RADIATION: ORIGIN, USES, RISKS, WASTES

John K. Sutherland.
Fredericton, New Brunswick, Canada

Keywords

Radiation, Radioactivity, Radioactive Wastes, Radiation Uses, Radiation Dose, Radiation Effects, Health Effects.

Contents

Glossary

Bq	Becquerel. A unit indicating one atomic decay disintegration each second.
CANDU	CANadian Deuterium (natural) Uranium
CNS	Central Nervous System syndrome following a massive acute radiation exposure
Curie	Named after Pierre Curie to describe the assumed radioactivity of one gram of radium, or radon gas in equilibrium with it, and subsequently fixed as 3.7E10 becquerels (Bq).
DNA	Deoxy riboNucleic Acid
GI	Gastro-Intestinal syndrome following a massive acute radiation exposure
Gy	gray, non-measurable SI unit of absorbed dose, influenced by incident radiation energy, radiation type, and density of the absorbing medium.
HLW	High Level Waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate Level Waste
LET	Linear Energy Transfer
LILW	Low/Intermediate Level Waste
LLW	Low Level Waste
LNT	Linear, No Threshold hypothesis concerning radiation and other 'toxic' agents
:Sv	microsievert, one millionth of a sievert
mGy	milligray, one thousandth of a gray
MMR	measles, mumps, rubella vaccine
mSv	millisievert, one thousandth of a sievert
N	Undefined quantity (ICRP) which may be used in the future in the derivation of 'dose equivalent' from 'absorbed dose'.
NORMS	Naturally Occurring Radioactive Materials
NRPB U.K.	National Radiological Protection Bureau

QF	Quality Factor - estimated and poorly defined quantity - to derive 'dose equivalent' radiation effect to tissue from different radiations
roentgen (R)	Quantity of radiation induced ionization in air of 2.58E-04 coulombs per kilogram
RIA	Radio-Immuno-Assay, in vitro use of radionuclides in Nuclear Medicine
RTG	Radio-isotope Thermo-electric Generator (for example plutonium-238)
SIT	Sterile Insect Technique method of eliminating certain insect populations
SNAP	Systems for Nuclear Auxiliary Power (Nuclear Space Reactors)
Sv	sievert, non-measurable unit of dose equivalent
TE-NORMS	Technologically Enhanced NORMS
TLD	Thermo-Luminescent Dosimeter, used to derive a measure of radiation dose
TV	Television
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

Summary

This article examines the general subject of radiation and radiation uses throughout society. It provides an overview of the major sources of radiation; natural, cosmic, terrestrial, and touches upon man made sources of radiation. A simple definition of radiation dose is briefly described. A brief outline of the history of radiation discovery and uses, traces the beginnings of the very broad uses of medical and industrial radiation from the pioneering work of Roentgen and Becquerel and the Curies. Some indication of common radiation doses to the public and society from the many various radiation uses, some of which are tabulated, is detailed, along with an indication of approximate proportions of the dose contributed by nature, medicine and industry. A logarithmic scale of radiation doses provides some perspective of the immense range of doses that occur throughout any advanced society.

The article continues with a description of what radiation is and how it is defined. Some examination of defined, empirical radiation effects upon human health is provided through reference to the most recent scientifically-defensible health studies throughout the world. These practical empirical data on extremely large populations and radiation worker groups, show how generally erroneous and socially damaging, are most of our assumptions of radiation risks.

The differences between chronic and acute radiation effects upon cells and their ability to make repairs is touched upon as well as a discussion of the significant failings of the LNT hypothesis which unsatisfactorily governs all aspects of radiation protection at this time.

1. RADIOACTIVITY AND RADIATION USES

1.1 Introduction

We are surrounded by natural radiation. Life evolved in an environment that was considerably more radioactive than at the present time, and much of our evolutionary progress probably came about because of it.

Man-made radiation has been used in society for many purposes, mostly in medical diagnoses and treatments since the discovery of X-rays in 1895. Our general high quality of life owes much to these uses. Despite its widespread use and great value in society over the last 100 years, radiation is poorly understood or appreciated by the general public, and the subject of radiation and its presumed adverse effects is frequently misused to deliberately arouse public fears and concerns.

Any attempt to describe how radiation is used or managed through society, especially concerning the subject of how we handle or manage radioactive waste, should first cover the basic subject of radiation. This describes what it is, where it arises, how we use it for the benefit of society, dose measurements, a comparison of risks versus benefits, what is implied by dose, magnitudes of dose, what its effects are, how dangerous it is and how we protect ourselves and to what degree and with what success.

1.2 Radiation in Society

In any ranking of relative risks throughout any advanced society in which all significant risks to humanity are identified and ranked based upon their effects upon public health, radiation - even at levels well above those typically encountered in nature or industry - falls near the bottom of the ranking.

All of humanity and all life on this planet are unavoidably exposed to natural radiation. Those of us fortunate enough to live in developed societies are also exposed to medical radiation when we undergo routine diagnostic evaluations, dental X-rays, or receive radiation therapy treatments for more serious health problems. Most of us are also exposed to small amounts of radiation associated with items in our homes and society: TVs, smoke detectors, luminous watches, uranium-glazed plates etc, and even the air filters on our cars, air systems in our houses, and vacuum cleaners, as well as lint traps in clothes dryers. All of these concentrate radon daughters (see Figure 2) that are pulled onto the filters and are trapped.

There is an extremely wide range of natural radiation environments throughout the world and a similar large range of natural radiation doses. In addition, millions of medical patients throughout the world undergo life-saving radiation diagnostic and therapy treatments using extremely large doses of radiation, often thousands of times those encountered in nature or the nuclear industry.

Some typical radiation doses which occur all around us, and which are shown in Table 1, indicate the considerable range of radiation exposures in nature, as well as in numerous medical treatments.

Table 1. Typical Individual Annual Radiation Doses (very Approximate) and Recommended Radiation Protection Quantities

	Annual dose (mSv)
'Average' natural radiation background in the world	3 to 5
Typical range in natural background	2 to 1000
Extreme values in natural background in some home basements and mines	Up to 10 000
Recommended regulatory annual occupational primary dose limit of 100 mSv maximum in 5 years for designated radiation workers	**20 average; no more than 50 in one year of the five**
Typical average and upper radiation dose received by radiation workers	2 to 20
Recommended regulatory public dose limit from industrial exposures	**1**
Typical dose to the public who live near a nuclear power facility	0.002 to 0.02
Average individual dose (approx.) to world population from nuclear power	0.000 01
Maximum estimated individual dose from all future nuclear waste disposal	0.000 000 1
	'One-time' individual dose (mSv)
Range in public diagnostic medical radiation doses (approximate)	0.01 to 100*
Range in public cancer therapy doses (approximate)	20 000 to 100 000*
Single medical CAT scan	10 to 60*
Single dental X-ray 1990 (TLD-measured data of about 100 dentists - Canada)	2*

* These are acute doses, the rest are chronic. In 1966 an average dental X-ray gave a dose of about 20 millisieverts (mSv).

The magnitude of a few natural and medical radiation exposures, and doses from some industrial uses of radiation throughout society are shown in Table 2 on a logarithmic scale. They span a range that could not be readily covered by a linear scale representation.

Table 2. Abbreviated Logarithmic-Scale of Typical Radiation Doses

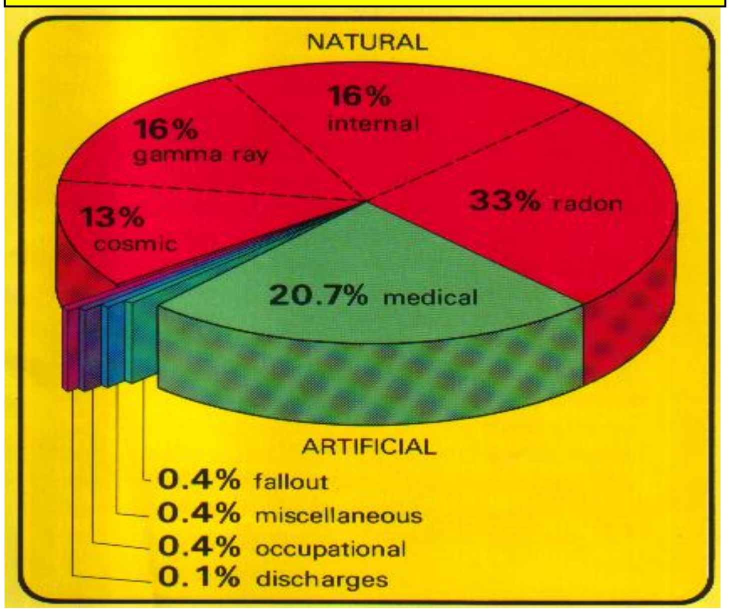
Grays/Sieverts	
100 000	
	Commercial sterilization of meat, poultry, special hospital foods and foods for cosmonauts and some military.
10000	
	Region of food irradiation. U.S. FDA now approves meat for irradiation (1997). Poultry was approved in 1990.
1000	
100	Typical acute dose to destroy the thyroid in radiation therapy.
	Area of chronic lifetime doses from high natural background.
	Region of radiation-therapy treatments.
10	Hospital Leukemia treatment (10 Sv acute) - 85 percent successful.
1	*900 mSv - Annual chronic dose in high natural background areas*
milli-sieverts	*200 mSv: Annual dose to many health spa workers.*
100	*100 mSv: Radiation worker occupational Dose Limit over 5 years.*
	50 mSv: Radiation worker occupational Annual Dose Limit.
	Two weeks dose on a beach in Brazil (about 15 mSv).
10	
	Typical natural background annual dose (3 - 5 mSv).
1	*1 mSv a^{-1}: Recommended Public Dose limit from Industrial Radiation.*
	Most medical diagnostic doses fall in the range from
0.1	0.01 to 5 mSv.
	Local dose from natural radiation from burning coal.
0.01	*Annual dose from luminous signs, TV, smoke detectors.*
0.001	*Dose to local residents from radioactive emissions from nuclear power plants.*
0.000 000 01	*Maximum annual ingestion dose from a failed geological repository for radioactive nuclear waste (same as for a rich uranium ore-body).*

ACUTE doses are shown in normal font. *CHRONIC doses are shown in italics.*
Occupational or General Public Dose Limits do not apply to medical patients undergoing medical radiation treatments. *Sutherland*

1.3 Sources of Radiation Dose

On average we receive about 75 percent or more of our entire radiation dose of about 5 millisieverts each year from nature; about 25 percent or more from medical treatments; and less than 1 percent from all industrial exposures, with less than about 0.1 percent from all nuclear power facilities throughout the world as shown in Figure 1 and Table 1. The populations in non-developed, third world countries do not receive the same benefits from medical radiation uses, as do those of us who live in developed countries.

