BASIC KNOWLEDGE OF NUCLEAR HAZARDS: LESSONS FROM CHERNOBYL AND FUKUSHIMA

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Foreword

One of the most important lessons emanating from the Chernobyl accident is that its effects on people were increased by the fact that authorities were late both in communicating the gravity of the accident and in taking the necessary measures of protection. These same hesitations and lack of transparency on the part of the authorities were unfortunately reiterated in the Fukushima accident. Such shortcomings are no longer tolerated by citizens. In democracy, authorities are accountable to the people and to the courts. Consequently, decisions affecting the life of all should be taken under the scrutiny of the public eye. This is why it is vital to rethink the governance of risks, including the radiation risk, and improve the way in which our democratic societies involve citizens in the main decisions affecting their safety and livelihoods.

The Council of Europe stands for a better participation of citizens in decisions affecting their lives. Our Organisation is built around the fundamental values of human rights, rule of law and democracy, all values which were ignored in the political system that witnessed the Chernobyl disaster. Democracy is a requisite if we are to build safer, more resilient societies. People have the right to be made aware of the risks surrounding them and public authorities have the duty to involve them in measures and procedures aimed to protect them from risks. One fundamental aspect of safety is access to the relevant information concerning the hazards that some industrial activity may pose to the population.

The present book is the result of a project commenced by the European and Mediterranean Major Hazards Agreement (EUR-OPA) of the Council of Europe on the radiation hazard, in the understanding that improving information on the risks will help the protection of the people. The aim of the book in your hands is ambitious – to present basic knowledge of nuclear hazards that is acceptable and interesting for different groups of people: teachers, journalists, decision makers, students and others. As illustrated by Chernobyl and Fukushima, there is only one trustworthy source of information in the case of an emergency – people's own analysis of initial information on the basis of their own basic knowledge.

Because we believe that nuclear scientists alone could not produce such a book, it was agreed that only the first draft should be prepared by a nuclear physicist. It was then subject to a very wide consultation among other professionals. The book was translated into eleven languages and discussed in Armenia, Azerbaijan, Belgium, Bulgaria, France, Georgia, Luxemburg, Moldova, Morocco, Russia, San Marino, Turkey, Ukraine, USA and other countries. We received many useful proposals from journalists, decision makers, teachers and students who contributed to improving the text and making it more comprehensible to people the world over (see appended list of co-authors). Our gratitude is extended to all and we sincerely hope this book may enhance the dissemination of basic knowledge on nuclear safety.

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1. Introduction

The nuclear accident at the Chernobyl reactor in 1986 shocked the world. More than 100,000 people in Belarus, Ukraine and Russia were evacuated from the contaminated area, and about five million people overall were exposed to radiation. In France, Germany, Poland and other European countries radiation protection measures have been implemented.

The Fukushima nuclear accident in 2011 proved that to every nuclear reactor there are attributed nuclear hazards. The public perception of the Chernobyl and Fukushima nuclear accidents clearly demonstrated tremendous inefficiency in informing people of radiation hazards corresponding to radionuclide releases.

The exposure doses in Europe from radioactive iodine-131 of Fukushima releases were less than one thousandth of an exposure from natural radionuclides, like radon or potassium. Nonetheless, iodine-131 created high fear for the general public in many European cities. In the case of nuclear accidents, only a few people trust the official information released by national authorities or experts on radiological risk assessment. This fact clearly reveals that there is only one way to provide people with trustworthy information about nuclear hazards. This is to give people basic knowledge about radiological hazard and allow them to build their own capability for risk assessment.

Unfortunately, recommendations of responding to nuclear emergencies in the form of frequently asked questions usually did not work, because to correctly understand answers of some important questions, one should have some basic knowledge. In many cases small doses of artificial radionuclides (like iodine-131, cesium-137 or strontium-90) are interpreted by the general public as having a much higher risk than exposure from natural radiation doses. However, in both cases the damaging agent is the same: gamma, beta or alpha particles (the measure of hazard is the exposure dose).

Nowadays, in some countries more than 50% of electricity is produced in Nuclear Power Plants (NPPs), and radioactive materials are used in medicine, industry, transport, military and other areas of human activity. We are exposed to natural radiation from space and earth (from granite, thorium sand) or through eating natural radioactive potassium and inhaling radioactive radon. The radiation exposure is a part of our lives. On the other hand, there are risks due to nuclear or radiological accidents, when as a result of radiation exposure you can lose your life.

All people must ask themselves:

What are the real nuclear or radiological hazards? What are their natures? What do we have to do in the case of a nuclear accident?

Everyone should know the answers to these questions.

2. The nature of radioactivity, the radioactive and stable atoms, and types of radiation

All materials are composed of atoms. An atom consists of a positively charged nucleus and negatively charged electrons which enclose it. An atomic nucleus consists of positively charged protons and neutrons, which lack a charge. The charge of the nucleus is equal to the number of protons in the nucleus. (see Attachments, page 5)

The chemical properties of atoms depend on only the number of electrons, equals number of protons in the nucleus. There are atoms with the same chemical properties, but different numbers of neutrons in the nucleus. Consequently, they have different physical properties. Some of these atoms could be unstable, or radioactive.

Radioactivity is the ability of some nuclei to be spontaneously transformed into another nucleus or into the same nucleus with less energy. The extra energy is released by emitting alpha, beta or gamma particles (in special cases neutrons or others particles can be released).

Atoms with the same chemical properties and a different numbers of neutrons in the nucleus are called isotopes or nuclides. The radioactive isotopes are called radionuclides. For example, there are three main isotopes of hydrogen. The light isotope has a nucleus with only one proton and it is stable, so its atomic mass number is **A**=1, and its symbol is ^{1}H. Deuterium is another isotope of hydrogen; it has a nucleus which consists of one proton and one neutron, and it is also stable. Its atomic mass number is **A**=2, and its symbol is ^{2}H. But the isotope of hydrogen, which has a nucleus consisting of one proton and two neutrons, is unstable. Its symbol is ^{3}H and its name is tritium. The stable isotope of iodine is ^{127}I; the isotope ^{131}I (or iodine – 131) is radioactive. Both isotopes have the same chemical properties. The chemical elements in the nature are in some cases the mixture of stable and long-lived isotopes, for example normal potassium, which presents in minerals and food, is mixture of stable isotopes ^{39}K and ^{41}K and long-lived isotope ^{40}K.

If an isotope is radioactive, what is a unit of radioactivity? One decay per second is a unit of radioactivity called becquerel (symbol Bq). The old unit curie (Ci) equals 3.7×10^{10} Bq. Different radioactive isotopes (radionuclides) have different rates of decay. The rate of decay is characterized by a half-life, which is the period of time when half of all the radionuclides will decay, transforming to other atoms. Within the half-life, radioactivity reduces two times, after 2 half-live 4 times, after 3 at 8 times, etc. The short-lived radionuclides have a higher radioactivity than the same amounts of long-lived radionuclides. For example, ^{131}I has a half-life of 8.02 days, and cesium-137 (^{137}Cs) has a half-life of 30.07 years, so ^{131}I has 1370 times higher radioactivity than ^{137}Cs.

