

**A Small Dose of Radiation
Or
An Introduction to the Health Effects of Radiation**

A book chapter of
A Small Dose of Toxicology - The Health Effects of Common Chemicals

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Supporting web sites
web: www.asmalldoseof.org - "A Small Dose of Toxicology"
web: www.toxipedia.org - Connecting Science and People

Dossier

Name: Nonionizing Radiation

Use: power transmission, communication, LEDs, light bulbs, heating, cooking, microwave ovens, vision, lasers, photosynthesis (sunlight), mobile phones, WiFi, etc.

Source: Ultraviolet light, visible light, infrared radiation, microwaves, radio & TV, mobile phones, power transmission

Recommended exposure: different depending on source, i.e. sunlight can damage skin

Absorption: depends on source

Sensitive individuals: variable, e.g. fair skinned children (sunburn)

Toxicity/symptoms: Depends on source. Solar radiation: sunburn, cataracts, cancer; microwave radiation: warming of skin or internal organs; controversy exists around exposure to low frequency energy such as AC power lines.

Regulatory facts: government regulates exposure

FDA and FCC set a SAR limit of 1.6 W/kg for mobile phones.

General facts: long history of use

Environmental: Our dependency on energy results in a range of consequences, for example drilling for oil and mining coal to run power plants to generate electricity, in turn mercury is released in the atmosphere from burning coal.

Recommendations: depending on individual sensitivity; limit exposure to solar radiation (ultraviolet radiation); reduce energy consumption

Name: Ionizing Radiation

Use: nuclear power, medical x-rays, medical diagnostics, scientific research, cancer treatment, cathode ray tube displays

Source: Radon, x-rays, radioactive material produce alpha, beta, and gamma radiation, cosmic rays from the sun and space

Recommended daily intake: none (not essential)

Absorption: interaction with atoms of tissue

Sensitive individuals: children, developing organisms

Toxicity/symptoms: damages DNA leading to cancer

Regulatory facts: heavily regulated

General facts: long history of exposure to low levels

Environmental: many nuclear cleanup sites contain radioactive waste that must be moved off site to prevent possible leakage

Recommendations: limit exposure, monitor workplace exposure where applicable

Case Studies

Radium Girls

"Not to worry," their bosses told them. "If you swallow any radium, it'll make your cheeks rosy."

The women at Radium Dial sometimes painted their teeth and faces and then turned off the lights for a laugh.

From: 'Radium Girls' By Martha Irvine, Associated Press, Buffalo News, 1998

Marie Curie discovered radium in her laboratory in Paris in 1898. The unique properties of this naturally occurring radioactive element suggested to many that it had therapeutic uses. In the early 1900s radium therapy was accepted by the American Medical Association. Radium was thought to cure a range of illness including arthritis, stomach ailments, and cancer. Tonics of radium were available for oral consumption, to “bring the sun to your stomach,” as well as by injection. In reality, the alpha particle emissions of radium caused rather than cured cancer.

This cancer-causing effect of radium was realized only after the tragic plight of young women working as radium-dial painters in watch factories came to the public's attention. The use of radium to illuminate watch dials began before World War I and continued during the 1920s. U.S. Radium Corporation employed young women to paint radium on watch dials. The women used their lips to point the brushes. Each time they pointed their brushes, they ingested a small amount of radium. The radium moved to the bone where it continued to emit alpha radiation. The alpha radiation damaged the cells near the radium particle. As a result of their exposure to radium, many of these women develop painfully debilitating bone decay and died of cancer. The long half-life of radium combined with its sequestration in the bone resulted in lifetime radiation exposure. During the 1920s a group of these women sued Radium Corporation. Many of them were victorious in court and received a small amount of money, becoming the first to receive compensation for occupational injury. It is estimated that 4,000 people, mostly women, were occupationally exposed to radium as watch dial painters. This population formed the basis of several studies into the long-term effects of radiation. Their story was made into the movie "Radium City" (1987) and more recently a play. There is also an excellent book entitled *Radium Girls: Women and Industrial Health Reform, 1910-1935* by Claudia Clark.

