type of imaging that can be utilized for the detection of cancer and memory disorders.[5] In addition, PET scans can measure the effectiveness of certain drugs on cancer treatments. The most common x-ray exam in cardiology is the angiogram. During an angiogram, non-radioactive contrast material is injected into the arteries of the heart so they are visible by x-ray. The angiogram is used to diagnose abnormalities in the arteries, including blockages. X-rays and other forms of radiation also have a variety of therapeutic uses including destroying cancerous tissue, shrinking a tumor, or reducing pain.

IIC2. Internal radiation: nuclear medicine

In nuclear medicine, a radioactive substance is introduced into the body. Within this category are areas such as radiation oncology (cancer treatment) and brachiotherapy. Brachiotherapy is a procedure where small radioactive metal implants (each usually about the size of a piece of rice) are put inside the body in or near a cancerous tumor.[6] The implants expose the tumor to a constant stream of radiation until the radioactivity decays away. Radioactive iodine, administered orally, is frequently used to treat thyroid cancer (a disease that strikes about 11,000 Americans every year).[7]

IIC3. Doses from medical procedures

The external uses of radiation and the internal administration of a radioactive material have led to great advances in both diagnostic capability and therapeutic treatment of the human body. Table 2 below lists the dosages received from the medical procedures

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[6] Hall 75.

[7] Wolbarst, AB. Looking within: How x-ray, CT, MRI, ultrasound, and other medical images are created and how they help physicians save lives. (Los Angeles: University of California Press, 1999) 120.

described earlier. Later in the paper, these doses will be compared to background radiation in different parts of the world, regulation standards, and the doses that are fatal.

Table 2: Doses from Medical Procedures[8]

Procedure	Dose (mSv)
X-Rays	
Abdomen	.40
Chest	.10
Pelvis	.60
Dental	.03
Mammography	2.50
CT (full body)	1.30
Nuclear Medicine	4.00

IID. Industrial uses of radiation

In addition to medical usage, radiation is also broadly used for academic research and industrial applications. One industrial use of radiation is to help remove toxic pollutants, such as exhaust gases from coal-fired power stations and industry. For example, electron beam radiation can remove dangerous sulfur dioxides and nitrogen oxides from our environment.[9] Additionally, many of the fabrics used to make clothing have been irradiated before being exposed to a soil-releasing or wrinkle-resistant chemical. The irradiation makes the chemicals bind to the fabric, keeping the items fresh and wrinkle-

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[8] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.
[9] Strzelczyk J, Damilaki J, Marx MV, Macura KJ. Facts and controversies about radiation exposure, Part 2: Low-level exposures and cancer risk. (J Am Coll Radiol 4:32-39, 2007) 33.

free.[10] Despite this treatment, the clothing does not become radioactive. Similarly, nonstick cookware is treated with gamma rays to keep food from sticking to the metal surface.[10]

The agricultural industry makes use of radiation to improve food production and packaging. Plant seeds, for example, have been exposed to radiation to help produce better, stronger types of plants. Radiation can also be used to control insect populations and thus decrease the use of dangerous pesticides. In addition, radioactive material is used in gauges that measure the thickness of eggshells to screen out thin, breakable eggs before they are packaged in egg cartons. Many of our foods are packaged in polyethylene shrink wrap that has been irradiated so that it can be heated above its usual melting point and wrapped around the foods to provide an airtight protective covering.[11]

IIE. Food irradiation

In food irradiation, germs are killed without harming the substance or making it radioactive. Food irradiation destroys food-borne bacteria and parasites and extends the shelf life of certain foods.[12] Up to 75 million illnesses happen each year due to the bacteria and other harmful germs in food.[13] Food irradiation provides an additional level of safety beyond that achieved with proper food handling and cooking. The process reduces the number of bacteria by as much as 10 million times and is approved by the Food and Drug Administration and USDA.[13] "Because of the significant impact that

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[10] Eisenbud, M, Gesell, T. Environmental radioactivity from natural, industrial and military sources. 4 th ed. (Boston: Academic Press, Inc., 1997) 52.
[11] Angelo 2.
[12] “sourcesanduses” *RadiationAnswers* 2007. July 31, 2008 <Radiationanswers.org>
[13] Wagner LK, Lester RG, Saldana LR. Exposure of the pregnant patient to diagnostic radiation: A guide to medical management. 2 nd ed. (Madison, WI: Medical Physics Publishing; 1997) 6.

irradiation can have on decreasing food-related illnesses, this process has been endorsed by such well-respected agencies as the World Health Organization, American Medical Association, American Dietetic Association, and Surgeon General."[12] A Table of U.S. approved irradiated foods can be found in the Appendix (Table B).