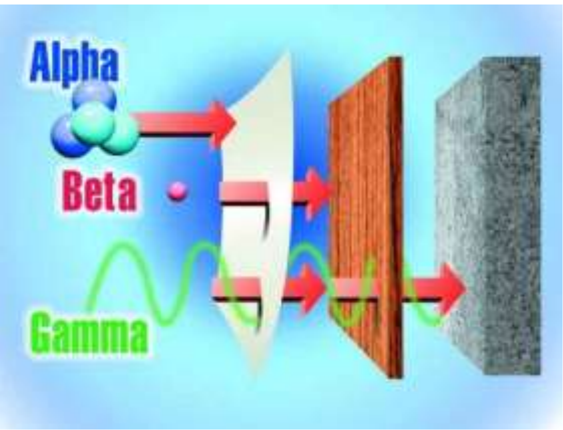
Nuclear energy could be released not only as a result of radioactive decay, but also from a nuclear reaction, which occurs when some nuclei interact with others and create new nuclei, and could generate energy. Our Sun and other stars shine as a result of nuclear reactions. All existing nuclear power reactors produce energy by a nuclear fission chain reaction, which, unfortunately, produces very high radioactive waste – the main source of radiological hazard. Theoretically, it is possible to create nuclear reactions which will produce energy without radioactive waste, but for now nobody knows how to do that. This is a good subject for future research.

3. The interaction of radiation with matter

Ionizing radiation - the flux of alpha, beta or gamma particles - is basically the result of radioactive decay. Ionizing radiation also can be produced by nuclear reactions, such as nuclear fission or nuclear fusion, and by the devices, in which the charged particles are accelerating.

The energy of radioactive decay is emitted as radiation in three main forms: alpha particles, beta particles and gamma rays with different energies.

Charged particles, such as beta particles (the flux of electrons or antielectrons) and alpha particles (the flux of nuclei of helium-4), directly interact with atomic electrons of matter, and transfer the energy for ionizing or excitation to the atoms and molecules. Because alpha particles are heavy and have a double charge, they react strongly with matter, producing large numbers of ions per unit length of their path. As a result, they are not very penetrating. For example, the alpha particle from ^{226}Ra will only travel about 4 cm in air and will not penetrate an ordinary piece of paper. It will only travel about 4 μm in tissue.



Like alpha particles, beta particles have an average traveling distance (range) through matter that is dependent upon their initial energy. For example, beta particles from ^{137}Cs decay will travel up to 8 m in air and about 10 mm in water, and will be completely absorbed by 1mm of steel.

Gamma quanta (rays) or X-rays do not ionize all atoms along their path like alpha or beta particles. Only few of them interact with atomic electrons and transfer energy to the electrons, but a significant part of radiation passes through matter without changing energy. Gamma rays have the highest penetrability, especially for high-energy gamma rays. They also have less capability to interact with tissue. The gamma rays from ^{137}Cs lose half of their intensity after 5 cm of concrete, 1.7 cm of steel or 1cm of lead.

Neutrons do not interact directly with electrons of matter, and they cannot directly ionize atoms. They interact with atomic nuclei, and after that transfer the energy to matter. Neutrons can produce radioactive nuclei, which produce ionizing radiation when they decay.

When the energy of radiation is absorbed by matter, chemical changes occur at the atomic and molecular levels. If the exposure is large enough these changes can be readily observed. For example, if glass is heavily irradiated it changes color.

The amount of radiation energy absorbed per gram of matter is called the absorbed dose. The absorbed dose is the measure of damage capability of radiation in tissue and of radiological hazard. The gray (Gy), which has units of (J/kg), is the SI unit of absorbed dose, and is the amount of radiation required to deposit 1 joule of energy in 1 kilogram of any kind of matter. The rad is the obsolete unit, equal to 0.01 J deposited per kg. 100 rad = 1 Gy.

4. Sources of radiation

Natural radiation

Terrestrial radiation. When our universe was created, stable isotopes were not the only ones to appear in the world, radionuclides appeared as well. Those stable and radioactive isotopes were the materials that formed our planet Earth. Since that time, a majority of the radionuclides decayed, but some of them, like uranium-235 and 238, thorium-232, and potasium-40, which have very long half-lives, still exists. The half-life of uranium-238 is about 4.5 billion (10^9) years, while uranium-235 has half-life of 0.71×10^9 years, ^{232}Th has half-life of 14×10^9years, and ^{40}K has half-life of 1.3×10^9 years.

When the original radionuclides uranium-235 and 238, thorium-232 decayed, they produced more radionuclides, which in turn produced more radionuclides. Uranium and thorium each initiate a chain of radioactive progeny, which are nearly always found in the presence of the parent nuclides. Although many of the daughter radionuclides are short-lived, like radon, they are distributed in the environment because they are continually being formed from long-lived precursors. (see Attachments, Table 1)

Radon, an odorless, invisible gas about eight times heavier than air, is the radionuclide, that most impact human in terms of radiation exposure (it produced about half of whole dose of human exposure from natural radiation). It has two main forms: radon-222, one of the radionuclides in the sequence formed by the decay of uranium-238, and radon-220, produced during the decay series of thorium-232.

Radon is the decay product of uranium or thorium, and is produced in any material containing uranium or thorium, which is bedrock, soil, and building materials. All these materials release radon into the atmosphere. Since radon is one of the inert gases (also known as a noble gas), it can escape from surfaces to the atmosphere. The amount of radon which emanates from a given mass of rock depends on the quantity of uranium or thorium present. The concentration of radon in the air also depends on the rate of fresh air movement into the space. In basements, caves, and mine shafts which have poor air circulation, the radon concentrations can build up to very high levels. Efficient ventilation in mines is often necessary to maintain radon concentrations below those which would be hazardous for workers.

Radon decays quite rapidly, forming a series of daughter radionuclides (Table 1, Attachments). Once formed in the atmosphere, the progeny of radon attach to small dust or water particles, which are subject to deposition on soil and plants and to inhalation. Rainfall is particularly efficient in scrubbing radon daughters from the atmosphere. The concentration of radon indoor, on average, is about 10 to 20 times higher than it is outdoor.

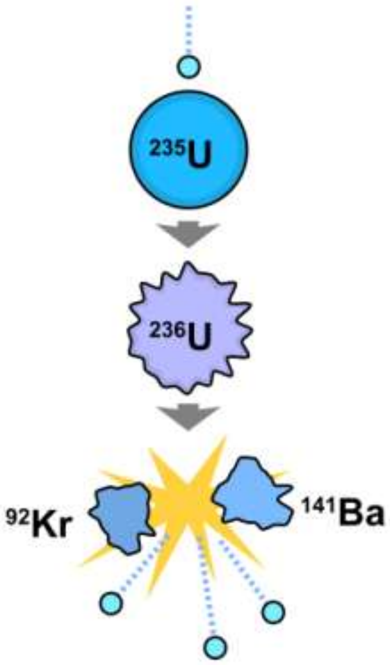
Cosmic radiation. Another natural source of radiation is from nuclear reactions in the stars. Nuclear reactions produce cosmic rays, which are energetic protons, electrons, other particles, gamma rays, and x-rays. Our nearest star, Sun, produces the largest portion of our cosmic radiation. The magnetic field of the Earth and atmosphere protect people from cosmic radiation and without it people would not be able to live on Earth's surface.

Cosmic radiation significantly rises when you are at a high altitude, in an airplane, or in the mountains. Cosmic radiation also produces some radionuclides like ^{14}C and ^{3}H in the atmosphere.

Man-made radiation

Man-made radionuclides are the result of human (man-made) activities. The main producers of man-made radiation are nuclear weapons production and nuclear reactors, also their supporting facilities (uranium mills, nuclear fuel preparation and reprocessing plants, nuclear waste management). Moreover, radioactive sources and other sources of radiation like x-rays generators, or charged particles accelerators are used in industry, military, and medicine.