Solar Radiation – Sunlight from warmth to sunburn

Sunlight is essential for life but, as with most things, too much can be harmful. The World Health Organization estimates that 2 to 3 million non-malignant skin cancers and

over 130,000 malignant melanomas occur globally each year. Ultraviolet (UV) radiation is the primary cause of skin cancer as well as many more acute cases of sunburn. Thinning of the atmospheric ozone layer, which filters much of the UV radiation, has increased the harmful effects of elevated UV exposure. UV exposure can increase the incidence of cataracts of the eye, reduce the effectiveness of the immune system, and accelerate the effects of aging. Skin damage is also common, particularly for fair skinned people exposed to too much UV radiation from the sun. Children need additional protection from the sun because their skin is more sensitive to the effects of UV radiation. Sunlight is necessary, however, because it stimulates the synthesis of Vitamin D, which is important in the metabolism of calcium.

Solar radiation is part of the electromagnetic spectrum of radiation. The wavelength of visible light is 400-760 nanometers (nm). Less than 400 nm is ultraviolet (UV) radiation and greater than 760 nm is infrared radiation, the heat of the sun. Our skin, the largest organ of the body, has naturally developed means to protect us from UV radiation. UV radiation stimulates the production of the melanin pigment, which absorbs UV radiation and protects the skin cells from damage. People with darker-colored skin have ongoing production of melanin and are better protected from damage than people with less skin color. There is considerable genetic variation in the production of melanin. Sunburn occurs when UV radiation damages a cell and the body responds by increasing blood flow, resulting in a reddish and hot presentation. UV radiation damages cellular DNA. Although the cells have built-in repair mechanisms, repeated DNA damage can result in skin cancer.

Chemicals in sunscreens work much like melanin to absorb UV radiation. The most common is para-aminobenzoic acid or PABA, but there are others. Most glass, but not clear plastic, will block UV radiation. Relatively simple measures, such as hats and clothing, will greatly reduce exposure. About 90% of UV radiation is reflected by snow, making snow blindness a significant concern.

UV radiation illustrates the basic the principles of toxicology in that individual sensitivity varies greatly and it is best to limit your dose (exposure) to control your response. The challenge is to understand and manage the risk and benefits of our individual exposure and resulting acute and long-term effects.

Microwave radiation, communication and your mobile phone

Mobile phones or cell phones are now an almost essential device with over 4 billion subscribers. The devices have become increasingly sophisticated with capabilities well beyond the simple phone call. These devices are now powerful computers with wireless internet access, global positioning, and many other features. From a toxicological perspective there are two primary concerns: 1) hazardous materials in the device that require proper disposal and 2) the potential health effects of the nonionizing radiation associated with data transmission. The billions of phones are now a serious source of pollution from an array of hazardous materials such lead, mercury, cadmium, PBDEs, and other materials. While a minimal hazard to the user, these material are significant environmental contaminants and are hazardous to people if not properly recycled.

The direct use-related health concern with mobile phones is associated with the nonionizing radiation used to transmit data to and from the device. These devices use radio waves or microwaves to transmit and receive information (electromagnetic waves with wavelengths ranging from 1mm - 1m, or frequencies between 0.3 GHz and 300 GHz). Nonionizing radiation is absorbed by the body and is standardized as the Specific Absorption Rate (SAR). In the United States, the Food and Drug Administration (FDA) and the Federal Communications Commission (FCC) share regulatory responsibilities related to mobile devices and set a SAR limit of 1.6 W/kg, averaged over a volume of 1 gram of tissue. In general, national and international governmental agencies do not believe that exposure to radiation from the use of mobile phones is related to any health effects. However, there is ongoing research on possible health effects, particularly those related to cancer. As a precaution, various devices can be used to keep the transmitter away from the head while using it for extended periods. There is also growing regulation regarding the use of mobile phones while operating a motor vehicle because the resulting distraction impairs concentration and reaction time.

Introduction and History

All life is dependent on small doses of electromagnetic radiation. Plants depend on small doses of radiation, living by converting this energy through photosynthesis to sustain them and in turn provide food for many of the earth's animals. We are surrounded by and depend on radiation-emitting devices, from the sun to our cell phones and radios, from medical x-rays to the electricity that powers our homes. There are many benefits from radiation-emitting devices, but we are still learning about some of the health effects. To effectively explore the health effects of radiation exposure, it is first necessary to examine the physics of radiation.