IIF. Safety and security

Radiation is also used for safety and security devices such as smoke detectors and screening devices. Many Smoke detectors contain a small amount of americium, a radioactive source. "The radioactivity in the source emits a constant stream of alpha particles that are sensed by a small radiation detector. If smoke comes between the source and the detector…the alarm goes off."[17]

There are also a few common devices used for security that involve x-rays. These devices are generally regulated by federal or state agencies. Cabinet x-ray systems are one of the most commonly used security devices.[14] They are found primarily at airports and entrances to federal and state agencies. Most items receive about .001 mSv of exposure, about a tenth of a day's worth of natural background radiation. Another type of device, an x-ray or electron-beam machine, is used to give high doses of radiation to mail that might contain some dangerous biological substance.[15]

IIG. Energy- nuclear power

Electricity produced by nuclear fission (splitting the atom) is one of the most important uses of radiation. Currently about one-third of the nation's energy resources are used to produce electricity and additional clean, abundant, reliable, and affordable sources are needed.[8] Electricity can be produced in many ways, using generators

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[14] Gips, Michael. GAO Blasts FAA Computer Security. (General Accounting Office, Federal Aviation Administration: Security Management, Dec, 2000) 1.
[15] Jack Rudman. Postal Machines Mechanic (USPS). (Plastic Comb, 2002). 15.

powered by the sun, wind, water, coal, oil, gas, or nuclear fission. In the United States, nuclear power plants are the second largest source of electricity, after coal fired plants, producing approximately 21 percent of the nation's electricity.[16]

The purpose of a nuclear power plant is to boil water to produce steam. The steam spins the propeller-like blades of a turbine that rotate the shaft of a generator. Inside the generator, coils of wire and magnetic fields interact to create electricity. Nothing is burned or exploded in a nuclear power plant. Rather, the uranium fuel generates heat through fission.[17]

IIH. Regulations and policy

Radiation regulations in the United States are governed primarily by two agencies, the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA).

IIH1. NRC

The NRC was established by the Energy Reorganization Act of 1974 and its scope of responsibility includes "regulation of commercial nuclear power plants; research, test, and training reactors; nuclear fuel cycle facilities; medical, academic, and industrial uses of radioactive materials and wastes."[18] The regulations are designed to "protect the public and occupational workers from radiation hazards in those industries using radioactive materials."[19]

IIH2. EPA

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[16] Nuclear Energy Institute. *Fact Sheet,* 2007
[17] Brent, RL. Utilization of developmental basic science principles in the evaluation of reproductive risks from pre- and postconception environmental radiation exposures. (Teratology 59:182-204, 1999). 182
[18] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.
[19] Nuclear Regulatory Commission NUREG-1350, Volume 16, Rev. 1, "Information Digest: 2007-2008 Edition," 2008

The regulations of the EPA encompass food, water, air, and other radiation sources outside of industry. However, there is some duplication between the two agencies that has historically resulted in an inflexible debate over standards.[20] These conflicting standards and reports create uncertainty for the public on an issue they are already anxious about.

II I. Current policy

Radiation has been briefly mentioned but not to the extent that is necessary in regards to public policy. Some recent bills examine safety in medicine and industry as well as regulation standards and, although important, do not address the overall topic of radiation understanding.

In March 2007 a senate bill pushing for greater safety and accuracy of medical imaging examinations and radiation therapy was introduced.[21] Although the bill represents a step in the right direction, it does not address the knowledge of the patients receiving the treatment and focuses instead on standards of personnel. The bill has stalled in committee. House bills currently being examined include one requiring the Nuclear Regulatory Commission to conduct an Independent Safety Assessment of the Indian Point Energy Center[22] and another requiring the Nuclear Regulatory Commission to retain and redistribute certain amounts collected as fines.[23] These bills are still in committee and only address the commercial issues pertaining to the regulatory dealings of the NRC. Another bill aims to amend the Atomic Energy Act of 1954 and focuses on