Many of these facilities generate radioactive waste, and some release a controlled amount of radiation into the environment. Radioactive materials are also used in common consumer products such as smoke detectors. Consequences of nuclear tests and nuclear accidents are also sources of man-made radiation.



Nuclear reactors are the highest source of radiation and the highest source of radiological risk. As of today, the main way for nuclear energy production is a nuclear fission chain reaction. Heavy nuclei like uranium-235 (^{235}U) splits into two more light nuclei and a few neutrons. Nuclear energy excesses finally transfer to heat energy and then to electricity. The main problem is safety. Nuclei produced in fission are radioactive.

Nowadays about 16% of all electricity in the world is produced in this way. There is about 300,000 tons of high radioactive spent fuel in storage. The amount of spent fuel rises about 12,000 tons annually.

In a nuclear power plant, the heat source is the reactor core. A heat source provides heat to generate steam. A turbine generator uses the energy of the steam to turn a turbine that generates electricity (see Reactor scheme, Attachments). The pump provides the force to circulate the water through the reactor and other system.

The nuclear fuel typically used is in the form of uranium dioxide (UO_2). The uranium dioxide is fabricated into cylindrical fuel pellets. These pellets are stacked end-to-end to form a fuel rod that is encased in fuel cladding.

Each reactor contains a huge amount of radionuclides. If they were distributed to everyone in the World, people would have significant exposure. The main activity in reactors is from fission products, which have different chemical properties – gases like xenon-133 (^{133}Xe), volatile elements like iodine-131 (^{131}I) or cesium-137 (^{137}Cs), or solid materials like strontium- 90 (^{90}Sr) or isotopes of plutonium. Table 2 (Attachments) presents the composition of the most important radiological radionuclides in the Chernobyl Unit 4 nuclear reactor core before explosion and in the blowout at the accident time.

The main problem for the safe reactor operation is blocking possible release of radionuclides into the environment. Four barriers prevent the release of radioactive fission products from the reactor core to the environment: fuel pellets, fuel cladding, the reactor vessel, and the containment building. Fuel rods trap 99% of all fission products in the fuel pellets and the remaining 1% in the fuel cladding. If the core is not sufficiently covered with water to provide cooling, it could overheat and cause a breakdown in the fuel cladding, and then a fuel meltdown. Even if the fuel cladding were to fail, two more restraints prevent a release to the atmosphere. The reactor core is located within a reactor vessel (for main types of reactors), that has walls of steel about 30 centimeters thick. The containment building is the last barrier between the radioactive products and the environment (not all types of reactors have a containment building and they have less safety barriers). It is made of high-density, reinforced concrete as much as two meters thick. The containment building is built to withstand severe accidents and natural and technological hazards (like aircraft crash). Even if the first three barriers are damaged, the containment building should prevent any significant release of fission products to the environment.

The average dose of exposure due to all nuclear industry and man-made radioactive sources is about 1% from doses due to natural radiation, but it is not the case of nuclear or radiological accident.

Nuclear or Radiological Accident generally refers to events involving the release of a significant amount of radioactivity from reactor (facility), the exposure of workers and/or the general public to radiation.

Radiological accidents are initiated by the lost radiation sources, accidents during transportation of radioactive sources or materials, equipment or human errors in radiation sources operation. Sources, often called "sealed sources," are usually small metal containers in which a small amount of a radioactive material is sealed. Lost source accidents are ones in which a radioactive source is lost, stolen or abandoned. A people finding these sources and not knowing what they are, keep them or even open them and suffer serious exposures.

The nuclear reactors are the most powerful sources of radiation and nuclear accident. If barriers preventing radioactivity release from the reactor core are damaged, first radioactive gases and volatile ^{131}I or ^{137}Cs will be released to the environment. One of the most severe types of accident is a core melt accident. A core melt accident occurs when the heat generated by a nuclear reactor exceeds the heat removed by the cooling systems to the point where at least one nuclear fuel rod exceeds its melting point. A core melt accident can occur even after a reactor is shut down because the fuel continues to produce heat from radionuclides decay. When a nuclear reactor has been shut down and chain nuclear fission is not occurring, a very high source of heat production will still exist due to the radioactive decay of fission fragments. At the moment of reactor shutdown, decay heat will be about 6.5% of the total core power if the reactor has had a long and steady power history. About 1 hour after shutdown, the decay heat will be about 1.5% of the previous core power. After a day, the decay heat falls to 0.4%, and after a week it will be only 0.2%. The decay heat production rate will continue to slowly decrease over time; the decay curve depends upon the proportions of the various fission products in the core and upon their respective half-lives.

The heating of fuel pellets can result in some of the fission products being lost from the pellet. If the radioactive xenon and iodine rapidly leave the pellet, the amount of ^{134}Cs and ^{137}Cs, which is present in the gap between the cladding and the fuel, will increase. If the zircaloy tubes holding the pellets are broken, a greater release of radioactive gases, iodine and cesium from the fuel will occur.

The potential danger from an accident at a nuclear reactor is from exposure to radiation. This exposure could come from the release of radioactive material from the reactor into the atmosphere, usually characterized by a plume (cloud-like) formation. The size of the affected area is determined by the amount and properties of radioactive material released from the reactor, wind direction and speed, and weather conditions (such as rain or snow), which would quickly drive the radioactive material to the ground, causing increased deposition of the radionuclides. Significant contamination could affect areas up to 30 kilometers from the accident site.

The radiation dose received by the public during the first days of a nuclear reactor accident comes mostly from five sources:

1) external gamma radiation from the radioactive cloud or plume, called cloud shine;
2) external gamma radiation from radioactive material deposited on the ground, called ground shine;
3) external beta and gamma radiation from radioactive material deposited on the skin and clothes, buildings and trees;
4) internal exposure from inhaling radioactive material in the plume; and
5) internal exposure from eating and drinking contaminated water and food.

During a release the exposure dose from cloud shine, ground shine, skin and clothing contamination and inhalation of radioactive material are the most dangerous. After the plume has passed, the dose from ground shine and eating of contaminated food and milk become most dangerous. Doses from external exposure and inhalation can be prevented or reduced by what are referred to as urgent protective measures. These are protective measures that must be implemented urgently or immediately and include sheltering, evacuation, and thyroid blocking. Doses from ingestion can be reduced by restricting immediate consumption of locally produced food.

Radiological accidents can occur wherever radioactive materials are used, stored, or transported. Hospitals, universities, research laboratories, industries, major highways, railroads, shipping yards and military stations could be the site of a radiological accident, in addition to nuclear power plants and other nuclear facilities.