Figure 1. Sources of Radiation Exposure. IAEA



The average is an extremely misleading value. There are hundreds of millions of people who live in parts of the world (Kerala, Iran, S. France, parts of Brazil, health spa regions, U.S. and Canadian Rockies, Cornwall England, etc.) where natural background radiation is unusually high, and may reach in excess of 1000 millisieverts per year.

Individuals who require heroic radiation treatments to combat cancer, may be subjected to doses that may reach about 100 000 millisieverts of acute dose. Their medical radiation dose in any year of treatment could be as high as 99 percent and more of their total radiation exposure from all sources including the treatment. These tens to hundreds of thousands of individuals are also the most highly exposed individuals in the world, receiving acute doses that are thousands of times larger than those doses - usually chronic - that are permitted for industrial radiation workers in any nuclear related industry.

Although this extremely large group of individuals would also represent the most fruitful population for an epidemiological evaluation of adverse health risks relative to radiation dose, they are generally ignored. Part of the reason for this is that their medical doses are not controlled by regulatory laws. There is no legal requirement that they be reported, and the data are neither routinely collected nor recorded or compiled in any common database at this time, though they affect millions of people.

The groups generally used for epidemiological evaluations are those who are employed in the various regulated industries which handle and use radiation, but who are subject to stringent dose limits, detailed dose accounting, and who receive relatively low doses. These are not the best population for evaluating health risks from radiation exposures. At the other extreme - those who receive the least radiation doses - are many nuclear submariners. Despite living intimately with a ship-board nuclear reactor - from which they receive little dose - they are shielded from all cosmic and terrestrial radiation for many months at a time when submerged. Unfortunately, any adverse health effects in this group of individuals would probably be initially attributed to the nuclear reactor, rather than to their unusually low radiation doses and other work-related issues.

An indication of the sources of greatest collective dose to the world's population is shown in Table 3. Population collective dose is used as a means of comparing contributions to collective dose totals. It should not be misused to try to indicate relative health effects or detriment from these contributions, though there have been attempts to misuse it in this way by certain special interest groups, though only by avoiding the perspective that is shown by the relative contributions in the table.

Table 3. Average Radiation Doses and Collective Dose at Year 2000 from some Natural and Man-Made Sources of Radiation (Most Data are from UNSCEAR 2000) Expressed in Millisieverts (mSv) and Person Sieverts

Radiation source	Worldwide* average annual effective dose (mSv)	Collective annual dose (person sieverts) over a world population of 6 billion
Natural background	2.4	14,000,000
Diagnostic medical examinations	0.4*	2,400,000
Atmospheric nuclear testing (ended)	0.005 (decreasing)	30,000
Chernobyl accident (one time)	0.002 (decreasing)	12,000
Coal burning	0.02 - 0.2	120,000 to 1,200,000
Nuclear power production	0.0002	1,200

* Worldwide averaging of data including those from undeveloped nations causes an understatement of medical exposure contributions in the populations in developed nations and an over-estimate of medical exposure contributions in undeveloped nations.

1.4 Units of Radiation Dose

The only scientifically measured or definable radiation measurement is the roentgen (R), defined as ionization in air of 2.58E-04 coulombs.kg^{-1}. Usually the roentgen is measured by use of an ionization extrapolation chamber, or thimble ion chamber of defined volume and character. The units of dose, the gray and the sievert are unsatisfactorily derived from it through the application of poorly defined secondary factors, such as the Quality Factor and others ('N') which might be defined in the future.

The basic units of radiation dose are the gray (Gy) and the sievert (Sv) as defined in Table 4. They cannot be scientifically measured in any direct way. These represent extremely large radiation doses to which very few people outside of hospital treatments might be exposed, and the units most often used are the milligray and millisievert. The gray is used generally to describe an assumed absorbed dose in any material exposed to radiation, as for example in the radiation sterilization of hospital materials such as gauzes, syringes and surgical materials; foods such as certain ground meats which may contain undesirable levels of bacteria; certain exported products such as lumber, which may contain insect pests; and sterilization of sewage at some international airports to kill tropical pathogens and parasites.

The sievert, millisieverts, and microsieverts are used to describe the presumed absorbed dose in human or other living tissue, as it cannot be directly measured. When this absorbed dose is corrected by a Quality Factor (QF) which makes approximate allowance for differences in linear energy transfer (LET) and presumed damage to tissue from different radiations, it is known as 'dose equivalent'. Most radiation meters used in radiation protection attempt to measure absorbed dose from a range of photon energies, but may display the units as either milligrays or millisieverts per hour. As the most commonly-encountered and readily-detected radiation is from photons, with a stipulated Quality Factor of one, no serious discrepancy seems likely to arise.

Table 4. Radiation Absorbed Dose and Dose Equivalent Definitions

Unit of Dose*	**Definition**
Gy (gray) the base unit of absorbed dose	The absorption of 1 joule (J) of energy in 1 kilogram of any material.
Sv (sievert) the base unit of Dose Equivalent (H)	The absorption of 1 joule of energy in 1 kilogram of tissue, where the Quality Factor (QF) is one.

* A gray and a sievert are not directly measurable. They are exceptionally large radiation doses that are encountered by the public usually only in medical treatments. Millisieverts (mSv) and microsieverts (:Sv) are the sub-units more commonly used in radiation protection. In terms of the older units the rad and the rem, the gray is equivalent to 100 rads, and the sievert is equivalent to 100 rems.

1.5 Natural Radionuclides

Everything in society is naturally radioactive to some degree. There are approximately 100 naturally occurring radionuclides surrounding us in our food, air, water, soil, rocks and building materials as indicated in Table 5, and schematically for uranium-238 in Figure 2 and appendix 2. These occur in Naturally Occurring Radioactive Materials or NORMS. The top 10 centimetres of soil on a typical one-hectare property anywhere in the world contains approximately 4 and 12 kilograms of naturally occurring uranium and thorium respectively, and all of their radioactive progeny.

Human activities in the past have occasionally concentrated some of these radionuclides and created materials that had elevated levels of radiation. These are known as Technologically Enhanced NORMS (TE-NORMS) indicated in Table 6. Most of these were regarded as wastes simply because no value or purpose for them was evident. This changed about the mid 1800s, when uranium - a byproduct of mining for other metals - began to be used as an additive to crockery glazes, producing various bright colors; to glass, producing a pale green color; or used for tinting in early photography.

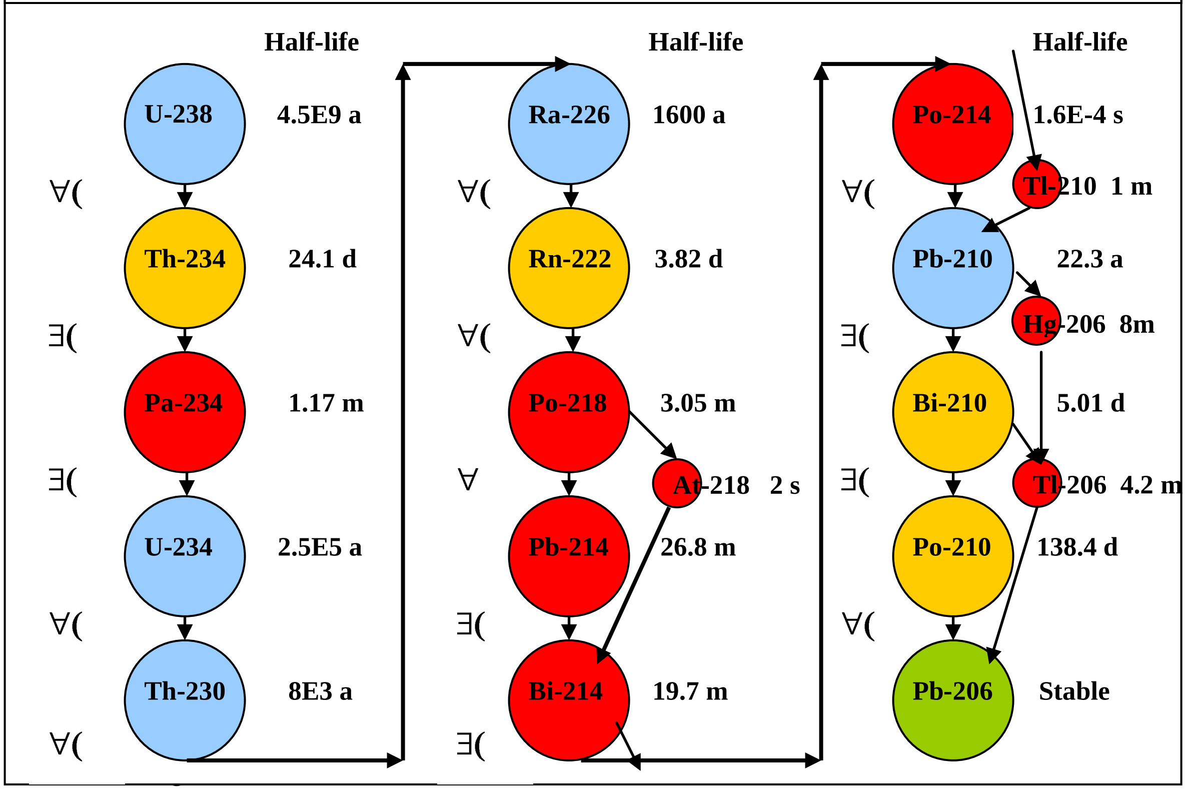
Today, uranium, which is of relatively low radioactivity, is used as a source of energy; as a radiation shield that is denser and more effective than lead; as a counterweight in aircraft; and as an armor-piercing tip in anti-tank weapons.