[20]Walker. Permissible Dose. (London, England: University of CA press, 2000) 71.
[21] S. 1042 "A bill to amend the Public Health Service Act to make the provision of technical services for medical imaging examinations and radiation therapy treatments safer, more accurate, and less costly." 2008
[22] H.R. 994 "To require the Nuclear Regulatory Commission to conduct an Independent Safety Assessment of the Indian Point Energy Center." 2007, and S. 649 "A bill to require the Nuclear Regulatory Commission to conduct an independent safety assessment of the Indian Point Nuclear Power Plant." 2007
[23] H.R. 3228 "To require the Nuclear Regulatory Commission to retain and redistribute certain amounts collected as fines." 2007

improving and strengthening the safety inspection process of nuclear facilities.[24] The bill is also still in committee and will probably not be brought to a vote due to the controversial issues addressed. Finally, the most recent bill dealing with radiation was introduced in May, 2008 and has already been referred to the Health committee. This new House bill aims to encourage "(1) radiologists, medical physicists, pediatricians, other pediatric health care providers, and parents to consider the different needs of children when it comes to radiation dosing; (2) appropriate use of computed tomography scans in children; and (3) radiation protection efforts in pediatric imaging."[25] Although this bill only examines dose levels (an arguably narrow issue) it represents an encouraging step. However, there are currently no bills that looks at specifically addressing public radiation awareness.

III Conflicts and concerns

There are many concerns among the public when the issue of radiation is addressed. The majority of the concern revolves around the fear of radiation from nuclear power plants as well as potential terrorist activities.[26] Many people do not know exactly what the various levels of radiation are for different activities or even where these levels fall within the standards. Complicating the matter is the fact that the regulating agencies are

[24] S. 1008 "A bill to amend the Atomic Energy Act of 1954 to improve and strengthen the safety inspection process of nuclear facilities." 2007

[25] H.RES.1216 "Supporting the efforts to reduce unnecessary radiation exposure through computed tomography scans for children, and for other purposes." 2008

[26] Saul, RL, Ames, BN. Background levels of DNA damage in the population. (Basic Life Sci. 38:529-35; 1986) 534.

sometimes at odds with each other. Policy must address these issues in a way that will inform and clarify.

IIIA. Nuclear power plants

The risks associated with Nuclear Power plants are poorly understood by the public. The most prevalent concerns are radiation release, past accidents, and terrorism.

IIIA1. Radiation release

As stated, nuclear power plants are fueled by uranium, which produces radioactive substances as a result of nuclear fission. Most of these substances are trapped in uranium fuel pellets or in sealed metal fuel rods.[27] However, small amounts of these radioactive substances (mostly gases) become mixed with the water that is used to cool the reactor. The water that passes through a reactor is processed and filtered to remove these radioactive impurities before being returned to the environment. Nonetheless, extremely small quantities of radioactive gases and liquids are ultimately released to the environment under controlled and monitored conditions.[28]

The U.S. Nuclear Regulatory Commission has established limits for the release of radioactivity from nuclear power plants. Although the effects of very low levels of radiation are difficult to detect, the limits established by the NRC are based on the assumption that the public's exposure to man-made sources of radiation should be only a small fraction of the exposure that people receive from natural background sources.[2]

Prior to being released, radioactive gases and liquid wastes are sampled and analyzed, and calculations are performed to ensure radioactivity levels are within limits. Once the calculations verify the radioactivity is below regulatory limits, the radioactive material is released in a controlled, monitored process.[28] Advance notifications to the public are not

[27] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.

required and are not routinely done when releases are made in accordance with the plant's procedures and regulations. The plants maintain records of all releases. Routine sampling of water from nearby lakes, ponds, etc., performed by the plant operators and independently by states also provides surveillance and detection of any radioactive liquid releases.[28]

Experience has shown that, during normal operations, nuclear power plants typically release only a small fraction of the radiation allowed by the established limits of the NRC. In fact, an individual who spends a full year at the boundary of a nuclear power plant site would receive an additional radiation exposure of less than 1 percent of the radiation that everyone receives from natural background sources. This additional exposure totals about .01 mSv.[29] Also, in the past 25 years, the average measureable dose per worker was reduced from 6.60 mSv to 1.40 mSv.[30] Despite these numbers and safety protocols, the public still remains concerned about radiation from nuclear power plants.