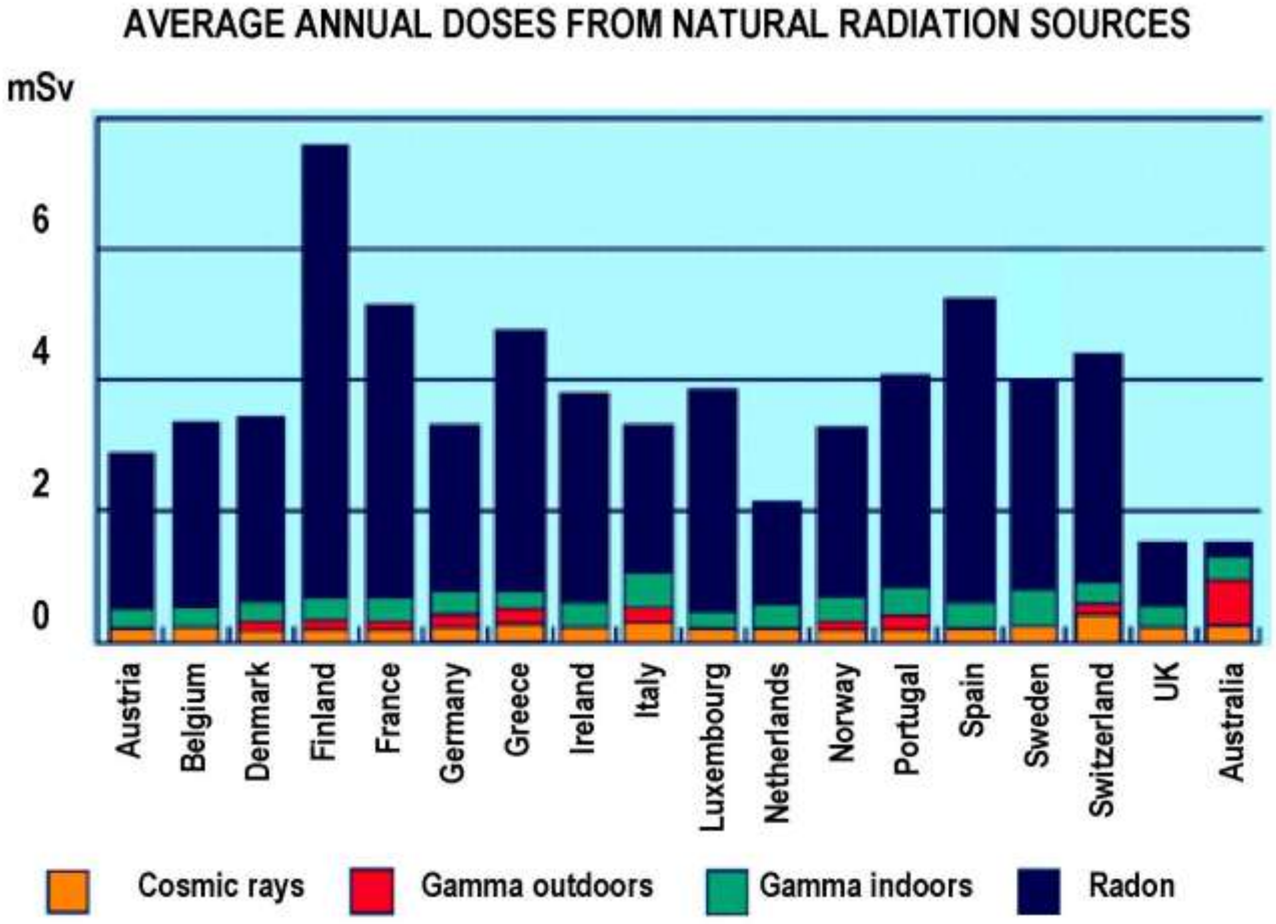
5. Human exposure to radiation

Throughout the history of life on earth, organisms have been exposed continuously to cosmic rays, radionuclides produced by cosmic ray interactions in the atmosphere, and radiation from naturally occurring substances which are ubiquitously distributed in all living and nonliving components of the environment. Humans have adjusted to the amounts of natural radiation. Although high levels of radiation are definitely harmful to organisms, some environmental radiation is important to life. For example, background radiation has contributed to the fundamental processes of biological evolution.

The amount of radiation energy deposited per unit mass in a material is called the 'absorbed dose'. The unit of absorbed dose is the gray (Gy), which is one joule per kilogram. Different ionizing radiations - beta, gamma, X-rays, neutrons and alpha particles - differ in the way in which they interact with biological materials, so equal absorbed doses do not always have equal biological effects. Also different sensitivity to radiation of various human organs has to be taken to account, so the measure of biological effects of radiation exposure is effective dose. Effective dose is the absorbed dose multiplied by a factor that takes into account the relative effectiveness in causing biological harm. The unit of effective dose is the sievert (Sv). For beta, gamma and X-rays, 1 Gy is the same as 1 Sv, but neutrons and alpha particles have more damaging biological effects, and, for these, 1 Gy is worth between 5 Sv and 20 Sv.

Radiation exposure from natural sources of background radiation

Background or natural radiation is that which is naturally present in our environment. Levels of this can vary greatly. People living in granite areas or on black thorium sands receive more terrestrial radiation than others, while people living or working at high altitudes receive more cosmic radiation. The main part of our natural exposure is due to radon, a gas which emanates from the earth's crust and is present in the air we breathe. The highest radon concentration in the air is in the premises. It depends on the type of house, building materials, and air ventilation, and could vary ten times.



Naturally occurring background radiation is the main source of exposure for most people. Levels typically range from about 1.5 to 3.5 millisievert per year, the annual average dose being 2.4 mSv (1 Sv=1000mSv), but it can be more than 50 mSv/yr. The high level of background radiation affecting a substantial population is in Kerala and Madras States in India, where some

140000 people receive doses averaging over 15 millisievert per year from external gamma radiation in addition to a similar internal dose from radon. Comparable levels occur in Brazil and Sudan, with average exposures up to about 40 mSv/yr to many people. Several places are known in Iran, India and Europe where natural background radiation gives an annual dose of more than 50 mSv and up to 260 mSv (at Ramsar in Iran). In Finland, average annual doses are about four times higher than in the UK. However, there is no evidence of increased cancers or other health problems arising from these high natural levels of exposure.

Radiation exposure from nuclear and radiation accidents

In a nuclear accident the safety barriers protecting people and the environment from the radiation of the reactor core are damaged and part of radionuclides are released to the environment.

The exposure of the population and workers vary depending on the scale of the accident and other factors. In nuclear energy history there have been three severe accidents: Three Mile Island Nuclear Power Plant, USA in 1979; Chernobyl Nuclear Power Plant, Soviet Union in 1986; Fukushima –1 Nuclear Power Plant, Japan in 2011.

The worst commercial accident in the United States occurred at the *Three Mile Island Nuclear Power Plant* in 1979. As a result of equipment failures and operator error the coolant water that covered the reactor core escaped from the reactor system. This radioactive water, nearly 260,000 liters, ended up on the basement floors of the containment building and auxiliary buildings. The loss of coolant water in the reactor core continued to the point that the fuel was no longer submerged in water. Without the cooling provided by the water, the cladding melted. Large quantities of water with radioactive material were released into the containment building. The containment building performed, as designed and radioactive releases to the atmosphere were small. It resulted in the release of up to 370 PBq (1 PBq = 10^{15} Bq) of radioactive noble gases, and about 0.55 TBq (1 TBq = 10^{12} Bq) of ^{131}I. The average radiation dose to people living within ten miles (16 km) of the plant was 0.08 mSv, and no more than 1 mSv to any single individual. Based on these emission figures, scientific publications on the health effects of the fallout estimated one or two possible additional cancer deaths in the 16 km area around nuclear power plant.

On April 26th 1986, the most serious accident in the history of the nuclear industry occurred at Unit 4 of the *Chernobyl Nuclear Power Plant* in the former Union of Soviet Socialist Republics, near the common borders of Belarus, the Russian Federation, and Ukraine. As a result of the explosion, Unit 4 was completely destroyed and radionuclides were released into the environment.

