MEDICINE AND NUCLEAR POWER

FACT SHEET PRODUCED BY THE CANADIAN COALITION FOR NUCLEAR RESPONSIBILITY

Gordon Edwards, Ph.D., September 2022

Modern medicine does not depend on nuclear power. All electricity producing reactors could be shut down permanently with little or no impact on best medical practices.

1) X-rays and CT-scans are by far the most common forms of "radiation" used by doctors, dentists and nurses in hospitals and clinics. These procedures have nothing to do with radioactivity or nuclear reactors.

2) When X-ray machines and CT scanners are turned off, they are completely harmless. There is no more radiation emitted. There is no radioactivity at all associated with such machines.

3) Some radioactive materials are used in medicine for diagnosis or therapy. In addition, some are used to sterilize instruments and equipment such as masks, needles, and other paraphernalia.

4) Radioactive materials for medical use are called "medical isotopes" or "radiopharmaceuticals". Some of them emit gamma radiation (similar to X-rays, but stronger). Some of them emit fast-moving subatomic projectiles – electrically charged alpha particles, beta particles, or positrons,

5) All radioactive emissions are harmful to living cells, especially rapidly dividing cells. They can accordingly be used to destroy malignant growths or kill micro-organisms in order to sterilize medical equipment.

6) Radioactivity is hazardous, and it cannot be turned off like an X-ray machine. So the use of radioactive materials in medicine requires careful control at all times – before, during and after use.

7) Some radioactive materials that are used in medicine, such as radium, radon and thorium, are extracted from naturally-occurring ores and have nothing at all to do with nuclear reactors.

8) Some radioactive materials used in medicine are created in a "particle accelerator" such as a cyclotron or linear accelerator. These devices have nothing in common with nuclear reactors.

9) Some radioactive materials used in medicine are created in small research reactors that do not generate electricity. They are typically 20 to 300 times smaller than nuclear power reactors.

10) A few medically useful radioactive isotopes are produced in power reactors, but they can equally well be produced in research reactors. Sometimes the same radioactive material, or an alternative material that serves the same purpose, can be produced in a particle accelerator.

11) Damage to healthy cells by radioactivity may lead to cancer years later or to undesired genetic mutations. Infants and foetuses are more readily harmed than adults because cell growth is rapid. Girls and women are more vulnerable than adult males.

12) Some medical procedures that once relied on radioactivity have been replaced by procedures that are just as good or better and do not require handling radioactive sources.

13) Many hospitals that used X-rays or gamma emitting cobalt-60 therapy to destroy cancerous tumors now use beams of charged particles. This more modern medical technology is very effective and has nothing to do with radioactivity or with nuclear reactors.

14) Powerful gamma-emitting cobalt-60, created in a reactor, is often used to sterilize medical equipment. But sterilization can be done in other ways that use no radioactive materials at all.

Hospitals do not need nuclear power for isotopes, and never have. Isotopes (radioactive materials) that are medically useful can be produced by accelerators or small research reactors. Also, in many instances, medical procedures that do not involve radioactivity are preferred.

FOR MORE INFORMATION ON ANY OF THESE 14 POINTS SEE **www.ccnr.org/medical_fact_sheet_2022.pdf**

Pour la version francaise de ces Notes Explicatives voir **www.ccnr.org/medical_fact_sheet_2022_f.pdf**

(1) X-rays were discovered in 1895 by Wilhelm Roentgen. He used electrical currents to cause visible electrical discharges in a partially evacuated glass tube (a "cathode ray" tube). He was surprised to observe that when the electrons strike the positively charged metallic terminal at the other end of the tube, a very penetrating form of invisible energy is given off laterally.

Not knowing what he had found, Roentgen referred to it as an X-ray (X for unknown). He noted that when the current is cut off, the electric discharge stops, and no more X-rays are produced.

This penetrating energy – a type of electromagnetic radiation with a very short wavelength – can easily pass through the soft tissues of the body, but not so the bones. The bones partially block the X-rays and therefore cast a shadow on a photographic plate. Voilà: a visible skeletal image.

X-rays are harmful to living cells, so all exposures must be limited in time and intensity. Lead aprons are often used to protect a patient's gonads, because X-rays can cause mutation damage to the reproductive cells (eggs or sperm). Such damage can result in the transmission of genetic defects to children and grandchildren for many generations to come. Chronic exposure to low levels of X-rays can also cause leukemia and other cancers that may develop years after the exposure has ceased. For these reasons, doctors, dentists, nurses and X-ray technicians normally step out of the room before taking a patient's X-ray photographs, called "radiographs".