IIIA2. Three Mile Island and Chernobyl

One of the general public's most pressing, high visibility issues concerning nuclear technology is the overall question of nuclear reactor safety and risk.[31] From the beginning of the commercial nuclear power program, nuclear engineers have been aware of both the potential hazard of uncontrolled nuclear criticality in a reactor core and the need to prevent the release of radioactivity into the environment. In over 10,000 cumulative reactor-years of power plant operation in 32 countries, there have only been

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[28] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.
[29] Cigna, Arrigo A. Radiation Risk Estimates in Normal and Emergency Situations, NATO Public Diplomacy division, 2006.
[30] Anderson, R. Health Physics News, (Health Physics Society: July 2008) 6
[31] Rockwell 95.

two major accidents involving commercial nuclear reactors.[32] The first of these accidents was the Three Mile Island accident that took place in the United States in 1979. Because the reactor had a containment vessel for safety, almost all the radioactivity remained contained within the plant and there were no adverse health effects or environmental consequences outside of the plant. (The reactor itself however was severely damaged).[34] The second major accident took place at the Chernobyl nuclear power plant in Ukraine in 1986. The lack of a containment vessel, poor reactor design, and human errors caused the destruction of the reactor. Thirty one workers and emergency response personnel died of acute radiation sickness.[34]

There is a distinct lack of legitimate technical comparison between the earlier, dangerous Soviet reactor designs and the modern commercial power plants. Present-day plants are designed under a rigorous defense depth safety philosophy by nuclear engineers in the United States, France, and other Western countries as well as Japan.[33] However, despite the current safety standards, the general public still tends to use the Chernobyl accident as the major measuring stick.[34]

IIIA3. Terrorism

The rise of global terrorism has heightened concerns about nuclear plant security. The defense-in-depth philosophy used in the construction and operation of nuclear power plants protects the public from exposure to radioactive material and makes the plants unattractive for sabotage or terrorist attacks. Responding to suicidal fanaticism, nuclear utilities have installed vehicle-barrier systems to protect against truck bombs and to keep

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[32] Angelo 5-7.
[33] International Atomic Energy Agency. The Chernobyl Forum: 2003-2005. (IAEA/PI/A.87 Rev.2/06-09181. Vienna: April 2006).
[34] Myers, David G. Psychology (Worth Publishers: March 17, 2006) 629.

intruders from driving into a nuclear plant's protected area. Since the World Trade Center attacks of September 11, 2001, nuclear plant safety experts have performed additional studies examining the consequences of a similar suicide attack on a modern nuclear power plant. These studies indicate that the nuclear reactors would be more resistant to such an airborne attack than virtually any other civilian installation.[35] A U.S. Department of Energy study concluded, for example, that "the U.S. reactor structures are robust and would protect the nuclear fuel from impacts of large commercial aircraft."[36] In 2007, Switzerland's Nuclear Safety Board examined a similar scenario and concluded that the danger of any radiation release from a commercial aircraft crash would be extremely low for newer nuclear power plants and low for older power plants.[37]

IIIB. Genetics

Over time, the general public has come to think of radiation in terms of its biological effect on living cells. For low levels of radiation exposure, these biological effects are so small that they may not even be detectable. In addition, the human body has defense mechanisms against many types of damage induced by radiation. Consequently, radiation may have one of three biological effects, with distinct outcomes for living cells: (1) injured or damaged cells repair themselves, resulting in no residual damage; (2) cells die, much like millions of body cells do every day, being replaced through normal biological processes; or (3) cells incorrectly repair themselves, resulting in a biophysical

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[35] Gianni Petrangeli. Nuclear Safety. (Burlington, MA: Elsevier, 2006) 23.
[36] United States. Future Plans for the Department of Energy's Nuclear Weapons Complex Infrastructure: Hearing Before the Strategic Forces Subcommittee of the Committee (Government Printing Office: January 2007)
[37] Angelo 53.

change.[38] The exact effect depends on the specific type and intensity of the radiation exposure.

There is only one fear greater than the thought of our bodies disintegrating at the cellular level; that is the terror that future generations might be irreversibly deformed through damage to the DNA. Genetic damage is a subject that many people associate uniquely with radiation. The fact remains, however, that nuclear radiation is not particularly effective in causing genetic damage.[39] When scientists want to cause genetic damage to fruit flies or mice or other organisms in the laboratory, they usually choose chemicals, ultraviolet light, or other agents more effective than nuclear radiation. In addition to our theoretical and laboratory knowledge of the effects of radiation, we have some direct evidence from people irradiated at Hiroshima and Nagasaki and their descendents. They were subjected to much higher radiation levels than those associated with nuclear power.[40] An internal team of physicians from various countries has been studying these survivors and their children for more than fifty years, and is now looking at some grandchildren of those survivors. They have found that the radiation has not affected subsequent generations; the number of birth defects in the descendants of irradiated persons does not exceed the number found in non-irradiated control groups.[41]

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[38] Saul 530.
[39] Rockwell 116.
[40] Turner JE. Atoms, radiation, and radiation protection. 2 nd ed. (New York: John Wiley & Sons, Inc., 1995) 87.
[41] International Atomic Energy Agency. Iaea Safeguards, Implementation at Nuclear Power (Iaea Safeguards Information Series, 6: September, 2005) 34.