Major releases of radionuclides from the Chernobyl reactor continued for ten days following the explosion on April 26. These included radioactive gases, condensed aerosols, and fuel particles. The total release of radioactive material was about 14 EBq (1 EBq = 10^{18} Bq), including 1.8 EBq of ^{131}I, 0.085 EBq of ^{137}Cs, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium isotopes. Radioactive noble gases contributed about 50% of the total activity released (Table 2, Attachments).

The Chernobyl accident was the result of an inherently unsafe reactor design. Additionally, the operators were not informed of design weaknesses and did not comply with all operational procedures. The combination of these factors provoked the worst type of nuclear accident, in which the reactor was totally destroyed within a few seconds.

The release and deposition of radioactive iodine caused the most immediate concern, but that problem was confined to the first months after the accident due to the rapid decay of the most important isotope ^{131}I. Radioactive iodine was rapidly taken into milk leading to large thyroid doses to those (particularly children) consuming milk. The highest contamination was in Belarus, Russia and Ukraine. In the rest of Europe, increased levels of radioactive iodine in milk were observed in areas where dairy animals were already outdoors. In France, Germany, Poland and other European countries radiation protection measures had been implemented.

More than 200,000 square kilometers of Europe was contaminated with levels of cesium-137 (half-life 30 years) above 37 kBq/m^2. Much of this area was within the three most affected countries, Belarus, Russia and Ukraine. The level of deposition was extremely varied, and was enhanced in areas where it was raining while the contaminated air masses passed. Most of the strontium and plutonium was deposited within 30 km of the destroyed reactor due to their larger particle sizes.

During 1986-1987, initially about 350,000 people (NPP staff members, firemen, medical and other workers) were involved in clean-up operations after the accident.

In the spring and summer of 1986, 116,000 people were evacuated from the most contaminated settlements in the 30 km Exclusion Zone. Later, about 220,000 more people were resettled.

25 years after the accident, approximately five million inhabitants of Belarus, Russia and Ukraine were living in territories contaminated at levels greater than 37 kBq/m^2 of ^{137}Cs (normalized to levels in 1986).

Acute radiation syndrome (ARS) was diagnosed in 134 emergency workers exposed from 1 to 16 Gy of whole-body irradiation. Twenty eight patients died within three months after exposure. Among the general population exposed to the Chernobyl radioactive fallout, the radiation doses were much lower than among the emergency workers, and ARS and associated fatalities did not occur (may be results of the ineffective health monitoring system) .

Thyroid cancer in those exposed to ^{131}I at a young age is recognized as a major health effect of the accident confirmed by findings of many national and international studies. 25 years after the accident, nearly 6000 cases of thyroid cancer have been diagnosed in persons exposed at the age of 0-18 in Belarus, Russia and Ukraine.

The *Fukushima-1(Dai-ichi)* nuclear accidents were a series of ongoing equipment failures and releases of radioactive materials at the Fukushima-1 Nuclear Power Plant, as a result of the 9.0 magnitude earthquake and tsunami on March 11, 2011. The nuclear plant was flooded by tsunami waves. All electric power for cooling was lost and reactors started to overheat, due to the decay energy of the fission products created before the reactors shutdown. The flooding and earthquake damage hindered external assistance.

Evidence soon arose of a partial core meltdown in reactors 1, 2, and 3; hydrogen explosions destroyed the upper cladding of the buildings housing reactors 1, 3, and 4; an explosion damaged the containment inside reactor 2; and multiple fires broke out at reactor 4. Despite being initially shutdown, reactors 5 and 6 began to overheat. Fuel rods stored in pools in each reactor building began to overheat, as water levels in the pools dropped.

The total discharge amounts from the reactors of Fukushima-1 NPP were estimated as 0.16 EBq for ^{131}I and 0.015 EBq ^{137}Cs.

Approximately 7800 emergency workers were exposed to about 7.7 mSv on average. Thirty people were recorded as receiving doses over 100 mSv.

Three workers are reported to have suffered suspected radiation burns on their feet/legs from inadvertent exposure to heavily contaminated water in a turbine basement. After hospital treatment they were released after four days with no reported likelihood of long-term significant harm. Three workers on site were confirmed as dead (from causes other than radiation exposure) and several were injured.

To avert potential radiation exposure to the public, the Japanese authorities took the precautionary action of instructing those within the first 3 km, then 10 km and finally 20 km of the plant to evacuate, and those between 20 km and 30 km to get to shelter and get ready to evacuate. More than 70,000 people have been evacuated since the incident.

The worst *radiation accident* occurred at the Goiania, State of Goias, Brazil, from September 12 through September 29, 1987.

A radiotherapy unit had been abandoned in a clinic, which was being demolished. The unit had a source consisting of 1375 curies of cesium-137, sealed within two nested stainless steel containers. Two individuals dismantled the unit and extracted the source, taking it to the home. Both began vomiting on 13 September. The unit material was sold to a junkyard owned by D., who noticed a blue glow from the source container that night. He and his wife M.F. examined the material closely, and also invited a number of people to view the capsule. On 21 September the source radioactive material was removed and distributed among several people, some of whom spread it on their skin. Many people were ill by 28 September. About 112,800 people were examined of whom 129 were found to be contaminated; 20 of them were hospitalized. Finally 5 people died, and 23 suffered localized radiation burns, which for several required amputation of fingers. During hospitalization many patients suffered depression and other emotional problems.

Table 3 presents the radiation exposure doses from different sources of exposure natural and man-made, as basis for hazard evaluation.

Table 3. Radiation exposure from different sources of radiation.

Source	**Typical dose (mSv)**
10 hour airplane flight	0.03
Chest x-ray	0.05
Computerized tomography scan	10
Annual dose from natural background	2.4
Annual cosmic radiation at sea level	0.4
Annual dose to nuclear worker (normal operation)	1
Annual cosmic radiation Mexico City (2 300m)	0.8
Accidental exposure of emergency workers in Chernobyl accident	Up to 16000
Average annual dose for population on the most contaminated area (about 150000 individuals) in 1986 due to Chernobyl contamination	16

6. Health effects of radiation

Ionizing radiation affects people by depositing energy in body tissue, which can cause cell damage or cell death. In some cases, there may be no effect for human health; in other cases, the cell may survive but become abnormal, either temporarily or permanently, or an abnormal cell may become malignant. Large doses of radiation can cause extensive cellular damage and result in death. With smaller doses, the person may survive, but the cells are damaged, increasing the chance of cancer. The extent of the damage depends upon the total amount of energy absorbed, the time period and dose rate of exposure, and the particular organ(s) exposed.

There are two types of physical health effects related to radiation exposure. The first is called a *deterministic effect*. Deterministic effects are the result of acute exposure, which is exposure to a large, single dose of radiation, or a series of doses, for a short period of time. In most cases, a large acute exposure to radiation (above 1 sievert) can cause both immediate and delayed effects. For humans and other mammals, acute exposure, if large enough, can cause rapid development of acute radiation sickness (ARS), evidenced by gastrointestinal disorders, bacterial infections, hemorrhaging, anemia and other. Immediate effects occur relatively soon (within days to weeks) after an exposure to a high dose at a high dose rate. Essentially, the damage to the tissue from the radiation is so extensive that the body does not have time to regenerate new tissue, and so the effect becomes visible with many of the features of a thermal burning, but usually it is much deeper and long lasting. Deterministic effects often appear localized on the body depending on the radiation exposure pattern and the level of penetration of the radiation. Delayed biological effects can include cataracts, temporary sterility, cancer, and genetic effects.