The electromagnetic spectrum is roughly divided into ionizing and nonionizing radiation (Figure 12.1). The distinction depends on the amount of energy carried by the radiation, which is directly related to the frequency of vibration of the electric and magnetic fields. When the frequency (and hence energy) is high enough, the radiation can separate electrons from atoms, ionizing the material it passes through. Nonionizing radiation includes ultraviolet, visible, infrared, microwaves, radio & TV, and power transmission. We depend on the sun's radiation for photosynthesis and heat. Ionizing radiation includes high-energy radiation such as cosmic rays, x-rays or gamma rays generated by nuclear decay. Ionizing radiation also includes several types of sub-atomic particles such as beta radiation (high energy electrons) and alpha radiation (helium ions) and others. Medical x-rays are an example of a common beneficial exposure to ionizing radiation. Nuclear radiation is used to generate electricity and cure disease, but is also an important element in military weapons. Uses of nuclear radiation pose serious issues of human exposure and environmental contamination.

The understanding and subsequent use of various forms of radiation provide a fascinating window into human civilization. The cave dwellers were probably the first to manage radiation when they learned to control and use fire. The control and use of electricity was another huge step forward. But the turn of the twentieth century really marked the beginning of rapid progress in the understanding and harnessing of the power of radiation. This period also ushered in a growing understanding of the potential adverse effects of radiation exposure. In 1903, Marie Curie and Pierre Curie, along with Henri Becquerel, were awarded the Nobel Prize in physics for their contributions to understanding radioactivity, including the properties of uranium. To this day, the "curie" and the "becquerel" are used as units of measure in radiation studies. In 1895, Wilhem Conrad Roentgen discovered X-rays, and in 1901 he was awarded the first Nobel Prize for physics. These discoveries lead to significant advances in medicine. Work by Enrico Fermi and others lead to the first sustained nuclear chain reaction in a laboratory beneath the University of Chicago football stadium on December 2, 1942. Subsequently, this knowledge was used to develop the atomic bombs that were dropped on Japan in an effort to end World War II. Much of our understanding of the effects of nuclear radiation exposure has come from the victims in Japan as well as the many workers in uranium mines.

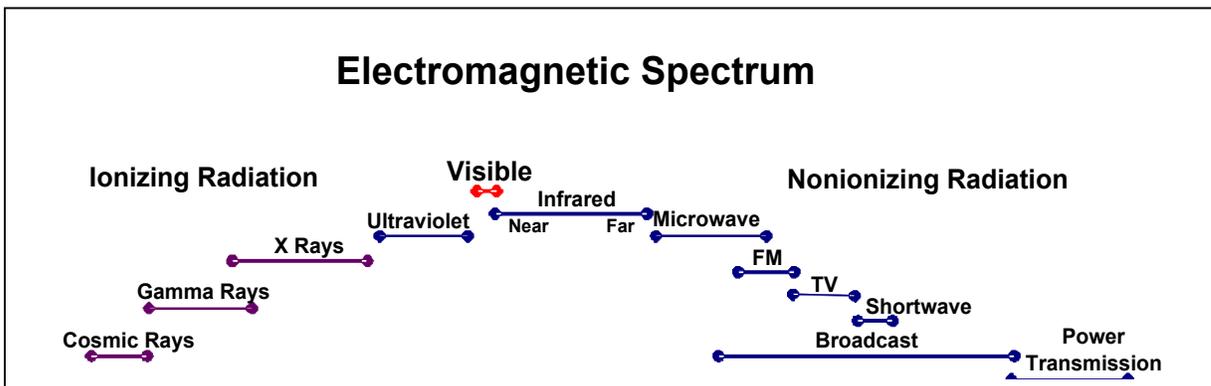


Figure 12.1 Electromagnetic Spectrum

Biological and Physical Properties

Nonionizing radiation

Nonionizing radiation has less energy and in general is less interactive with biological material than ionizing radiation. We are surrounded by energy from devices and products that emit nonionizing radiation. For example, radio and TV transmission surround us but do not significantly interact with our bodies. Light bulbs convert electrical energy into visible light and heat, all forms of nonionizing radiation.

On the other hand, a microwave oven is designed to interact with biological material to produce heat. The microwave energy readily passes through paper, glass, and plastic but

is absorbed by water molecules in food, causing them to vibrate, which heats the material. The microwave oven generates enough energy to be potentially harmful without appropriate shielding. Government regulations are in place to limit the amount of energy leakage permitted from a microwave oven. Note that the interaction of microwaves with human tissue is not through ionization but rather heating.