IIIC. Legitimate concerns

Many of the fears about radiation are based on lack of knowledge; however, some concerns are legitimate and need to be addressed. Changing technology, human error, and the unexpected are cause for scrutiny.

Rapid technological progress in regards to radiation is cited as a reason for increasing the level of understanding. However, new technology is not always understood, even by the experts. Sometimes it can take years to fully grasp the benefits and risks created. Also, despite competent engineers doing good work and sincere attempts at regulation, unfortunate events and tragedies can occur. Human errors, disjointed policies, lack of foresight, poor design, etc., are commonplace in industry. Terrorist attacks are possible and could be accomplished with something unexpected. So, while the risks incurred with radiation are very low, complacency is ill-advised. Education and risk reduction are both necessary. Skepticism and concern can sometimes be healthy in that both can serve to keep regulators, industry, and the public in general on their toes.

IIID. Public perception

When asked about radiation, almost half of the respondents in a Cambridge study felt that radiation from nuclear energy was more harmful than the same amount of radiation from the sun.[42] These results show not only a lack of understanding but unfounded fear as well.

"The federal government calculated the maximum health risk of a person being exposed to 1 mSv of radiation for every year of an entire lifetime.

That risk was then compared to other known risks in life:

-Smoking a pack of cigarettes a day is 400 times greater risk.

[42] Cambridge 1990.

-Being 15% overweight is 100 times greater risk.

-Driving a car 12,000 miles per year is 40 times greater risk."[45]

These statistics are interesting but do little to ease concern. Instead, they can create more.[43] The following information is more helpful. Radiation is a natural and ever-present part of our environment in which humankind and other species have evolved and thrived. The sun, the earth, and all living things emit radiation. Scientific studies of larger populations have found that people exposed to above-average amounts of radiation, such as people living at high altitudes where there is less atmospheric shielding of solar radiation, actually had fewer incidences of cancer and lived longer.

To properly address the public perception issue, Bisconti Reasearch Inc. performed the following surveys as indicated in Table 3 and 4.

Table 3: Percentage of people who found the message about radiation reassuring[43]

Benefits society	54
Understood, detected, measured	17
Natural	15
Radiation benefits society in many ways	54
Radiation constantly monitored and controlled	52
Strict standards set by EPA, enforced by NRC	48
NCI study shows no rise in cancer near plants	45
Radiation understood	44

Table 4: Best Points from survey[43]

Best Points	% Saying
Radiation in our world exists naturally—from the sun and stars and elements in the Earth	60
Workers highly qualified professionals	59
Radioactive materials used in thousands of ways	58
Workers well trained and retrained	55
Workers carefully monitored, wear dosimeter	54

[43] Bisconti Research Inc.

In summary, the specific points that the public needs to hear for reassurance about radiation and its applications are that it's exists naturally, benefits society, and is closely monitored by professionals.

IIIE. Radiation doses

As mentioned earlier, there is ample confusion regarding dosages and possible related dangers. The table below outlines the varying dose ranges that represent typical exposures as well as the regulation guidelines. Medical Procedures are *italicized,* Natural Background Radiation in underlined and regulations are in **bold.** Radiation dose can be measured in acute exposure (all at once) or chronic exposure (over the course of ones lifetime). Unless noted, exposure is chronic and per year.

Data Table 5: Radiation Dose[44]

	Dose (mSv)
EPA dose limit for public drinking water	**.04**
Round-trip plane flight, NY to London	.10
EPA dose limit from releases in air	**.10**
Chest x-ray	*.10*
ANSI Standard N43.17 limit Security Personnel Scanners	**.25**
NRC cleanup criteria for site decommissioning	**.25**
DOE, NRC dose limit for public	**1**
Dental Oral Exam	*1.6*
Average Natural Background Radiation in the United States	3
Mammogram	*2.5*
Lumbosacral Spine	*3.2*
PET	*3.7*
Bone (Tc-99m)	*4.4*
Average Natural Background Radiation in Yangjiang, China	6.3
Cardiac (Tc-99m)	*10*
Average Natural Background Radiation in Kerala, India	12
"Storefront" full-body CT screening	12
EPA radiological emergency guideline for public relocation	**20**
DOE administrative control	**20**
Cranial CT (MSAD)	*50*

44 Office of Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy. *Radiation Dose: Ppowers of Ten.* Washington: Government Printing Office, 2008.