Table 5. Some Naturally-Occurring Radionuclides

Uranium-238 Decay Chain. *		**Natural Radionuclides from Cosmic Particle Bombardment of the Atmosphere.**			**Some Natural Radionuclides of Terrestrial Origin (other than from Uranium and Thorium Decay Chains).**		
Isotope	Half-life		Production rate (Atoms cm $^{-2}$ s $^{-1}$)	Half-life	Radionuclide	*(Abundance (percent) Relative to stable element)*	Half-life
Uranium-238	4.5E9 y	H-3	0.25	12.3 y	K-40	0.012	1.28E10y
Thorium-234	24 d	Be-7	8.1E-3	53.6 d	V-50	0.25	6E15 y
Protactinium-234m	1.2 m	Be-10	3.6E-2	2.5E6 y	Rb-87	27.9	4.8E10y
Uranium-234	2.5E5 y	C-14	2.2	5730 y	In-115	95.8	6E14 y
Thorium-230	8E4 y	Na-22	5.6E-5	2.6 y	Te-123	0.87	1.2E13y
Radium-226	1622 y	Na-24	?	15 h	La-138	0.089	1.1E11y
Radon-222	3.8 d	Si-32	1.6E-4	650 y	Ce-142	11.07	>5E16 y
Polonium-218	3 m	P-32	8.1E-4	14.3 d	Nd-144	23.9	2.4E15y
Astatine-218	2 s	P-33	6.8E-4	24.4 d	Sm-147	15.1	1.0E11y
Lead-214	27 m	S-35	1.4E-3	88 d	Sm-148	11.27	>2E14 y
Bismuth-214	20 m	Cl-36	1.1E-3	3.1E5 y	Sm-146	13.82	>1E15 y
Polonium-214	1.6E-4 s	S-38	?	2.87 h	Gd-152	0.20	1.1E14y
Thallium-210	1.3 m	Cl-38	?	37 m	Dy-156	0.052	>1E18 y
Lead-210	22 y	Cl-39	1.6E-3	55 m	Hf-174	0.163	2E15 y
Bismuth-210	5 d				Lu-176	2.6	2.2E10y
Polonium-210	138 d				Ta-180	0.012	>1E12 y
Mercury-206	8.2 m				Re-187	62.9	4.3E10y
Thallium-206	4.2 m				Pt-190	0.013	6.9E11y
Lead-206	Stable						

*** Similar decay chains exist for naturally occurring uranium-235 and thorium-232.**

Figure 2. Schematic of the Uranium-238 Decay Chain Showing the Decay Relationships, Half-lives and Radiations Emitted.



With respect to Figure 2, pure uranium (consisting of 99.3 percent uranium-238) which is separated from its progeny, is practically non-radioactive - as first noted with some surprise by Sir William Crookes - because of its very long half-life. However, the presence of its decay progeny - many of extremely short half-life - is what gives natural uranium its obvious radioactivity. It took many years at the beginning of the last century for researchers such as Marie and Pierre Curie, Crookes, Rutherford, Hahn, Boltwood and others to understand the parent-daughter relationships and to determine half-lives and the character of not only radioactivity and radioactive decay, but of radioactive ingrowth.

Table 6. Estimated Annual Production (Tonnes) of TE-NORM and Nuclear Wastes in the U.S. (Most Data are from the IAEA).

TE-NORMS (LILW)	**Tonnes**	**Common Radionuclides**
Metal Mining	1 000 000 000	U and Th daughters
Coal Ash	85 000 000	U and Th daughters
Oil/Gas	640 000	Radium daughters
Water Treatment	300 000	Radium daughters
Phosphate Processing	40 000 000	U and Th daughters
Geothermal	50 000	Radium daughters
NUCLEAR		
Spent Fuel (HLW)	2000	U Fission nuclides
Nuclear Utilities LLW	10 000	U Fission nuclides
Other Commercial LLW	5000	Industrial and Medical nuclides.

Table 6 identifies some TE-NORMS and compares their tonnages with those of Commercial Low Level (LILW) and High Level Wastes (HLW) in the U.S.

1.6 Radiation Discovery, Uses, and Waste: Historical Overview

Some of the properties of radiation - as X-rays - were first recognized by Wilhelm Roentgen in 1895. X-rays were widely adopted in medical use within weeks of their discovery provided there was a source of electricity to produce them. Other properties and sources of different radiations, requiring no external power source to generate them, were outlined by Becquerel and the Curies in 1896. Following Marie Curie's separation of radium-226 in 1897 from uranium-rich waste rock discarded from the Joachimstal silver mine, the demand for radium in medical use far exceeded the supply. This scarcity was not surprising as there is only about 3 milligrams of radium-226 in each tonne of 1 percent uranium ore. Previously discarded mine tailings containing uranium, and uranium deposits from which the minute quantities of radium could be extracted, began to be exploited throughout the world as the price of radium climbed to more than US$180 milligram^{-1} by 1914, before declining in value. Total world production of radium by the 1930s seems to have been no more than about 750 grams. As a result of this exploitation, Low Level Radioactive Wastes (LLW) began to accumulate in rapidly increasing quantities. Some bank vaults are said to still contain small quantities of horded radium-226, accumulated by speculators, but now almost worthless. The presence of elevated radon-222 gas concentration (indicated by its activity - measured in becquerels per litre or cubic meter of air) in the bank vaults is often used to indicate the likelihood of radium-226 being stored in one or more of the safety deposit boxes in the vault.

The development of particle accelerators in the 1930s produced a new stream of high-purity man-made radionuclides (neutron deficient) which were also in great demand in medical procedures. Again, supply could never keep up with demand. Unlike the process for production of radium (which could reject tonnes of long-lived radioactive materials for each milligram of radium produced), radioactive byproducts and wastes from particle accelerators were both very small in quantity and usually of short half-life.

With the development of nuclear fission in 1942 the demand for uranium increased dramatically, along with the production of uranium mine tailings wastes containing small quantities of residual uranium and radium.

Numerous medical and research isotopes were and are produced in quantity by neutron activation and transmutation of pure materials introduced temporarily into the core of those small reactors which are usually operated solely for commercial medical-isotope production. Medical isotope shortages - a critical impediment to their broader and more widespread use - disappeared with this development, and every major hospital of any standing, soon established a department of nuclear medicine, using both in vivo (in the patient) and in vitro (bodily fluids and tissues external to the body) techniques for defining illness and bodily function.

A few large commercial electrical production reactors (CANDU) are also used to produce large quantities of industrial-grade cobalt-60 by activation of rods of cobalt-59 introduced into the reactor core for a period of about one year before being removed and chemically processed.

All of these radioactive materials are widely used throughout society for the benefit and improved health of humanity. Some of the many hundreds of uses are detailed in Table 7.

The rapid growth of civilian nuclear energy uses, following their first military demonstration in weapons of mass destruction, began to produce relatively large quantities of radioactive wastes, especially from mining. Reactors used in research, submarines, ships, and then for civilian nuclear power began to produce **small** volumes of very highly radioactive fission product wastes and larger volumes of lower radioactivity maintenance wastes. These fission wastes contain about 700 radionuclides, most of which are of very short half-life - mostly less than 24 hours. They are almost entirely of little value, as they are not cost-effectively extracted from the fuel matrix. However, these radionuclides and their energetic emissions in the operating reactor contribute up to about 7 percent of the continuous energy production within the core, and are responsible for the continuing but diminishing decay-heat production after the reactor fission process has been terminated. Once discharged from the reactor, these decaying radionuclides in the discharged fuel become an unwanted byproduct (waste) of the neutron and energy production process and must be safely managed.

1.7 Modern Uses of Radiation and Sources of Radioactive Wastes

Radiation is used in thousands of different ways to the great benefit of modern society, and very few of which are known or appreciated by the general public. Some of these many uses are shown in Table 7.

All of these uses are associated with the production of some quantities of radioactive wastes, mostly of very small volume and subject to stringent regulatory control.

Table 7. Some Modern Uses of Radiation - Most of which Contribute to Sources of Radioactive Wastes in Society

Medical Processes	**Industry**	**Consumer Products**	**Scientific Research**
Medical isotope production. Radiation Therapy devices. RIA. Sterilizing medical equipment and hospital supplies.	Irradiation Facilities for sterilizing packaged products. Sterilizing sewage & water. Weld inspection. Process tracers.	Exit Signs. Smoke detectors. Antistatic devices. Sterilizing cosmetics, tampons & other consumer products.	DNA matching. Biomedical research. Detecting art forgery. Biological and Industrial process tracing & tracking.
Agriculture	**Pest Control**	**Energy**	**Others**
Irradiation of meats & poultry to kill salmonella & other pathogens. Irradiation of fruits to avoid spoilage & prolong shelf life. Tracing Irrigation and other Water Resources	Eradicating insect pests - SIT (screw-fly, fruit fly, tsetse fly, blow-fly). Protecting stored foods from insects. Irradiating exported forestry products to kill insects and larvae.	Commercial electrical energy. Industrial Co-60 production. Thermo-electric generation (RTGs and SNAP). Satellite energy systems. Remote buoy and navigation and location systems.	Security devices at border crossings. Oil well logging. Level gauges. Polymerization. Engine-wear measurements. Wood laminate hardening. Remote locations lighting. Emergency signs.

Today, radioactive wastes include various wastes from: -

- Base-metal and uranium mining;
- Oil drilling piping and oil and gas processing and distribution pipelines (this can allow some buried gas pipes to be readily located);
- Phosphate fertilizer processing residues - also a source of commercial uranium;
- Some low grade coals and coal ash with up to 1000 ppm uranium (the Dakotas and Montana in the U.S.) as well as some alum shales - all of which were formerly used as sources of commercial uranium;
- Accelerator wastes;
- Some hospital medical wastes and other discarded radiological materials;
- Spent sealed radiation sources, including medical therapy devices and radiography sources;
- Some hospital biological wastes, including some hospital sewage;

- Most wastes from various stages in the nuclear reactor cycle, ranging from uranium tailings wastes to spent fuel (which is not 'waste' as it can be, and often is, recycled) and associated wastes;
- A few materials that are radioactive wastes but are not regarded as such, including hardwood ash in the U.S. Northeast, which contains fallout cesium-137 and strontium-90 from atmospheric bomb testing since 1945.

With regard to coal ash containing uranium and thorium and their radioactive progeny, the total worldwide release of uranium and thorium in coal ash each year into the environment at the present time in fly-ash and bottom-ash, is roughly estimated to be about 8000 tonnes and 20 000 tonnes respectively, and is likely to increase over the next 50 years as coal consumption increases. None of this is controlled as radioactive waste.

This quantity of uranium is comparable to the amount of uranium used to fuel the worlds' reactors in a year (about 15 000 tonnes of uranium oxide as fabricated fuel, derived from about 75 000 tonnes of refined yellowcake). Only about 3 percent (about 450 tonnes) of the uranium in all of the world's reactors is converted to energy before the spent fuel is discharged from the reactors, and placed into a managed environment for storage and possible future reprocessing to recover the remaining 14 550 tonnes of unused uranium.

In addition, the calculated population radiation dose from such releases in fly ash produced by burning coal, is about 100 times that from all nuclear power plants and any of their wastes, throughout the world as was shown in Table 3. Despite this, the major health risks from coal burning emissions are those related to sulfur dioxide, and toxic trace metals like mercury and arsenic.

Similarly, the releases of radio-iodines into the atmosphere and into wastewater streams from hospital treatments and hospital waste incineration in major cities - sometimes detectable hundreds of kilometers away, is usually many thousands of times larger than is routinely released from nuclear power operations, and these medically-related releases contribute to minor but elevated population radiation doses in those areas. Despite this, the doses tend to be trivial and of no definable effect.

The calculation of a population radiation dose from any industrial or medical process as given in Table 3, is a means of comparing the relative radiation contribution to society from many different activities and circumstances. It can be used to suggest which of these activities, or parts of them, might be cost-effectively adjusted to minimize dose, but only if the radiation risk estimates are valid - and they generally are not, as they overestimate the probable risk by up to a factor of at least 10 (more data are provided in Sections 2.4 and 2.7).