Around our home we are exposed to a variety of different types of radiation. Home appliances such as hair dryers emit electromagnetic radiation. Our TVs and computer monitors expose us to additional electromagnetic radiation, as do our cell phones and radios.

Table 12.1 Products that depend on nonionizing radiation

- Mobile/Cellular phones
- Mobile/Cellular telephone base stations
- Radio towers
- Microwave towers
- Lasers (including laser pointers)
- Magnetic Resonance Imaging (MRI)
- Radio transmissions (am or fm)
- TV transmissions
- Short-wave radio transmissions
- Satellite transmissions
- Electrical blankets
- Appliances
- Light bulbs
- Computer and TV monitors
- Microwave ovens
- Power lines (both large and small)
- Visible light
- Ultraviolet radiation
- Radar
 - WiFi networks

Ionizing radiation

Ionizing radiation has sufficient energy to produce ion pairs as it passes through matter that is it frees electrons and leaves the rest of the atoms positively charged. In other words, there is enough energy to remove an electron from an atom. The energy released is enough to break bonds in DNA, which can lead to significant cellular damage and cancer. The health effects and dose / response relationship for radiation exposure are well

established from human exposures to radiation and from other research. The four main types of ionizing radiation are alpha particles, beta particles (electrons), gamma rays, and x-rays.

Alpha particles are heavyweight and relatively low-energy emissions from the nucleus of radioactive material. The transfer of energy occurs over a very short distance of about 10 cm in air. A piece of paper or layer of skin will stop an alpha particle. The primary hazard occurs in the case of internal exposure to an alpha-emitting material. Cells close to the alpha-particle-emitting material will be damaged. Typical sites of accumulation include bone, kidney, liver, lung, and spleen. Radium is an alpha-particle emitter that when ingested accumulates in the bone, causing a bone sarcoma.

Airplane travel increases our exposure to cosmic and solar radiation that is normally blocked by the atmosphere. Radiation intensity is greater across the poles and at higher altitudes, thus individual exposure varies depending on the route of travel. Storms on the sun can produce solar flares that can release larger amounts of radiation than normal. For the occasional traveler this radiation exposure is well below recommended limits established by regulatory authorities. However, frequent fliers and airline workers can be exposed levels of radiation that exceed established guidelines.

Sources of ionizing radiation or exposed populations:

- Medical x-ray devices (patients, medical workers)
- Radioactive material producing alpha, beta, and gamma radiation (Laboratory workers, hospital workers, patients)
- Cosmic rays from the sun and space (Airplane travelers)

Radiation Units

The units used to describe exposure and dose of ionizing radiation to living material are confusing, at best. First, the units have changed to an international system, SI, which stands for Systeme Internationale. We will use the SI system, but the table below compares the SI system with the older system.

The fundamental descriptive unit of ionizing radiation is the amount energy, expressed in Coulombs per kilogram of air, and is the unit of exposure in air. The absorbed dose is the amount of energy absorbed by a specific material such as the human body and is described as the Gray (Gy), previously the Rad. The energy transfer of the different particles and gamma rays is different. A weighting factor is used to allow comparison between these different energy transfers. The unit for the equivalent dose is the Sievert (Sv). A further refinement is possible that applies a weighting factor to each type of tissue. Recommended limits on radiation exposure are expressed in Sv (Table 12.2).

Table 12.2 Measures of Radiation Energy

Item	Previous Unit	SI Unit	Ratios
Activity (i.e. quantity rays or particles)	Curie (Ci)	Bequerel(Bq)	1 Ci = 3.7×10^{10} Bq 1 mCi = 37 MBq 1 μ Ci = 37 KBq
Exposure	Roentgen (R)	X (Coul/kg)	1 R = 2.58×10^{-4} coul/kg
Absorbed Dose	Rad	Gray (Gy) Gy = 1 J/kg	1 Gy = 100 rad 1 rad = 10 mGy
Equivalent Dose	Rem	Sievert (Sv)	1 Sv = 100 Rem 1 rem = 10 mSv

m = milli = 1/1000

SI = international system of units (Systeme Internationale)

Health Effects

We are constantly exposed to ionizing and nonionizing radiation from natural occurring sources as well as radiation generated and managed by our society. The challenge is to understand and manage the risk and benefits of our individual exposure.