DOE, NRC Dose Limit for Workers	**50**
Barium contrast G- *I fluoroscopy (2 min scan)*	*85*
Spiral CT- full body	*30-100*
Typical missions does on the International Space Station	100
Evidence for small increase in human cancer	100 acute
Evidence for small increase in human cancer	200 chronic
Average Natural Background Radiation in Ramsar, Iran	200
EPA guideline for lifesaving	**250**
Solar flare dose on moon, no shielding	1,000
Estimated dose for 3-yr Mars mission, with current shielding	1,300
Human LD_{50} range (50% death in 3-6 weeks if no medical intervention)	3,500-5,500 acute exposure
Human LD_{50} medical range (50% death in 3-6 weeks with medical intervention)	4,800-10,000 acute exposure
Total Body Irradiation (TBI) Therapy	3,000-12,000
Whole Body, acute: G-I destruction; luge damage; cognitive dysfunction (death in 5-12 days, assume no medical intervention)	13,000 acute exposure
Whole body, acute: cerebral/vascular breakdown (death in 0-5 days, assume no medical itervention)	20,000-100,000 acute exposure

From the data table it is clear that doses we receive in our everyday lives, even from nuclear power plants and medical treatments are minimal if done properly. Also, the regulation guidelines are far below the dose levels needed to see increased cancer risk. The natural background radiation in the United States is 3mSv while the amount of radiation from a chest x-ray is .1mSv and the amount of radiation from radiation emissions are only .01mSv per year. In contrast the amount of radiation needed to have a 50% chance of causing death in 3-6 weeks with medical intervention is 4,800-10,000 mSv.[47] Most of the public is not familiar with the doses they get everyday and do not know what levels of doses are safe and unsafe.

IIIF. NRC vs. EPA

The NRC and EPA both feel pressures from different interest groups and are organized in different ways. There is also a history of animosity going back to when the

NRC was first created that has resulted in, among other things, direct conflict in front of congress and public documents by the EPA which contradict some of the NRC's scientific findings, which are supported by the international community.[45]

IIIG. Dangers of an ill informed public

Lack of knowledge about radiation does not only hinder technological advancements and mask actual safety issues but also effects medical and food treatments as well as safety.

IIIF1. Medical and food treatments

Being ignorant and misinformed about radiation is not just quaint; it can actually be life threatening. It is estimated that about 100,000 needless additional abortions were performed in Europe after the Chernobyl accident assumedly because the parents feared that radiation might have deformed their child.[46] This fear was without a scientific basis. Each of us has to make decisions from time to time that require a basic understanding of radiation. We have to accept the use of x-rays or other diagnostic or therapeutic uses of radiation or else we must choose alternatives that may be dangerous to our health or of lesser therapeutic value. The use of radiation and radioactivity for diagnostic and therapeutic purposes is saving thousands of lives each year, yet irrational fear of radiation leads many people to refuse such healing treatments. In 1995, Professor Bernard Cohen, a radiation expert at the University of Pittsburgh published these findings. In one major hospital, about 20 percent of patients refuse the use of radioactive iodine treatment for hyperthyroidism, opting instead for a less effective drug that often leads to relapse.[47]

[45] Walker 56.
[46] Rockwell 121.
[47] Wolbarst 25.

Despite evidence that early detection by mammograms is the best defense against lethal breast cancer, the leading cause of cancer deaths among women, more and more women are refusing to have mammograms, solely because of a fear of the radiation.[48]

Ralph Nader and others campaigned against smoke detectors that use a small radiation source, on the basis that "any amount of radiation is harmful" a statement without scientific merit. There have also been crusades against irradiated food leading to salmonella poisoning in the non-irradiated food.[49]

IIIF3. Unfounded terror

These are unfortunate examples of popular misconception that often forms the roots of what psychologists refer to as radiation phobia or nuclear neurosis.[50] A radiological incident, whether accident-caused or terrorist-caused, can produce profound psychosocial impacts at all levels of a society: individual, family, local, and national. For example, in the immediate aftermath of a radiological accident, thousands of people who fear exposure to radiation will attempt to leave the area and seek health services and medical assistance.[51] With orderly emergency response and evacuation plans, this mass exodus should be without significant social incidents or loss of life. In the United States, the NRC requires that each licensed commercial nuclear power plant have an approved emergency-response and evacuation plan.[52]

However, a disorderly, panic-driven movement by thousands of people would overwhelm health facilities and would probably cause more transportation fatalities and injuries than inflicted by the nuclear accident itself. The Three Mile Island public panic

[48] Wolbarst 26.
[49] Angelo 50.
[50] Myers 600.
[51] Angelo 7.
[52] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.