(2) X-ray machines are harmless when they are turned off. When the electricity is on, the atoms in the target material become "excited" as they are struck by the electrical discharge. Some of the electrons orbiting around the nucleus of such an atom are temporarily jolted intoa much higher orbit, further away from the nucleus. These "excited electrons" then fall back into a lower orbit rather quickly, emitting bursts of energy called "photons". All photons travel at the speed of light, but each photon has its own distinct energy level. A very high-energy photon has a very short wavelength. That is the case with an X-ray. Once all the excited electrons in the target material have dropped down into their lowest orbits, no more X-rays are emitted.

Radioactivity is altogether different. It was discovered by Henri Becquerel in 1896, less than a year after the discovery of X-rays. Whereas X-rays are created momentarily by electrons changing orbits, radioactivity occurs because the core of the atom – the nucleus – is unstable. An unstable nucleus will suddenly and violently disintegrate. When that happens, the disintegrating nucleus throws off an electrically charged "alpha" or "beta" particle. In some cases a very energetic photon called a "gamma ray" is emitted. These subatomic projectiles – alpha, beta & gamma – are damaging to living cells. Collectively, they are referred to as "atomic radiation". It is impossible to predict when an individual radioactive nucleus will disintegrate. Nuclear disintegrations occur spontaneously, so there is no way to "turn off" radioactivity.

A radioactive element will continue to "radiate" at an ever diminishing rate until all of its unstable atoms have disintegrated. How long that takes depends upon the "half-life" of the radioactive element. That's the time required for half of the atoms to disintegrate.

(3) Diagnostic Use: When a small amount of a gamma-emitting radioactive material is injected into or ingested by a patient, it is circulated by bodily fluids moving inside the body. The gamma rays penetrate the soft tissues, leaving an image on a photographic film or monitor located outside the body. This lets doctors see what's going on inside the body & helps them make a correct diagnosis. In such a scenario the radioactive material (radioisotope) is being used for diagnostic purposes.

***Therapeutic Use:** If an unwanted growth is detected in a patient's body, a suitable radioactive material may be inserted into the tumor as a "seed" to kill it, or used therapeutically as an external radiation source. Alternatively, radioactive material may be administered internally as a "radiopharmaceutical". After injection or ingestion, the substance migrates to the affected organ, and upon arrival the damaging radioactive emissions "burn" the unwanted growth.*

***Sterilization Use:** Cobalt-60 is an exceptionally powerful gamma-emitter. It is created inside a nuclear reactor as a byproduct of the fission process. Often used for external radiation therapy, cobalt-60 is also utilized in specially-built facilities to sterilize medical instruments and paraphernalia. Behind the heavily-shielded walls of the facility, all micro-organisms are killed by a powerful blast of gamma radiation – a dose that would kill any human being very quickly. Cesium-137, another potent gamma-emitter, can also be used for sterilization in a similar way.*

(4) Because of its highly penetrating energy, gamma radiation can be used externally to target an unhealthy tumor inside the body and burn it out. In other cases gamma-emitting materials are placed in needles that are inserted into a solid tumor to kill it. Diagnostically, weak gamma-emitters inside the body – administered as radiopharmaceuticals – can "illuminate" the body from inside and give doctors a clearer picture to help them in formulating a medical diagnosis.

Beta particles are much less penetrating than gamma rays. In soft tissue, most beta particles cannot travel more than a centimeter. For that reason beta emitters are mainly internal hazards rather than external hazards, although they can severely damage the skin and the eyes from outside. The rather short path of beta particles means that most of the biological damage done by an internally deposited beta-emitter is limited to a relatively small volume of tissue. It also means that beta particles cannot be used as diagnostic tools unless there is a gamma ray as well.

For example, when radioactive iodine-131 is administered to a patient with a thyroid tumor, the radioactive isotope goes to the thyroid gland just as non-radioactive iodine will do. That's because the chemical properties of the two are identical, unaffected by radioactivity. But the radioactive iodine atoms disintegrate, giving off beta particles and gamma rays. Almost all of the biological damage to the tumor is done by the beta particles because their energy is concentrated in a rather small volume, while the energy of the gamma rays is dissipated over large distances.