Nonionizing radiation

We are surrounded by nonionizing radiation, the majority of which does us no harm. The visible light from the sun, the in-house light bulbs, radio and TV transmissions, and electric appliances all contribute to our background exposure to nonionizing radiation. Most evidence indicates that this radiation is harmless, although some studies have found possible effects. However, at higher levels and longer durations of exposure, nonionizing radiation can be harmful.

The classic example is sunlight or solar radiation. Ultraviolet radiation from the sun, part of the electromagnetic spectrum with wavelengths less than 400 nm, can damage the skin. Sunburn (erythema) is the result of excessive exposure of our skin to UV radiation when we lack the protection of UV absorbing melanin (see case study above). Acute cellular damage causes an inflammatory type response and increased vascular circulation (vasodilation) close to the skin. The increased circulation cause the redness and hot feeling to the skin. Lightly pressing on the skin pushes the blood away and the spot appears white. Darker-skinned people have an ongoing production of melanin, which protects them to some extent from UV radiation. In lighter-skinned people, UV radiation stimulates the production of melanin, producing a tan and protection against UV radiation. Extreme exposure can result in blistering and severe skin damage. UV radiation can also damage cellular DNA. Repeated damage can overwhelm the DNA repair mechanism, resulting in skin cancer. Skin cancer accounts for approximately one-third of all cancers diagnosed each year. Thinning of the atmospheric ozone layer, which filters UV radiation, is suspected as being one cause of the increased incidence of skin cancer. Wearing protective clothing can reduce UV radiation exposure. Sunscreen locations

contain chemicals that absorb the UV radiation as does melanin. Solar radiation is a classic example of the principle of toxicology: beware of individual sensitivity and dose yourself in a way that limits any adverse response.

The use of microwave and radio-frequency (MW/RF) devices has grown dramatically in the past 20 years. The most popular consumer products are microwave ovens and cell or mobile phones. MW/RF radiation is also used in a wide range of commercial application such as radar, solder machines, welders, heat sealers, drying equipment, glue curing and others. In biological tissues microwave radiation produce heat. A warming sensation can be felt on the skin or even internal organs and body temperature can be raised.

Microwave ovens must comply with government standards to minimize exposure. Cell phones use low level radio-frequency energy that is well below a level that would warm tissue, but there is ongoing research on effects related to chronic exposure. In the United States, the Food and Drug Administration (FDA) is responsible for protecting the public from radiation from microwave ovens, television sets, computer monitors, and cell phones. The FDA and the Federal Communications Commission (FCC) share regulatory responsibilities related to mobile devices and set a SAR limit of 1.6 W/kg.

Ionizing radiation

Ionizing radiation is more harmful than nonionizing radiation because it has enough energy to remove an electron from an atom and thus directly damage biological material. The energy is enough to damage DNA, which can result in cell death or cancer. The study of ionizing radiation is a large area of classical toxicology, which has produced a tremendous understanding of the dose/ — response relationship of exposure. The primary effect of ionizing radiation is cancer. It can also affect the developing fetus of mothers exposed during pregnancy. Radiation exposure has a direct dose – response relationship: the more radiation you receive the greater your chance of developing cancer.

Our knowledge of the effects of radiation developed gradually from tragic experience over the last century. Early in the century, researchers such as Marie Curie died of cancer presumably related to her radiation exposure. At the time some writers even extolled the virtues of people dying to advance the cause of science. Occupational exposure was another tragic learning environment. Young women employed to paint radium on watch dials died from bone cancer in the 1920s and 1930s (see above case study). During this time radium was promoted as a cure of many maladies and even recognized by the American Medical Association. We had a lot to learn.

From uranium miners we learned of the hazards of radon exposure. Radon is a radioactive gas that is present in the uranium mines, as well as in high concentration in the soil in some places. Radon exposure results in lung and esophagus cancer. The actual carcinogens are daughter products of radon that adhere to the internal tissue and emit alpha particles. While excess cancer in mine workers is well established, there is considerable concern about the effects of lower-level chronic exposure that might be found in homes, particularly in the basement (see chapter on Cancer and Genetic Disease).

A great deal was learned from the atomic bomb survivors. The U.S. military dropped the first atomic bomb on Hiroshima, Japan on August 6, 1945 and a second on Nagasaki, Japan, three days later. The bombs used two different types of radioactive material, ^{235}U in the first bomb and ^{239}Pu in the second. It is estimated that 64,000 people died from the initial blasts and radiation exposure. Approximately 100,000 survivors were enrolled in follow-up studies, which confirmed an increased incidence of cancer.