Extremely high levels of acute radiation exposure can result in death within a few hours, days or weeks. Because radiation affects different people in different ways, it is not possible to indicate what doses are fatal. However, it is believed that 50% of a population would die within thirty days after receiving a dose to the whole body, over a period ranging from a few minutes to a few hours, between 3.5 to 5 Sv. This would vary depending on the health of the individuals before the exposure, and the medical care received after the exposure. Similar exposure of only parts of the body will likely lead to more localized effects, such as skin radiation burns.

The higher the radiation dose, the more severe the damage is to the tissue and the sooner the onset of symptoms (at very high doses the effects can appear within hours). However, at low doses and dose rates these effects do not occur at all - there appears to be a dose threshold below which there are no deterministic effects. This has an important bearing on the goals of emergency response - namely to try to keep the doses received below the threshold for deterministic effects. Deterministic effects need specialized medical treatment to aid patient recovery.

The second type of health effect that can be caused by radiation is a so-called *stochastic effect*, such as cancer or hereditary effects in any future offspring. It is mainly a result of chronic exposure that is continuous or intermittent exposure to low levels of radiation over a long period of time. Chronic exposure is considered to only produce effects that can be observed some time following the initial exposure. These include genetic effects and others like leukemia or cancer.

Stochastic effects are characterized by their late appearance after exposure (several years up to decades), and specifically that its occurrence is not certain. The radiation may cause some damage to the cells of the body, which is not visible but changes the function of those cells. These changes may manifest themselves at a much later date, as a cancer for example. Notice that we say ‘may’ occur, there is no certainty of occurrence. For stochastic effects, we find that the chance or probability of an effect increases for higher the radiation dose. So at low doses, there is a very low chance of cancer developing - at higher doses, there is a higher chance of cancer. However, it appears that there is no ‘safe’ dose, or dose threshold below which addition cancers do not occur.

Are the cancers induced by radiation different from those induced by other hazards (e.g. chemicals, biological agents, naturally from one’s genetic make-up etc.)? The answer appears to be no - they are indistinguishable, unlike a deterministic effect, which can readily be attributed specifically to radiation. This means that the only way these effects can be detected is by studying cancer statistics for a population, using careful cancer and dose registration.

7. Radiation detection

In order to estimate radiological hazard, doses of external exposure, and contamination of soil, water, and food, must be measured. There are a wide variety of instruments used to measure different types of radiation, different energy ranges, and different precision. Here are a few examples. In radiography such as a chest X-ray, the variation of the penetrating power of X-rays in bone and tissue gives rise to an image on photographic film or other device. An ionization chamber collects the charge produced by radiation in a gas. Other instruments measure scintillations in crystals that are produced by radiation.

To measure external exposure from a radioactive cloud or contaminated surface, the dose rate or dose meters are used. For evaluation of internal exposure, we have to know the concentration of different radionuclides like ^{131}I, ^{137}Cs, ^{90}Sr, ^{239}Pu in air, water, and food. Different radionuclides will have different effects upon internal exposure depending on their metabolism in the human organism, and the type of radiation emitting (alpha, beta or gamma). To detect radioactivity, samples of water, and food, etc. are collected, prepared, and measured by a gamma-spectrometer or other instruments. To determine the concentration of radionuclides in the air, it is pumped through filters and concentrations of radionuclides are measured.

8. Nuclear emergency management – prevention, preparedness and response

Nuclear reactors (power, military, or research) are the main sources of man-made radiation. The radioactivity of a nuclear reactor core is millions of times higher, than any other source of radiation. The construction and operation of nuclear power plants is closely monitored and regulated. There are many efforts for prevention of nuclear accidents, but an accident, though unlikely, is possible.

If a severe nuclear accident happened – workers and general public would be at radiological risk from radionuclides released into the environment. The people have to be protected. The exposure coming from the release of radioactive material from the reactor into the air is usually characterized by a plume (cloud-like) formation. The size of the area affected is determined by the amount of radioactive material released from the plant, wind direction, speed, and weather conditions (i.e., rain, snow, etc.), which would quickly drive the radioactive material to the ground, causing increased deposition of radionuclides. Significant contamination could affect mainly areas up to 30 kilometers from the accident site. The purpose of protective actions is to minimize the health effects to the public and workers, also via better information and education about nuclear hazards of the citizens with a special attention to the children.

Nuclear emergency protective actions include:

Urgent protective actions, which must be taken within hours of an accident to be effective. These include: *evacuation, intake of stable iodine tablets* (*iodine prophylaxis*) and *sheltering* (keep the public inside the building to prevent them from exposure to direct radiation and inhalation of contaminated air);

Longer-term protective actions, these measures may need to be put place in the days following an accident. These include: *restrictions on the use of contaminated food and water, relocation and resettlement*.

Evacuation is the urgent removal of the population from the area, where people could be significantly exposed. It is the most effective protective action against major airborne releases of radioactive material, but there are some difficulties. First, people have to be informed in advance about this possible measure, in the case of an accident they have to receive a clear message or signal about evacuation, there must be sufficient means of transportation to remove the all population which could be affected, including people from hospitals and prisons. Then, the road infrastructure must be sufficient to support a mass evacuation without traffic jams. People need to change clothing that has been contaminated in the disaster area, and rinse contamination from the skin and hair, organizing washing people with water and detergent.

And finally, there is the problem of where to keep the evacuated people for several days. In general, it is not recommended that evacuation and accommodation in emergency centers is in effect for more than about seven days. Moreover, an evacuation itself takes time to implement, and this time must be taken to account in emergency planning and response.

Iodine prophylaxis. When the fuel of a reactor overheats and the fuel cladding fails, large amounts of radioactive iodine can be released. This iodine can be inhaled or deposited on vegetables, plants and concentrate in the milk of animals grazing on contaminated grass. Inhaled or ingested iodine will concentrate in the human thyroid gland. High thyroid doses can destroy the thyroid and greatly increase the risk of thyroid cancer, especially for children. The input of radioactive iodine can be reducing by preventing of radionuclides inhalation and not eating or drinking potentially contaminated food or water. The dose to the thyroid can be reduced by taking stable (non-radioactive) iodine, called thyroid blocking (iodine prophylaxis). The stable iodine will saturate the thyroid and prevent or reduce its uptake of the radioactive iodine. Normally stable iodine is taken in the form of KI or KIO_3 pills, or drops of liquid iodine diluted in a glass of water. Recommended single dosage of stable iodine is presented in Table 4, Attachments.

Protecting the public from high thyroid doses requires administration of thyroid blocking before, or shortly after the radionuclide release. Thyroid blocking only protects the thyroid, but it is the dose to the entire body that is the source of most of the early deaths from a reactor accident. Therefore, care must be taken to be sure that the distribution of stable iodine for thyroid blocking will not delay evacuation or sheltering.

Sheltering. Sheltering involves keeping members of the population indoors, in suitable buildings, to reduce radiation exposure from airborne radioactive material and from the contaminated surface. Sheltering is not recommended for a period exceeding 48 hours. Substantial sheltering refers to the use of facilities with specially designed shielded walls or the basements of large buildings. Ventilation systems with activated charcoal filters to protect against radioactive iodine may also be used in some substantial shelters.