An alpha particle is even less penetrating than a beta particle, in large part because the former is 7300 times more massive than the latter. In soft tissue, an alpha particle will only travel a few micrometres. Nevertheless, per unit of energy deposited in tissue, alpha radiation is 20 times more biologically damaging than either beta or gamma radiation. A nuclear executive recently said the difference between alpha and beta radiation is like the difference between a howitzer (a small cannon) and a rifle. Indeed, most of the dangerous radioactive elements known as public risks are alpha emitters, such as radium, radon, plutonium, polonium, thorium, and uranium.

Recently, medical practitioners have become interested in targeted alpha radiation therapy. When a short-lived alpha emitter is introduced into the body in such a way that it seeks out unhealthy cells and blasts them with alpha particles at short range, remarkable improvements can be seen even in cases of metastasized cancer. This does not require nuclear reactors at all.

(5) X-rays have an important characteristic in common with radioactive emissions – they are all forms of "ionizing radiation". X-rays, gamma rays, alpha particles, and beta particles, all carry so much electromagnetic energy that they can easily break the chemical bonds holding molecules together. After a molecule is broken, the electrically charged fragments are called

"ions". Each breakage produces a pair of ions, positively and negatively charged. This allows for the passage of an electrical current, and that can produce a "click" on a Geiger counter.

Ionizing radiation is considered to be more hazardous than non-ionizing radiation such as infrared, ultraviolent, or microwave radiation. In particular, direct damage to the DNA molecules by ionizing radiation can create rogue cells that proliferate and grow into cancerous tumors or blood disorders like leukemia. If a person's reproductive cells (eggs or sperm) are damaged in a similar manner, the harmful consequences may be felt in future generations.

In general, carcinogens (cancer-causing poisons) and mutagens (mutation-causing agents) do not have a "safe threshold" of exposure. Even very low doses, if administered to a large population, will cause an increased incidence of cancer or mutations. Because all radioactive materials are carcinogenic and mutagenic, any exposure to them should be eliminated whenever possible, or kept at the lowest achievable level in cases where contact cannot be avoided. That goes just as well for gamma radiation and X-rays as it does for alpha and beta contamination.

(6) Because the forces holding the nucleus of an atom together are the strongest forces in the universe, energy that is released from the nucleus – "nuclear energy" – is millions of times more powerful than the chemical energy derived from electrons in their orbits around the nucleus. A portion of the stored nuclear energy is released during each radioactive disintegration. High doses of the resulting radiation can kill; lower doses can cause cancer and genetic mutations.

Since radioactivity is a form of nuclear energy that cannot be shut off, radioactive materials used for commercial or medical purposes inevitably become radioactive garbage after use. If they are gamma-emitters, they have to be kept at a safe distance and heavily shielded. And all radioactive wastes must be kept out of the air we breathe, the food we eat, and the water we drink.

It is particularly difficult to manage the hazard when the wastes are long-lived – with half-lives measured in decades, centuries, millennia or in some cases billions of years. Isotopes used in medicine like radium-226 (1600 year half-life), plutonium-238 (88 year half-life), thorium-232 (14 billion year half-life), have been largely abandoned in favor of shorter-lived isotopes.

But even short-lived medical isotopes can have long-lived radiological repercussions. The most widely used diagnostic isotope in the world is radioactive technetium-99m, a weak gamma-emitter with a half-life of only 6 hours. But when an atom of technetium-99m disintegrates, it is transformed into an atom of technetium-99 – a beta-emitter with a half-life of 210,000 years. Also, until recently, technetium-99m was produced in research reactors using a process that simultaneously produces intensely radioactive waste with a hazardous life of 10 million years.

(7) Uranium is a naturally occurring radioactive element with a 4.5 billion year half-life. That is approximately the age of the Earth, so half of the uranium that was here when the Earth was formed, is still here. Some of it is in the Earth's crust, and some of it is in the molten core.

When a uranium atom disintegrates it does not disappear, but turns into an atom of a different element – protactinium – that is also radioactive with a very much shorter half-life. When that atom of protactinium disintegrates, it turns into an atom of a still different radioactive element, and that atom in turn disintegrates. And so the chain of disintegrations continues, producing about a dozen radioactive "progeny", finally terminating with a non-radioactive atom of lead.