A report from the Royal College of Radiologists and the NRPB (UK) pointed out in the 1980s that half the collective dose from diagnostic X-rays in the UK could be avoided without detriment, simply by changing the process temperature of the development baths to that recommended by the film manufacturer. Today, such X-rays are collected electronically, rather than on film. At that time the annual collective dose (number exposed, times average dose) from X-rays in the 57 million people was estimated to be about 16 000 person-Sv, suggesting a possible saving of about 8000 person-Sv. Such radiation doses are also acute doses. Without any attempt to differentiate between acute and chronic exposures (Sections 2.7 and 2.8), a comparison of population doses and presumed risks from different sources of radiation is practically meaningless as the long-term biological impact of the same radiation dose, delivered acutely or chronically, is very different.

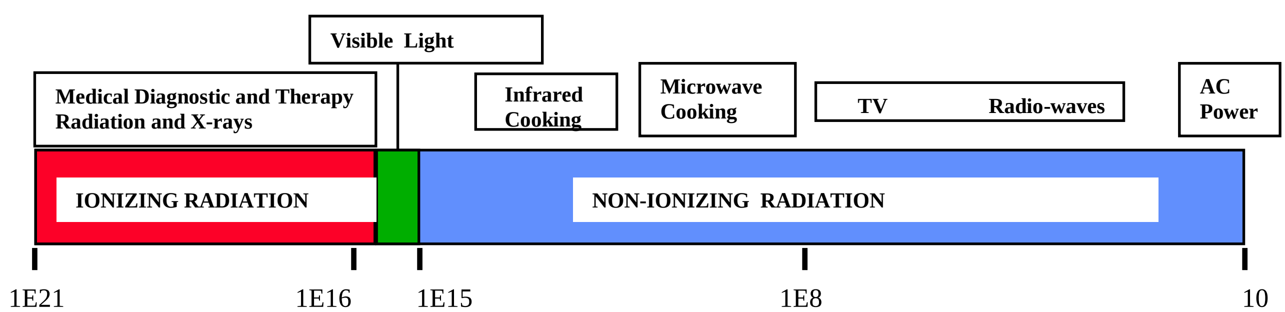
The estimated population dose saving from this simple attention to development temperature was shown as likely to reduce the overall population radiation exposure in just one country by almost as much as attempting to eliminate all environmental radiation emissions from all nuclear power facilities in the whole world.

2. RADIATION AND RADIATION EFFECTS.

2.1 The Electromagnetic Spectrum of Radiation Energies

The radiation spectrum shown in Figure 3, is broadly divided into regions of ‘ionizing’, and ‘non-ionizing’ radiation. It covers all radiation energies from the extremely long wavelength, low-energy AC power transmission frequencies, through sound and communication transmission waves, to the very short wavelength, high-energy cosmic rays and those radiations used in medical diagnosis and treatment. Between the two broad areas of ionizing and non-ionizing radiations is the region of visible light.

Figure 3. The Electromagnetic Spectrum



'Ionizing', means that the radiation energies have sufficient energy to be able to remove electrons from the atoms with which they interact and thus cause them to become ionized. The formation of free radicals through this ionizing process, and the deposition of the liberated energies through the processes of radioactive decay, or the generation of X-rays, are what cause radiation damage to tissue and radiation dose. Ultra-violet radiation burns and tanning from exposure to the sun’s energetic rays are an example of a superficial radiation burn, which if continued over a prolonged period, may lead to skin cancer in light skinned (especially if they have 'red' hair) and genetically susceptible individuals (those with Xeroderma pigmentosum). However, UV radiation, like many other agents that may be undesirable and harmful at high doses is essential and beneficial at lower ones, as for example for the production of vitamin D in the human body. This extreme contrast in effects according to dose ('it is the dose that makes the poison' - Paracelsus), is well known, with the stimulative and beneficial effects - even of known poisons, like strychnine or arsenic - being called 'Hormesis'. One of the major failures of the 'Biosphere 2' project was said to be that the lack of UV light (too low a dose) caused the death of many organisms essential for the health of the project environment. However, UV light at high doses is used to kill the same organisms in the water of many pop-bottling facilities. Similarly, vaccines (e.g. polio, MMR, smallpox, influenza), are stimulative doses of agents that are harmful at higher doses.

'Non-ionizing' radiation does not obviously produce similar harmful effects, though the longer transmission wavelengths - for example from AC power transmission lines, radar guns and cellular telephones - have been and continue to be linked to various human health effects, though the supportive statistics are weak to non-existent, even after decades of study. The heating effects of microwave radiation (microwave ovens) are obvious. One rumored use of this effect was on ships during WWII, fitted with radar, where the deck watch could supposedly get warm in front of the radar dish.

2.2 Ionizing Radiation

Ionizing radiation is the name applied to all radiation of short enough wavelength (high energy) to ionize atoms with which they come into contact. These ionizing radiations occur throughout the natural environment, throughout space, and occur throughout all living organisms. Some perspective of their relative profusion in our living space is shown by the following estimates of their unavoidable and natural interactions with our bodies, none of which are sensed by any of us:

- From the sky, there are about 100 000 cosmic ray neutrons, and about 400 000 secondary cosmic rays which interact with each of us every hour, as well as billions of neutrinos which pass through us without interaction.
- From the air we breath, there are about 30 000 atoms which disintegrate in an individual’s lungs every hour.
- From our diets, there are about 15 000 000 potassium-40 atoms, and about 7000 uranium atoms which disintegrate in each of our bodies every hour. Brazil nuts are a well-known source of alpha emitting energies because of the radium that is concentrated by the plant into these nuts. Tobacco use is a major source of radiation dose to smokers from polonium-210 in the tobacco leaf.
- From soil and building materials, there are over 200 000 000 gamma rays which pass through each of us every hour.

The common types of radiation are shown in Table 8.

Alpha, or beta particle emitters outside the body, pose little external hazard as their radiation energy often cannot penetrate clothing or skin, and the particles travel from only a few millimeters (alpha) to a few metres (beta) in air, whereas photons can travel long distances through most low density materials with few interactions, though can be shielded by a few centimeters of lead or a few meters of water. Because of their highly ionizing trail, alpha particles are regarded with especial concern if they are accidentally ingested and incorporated into living tissue. Photons (gamma rays and X-rays) are the most useful and widely used radiation in medical treatments.

Table 8. Ionizing Radiation, Radioactive Emissions and Energetic Particles	
Particle or Radiation	**Common Origins and Uses**
Alpha - helium nucleus, relatively massive particle, double positive charge; dense, ionizing track through coulombic interactions	Emitted from unstable heavy elements. Thermo-electric energy source.
Beta (negatron) - single negative electron, light particle; medium density ionizing track	From decay of a neutron to a proton - the usual radioactive decay process.
Beta (positron) - single positive electron	From decay of a proton to a neutron (rare).
Gamma - photon - uncharged particle or wavelength (it displays both properties - known as particle duality); low density ionizing track	Energy quantum ejected to achieve stability after beta decay. Radiation therapy.
X-ray* - photon - uncharged particle or wavelength as above; low density ionizing track	Energy emitted from electron shell re-arrangement, and rarely from a nucleus. Medical X-rays.
Neutron - nuclear particle, relatively massive – neutral; damaging through nuclear collisions with hydrogen and other light elements	Released during fission and from special neutron generators (e.g., Ra-Be). Medical uses.
Proton - nuclear particle, relatively massive - positive charge; damaging through collisions and coulombic interactions	Cosmic and Accelerator particle. Medical uses.
* X-rays are most commonly produced by the bombardment of a specific metal target by electrons emitted from an electrically resistance-heated filament in a vacuum. Removal of the applied voltage eliminates the production of X-rays.	

2.3 Radiation Doses and Radiation Effects

Over the last 100 years, radiation has been widely adopted and used in society for many beneficial purposes, especially in medicine. However, nothing in society is risk free (not even foods, medicines, or safety devices), and individual injuries were noted in patients from its very earliest external medical uses (even as early as 1896) at relatively high acute doses (treating breast cancer, Tinea capitis (ringworm), and in depilation). Other injuries were noted from the repetitive sales demonstrations of the operation of the first commercial medical radiation devices and in some aspects of radiation research. After a few years, the relatively large population of radiologists - who manipulated the usually unshielded radiation sources while attending to their many patients - also began to show the adverse effects of relatively large uncontrolled, and unmonitored acute radiation exposures. In this case, although the patient received what was generally a tangible benefit from the radiation, as well as receiving a moderate to high dose that could redden the skin (an erythema dose), the radiologist who attended each and every patient in succession, was exposed to a cumulative high dose, which eventually could prove injurious or even fatal.

Radiation protection practices and radiation dose limits were formulated in the 1920s and earlier, to protect hospital radiologists and others who worked occupationally with radiation, from the observed effects of uncontrolled acute radiation exposures. For those occupationally exposed for up to 2000 hours each year it is clear that a low dose rate only, can be tolerated in order to remain below occupational dose limits (20 mSv annual average, or 50 mSv in any one year of five). However, there are no dose limits for medical patients, and in this case the medical profession - as guided by the International Commission on Radiological Protection - regards a low dose rate to be less than 100 mSv h^{-1}, and a low dose to be below 200 milligrays (millisieverts). With a dose rate of less than 100 mSv h^{-1}, generally used for only a few milliseconds in most diagnostic procedures, the cells within the body have time to correctly repair any cellular injury caused by radiation-energy temporarily breaking the cross linkages in cellular DNA.

Wherever radiation is encountered today, these protection practices are strongly enforced and govern how radiation is both used and handled in the workplace, and how the radioactive wastes from all of its various uses are controlled such that the general public cannot encounter them.

The prevailing paradigm in all radiation work is to regard all radiation - acute or chronic - as being potentially harmful, and to avoid it where possible. Although the public can be readily persuaded that all radiation is industrial in origin and is harmful and must be eliminated, controlled, or avoided, there is no rational way to avoid natural radiation, and the use of radiation in medicine - often at extremely high doses - confers overwhelmingly greater benefit rather than harm, on those undergoing treatment.

In contrast, laboratory experiments in which natural chronic radiation exposures are reduced as low as possible to the point of elimination, invariably result in ill health or premature death of the exposed organism. Radiation therefore appears to be an essential agent to a healthy life, as thousands of studies have demonstrated, and is required to provoke and promote all of the beneficial immune responses found in living organisms including humans. Despite various rumors following the Chernobyl accident that radiation compromises or knocks out the immune system, the effect was actually the opposite; the immune system was helped, as few doses were large enough to adversely affect the civilian population. Radiation is also demonstrably a very weak carcinogen, or we would very quickly have abandoned it from routine medical use in hospitals where the highest radiation doses are typically encountered.