X-rays were also used to treat disease. From 1905 to 1960 x-rays were used to treat ringworm in children. Well into the 1950s x-rays were used to treat a degenerative bone disease called ankylosing spondylitis.

The primary lesson learned in all these is that the greater the dose, the greater the likelihood of developing cancer. The second lesson was that there could be a very long delay in the onset of the cancer, from 10 to 40 years. It should be remembered that we evolved with a background exposure to naturally occurring ionizing radiation, and we continue to be exposed to low levels of natural background radiation. Some have estimated that 1 in 100 cancers are the result of this background exposure.

Reducing Exposure

Three ways to reduce exposure to radiation are:

- **Time**
Limit the amount of time you spend near the source of radiation. One of the easiest examples is that you avoid getting sunburned by limiting the amount of time in bright sunlight. This same principle applies to ionizing radiation such as a radioactive material.
- **Distance**
Increase your distance from the source of radiation. Emissions from the source of radiation decrease in intensity rapidly.
- **Shielding**
The effectiveness of shielding depends on the type of radiation and the shielding material itself, but in general placing absorbent shielding material between you and the radiation source reduces exposure. This can be as simple as wearing a hat to protect your face from the sun or using a lead apron in the dentist's chair to shield other parts of your body from the dental x-rays.

Regulatory Standards

The first organized effort to protect people from radiation exposure began in 1915 when the British Roentgen Society adopted a resolution to protect people from X-rays.

In 1922 the United States adopted the British protection rules and various government and nongovernmental groups were formed to protect people from radiation. In 1959, the Federal Radiation Council was formed to advise the president and recommend standards. In 1970 the U.S. Environmental Protection Agency was formed and took over these responsibilities. Now several government agencies are responsible for protecting people from radiation-emitting devices.

Standards for Radiation Exposure

Recommended exposure limits are set by the U.S. National Council on Radiation Protection (NCRP) and worldwide by the International Council on Radiation Protection (ICRP). The occupational exposure guidelines are 100 mSv in 5 years (average, 20 mSv per year) with a limit of 50 mSv in any single year. For the general public the standard is 1 mSv per year. This must be put in the context of natural background radiation, which is approximately 3 mSv/year depending upon location (such as elevation) as well as other variables. [Do you mean to say that the general public standard is 1 mSv over and above the typical background? Otherwise it sounds like everyone is already getting three times the standard. Clarify.]

Recommendation and Conclusions

We evolved in an environment of natural radiation from the solar energy of the sun to radioactive elements. Radiation is described by the electromagnetic spectrum in terms of wavelength and frequency. A further division is made between ionizing and nonionizing radiations. Ionizing radiation has sufficient energy remove electrons, thus the ability to directly damage biological tissue. During the past century we have learned how to exploit the electromagnetic spectrum for many useful purposes (and some not so useful) and along the way learned about some of the hazards of radiation exposure.

Some radiation is helpful and necessary, as in the case of sunlight, which allows us to see the world. The nonionizing radiation of the sun warms us, but too much ultraviolet radiation can cause sunburn or cancer depending on our individual sensitivity. There is clearly a dose — response relationship between exposure and effect, with individual sensitivity playing an important role. Microwave and radio-frequency radiation are incredibly useful in heating and in transmitting information.

Ionizing radiation is far more dangerous than nonionizing radiation because it can directly damage cellular DNA and proteins, causing cell death or possibly cancer. Ionizing radiation is divided into alpha and beta particles and gamma rays. Each has its unique characteristics, which require different safety approaches. In general, the more radiation exposure a person receives, the greater the likelihood of cancer. Thus a precautionary approach that limits radiation exposure is best.

More Information and References

Slide Presentation

A Small Dose of Radiation presentation material and references online:
<http://www.toxipedia> or <http://www.toxipedia.org/display/dose/Radiation> .

Web site contains presentation material on the health effects of radiation.

European, Asian, and International Agencies

- Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).
Online: <<http://www.arpansa.gov.au/>> (accessed: 5 May 2009).
ARPANSA is “charged with responsibility for protecting the health and safety of people, and the environment, from the harmful effects of ionizing and non-ionizing radiation”.
- England – Health Protection Agency (HPA) - Centre for Radiation, Chemical and Environmental Hazards. Online: < <http://www.hpa.org.uk>> (accessed: 5 May 2009).
The radiation section of HPA does research, provides information and advice on the effects of radiation on humans and the environment.
- World Health Organization (WHO) - Ultraviolet radiation. Online: <http://www.who.int/health_topics/ultraviolet_rays/en/> (accessed: 5 May 2009).
Site contains information on the global efforts to reduce UV (sun-light) radiation exposure.