In this way, each atom of uranium produces a "decay chain" of a dozen other radioactive elements. The decay chain of uranium includes both radium-226 (half-life 1600 years) and radon-222 (half-life 3.8 days). These two radioactive elements have been responsible for the

deaths of countless thousands. Radon, by itself, would disappear in a matter of weeks – but if it is continually replenished by the disintegration of radium atoms, it will last for millennia.

Radium and radon are both alpha emitters, but some of their atoms quickly disintegrate into radioactive progeny that are powerful beta emitters and gamma emitters. So it is possible to shrink solid tumors by inserting golden needles filled with radium (a heavy metal) or radon (a noble gas) for a period of time. Although the alpha particles cannot penetrate through the wall of the needle, the beta particles can do so to a certain degree, and the gamma rays simply burst forth with no difficulty. Subjected to a withering attack by gamma rays and beta particles, the tumor simply shrivels up. Not a cure, perhaps, but certainly an efficacious treatment.

Like uranium, thorium is a primordial radioactive element – one that was here when the Earth was formed. It is about three times as abundant as uranium in natural ore bodies. It too has been used in medicine, notably as "thorotrast" – a contrast agent in fluoroscopy until the 1950s. The use of both radium and thorium has been largely discontinued due to the harmful medical side effects of using and/or handling these materials. Radon needles are still commonly used.

(8) Charged particles such as electrons or protons can be accelerated to very high speeds by using the electromagnetic forces of attraction and repulsion in a carefully designed machine.

A cyclotron pushes such charged particles outwards along spiral paths that are curved by magnetic attraction and accelerated by rapidly changing electrical fields. The first cyclotron was constructed before the first reactor was ever built. A linear accelerator uses straight paths instead of curved paths to achieve similarly high velocities of charged subatomic particle or ions. Cyclotrons and linear accelerators have nothing in common with nuclear power plants.

When a very fast, highly energetic charged particle collides with a target, some of the atoms in the target can be altered so as to become radioactive. In recent years cyclotrons have been used to create technetium-99m without any need for a nuclear reactor. This method of production does not create long-lived intensely radioactive waste as the reactor production method does.

Cyclotrons are routinely used to produce medical isotopes like carbon-11, fluorine-18, oxygen-15 and nitrogen-13, which are used in Positron Emission Tomography (PET) scans. These four isotopes give off beta particles that are positively charged – called "positrons" – whereas the vast majority of beta particles are negatively charged. The advantage of positrons is that they are annihilated when they collide with a negatively charged electron inside the body, giving off two gamma rays that can be captured on film for diagnostic purposes.

Cyclotrons and linear accelerators currently provide more than 10 percent of medical isotopes, but this share is growing steadily as more and more versatile applications are being discovered. One of the newer medical isotopes, actinium-225, is produced using a cyclotron with radium-226 as the target. Since radium is naturally occurring, this process doesn't require nuclear reactors.

(9) Until the year 2010, the world's entire supply of technetium-99m (the most widely used of all diagnostic isotopes, servicing millions of patients annually) was produced by just five reactors in the western world. All of them were very old, fairly small research reactors that never produced electricity. In Canada, two tiny new reactors called MAPLEs (10 megawatts of heat) were built in 2000 specifically to mass-produce about half of the world's supply of technetium-99m along with several other medical isotopes. Evidently there is no need for large electricity producing power reactors to satisfy the global demand for medical isotopes. Indeed, much of the market for technetium-99m may now be satisfied by cleaner methods of production using accelerators.

(10) Worldwide, nuclear power as an energy source has been in steep decline for the last quarter century. The nuclear contribution to global electricity use has slipped from 17% in 1997 to only 10% today, and it is still going down. Negative public perceptions regarding nuclear waste, catastrophic reactor accidents, proliferation of nuclear weapons, and enormous cost overruns, have plagued the industry for the last few decades.

The production and use of medical isotopes has never been dependent on the nuclear power industry. However, promoters of nuclear power have realized that emphasizing the potential medical connection is very useful to overcome the bad publicity surrounding nuclear power. This may be the reason why large power reactors are now being tasked with producing medical isotopes that could more easily be created in small research reactors or in particle accelerators. Politicians and the public are easily misled into thinking that modern medicine actually requires a vibrant nuclear power industry, which is not at all the case.