Once radiation doses could be accurately measured and understood, it became clear that a single acute dose of about 5 to 10 sieverts of whole-body dose to a human, without medical treatment, usually represented a fatal dose over the next few weeks from somatic (body) radiation injuries. This whole body acute dose is also deliberately used in hospital-treatments of individuals to destroy leukemia. Such extremely large and near-fatal doses actually do affect the body's immune system, and require that the patient receive heroic protection from infection until the immune system is re-established after a bone marrow transplant. This protection includes treatment with anti-biotics and a diet including irradiated foods, which are essentially microbe free. The survival rate after this treatment is now close to 85 percent as opposed to the nearly 100 percent chance of rapidly succumbing to the disease if left untreated. In at least two cases, those who were bone marrow donors later developed leukemia themselves, and were in the fortunate position - after treatment - of being able to receive exactly their own blood-forming cells back from the then healthy earlier recipients. Although the simplistic view of medicine is that doctors must do no harm, the practical reality is that doctors should weigh the risks, (human cost and human benefit), and strive to do more benefit than harm, as it is impossible to avoid the significant risks associated with medical treatments of any kind, especially when people are ill.

Below about 3 sieverts of acute dose, such short-term fatalities were not obvious and did not occur, as the body was able to repair and recover from the injuries. However, any acute exposure - even down to zero dose - was protectively assumed to present a probabilistic risk (of about 5 percent per sievert) to the exposed individual, of developing a future fatal cancer from the exposure, but usually some 10 to 30 years or more in the future. This assumed exposure risk is additional to that increasing risk of developing cancer in everyone as they age (probability about 30 percent) and as their cells 'forget' how to die. This raises the interesting question of the outcomes of the previously described leukemia treatments, which have been in use for at least 30 years. Unfortunately there does not seem to be a consistent database of these patients.

2.4 Radiation and Health Data

Fear of radiation is itself recognized as a major health detriment, especially following the bombings of Hiroshima and Nagasaki, and the Chernobyl nuclear accident. None of the various allegations concerning long-term injuries to those exposed following these events has actually proved correct. This is true even where the radiation doses – which are rarely provided with any of the allegations of injury - are relatively major, but are certainly not valid where doses are relatively trivial though still high.

The last 30 years have seen many allegations of serious health effects as a result of exposure to small doses of radiation. None of these allegations stand up to scientific scrutiny, although they are still widely repeated and publicized. Indeed the mounting scientific evidence shows that low doses of radiation (still well above natural background) appear to be more beneficial than harmful to the general population.

There are many reliable occupational and population health studies which are statistically powerful and which show that populations exposed to chronic low doses of radiation - still above a 'normal' background - are consistently in better health than those lesser exposed members of the same populations (U.S. radon data; Misasa spa data, Japan; U.S. nuclear shipyard worker study; the Canadian TB fluoroscopy study, etc.).

Data on the inhalation of radon gas in homes (as in 'health spas') through many countries of the world, including the U.S., India, Japan and China, and affecting millions of individuals, although widely assumed to cause injury, do not show injuries from such chronic inhalation doses. Such elevated radon exposures are more consistently associated with fewer cases of lung cancer, compared with a matching population living in lower radiation background areas. This is sometimes only obvious when the confounding effects of smoking - a known cause of significant lung cancer - are taken into account.

Studies of certain medically exposed groups such as in the Canadian Fluoroscopy study, where tuberculosis patients were exposed to cumulative lung doses of about 1 sievert, show no positive association between lung cancer and dose. This is notably contrary to the expected theoretical outcome following such high dose treatments over the 30 or more years since exposure of these many thousands of patients. Other comparable medical studies were of Ankylosing spondylitis patients (high doses of X-rays used to alleviate extreme lower back joint pain), thorotrast patients (liver tumors), cervical cancer patients and Tinea capitis (ringworm) patients and radiotherapy patients (for second tumors). None showed the theoretically expected rate of injury that might have been expected from the delivered doses, but showed either no statistically validated effect or showed actual significant long-term health benefit over and above that produced by the treatment. It is axiomatic that if the observed facts do not fit the theory, that the theory must be wrong.

Industrial exposures and follow-up studies include uranium and iron ore miners, radium dial painters, weapon’s facility workers, nuclear shipyard workers, nuclear energy workers, military personnel, and others. The mineworkers' studies show typical elevated lung cancer rates for most underground miners who work in high dust atmospheres and who smoke. The radium dial painters showed a slight but significant elevation of bone cancers because of their ingestion of radium. Data on the other major groups are shown in Table 9. They show an increasingly recognized phenomenon; that radiation workers are usually healthier and live longer than their non-radiation worker colleagues in the same industry. A report recently released (2003) of a 50 year study of 20 000 military personnel in bomb-blast areas, showed that they are at least as healthy as the rest of the military population not exposed to radiation, despite the allegations and rumors that have persistently circulated for those 50 or more years.

Table 9. Total Cancer Mortality in Nuclear Workers

Facility	Shipyard Workers (U.S.)	Weapons Program (U.S.)	Weapons Program (U.K.)	Energy (Ontario Hydro, Canada)
Exposed Workers	40 774	15 318	36 272	4000
Control Workers	111 757	20 619	58 945	21 000
Years Observed	16	33	30	20
Average annual occupational dose	3.4	4.3	5.7	7.0
Cancer Mortality in Workers	968	318	96	8
Cancer Mortality in Matched Controls	3086	718	584	463
Ratio*	0.84	0.60	0.27	0.09
p value	<0.001	<0.001	<0.001	<0.001

Data from various published sources.
* Ratio of the mortality rate in workers, over the mortality rate in the matched controls.

Despite these strong data on relatively large groups of workers showing that radiation workers are generally much healthier than their unexposed counterparts, these data do not provide details on individuals who may be relatively sensitive to radiation, although they may be part of the exposed working population.

It has long been recognized that certain individuals with severe genetic disorders (Down's syndrome, Ataxia telangiectasia, and Xeroderma pigmentosum) are susceptible to injury from many otherwise innocuous agents in society: sunlight, certain treatments and medications, and low dose radiation. Such disorders are rare, but are sufficiently medically well defined today, that doctors are able to protect these individuals to a better degree than previously, where life expectancy for these susceptible individuals was extremely low. Fortunately, these individuals are rarely encountered in any working population, because of their disability, though they do show up in the general population statistics and skew some of the risk evaluations.

Health spas throughout the world, originating from at least the time of the ancient Romans in Europe, and obviously long before their association with radiation exposures was appreciated, have long been associated with improved health of those who imbibe and bathe in the relatively highly radioactive waters and smear themselves with radioactive mud. Scientific studies have documented such beneficial outcomes. Others, knowingly expose themselves in the highly radioactive radon-rich atmospheres of underground mines, or casually lounge on the thorium-rich sands on the beaches of Brazil where they are exposed both to the sun's usually detrimental tanning effects, and to elevated radiation doses from the black monazite sand. The sun's effect is by far the more serious.

Despite the unscientific precautionary assumption that the same radiation doses, whether acute or chronic, will produce the same degree of injury, there are no epidemiological data which show any effect from chronic doses even up to several tens of sieverts in a year, but instead, do show bio-positive effects. Theory is again shown to be deficient.

2.5 Industrial and Medical Radiation Accidents and Experience

Accidents with radiation are usually extremely rare. Over the last twenty or so years there have been about 2 to 10 fatalities reported in industrial uses or accidents each year - usually where operators of radiography or industrial irradiation devices became careless and ignored their training - and many more in medical uses. In this latter case they are either difficult to identify and may be ignored or are not recognized unless a specific instrument malfunction or calculation error is reported and a follow-up enquiry takes place. This occurred at Zaragoza, Spain in 1990 when possibly 20 patients may have been fatally injured by excessive radiation exposure. The number is uncertain because of the extremely high radiation doses routinely given to most patients undergoing cancer therapy; the marginal health of many patients; the uncertain eventual outcome of the procedure on any 'terminally ill' patient; and the time during which the malfunction was allowed to exist.

Medical uses of radiation, as they affect a patient, are not subject to restrictive regulatory personal dose limits but frequently exceed them; sometimes by several orders of magnitude and generally without obvious harm in either the short or the long term, but mostly with defined benefit. Doses far in excess of 10 sieverts are usually required to kill cancers, but are delivered to the target in such a way as to spare the surrounding healthy tissue as far as possible, usually by source rotation and bringing the beam to focus only on the cancer site, and sometimes by delivering the total dose in several stages over a few weeks. Such fractionation of dose must carefully consider the short-term stimulation of a defensive response by those cells that are targeted for destruction.

When used in internal medical procedures those radionuclides of most value are usually those of short half-life (iodine-131, molybdenum-99), emitting their penetrating radiation energy from a very small and easily shielded quantity of material in a short space of time. Their dual character - useful or hazardous - depends upon where they are located, what they are used for, and their interaction with people. In medical procedures, they are usually beneficial for a patient when used outside or inside the body, in allowing the doctor to diagnose injury or malfunction, or to kill a cancerous growth. However, the same radiation is regarded as harmful to the doctor, nursing staff, or other patients in the vicinity, and is strenuously regulated (but not for the patient) and controlled to avoid the build-up of cumulative radiation exposures and potential effects over their working lives.

Ingested radionuclides within a patient, such as in those patients undergoing thyroid ablation (destruction), requiring a dose to the thyroid of about 100 sieverts, may also pose a continuing risk to nurses and visiting family members over several days until the nuclide decays or is eliminated from the body into the broader environment. Some patients are discharged soon after treatment and significantly contaminate mall washrooms, restaurants and homes for several days, though these events are not generally publicized.

By comparison, industrial and occupational uses of radiation are so strongly controlled and regulated, that they are rarely encountered by any member of the General Public.

2.6 Cellular Defense Mechanisms

Cellular biology studies note that each cell in the human body undergoes a very high background of intrinsic potential mutations (DNA strand breaks) of about 240 000 in each cell per day, produced by reactive oxygen metabolites, enzymes, bacteria, and thermal effects. By comparison, about 20 potential mutations (single-strand DNA breaks) are produced in each cell by the free radicals generated by each 10 mSv of low LET (Linear Energy Transfer) radiation over whatever time frame. Clearly, radiation is not a significant carcinogen, considering the many thousands of times greater burden of natural insults faced by any cell, and successfully dealt with.