is an example of an unwarranted societal level of anxiety. Since nuclear radiation cannot be seen or sensed, people often believe that any environmental radiation threat, no matter how minor or physically insignificant, represents an unbounded or open-ended, life-endangering threat. Under such societal anxiety, once even a minor amount of radioactive contamination appears in the environment people feel immediately vulnerable and then tend to remain in a more or less permanent state of alarm.[53] Nuclear radiation is generally perceived as a dreaded risk no matter the actual potential for exposure.[54]

In fact, the risk of a modern nuclear power plant accident with a significant amount of radioactivity being released off site to the public is very small. According to the NRC, this risk is small due to diverse, redundant, and numerous safety systems in the plant; training and skills of the reactor operators; testing and maintenance activities; and regulatory requirements and oversight.[55] Nuclear engineers have designed modern western nuclear power plants to be safe and to be operated without significant effect on public health and safety and the environment.

IV. The Future: How to address the confusion

Radiation understanding and education has not been adequate. We generate almost a third of our power from nuclear energy and use radiation in everything from medical procedures to make our food safe. A better approach to explaining radiation through education, industry, and regulatory policies is needed. Radiation must be presented in a beneficial manor, as stated in section III, while still addressing concerns.

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[53] Angelo 7.

[54] Kereiakes JG, Rosenstein M, Handbook of radiation doses in nuclear medicine and diagnostic x ray. (Boca Raton, FL: CRC Press; 1980) 1.

[55] Nuclear Regulatory Commission. *Fact Sheets*. Washington: Government Printing Office, 2008.

IVA. Nuclear power

Opponents of nuclear power point to the Three Mile Island nuclear power plant as a milestone that marks the beginning of the end of commercial nuclear power generation in the United States. Advocates of nuclear power point out that the TMI accident clearly demonstrated the efficacy of the plant's safety and containment features, since no significant radioactivity escaped from the plant.[56] This debate continues to the present day.

There is no doubt that the accident at TMI permanently changed both the nuclear industry within the United States and the NRC. Public fear and distrust increased, the NRC's regulations and oversights became broader and more robust, and the management of commercial nuclear plants fell under more intense internal and external scrutiny. Many of the technical and administrative problems identified from carful analysis of the events have produced more rigorous licensing, management-training, and emergency response procedures-effectively enhancing the overall safety of commercial nuclear power plants in the United States and other developed countries.[57]

Informed individuals recognize that the Chernobyl accident involved a poorly designed reactor operated improperly by poorly trained and managed workers.[58] But members of the general public frequently overlook the technical differences between Chernobyl and TMI accidents and erroneously assume that all nuclear reactors have significant chances of the same type of catastrophic accident. The nuclear power industry must work hard to overcome this unfortunate misunderstanding. The defense in depth safety philosophy has produced robust designs and sturdy structures that are designed to

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[56] "radiationandme" *RadiationAnswers* 2007. July 31st, 2008 <Radiationanswers.org>
[57] Angelo 8-9.
[58] Saul 529.

contain and control any significant release of radioactivity in reactors in the United States and Western Europe.[59]

During the last century, nuclear power has been established as a reliable source of energy in the major industrialized countries. It has a potentially important role in the future since it does not contribute to the production of Greenhouse gases: a growing concern of continued fossil fuel power generation.

There is a reason the public perception of nuclear power has been focused on. Although we are exposed to more radiation from medical treatments, the public is less fearful of radiation exposure in hospitals. Why? Because the medical industry has great advertising power and a face we trust; our doctor. Another example, food irradiation, usually, slips under the radar because 70% of people have no idea that the majority of our fresh fruits and vegetables undergo this treatment. In regards to addressing the confusion about radiation I firmly believe the medical approach of personal contact combined with dissemination of accurate information to be of greater integrity then simple trust due to personal contact or lack of knowledge.

IVB. Policy recommendations

There are many possibilities in how to address radiation confusion. Among them are K-12 education, adult education, community forums, speakers at schools/colleges/town halls, increased discussion on how radiation occurs naturally, and involvement from industry as well as regulation cohesion. The recommended policy, based on feasibility and the research in this paper is: education in K-12 through industry, academic, and regulatory involvement.

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[59] Ballard, G.M. Nuclear Safety after three mile Island & Chernobyl, (New York, NY: Elsevier applied science, 1988) 293.