The effectiveness of sheltering to protect against external radiation from the cloud and ‘ground shine’ depends on the type of dwelling used and on the ability of the population to properly shelter themselves. For example, low roofed houses in hot climates tend not to provide very good protection.

If you were on the street during the passage of the radioactive cloud, you need to change your clothes and wash away the contamination from the skin and hair, having washed with water and detergent. In “real life”, it is also difficult to ask people to stay confined to their house for more than a couple of days. In regions where the average family has access to one or more cars, such as at the Three Mile Island accident, an order to shelter could prompt spontaneous evacuation. This could cause more difficulties and even more radiological consequences, especially if the evacuation is chaotic and leads to traffic jams during cloud passage or while contamination levels are high.

The longer-term protective actions are inherently very expensive and complex. They require that alternative living arrangements and food supplies be found for a large population. There is a great psychological cost associated with this measures. In the case of Chernobyl accident for example, the relocation of rural population to urban areas is believed to be responsible in part for a significant decrease in life expectancy due to medical problems associated with the stress of the move. Agricultural countermeasures are especially hard on farmers and food producers, who will suffer significant financial losses. Financial compensation is a problem in all cases involving longer-term protective actions.

Temporary relocation and resettlement. Temporary relocation is used when it is necessary to keep the population out of the affected area for a period exceeding approximately 7 days, but not more than a few months. This measure is used when the dose to the affected population over a lifetime would exceed a certain limit. For this measure to be effective, it is requires that temporary, but substantial facilities be provided for the affected population. It is expected that the temporarily relocated population will be able to return to their homes in due course. However, in reality, resettlement could be permanent.

Agricultural countermeasures. Protective actions related to food include: an immediate ban on consuming food grown locally in the affected area; local food and water supplies should be protected, by, for example, covering open wells, or sheltering animals and animal feed; locally grown food should be periodically tested for radionuclide contamination in the months following a nuclear accident. Monitoring the contamination of milk is particularly important because it is a significant part of the diet of children; it also concentrates important radionuclides, such as iodine and cesium.

If the radioactive contamination is expected to include ^{131}I, the immediate action should be to consider stopping local milk consumption until levels of ^{131}I contamination have been measured. Detailed information and instructions would be obtained from the relevant government authority.

However, if there is time before direct radioactive fallout reaches your area, undertake the following immediate preventive measures:

-Protect growing vegetables and animal fodder - cover with plastic sheets;
-Bring livestock in from pasture - move animals into a shed or barn;
-Harvest any ripe crops and place under cover.

After direct radioactive fallout:
-Do not consume locally produced milk or vegetables (if preventive measures were not implemented);
-House animals that would normally be grazing outdoors and provide uncontaminated forage;
-Prohibit hunting, fishing, mushroom collecting, and consumption of vegetables and water derived from surface water or precipitation.

In potentially contaminated areas:
-Do not use water for irrigation;
-Avoid direct contamination of food or agricultural products (dust, rain);
-Do not burn vegetation or any materials stored outdoors, including firewood;
-Do not create dust, which is radioactive after fallout.

The key objective of emergency preparedness should be to localize any accidents that may occur, and to minimize the harmful effects of the accident on public health and the environment, including property.

Emergency preparedness plan is a key tool of emergency preparedness (see Attachments, page 20, Emergency planning). It has to be developed and clearly define all measures for effective emergency response. It has to identify the roles and responsibilities of all the parties concerned, including the general public, and should clearly indicate the chain of command and co-ordination among the parties, as well as the lines of communication and the means of obtaining the necessary technical, meteorological, and medical information.

9. What do we have to do in the case of a nuclear accident?

From previous chapters, you have received basic knowledge about nuclear hazard; you know what ionizing radiation is, how it can affects your body, what natural background radiation is, and about the health effects of radiation. You know about sources of radiation, what nuclear accidents are, the effects of a radionuclides release and the appropriate protection measures. You have a minimal basis of knowledge to understand any, even minimal, information about nuclear accidents; and you will understand the reason for any protection measures recommended to you by authority.

If you are living with nuclear power, and by extension under radiological risk, it is your obligation to know more about nuclear hazards. If you use fire or electricity – you know about corresponding hazards and protection measures, the same with nuclear energy – you have to know about radioactivity, iodine prophylaxis, and doses of exposure. If you live in 30 km. zone around a Nuclear Power Plant, you need to understand that in the case of a severe nuclear accident you will be informed about protection measures and you will have to be ready for evacuation, or sheltering and iodine prophylaxis. If you do not remember where your KI pills are, you can just take few drops of liquid iodine, mixed with a glass of water and drink it. Later, you will receive KI pills from authorities to use, but you will have better protection if you intake stable iodine before a radioactive cloud comes. But certainly – first you have to receive official information about a radionuclide release from NPP.

In many cases for public awareness on nuclear hazards, frequently asked questions (FAQs) and answers are published. Now you are able better understand the nature of these recommendations and how to follow them, take the following examples of FAQs and explain the reasoning for the safety measures given in the answers.

Question #1. If a nuclear accident occurs, what should you do?

Answer: Listen for a warning that will be presented through a range of media—TV, radio, or emergency communication. Listen carefully for instructions to learn what protection measures should be implemented.

You know that in order to protect the body from external exposure, the following protection measures could be recommended:

- Protection by distance (going as far away as possible from the source of radiation).
- Protection by time (get away from the source as quickly as possible).
- Protection by sheltering (get in a safe building made from concrete or stone).

In order to protect the body from internal exposure, the following protection measures could be recommended:

- Preventing radionuclides inhalation: (with mask or wet handkerchief).
- Preventing radionuclides ingestion (do not drink water from open sources, do not eat fruits or vegetables that were outside after a release).
- Iodine prophylaxis (take stable iodine following the instructions).

Question #2. If you are asked to take shelter indoors, what should you do?
Answer: You must go to the nearest available building, house, public facility, etc.

- Shut all doors and windows.
- Take a shower, wash your hands, face and hair, and change your clothes, if you were outside.
- Stop ventilation fans, fan heaters, and air conditioning.
- Put food into containers and wrap it.
- Secure drinking water in a sealed container for use during the next week.
- Do not consume locally produced milk or vegetables.
- House animals that would normally be grazing outdoors and provide uncontaminated forage.

Question #3. If you are asked to take evacuation, what should you do?
Answer: Shelter indoors and calmly prepare for evacuation.

- Turn the gas and electricity off and remove plugs from sockets.
- Call neighbours to inform them.
- Contact the local authority about disabilities, so they can help with evacuation.
- Provide pets with food and water and keep them inside.
- Close all doors when leaving the house.
- Follow directions of competent authority, like police, risqué, or local authorities for the next steps of evacuation

We hope that basic knowledge from our book will give you the ability to understand the real value of nuclear hazards in the case of an emergency, and the knowledge to help protect you and save your life.

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The structure of atoms

In 1911 Ernest Rutherford showed that the mass of an atom is mainly concentrated (99.9% of it) in the nucleus. The size of the nucleus is approximately 10,000 times smaller than an atom (about 10^{-10} m.).

The atom has no electric charge. The charge of the nucleus **Z** is positive and equals the number of atomic electrons (the serial number of a current chemical element in the Periodic Table of the Elements).

An atomic nucleus consists of positively charged protons, and neutrons without a charge (both of them are called nucleons). The charge of the nucleus is equal to the number of protons in the nucleus. The number of protons and neutrons in the nucleus is called the atomic mass number **A**.