One of the major concerns in society following the use of the first atomic bombs was of genetic effects upon future generations. These concerns had followed from the work of Muller in the 1920s, and his research on fruit flies in which genetic changes had been induced by - among other agents - massive acute doses of radiation. Insects are relatively radiation resistant, with acute fatal doses ranging from about 20 grays up to 1000 grays. Although the public is concerned about genetic damage from radiation, the accumulated scientific data to the present time has shown that the initial fears, assuming Muller's data were also applicable in some way to humans, were considerably exaggerated. The radiation dose required to produce obvious mutations in many organisms is relatively large, but is generally well above the dose required to produce fatalities in humans. In mammals - generally the most radiation sensitive species - the fatality threshold is typically reached first. Death usually occurs before mutation effects, which might significantly affect the organism, could occur.

All organisms also have defensive mechanisms against cellular damage. Repair mechanisms are capable of repairing both single and double strand breaks in DNA material no matter how they may occur. If a cell detects that such a repair was incorrectly made (double-strand breaks are less likely to be correctly repaired), it is likely to undergo a process known as programmed cell death or apoptosis, in which the cell destroys itself and is removed from the reproductive pathway. Undetected changes may result in the early death of the entire organism or of the development of desirable or undesirable mutational changes that become part of the evolutionary and hereditary process. Spontaneous abortion in humans - often unrecognized, as most occur before a woman is even aware that she is pregnant - eliminates about 70 percent or more of those conceptions that would generally not survive birth because of such cellular or hereditary damage, and these have little, if anything, to do with radiation exposure.

Whether radiation is assumed to be harmful or beneficial, is a matter of degree and purpose, as by far the biggest radiation doses to anyone arise through deliberate and planned medical uses of radiation, both external to the body and internally. Such treatments are not rare, with tens of millions of individuals receiving significant and mostly beneficial medical radiation treatments each year. Although a hypothetical risk of future population long-term health detriment can be calculated from such medical radiation exposures, as with any radiation exposure, such uncertain calculations ignore empirical epidemiological realities. Although predictions of expected detriment can sometimes be derived from extrapolation from very high acute doses, epidemiologically supported and observed effects show that at lower acute and chronic radiation doses, benefit, rather than detriment is demonstrated.

In contrast to what is usually reported in the media, the effect of most elevated radiation doses encountered in nature and medicine (except for the massive doses encountered in leukemia treatments described earlier) is provocation of a defensive response in the immune system, in the same way as vaccines do, and appear to have a beneficial rather than a harmful effect. The so-called 'healthy worker' effect is most notable in nuclear worker populations, as recent studies show. However, most of the original early accusations of health detriment, long since disproved, appear to still have some considerable currency in both the media and among critics, where they can still be used to arouse the concerns and fears of the general public.

Such radiation phobia is well known to be much more injurious than the radiation exposure itself. When allowed to influence political decisions, some tragic and strange outcomes are possible. For example, following the Chernobyl accident, fear of genetic mutations (entirely unfounded) caused many tens of thousands of pregnant women in southern Europe to undergo needless and ill-advised abortions. This was especially tragic when one realizes that the total and well documented radiation doses to which these women had been exposed were even less than natural background radiation in many areas of the world where millions of people live in good health, including many of these same women, and were considerably less than the medical doses many of these women are likely to receive during routine evaluation of their health and pregnancy. Human genetic effects have never been seen in any children born following even those massive and near-fatal doses of radiation delivered to hundreds of thousands of medically treated patients, nor in the offspring of survivors of the Hiroshima-Nagasaki bombings.

2.7 Radiation: Acute versus Chronic Doses and the LNT Hypothesis

In discussing hazards of radiation, it is increasingly recognized that it is essential to distinguish between the very real differences of acute and chronic exposures.

- Acute, very large and perhaps fatal exposures are indicated by the rapid development of increasingly serious radiation syndromes with increasing dose - Hematopoietic, Gastro-intestinal, and Central Nervous System syndromes. If those who are very highly exposed survive beyond a few weeks, they are likely to recover completely, but incur a future calculated probabilistic risk of developing a radiation related cancer, though the risk may be much lower than protectively assumed.

- Chronic radiation exposures, even to a very large cumulative dose, do not produce radiation sickness syndromes, and are usually not associated with significant injury.

Table 10 shows the different observed effects of specific acute and chronic radiation doses. However, in terms of assessing radiation risks and controlling radiation exposures, there is assumed (wrongly) to be no significant difference between the effects of acute and chronic dose effects at the same exposure, or between the same doses delivered at a low dose rate or at a high dose rate. These assumptions which stem from the LNT hypothesis, lead to a significant over-estimate of harm, by a factor of from two to ten, from chronic low doses, and low-dose-rate radiation, and a corresponding misallocation of scarce protection resources into dealing with a relatively minor risk that has a highly emotional aspect.

Table 10. Human Health Response to Acute and Chronic Whole-Body Radiation Doses *		
**Total Dose (grays) ** **	**Delivered Acutely (seconds to hours). Cellular repair is only partially effective.**	**Delivered Chronically (usually over the course of one year). Cellular repair is effective.**
	Risk of long-term injury is assumed from all survivable exposures.	Risk of injury is assumed from all exposures, even though injuries are not observed.
50 to 100	Nausea, vomiting, diarrhea. Rapid onset of unconsciousness. Death in hours or days from the CNS syndrome.	Few data. No epidemiologically defined deaths. Injuries difficult to define and not obvious.
10 to 50	Nausea, vomiting, diarrhea. Death in weeks, mostly from Gastro-intestinal complications.	Few data. Injuries difficult to define, if they occur. Confounding effects arise from smoking and other hazards in the Uranium mine worker data.
3 to 10	Nausea, vomiting, diarrhea in most individuals. About 50 percent survival rate without hospital treatment.	No definable health effects attributable solely to radiation. Many confounding effects.
1 to 3	Nausea and fatigue in some individuals. Eventual recovery.	No definable health effects.
0.1 to 1	Somatic injury unlikely. Delayed effects possible but improbable.	No definable adverse health effects
0 to 0.1	No detectable adverse health effects, though minor blood changes can be temporarily detected.	No definable adverse health effects. Significant benefits possible and likely through adaptive response.
* Cellular responses and changes can be detected at all doses, as with any toxicity insult. ** The gray is the unit of absorbed dose, and the sievert is the unit of dose equivalent allowing for the effects of different radiations on living tissue. For X-ray and gamma doses they are comparable. At very high doses, above occupational dose limits, the gray is used rather than the sievert.		

The assumption of a linear risk of harm from radiation (whether acutely or chronically delivered) even down to close to zero dose and without assuming that there may be a threshold for injury, is known as the Linear No Threshold, or LNT hypothesis.

This hypothesis is the basis for current radiation protection assumptions and regulations. It completely ignores the reality of cellular repair mechanism or immune adaptive response in countering damaging effects, or hormetic effects, and thus considerably over-estimates the dangers of all radiation exposures, but especially of the chronic low dose exposures universally and unavoidably encountered throughout society and industry.

It was derived from incomplete and uncertain data on the very large acute doses to the Japanese survivors of the Hiroshima and Nagasaki bombings in 1945, many of whom are still alive and in apparently unusually good health compared with the control populations. Those bomb survivors who received less than about 100 mSv of acute dose (in milliseconds), do not appear to have suffered any epidemiologically definable adverse health effects, yet the assumption is made that even minuscule doses just above zero and spread out over days, weeks or months, have an associated detriment.

Unfortunately, the assumed linear risk derived from the Japanese bombing survivors exposed to acute and very large doses, was also assumed to be equally applicable for all chronic and low dose rate exposures throughout society including natural radiation, workplace occupational exposures and certain medical treatments, although only workplace exposures are subject to regulatory controls.

Decades of empirical data and painstaking observations do not support the assumption that a linear risk applies to chronic and low dose and low dose rate exposures, but they generally do support the opposite; that low doses of radiation - still well above natural background - are more beneficial than harmful.

The LNT assumption should be reviewed and modified to allow for what is known about cellular repair mechanisms, adaptive response through stimulation, and hormesis. It does not contribute to radiation protection, but through its overestimate of radiation risks, causes radiation protection efforts to be too costly for what is achieved - denying funding to address risks that are well-defined to be truly more serious - and contributes to radiation fear and further regulations by over-estimating likely harm from any radiation exposure, even down to zero dose.

Every few years, some unaccountable special interest group, attempts to arouse public and political fears by publicizing some particular study (usually not conducted by scientifically qualified individuals) which purports to show that radiation risks are underestimated by factors of hundreds or even thousands of times. If the actual radiation risks were really so large then it would be extremely simple to convincingly demonstrate valid adverse health effects on fairly highly exposed (acute exposures), medically-treated individuals of whom there are millions, and on those millions of people who have lived for decades in regions of high natural background radiation which give doses well in excess of allowable occupational radiation exposures. Such alleged demonstrations of increased risk do not - without exception - survive scientific scrutiny, but by the time valid data are presented, the damage to public perceptions has been achieved.

Clearly, how a radiation dose is received - whether acutely or chronically- what region of the body it interacts with, as well as how big a radiation dose is received, influences how our bodies respond. These differences and their general effects are described in Tables 10 and 11.

Any comparison of risks throughout our prosperous society shows that radiation use in all of its many hundreds of applications, confers thousands of times greater benefit than risk. The data over the last 100 and more years of radiation use in medicine, research and industry, continue to show that even moderate to high doses of radiation are relatively innocuous. Radiation is at worst, a weak carcinogen just as most things in society are, and is also essential to life, health, and longevity.

Table 11. Some Definitions of Radiation Dose and Probable Effect	
Delivery and Effect	**Meaning**
Acute Dose	An acute dose usually refers to a very large dose delivered at an extremely large dose rate from a fraction of a second, up to several hours, as with most cancer therapy treatments. It implies a dose delivered in a short enough time that the cells' natural defense mechanisms to repair cellular damage are relatively ineffective and may be overwhelmed. This can lead to the severe somatic effects of radiation sickness in the case of a whole body exposure, or to the death of the specifically targeted organ (e.g., thyroid) or a cancer. Acute doses of less than about 3 sieverts usually have no discernible adverse health effect.
Chronic Dose	A chronic dose is one encountered over a period of time from days, to years, to a lifetime. Examples are with radiation encountered in a health spa, at altitude while flying or mountaineering, or from lifetime natural background radiation exposures where one lives. Cellular radiation damage is continuously repaired; the body's immune response function is generally enhanced by such reparative activities, and there are no significant residual effects until old-age effects take over.
Somatic Effects and Radiation Syndromes	These occur only in the exposed person, whether in the womb or as a fully developed individual of any age. They occur from massive acute exposures where non-repairable cell damage occurs, as with a sunburn where dead skin cells are sloughed off. In the case of internal radiation injuries, the Hematopoietic syndrome (blood changes) with acute doses up to about 3 sieverts is usually survivable, while the Gastro-intestinal (GI) and Central Nervous System (CNS) syndromes at much larger doses are not.
Genetic or hereditary Effect	Genetic effects may occur in offspring where reproduction takes place using genetically changed (mutated) chromosomes in the parent from previous somatic changes in the egg or sperm from whatever cause. Where there is no reproduction, there can be no hereditable effect. Hereditary mutations range from harmful to beneficial. Those mutations with unfavorable or damaging effects are usually gradually eliminated from a population by natural cellular response. In the case of the Japanese bomb survivors, children conceived and born after the bombings do not show any change in the natural mutation rate.
Stochastic Effect	The ICRP states that Stochastic effects (usually cancers) are those for which the probability of an effect occurring rather than its severity, is regarded as a function of dose, without threshold. For example the small risk of developing leukemia following a large, survivable, acute exposure becomes more probable, the larger the dose. Winning a lottery is also stochastic. The more you play, the greater your chance of winning.
Deterministic Effect	The ICRP states that Deterministic effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur. For example the development of cataracts becomes more likely with radiation doses above a threshold of about 8 gray. Sunburn is also a deterministic effect.