IVB1. Accuracy and adequacy of public education about radiation benefits and health effects

The accuracy and adequacy of public education is severely lacking. Science textbooks in K-12 gloss over the topic of radiation and briefly, if at all, mention nuclear power generation or medical diagnostics. Many teachers are ill prepared to teach the topic. Science textbooks widely used by schools in the US have been judged to be unsatisfactory.[60] Not one textbook commonly used by middle schools was rated satisfactory in a study carried out by an education reform project.

It was found in a recent BBC study that most textbooks covered too many topics and did not develop any of them well. The study was carried out by Project 2061, the long-term science, mathematics and technology education reform initiative of the American Association for the Advancement of Science (AAAS). A possible way to get the needed information to students is to have it prepared for them through academic, industry, and government (regulatory) support.

IVB2. Industry involvement

The relations between the American public and industry are not always good. However, in order for industry and the public to fully benefit from radiation, there must be increased involvement and awareness. The expertise that industry (nuclear, medical, agriculture, etc) has in radiation is vital to helping the public understand its importance, prevalence, and safety issues.

IVB3. Standards

The EPA and NRC both have valuable knowledge of radiation as well as its context. The standards that they hold for various doses is information that should be uniform and

[60] Shaw, P. BBC: Studies in Context. (London, England: Cambridge Press, 2002) 209.

readily available. However, asking for cohesion and agreement in their regulations or for a restructure to reduce duality might involve drawn out conflict.[61] Legislation for the more distant future should reexamine the roles of the NRC and EPA in radiation guidelines as well as some of the scientific models that, specifically the EPA, go by. Currently, their continued oversight over industry is vital in order for information on radiation to be received well.

IVB4. The combined effort

This knowledge mentioned about radiation and its health effects is publically available through many websites sponsored by industry, regulatory bodies, and other groups. In fact, the information, for the most part, is accurate and written to inform. However, the lack of understanding still exists. What can be done to bridge the gap? Based on research, the education should be not only in the form of online pamphlets for teachers, specifically middle school where physics is usually first discussed, but this information presented by volunteers from academia, industry, and regulatory bodies. As mentioned, the medical community has the face of someone we trust, our doctor. Radiation in general needs that face. Various federal government studies have shown that the presentation of material is just as important as the material itself especially when dealing with a socio scientific issue. After that trust in built in all fields, power, agriculture, medical, etc., can accurate information be disseminated. Increased understanding and frankness will hopefully build trust between industry, public, and government and most importantly, knowledge will help divert potential disasters and increase speed of technology advancements.

[61] Walker 76.

IVC. Concluding remarks

While radiation is a broad topic, the issue of radiation perception and confusion can also be address in a series of small steps. Increased public awareness and education through unified efforts by industry and the regulating bodies to present accurate, honest, and up to date information: both the benefits and the risks.

The many uses of radioactive materials and applications will continue to evolve. Whether one is for or against some of its uses, it is beneficial if we are properly informed about radiation. The uses of nuclear technology are many. Today's students need to understand the benefits and risks of radiation. Nuclear power generates twenty percent of the United States' energy and is potentially poised to provide more. Medical and industrial uses of radiation and nuclear materials are developing at a rapid pace. A society that knows how to utilize the radioactivity of the earth without unnecessary fear will be better able to recognize and mitigate the real risks while avoiding decisions that unnecessarily reduce the benefits.

Appendix

Table A: U.S. Approved Irradiated Foods[62]

Product	Date Approved
Wheat, Wheat Flour	1963
White Potatoes	1964
Spice and Vegetable Seasonings	1983
Pork	1986
Fruits and Vegetables	1986
Herbs, Spices	1986
Dehydrated Enzymes	1986
Papaya Fruit	1987
Poultry	1992
Red Meat Unfrozen	1999
Red Meat Frozen	1999
Eggs	2000

[62] United States Department of Agriculture. *Approved Irradiated Foods*, Washington: Government Printing Office, 2005.

Some foods become radioactive by absorbing naturally occurring radionuclides from surrounding soils in the form of potassium(^{40}K) or radium (^{226}Ra) totaling about .30 mSv/year.

Table B: Natural Radioactivity in Food[63]

Food	40K (pCi/kg)	226Ra (pCi/kg)
Bananas	3,520	1
Carrots	3,400	0.6 - 2
White Potatoes	3,400	1 - 2.5
Lima Beans (raw)	4,640	2 - 5
Red Meat	3,000	0.5
Brazil Nuts	5,600	1,000 - 7,000
Beer	390	---
Drinking Water	---	0 - 0.17

[63] Nuclear Regulatory Commission. *Food Radioactivity*, Washington: Government Printing Office, 2007.