For example, the large CANDU reactors at Darlington NPP, just east of Toronto, are slated to begin producing technetium-99m in the near future using a somewhat cleaner method (neutron activation) than the one previously used at Chalk River (fissioning weapons-grade uranium). But alternative accelerator-driven methods are available. Meanwhile, the CANDU reactors at Bruce NPP are intended to produce a relatively new medical isotopes, lutetium-177, for therapeutic use. In both cases, the process depends on neutrons from a nuclear chain reaction hitting a suitable target to produce the required isotope. But that process can be carried out in any research reactor with much greater ease. The use of electricity-generating power reactors for these particular purposes seems to be, in large part, for public relations reasons.

(11) From the discovery of ionizing radiation in 1895-96, sixty years before the first nuclear power plant was built, X-rays and radioactive materials have been accepted as useful tools in medicine. With the advent of particle accelerators and research reactors, a host of new medical isotopes could be created for specific diagnostic and therapeutic purposes. At no time were these developments dependent on the existence of a large nuclear power industry. And, from the earliest years, it was crystal clear that ionizing radiation is harmful. It can burn and kill at high doses, and at low doses it is a potent carcinogen and mutagen as well as a teratogen.

Whenever radiopharmaceuticals are used, some of the patient's healthy tissues will be damaged by radioactive emissions, so the health professional must make a careful trade-off to ensure that the benefit to the patient outweighs the radiation risk. Some past radiation therapy practices have been discontinued because the risks have been found, over time, to be much greater than the benefits. If there is an alternative form of therapy that does not require radioactive isotopes, health professionals will often choose that procedure for safety reasons.

There was a time when X-ray machines were used in shoe stores to let customers see their toes wiggling inside their new shoes. That's gone. Special buses would arrive in elementary school playgrounds once a year to give every single child a chest X-ray. That's gone. In both cases, it was eventually realized that the cumulative risks far outweighed the scant benefits.

The long-term harmful effects of ionizing radiation were discovered in almost all cases by health professionals working outside of the nuclear industry. It was a forensic pathologist, Dr. Martland, who discovered in the 1920s that teenage girls hired to use radium paint to make instruments glow in the dark suffered from a variety of life-threatening radiation-induced illnesses ranging from fatal anemia to bone cancer (and head cancer many years later). It was a pediatrician, Dr. Alice Stewart, who showed in the 1950s that a single X-ray to the abdomen of a pregnant woman could cause a 50 percent increase in subsequent cases of childhood leukemia.

It was a Nova Scotia general practitioner, Dr. Mackenzie, who discovered in the 1960s that X-ray exposures to the chest do trigger an increased incidence of female breast cancer in later years. German epidemiologists in 2008 found an increase in leukemia among children under 5 years of age living in the vicinity of any one of the country's 17 nuclear power plants.

Medical practitioners are not aways aware of the long-term health consequences of chronic exposures to ionizing radiation, as it is seldom included in the curriculum of medical schools. Some health professionals are unaware of the long-standing dictum that all unnecessary exposures to ionizing radiation should be avoided, and needful exposures should be kept as low as possible based on a balancing of the long-term risks and the medical benefits to the patient.

It is well known that embryos and young children are far more radio-sensitive than adults. In recent decades it has become increasingly clear that women and girls are significantly more susceptible than men to the long-term harmful effects of low-level ionizing radiation.

(12) For a number of years, plutonium-powered pacemakers were surgically implanted in patients in order to ensure that the power source could be relied upon for the rest of the patient's life. The isotope used was plutonium-238, having an 88 year half-life. Since plutonium is a highly radiotoxic material (a powerful alpha emitter, as well as a gamma and neutron emitter) this practice created a radioactive waste problem. On average, the patient would receive a whole-body radiation dose of one millisievert per year, which is the maximum permissible exposure for a member of the public. The pacemaker would have to be removed from the patient's body after death to allow for the plutonium to be "shipped to Los Alamos" and properly disposed of as radioactive waste. Since 1985, plutonium is no longer used in heart pacemakers; only about nine of them are still in use. Lithium batteries are used instead.

(13) A particle beam is produced by a linear accelerator. It consists of a highly energetic stream of very fast-moving electrically charged particles. Like the alpha particles and beta particles emitted from a disintegrating nucleus, these accelerated particles are another form of ionizing radiation, but they do not involve radioactivity or nuclear reactors in any way.