3. Summary Points About Radiation

1. We are surrounded by natural radiation. We can neither see it, hear it, feel it, taste it, or smell it, but it is readily detected by sensitive instrumentation - the gold leaf electroscope, the spinthariscope, and other scintillation devices used about 1896, and the many more modern and much more sensitive instruments.
2. We have been using man-made radiation in medical treatments in society since 1895, to the very great benefit of society.
3. Radiation is also mostly natural and entirely unavoidable. It occurs naturally, everywhere in our food, air, water, and in us. Without it, we would be dead.
4. We are here today not despite the effects of radiation, but because of them. Our genetic health and genetic variability owes much to our evolution in a naturally radioactive environment.
5. In the early history of the earth, when life was evolving, radiation levels were much higher than at the present time.
6. Efforts to experimentally shield and protect many organisms from radiation have invariably resulted in their early death.
7. Extremely large doses of radiation to any organism, are generally fatal, as for large doses of anything, including vitamins, essential nutrients, foods and medicines.
8. Moderate to fairly high doses of radiation appear to be stimulatory (like vaccines) and result in life extension for many animals, including humans.
9. There are more than 2000 reputable studies which demonstrate the beneficial, stimulatory, and life-extending benefits of radiation to many organisms.
10. The most radiation resistant organisms are also the most primitive (Deinococcus radiodurans).
11. The largest individual radiation doses, by far, received by millions of people in society each year are from medical treatments, especially in cancer therapy treatments. The largest population doses are from natural background radiation.
12. Radiation uses in the world cure far more cancers than they might cause - hence its widespread use in hospitals.
13. Radiation, even at very large doses, is a very weak carcinogen, which is why it can be used to kill cancers, without significantly producing them.
14. Most cellular and DNA damage is caused by natural body processes: failure to replicate accurately, enzymes, viruses, temperature, genetics. A very small part of such repairable damage can be caused by radiation.
15. Cellular and DNA damage from even large doses of radiation is easily repaired by cellular mechanisms. Where DNA injury cannot be repaired, the cell will often adopt the ultimate protective step, and commit suicide (apoptosis).
16. In the 1920s, Muller irradiated fruit flies at massive doses to produce genetic mutations. This gave rise to fears of corresponding human effects. However, human Genetic Effects from very high doses of radiation have never been demonstrated. Fatalities generally occur before mutations.
17. Natural radiation is unavoidable, and provides the most radiation dose to the most people, with no demonstrable harm.
18. Many areas of the world, especially regions of geothermal activity, and many mines, are naturally radioactive at thousands of times higher levels than others.

19. Higher topographic elevations (e.g., Denver) receive more cosmic radiation than those close to sea level. Frequent flyers and cosmonauts are significantly exposed.
20. The large populations in many high radiation areas show signs of unusually good health rather than ill health.
21. Locations with measured relatively-high radon doses also are the regions which have the lowest observed lung cancer rates, as many reputable studies have demonstrated. However, EPA calculations suggest that the opposite is true. The calculations - using the LNT hypothesis - are therefore wrong. Observations outweigh hypothesis.
22. The least radiation doses to the world's population come from nuclear power plants, which contribute about 0.1 percent or less of an average individual dose each year.
23. Nuclear power plants emit far less radiation into the environment than comes from burning coal for the same energy.
24. All radioactive wastes from Nuclear Power facilities are 100% managed and controlled.
25. Nuclear radiation workers are generally much more healthy than their fellow workers who receive less occupational radiation exposure, and are much healthier than the general population. They show what has come to be known as the healthy worker effect.
26. Fear of radiation - radiation hysteria - has a much greater adverse health effect than the radiation itself. Many special interest groups use our own fear of radiation against us for their own gain.
27. Most of what the public believes about radiation is untrue.

Bibliography

Eisenbud, M. (1987) Environmental Radioactivity from Natural, Industrial and Military Sources. Academic Press Inc. (This text is one of the most thorough and best introductions to the subject, providing data for the beginning student as well as the advanced specialist).

Belle Newsletter. A reputable scientific newsletter available on the web detailing the Biological Effects of Low Level Exposures to chemicals and radiation and addressing the subjects of Hormesis and Adaptive Response. Website address: www.belleonline.com.

International Atomic Energy Agency (IAEA). Web site address: www.iaea.org (this United Nations site is a comprehensive source of detailed international nuclear and radiation related information of high quality).

U.S. Health Physics Society. www.hps.org. (The related web site in the University of Michigan, from which current factual radiation and radiation protection information is most readily and comprehensively obtained, is www.umich.edu and by following 'radinfo' links).

World Nuclear Association. Web site address: www.world-nuclear.org. This site provides recent comprehensive and factual general information on almost everything nuclear in the world.

Appendix 1

Some Milestones And Discoveries In The Use Of Radiation.

1530	`Mountain sickness' (lung cancer) in Joachimstal miners - Paracelsus
1709	Description of colors in vacuum tube experiments suggests X-rays!
1789	Klaproth isolates U from pitchblende ores: colorant in glazes
1803	'thou knowest no man can split the atom.' John Dalton
1829	Berzelius isolates thorium
1842	Photographic effects of ionizing radiation
1850	First commercial use of uranium in glass in England
1859	Plucker notes fluorescence from Vacuum tube at high voltage: misses X-rays!
1869	Crookes notes fogging in photographic plates in his lab. and complains of defective packaging, rather than recognizing the effect of X-rays from his tubes.
1875	Crookes tube, cathode rays. Noted to penetrate solids by Herz: misses X-rays!
1890	Goodspeed exposes film and coins accidentally to X-rays: ignores them!
1895	Roentgen discovers and names the penetrating rays, X-Rays - At last! X-ray photographs his wife's hand. This becomes the most famous photograph in the world.
1896	First Commercial X-ray tubes and uses. First diagnostic X-ray. First x-ray picture of a fetus in utero. First application of X-rays in dentistry. Depilation, breast cancer, Edison and Alexander Graham Bell investigate X-rays.
	Lead sheets used for shielding; injuries:- dermatitis, erythema
	Becquerel accidentally discovers radiation; film darkening from U ore
	Radiation therapy for eczema, lupus and hypertrichosis
	Experimental self-injury by X-rays: Elihu Thompson
	Shielding (glass) for X-rays by W. H. Rollins
1897	American X-ray Journal documented 69 X-ray injuries
	Roentgen Societies formed in England
	Public controversy about radiation risks
	Fluoroscope invented by Edison
1898	Madame Curie extracts polonium and purifies radium. Marie and Pierre Curie coin the word 'radiation'. X-ray filter (aluminum) introduced by Elihu Thompson
	Leaded X-ray housing and collimators introduced by Rollins
	Gamma rays discovered by Paul Ulrich Villard
1899	Malpractice award for X-ray burns
1900	Crookes shows that pure uranium separated from impurities is almost non-radioactive. Obviously the impurities are the source of the radiation.
1900	Proof that radiation causes biological damage by Robert Keinbock
	Roentgen society formed in U.S.
	`Radon' discovered by Frederick Dorn
1901	Roentgen wins first Nobel prize in Physics
	Becquerel accidentally burns himself with Ra-226, observes the effects.
	Everything in the Curie laboratory is radioactive from unknown Rn.
	GL electroscopes rapidly lose their charge when Mme Curie enters any laboratory.
	X-ray lethality to a person, alleged
	Laboratory animals deliberately killed by X-rays: Rollins
1902	X-ray lethality to mammalian fetus demonstrated: Rollins
1903	Sterilization of rats by high dose X-rays
	Direct reading radiation instrument - Spinthariscope: Crookes
	Leukemia induced by radiation in laboratory animals: Heineke
	Nobel prize in physics for Becquerel, and the Curies
1904	Death attributed to X-ray cumulative exposure: Clarence Dally: Assistant to Edison. Edison abandons X-ray research after Dally's death.
1906	`Law' of tissue radio-sensitivity formulated by Bergonie and Tribondeau
1907	X-ray induced mutation in toads at high doses reported by Bardeen