North American Agencies

- Health Canada – Radiation Protection Bureau. Online: < <http://www.hc-sc.gc.ca/>> (accessed: 5 May 2009).
Health Canada provides information on the health effects radiation for consumer and clinical radiation protection.
- US Centers for Disease Control and Prevention (CDC) National Center for Environmental Health. Online: <<http://www.cdc.gov/nceh/>> (accessed: 5 May 2009).
This site contains information on health effects and emergency response to radiation exposure.
- US Environmental Protection Agency (EPA) - Radiation Protection. Online: <<http://www.epa.gov/radiation/>> (accessed: 5 May 2009).
This site has a tremendous amount of information on ionizing and nonionizing radiation and environmental contamination.
- US Environmental Protection Agency (EPA) - Radiation Protection - Calculate Your Radiation Dose. Online: <<http://www.epa.gov/radiation/understand/calculate.html>> (accessed: 5 May 2009).

This site shows you how to examine your current exposure to radiation.

- US Food and Drug Administration – Center for Devices and Radiological Health. Online: <<http://www.fda.gov/cdrh/radhealth/>> (accessed: 5 May 2009). This site contains information on the health effects and regulation of radiation emitting devices and products. The mission of the CDRH radiological health program is to protect the public from hazardous or unnecessary radiation emissions from electronic products.
- U.S. Food and Drug Administration – Cell Phones. Online: <<http://www.fda.gov/cellphones/>> (accessed: 5 May 2009). Site contains general and regulatory information on cell phones and related technology.
- US Federal Communications Commission (FCC) – Office of Engineering and Technology – Radio Frequency Safety. Online: <<http://www.fcc.gov/oet/rfsafety/>> (accessed: 5 May 2009). The FCC is required “to evaluate the effect of emissions from FCC-regulated transmitters on the quality of the human environment”.
- US Department of Labor, Occupational Safety & Health Administration (OSHA), Radiofrequency and Microwave Radiation. Online: <<http://www.osha.gov/SLTC/radiofrequencyradiation/>> (accessed: 5 May 2009). The OSHA site contains information on microwave and radio-frequency devices.
- US New Jersey - Nonionizing Radiation Section. Online: <<http://www.state.nj.us/dep/rpp/>> (accessed: 5 May 2009). New Jersey has an excellent with a wide range of information on radiation.
- US Agency for Toxic Substance Disease Registry (ATSDR). Online. <<http://www.atsdr.cdc.gov/>> (accessed: 5 May 2009). See fact sheets ToxFAQs™ and case studies in environmental health.
- US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Air Resources Laboratory. Online: <<http://www.arl.noaa.gov/>> (accessed: 5 May 2009). Site contains UV radiation monitoring information for the U.S.
- US Nuclear Regulatory Commission (NRC). Online: <<http://www.nrc.gov/>> (accessed: 5 May 2009). “The NRC regulates U.S. commercial nuclear power plants and the civilian use of nuclear materials.”

Non-Government Organizations

- National Council on Radiation Protection and Measurements (NCRP). Online: <<http://www.ncrp.com/>> (accessed: 5 May 2009).
“The NCRP seeks to formulate and widely disseminate information, guidance and recommendations on radiation protection and measurements which represent the consensus of leading scientific thinking.”
- Health Physics Society. Online: <<http://www.hps.org/>> (accessed: 5 May 2009).
Site has extensive information about the health physics and radiation protection.
- University of Michigan - Radiation & Health Physics. Online: <<http://www.umich.edu/~radinfo/>> (accessed: 5 May 2009).
Site contains information “written for three distinct groups: the General Public, Students and the Health Physics community at large.”
- Washington Nuclear Museum and Educational Center (WANMEC). Online: <<http://www.wanmec.org>> (accessed: 5 May 2009).
WANMEC provides information on the history of nuclear material use in the state of Washington.

References

Radium Girls: Women and Industrial Health Reform, 1910-1935
by Claudia Clark, Publisher: University of North Carolina Pr; ISBN: 0807823317; (June 1997). 384 pages.