A beam of accelerated electrons can be used to treat very shallow (superficial) tumors, such as skin lymphomas. A beam of accelerated protons can reach much deeper tumors. In addition, a photon beam consisting of penetrating X-rays can be produced and utilized when an electron beam is made to collides with a suitable target material.

Traditional radiation therapy delivers X-rays, or gamma rays, to the tumor – and beyond. This damages healthy tissues and can cause significant side effects. By contrast, particle beam therapy delivers a beam of charged particles that stops at the tumor, so it's less likely to damage as much healthy tissue. Side effects are much reduced.

A particle beam can be just as effective as gamma rays in destroying unhealthy tumors. In a recent study, after 3 years, 46% of patients in the proton therapy group and 49% of those in the traditional radiation therapy group were cancer free. Fifty-six percent of those receiving proton therapy and 58% of those receiving traditional radiation were still alive after 3 years.

(14) A typical medical irradiation facility houses between 1 and 5 million curies of cobalt-60. Unshielded, this radioactive material will deliver a dose of 12 to 60 thousand sieverts per hour at a distance of one metre. That's an enormous blast of gamma radiation, enough to kill even the most radiation resistant organisms instantly. Five sieverts is sufficient to kill a human.

Cobalt-60 is initially stored under water (like irradiated nuclear fuel) to shield workers from the gamma rays. Medical equipment is placed on shelves, and once the doors are closed and sealed, the cobalt-60 source is lifted from the pool into the air from whence it irradiates the equipment.

The widespread use of cobalt-60 for sterilization, in relatively unsecured facilities, has spurred concerns about the possible loss, theft or malicious use of this dangerous radioactive material. One small cobalt-60 device ended up in a Mexican scrapyard, leading to thousands of tonnes of gamma-emitting steel being shipped throughout the USA and Canada, some of it ending up as radioactive table legs in a Winnipeg café.

If stolen, cobalt-60 can be used by terrorists in a "dirty bomb" – a radiological explosive device that would cause panic, radiation burns, loss of life and irreparable property damage if detonated in the heart of a city or elsewhere. Moreover, if an irradiation facility were located in a war zone, it could be bombed, spreading radioactive contamination far and wide. For such reasons many governments are calling for a halt to the use of cobalt-60 for sterilization.

X-rays, particle beams, and photon beams are among the alternative technologies that can be used to sterilize equipment using ionizing radiation without the use of radioactive materials. Microwaves, dry heat, and certain chemical treatments are also effective in various forms. But as long as radioactive materials continue to be used for sterilization, these gamma-emitting source materials need not be produced in electricity-generating power reactors.

Because cobalt-60 has a half-life of 5.26 years, the radioactive inventory in a typical irradiator diminishes by about 12 percent per year. It must be replenished. As a result, shipments of very large quantities of cobalt-60 must take place at regular intervals, increasing the risks of accidental loss or dispersal of the material, and maximizing opportunities for would-be thieves.

Many health professionals assume that used cobalt-60 is routinely recuperated, repackaged, and reused in new cobalt-60 devices, but this is not generally the case. Much of it is returned to Canada – one of the largest suppliers of cobalt-60 – where it is discarded as radioactive waste. At Chalk River, Ontario, a permanent "megadump" of one million cubic metres of radioactive and other toxic wastes is planned (as of 2022) as a surface landfill just one kilometre from the Ottawa River. Approximately 99 percent of the initial radioactive inventory of this megadump is expected to be discarded cobalt-60 sources. The dump will also include 30 other radioactive waste products, 15 of them having half-lives greater than 100,000 years. Over 140 municipalities (including Montreal) and five Indigenous First Nations, all drawing their drinking water from the Ottawa River, have expressed strong opposition to this proposed dump, but so far to no avail.

The radioactive waste legacy of the nuclear age is never properly considered in the cost of using radioactive materials for medical or industrial purposes. Nuclear power and particle accelerators are the only industrial enterprises that actually create new, highly toxic elements, as routine waste byproducts. Except for the natural process of radioactive decay, which cannot be slowed, stopped or speeded up by any method known to science, these human-made unstable elements are indestructible and remain hazardous to living things due to their ionizing emissions.

Some of these new radioactive elements have proven to be medically useful, without doubt, but their hazards – and alternatives to their mode of production and use – must be borne in mind.