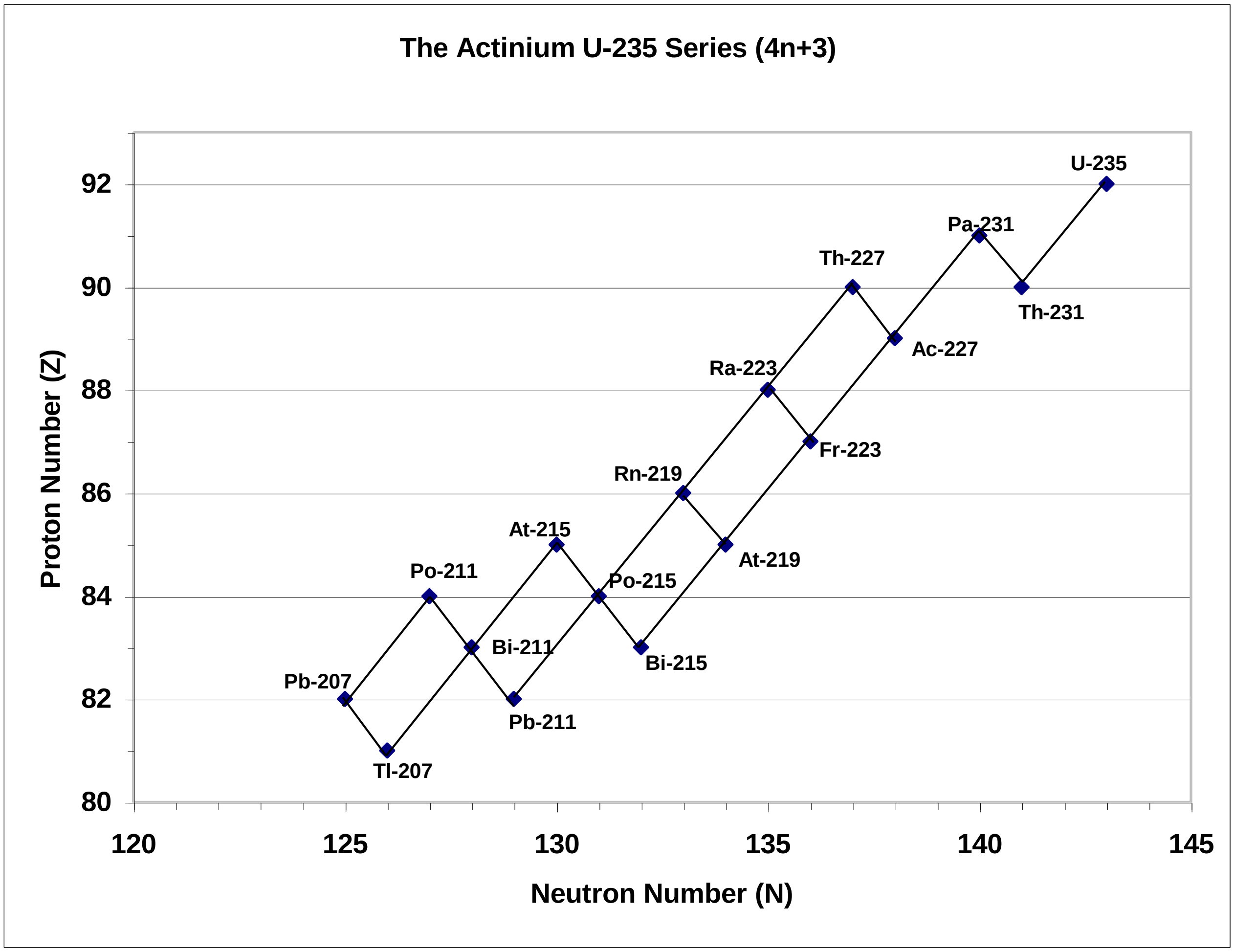
	Radiation detection using gas-filled tubes: Geiger and Rutherford
1910	The Curie, is attempted to be defined as the radioactivity of 1 gram of pure radium: a problem-prone definition, which led to injury in health faddists imbibing radium.
1911	Nobel prize in chemistry for Madame Curie
1912	First internal medical administration of radium.
	Particle accelerators.
	Bragg, X-ray crystallography used to show mineral structure.
1913	Benefits of radon (and smoking!) promoted by doctors
	German recommendations of Deutsche Roentgengesellschaft
	Hot cathode tungsten targets for X-rays introduced by Coolidge
1915	British Roentgen Society proposal for radiation protection
1920	Quantification of radiation by film: early dosimeter
	Radium dial painters (less than 1% health problems).
	Proposed radiation protection regulations.
	Rutherford postulated the neutron: Chadwick finds it.
1921	Death of Ironside Bruce of aplastic anemia attributed to X-rays; move to abandon the use of X-rays - failed.
1922	American Roentgen Ray Society adopts protection rules
1923	First use of radioactive tracers (Bi: Hevesy). George Hevesy used a radioactive tracer to show that his Manchester landlady - to her annoyance and his discomfort - was recycling the previous day's dinner leftovers
1924	About 1% of Radium dial painters - `radium jaw':- Theodore Blum
1925	First International Congress of Radiology
	Tolerance dose proposed by Mutscheller
1927	Muller and Fruit Fly mutagenesis with high doses of X-rays
	Commercial ionization chamber - Victoreen
1928	Forerunner of ICRP and ICRU founded
	X-ray intensity unit proposed by 2nd International Congress of Radiology
1929	Thorotrast, X-ray contrast medium in medicine
	Advisory Committee on X-ray and Radium Prot. established in U.S.
	Osteogenic sarcoma of radium dial painters reported: Martland and Humphries
	`Cleveland disaster'. 125 people killed by X-ray film fire
1930	Ankylosing Spondylitis treatment. Occupational dose limits.
1931	Cyclotron. First man-made radionuclides
	The Roentgen adopted as a unit of X-radiation
	League of Nations radiation safety report by Wintz and Rump
1942	Fermi. Sustained fission, Chicago
	Manhattan Project (criticality deaths - Slotin, Dagnian) - and birth of Health Physics
	Radio-isotopes from medical nuclear reactors possible - no shortages.
1944	Treatment of TB with internal Ra-224.
1945	Alomagordo bomb test - some army generals betting it would fizz.
	Hiroshima and Nagasaki bombed; rumor mills begin; deformed births etc.
	ABCC Atomic Bomb Casualty Commission established: forerunner of RERF
	Groves dumped Japanese cyclotrons at sea
1946	ACXRP re-organized to NCRP
1949	New Dose limits: 3 mSv/week
1950	ICRP and ICRU re-organized from pre-war committees
	Start of nuclear medicine.
	`ALAP' (as low as possible), organ limits and skin dose limits
1953	ICRU introduces concept of absorbed dose
1954	X-rays and screw worm elimination from Curacao (Muller's idea).
1956	ICRP 50 mSv/a for Radiation Workers
1957	NCRP introduces age proration for occup. exp limits and 5 mSv/y for public
1958	As low as practicable. 2.5E9 sterile screw-worms released in SW US.
1959	ICRP recommended limit of genetically significant dose to population, of 50 mSv in 30 years

1961	10 CFR 20: US Standards for protection against radiation
1965	T65D - tentative 1965 dose calculated for Hiroshima/Nagasaki bombings ALARA: As Low As Reasonably Achievable; economic and social factors being taken into account
1970	130 million medical diagnoses and treatments each year
1972	H. Bouzigues (France), noted that OKLO ore was deficient in U-235
1979	Three Mile Island accident - radiation hysteria - no injuries
1980	300 million medical diagnoses and treatments each year
1986	DS86 - revised dosimetry estimate for Hiroshima/Nagasaki - less neutron, more gamma contributions Chernobyl - more radiation misinformation - 28 avoidable firefighter deaths, few actual injuries to the general population. Evacuations widespread. Returns discouraged but possible since the first months. Some people refused to leave and are in good health.
1990	Epidemiological studies cannot pinpoint adverse health effects from low doses, but typically show beneficial health effects.
1991	ICRP 60. New Dose limits based on New Hiroshima/Nagasaki dosimetry estimates. New tissue weighting factors. New Quality factors. ARWs: 100 mSv in 5 years. General Public: 1 mSv/a.
1995	Debate over applicability at low and chronic doses, of Linear Dose Response without Threshold (LNT) hypothesis. Adaptive response. Hormesis. Fifty years after Hiroshima/Nagasaki. No genetic effects. No mutations, no birth defects. About 300 excess cancers; about 80 excess leukemias Age related death rates unusually LOW! Survivors living longer than expected and in better health so there will, of course, be more cancers; the longer we survive the higher the probability of dying of cancer.

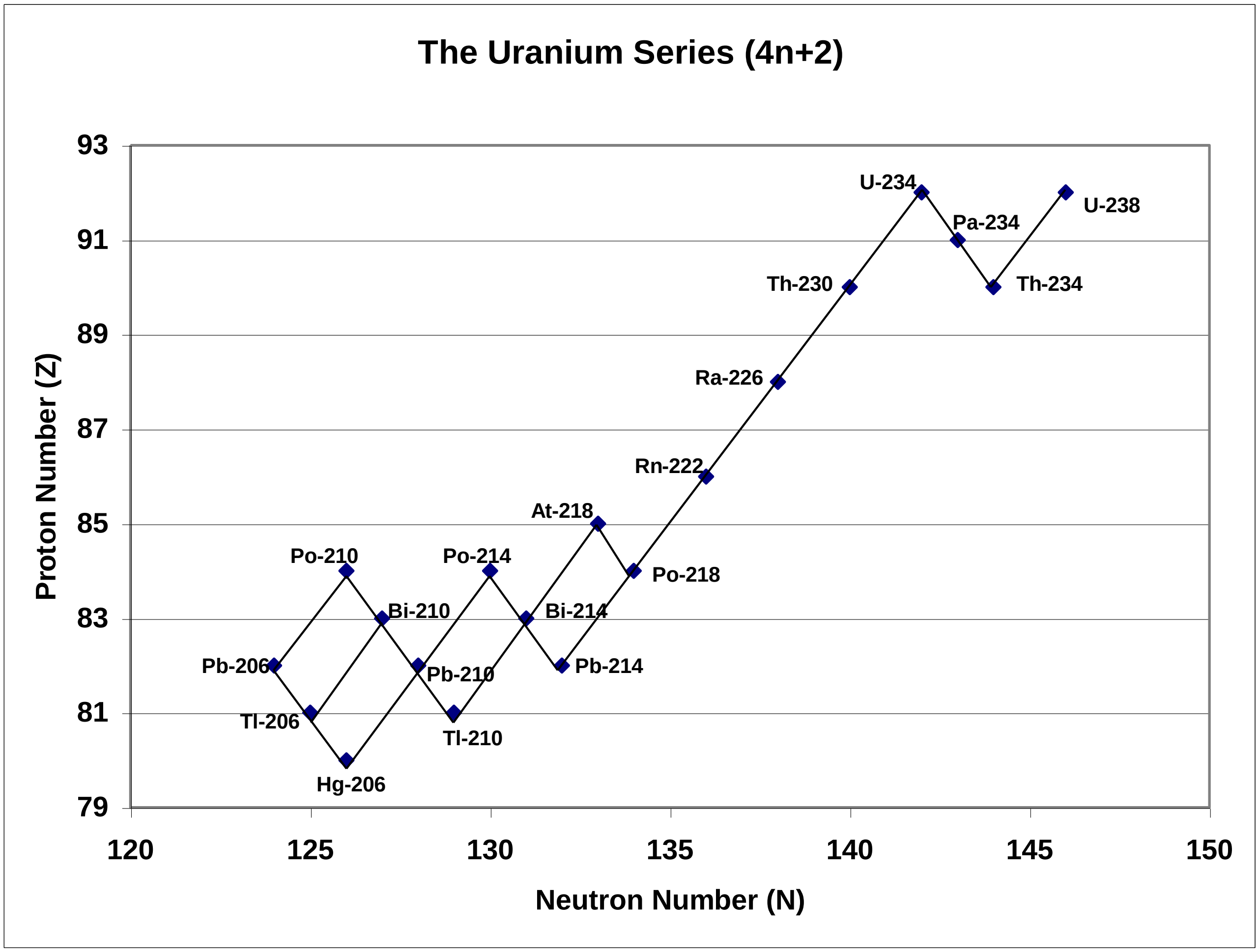
Most data from Health Physics Journal, Vol. 69, November, 1995.

Appendix 2.

The Uranium-235 Decay Series



The Uranium-238 Decay Series



The Thorium-232 Decay Series