The chemical properties of atoms depend on only the number of protons in the nucleus. There are atoms with the same chemical properties, but different numbers of neutrons. Consequently, they have a different mass number **A** and different physical properties. Some of these atoms could be unstable, or radioactive.

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Table 1. Decay schemes of U-238 and Th-232.

Uranium-238			**Thorium-232**		
Radionuclide	Half-life	Radiation	Radionuclide	Half-life	Radiation
^{238}U	$4.5 \cdot 10^9$ year	α, γ	^{232}Th	$14 \cdot 10^9$ year	α, γ
^{234}Th	24 day	β, γ	^{228}Ra	6.7 year	γ, β
^{234}Pa	1.2 min	β, γ	^{228}Ac	6.1 hr	γ, β
^{234}U	$2.5 \cdot 10^5$ year	α, γ	^{228}Th	1.9 year	α, γ
^{230}Th	$8 \cdot 10^4$ year	α, γ	^{224}Ra	3.6 day	α, γ
^{226}Ra	1620 year	α, γ	^{220}Rn	55 sec	α, γ
^{222}Rn	3.8 day	α, γ	^{216}Po	0.16 sec	α, β
^{218}Po*	3.1 min	α, β	^{212}Pb	11 hr	γ, β
^{214}Pb	27 min	β, γ	^{212}Bi	61 min	α, γ, β
^{214}Bi*	20 min	α, γ, β	^{212}Po	$3 \cdot 10^{-7}$ sec	α
^{214}Po	$1.6 \cdot 10^{-4}$ sec	α	^{208}Pb	Stable	None
^{210}Pb	19 year	β, γ			
^{210}Bi*	5 day	α, γ, β			
^{210}Po	138 day	α, γ			
^{206}Pb	Stable	None			

* Only main ways of decays are shown.

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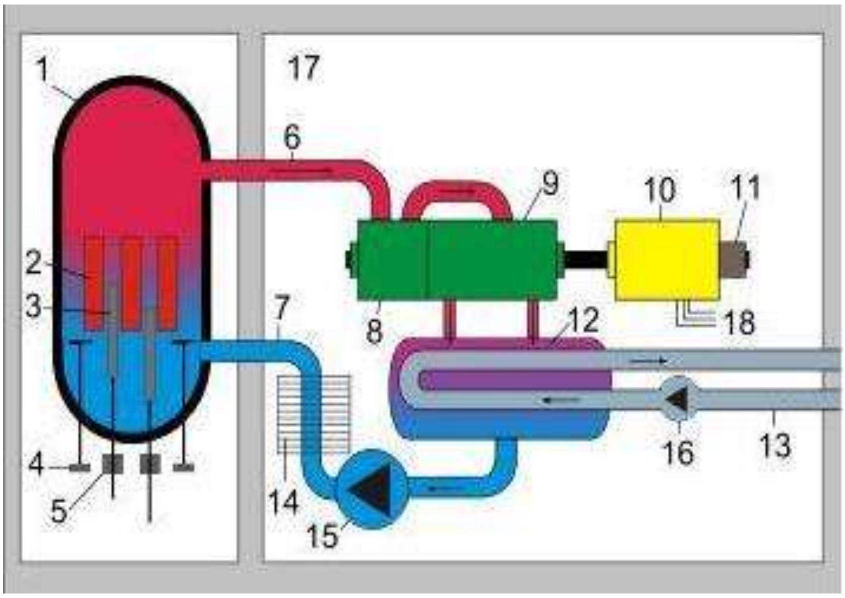
Reactor scheme



1. Reactor pressure vessel (RPV)
2. Nuclear fuel element
3. Control rods
4. Circulation pumps
5. Control rod motors
6. Steam
7. Feedwater
8. High pressure turbine (HPT)
9. Low pressure turbine
10. Generator
11. Exciter
12. Condenser
13. Coolant
14. Pre-heater
15. Feedwater pump
16. Cold water pump
17. Concrete enclosure
18. Connection to electricity grid

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Table 2. The composition of the most important radiological radionuclides in the Chernobyl Unit 4 nuclear reactor core before explosion and in the blowout at the accident time.

Core content on April 26, 1986			**Total blowout scaled to April 26, 1986**	
Nuclide	Half-life	Activity (PBq)	Store (%)	Activity (PBq)
^{133}Xe	5.3 d	6500	100	6290
^{131}I	8.0 d	3200	20	1650
^{134}Cs	2.0 y	180	20	52
^{137}Cs	30.0 y	280	13	85
^{132}Te	78.0 h	2700	25-60	~1020
^{89}Sr	52.0 d	2300	4-6	93
^{90}Sr	28.0 y	200	4-6	8.1
^{140}Ba	12.8 d	4800	4-6	180
^{95}Zr	64.0 d	5600	3.2	155
^{99}Mo	67.0 h	4800	>3.5	-
^{103}Ru	39.6 d	4800	2.9	170
^{106}Ru	1.0 y	2100	2.9	59
^{141}Ce	33.0 d	5600	2.3	190
^{144}Ce	285.0 d	3300	2.8	137
^{239}Np	2.4 d	2700	3	1440
^{238}Pu	86.0 y	1	3	0.03
^{239}Pu	24400.0 y	0.85	3	0.03
^{240}Pu	6580.0 y	1.2	3	0.044
^{241}Pu	13.2 y	170	3	5.9
^{242}Cm	163.0 d	26	3.5	~0.9
TOTAL		73559		~10933

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Administration of stable iodine tablets

The distribution of stable iodine is an effective way to protect against the harmful consequences of inhaling radioactive iodine, provided that it is taken before, or early into the release. However, getting stable iodine to the people is not easy. For example, if the iodine supplies are kept at a central location, as it is administered in some countries, one has to deal with the logistic difficulties of distributing the iodine to all affected people during an emergency. This is time consuming, people intensive, and may put the emergency workers in danger of additional exposure. Pre-distributing stable iodine has the problems such as periodic refreshment before end-of-shelf life, updating distribution for new arrivals, and keeping track of transient populations. Also, this protective action requires that large stocks of stable iodine be kept at all times.

The effectiveness of stable iodine decreases rapidly if it is taken after the period of exposure. Thyroid blocking is more than 90% effective if administered before, or at the time of radioiodine intake. Its effectiveness falls rapidly if taken after radioiodine intake. Therefore, protecting the public from high thyroid doses requires administration of thyroid blocking before, or shortly after the radionuclide release. Thyroid blocking only protects the thyroid, but it is the dose to the entire body that is the source of most of the early deaths from a reactor accident. Therefore, care must be taken to be sure that the distribution of stable iodine for thyroid blocking will not delay evacuation or sheltering.

For severe accidents, the dose from inhalation may be high enough to warrant thyroid blocking more than 100 km from the accident. However, for practical reasons, distribution of stable iodine for thyroid blocking may be limited to a smaller area with the greatest risk. Thyroid blocking is considered safe. In response to the Chernobyl accident, the Polish government carried out thyroid blocking to about 18 million people and there were only two serious adverse reactions, both among adults with known iodine sensitivity.

Table 4. Recommended by World Health Organization (Guidelines for Iodine Prophylaxis following Nuclear Accidents, Geneva, 1999) single dosage of stable iodine according to age group.

Age group	Mass of iodine (mg)	Mass of KI (mg)	Mass of KIO_3 (mg)	Fraction of 100 mg tablet
Adults and adolescents (over 12 years)	100	130	170	1
Children (3–12 years)	50	65	85	0.5
Infants (1 month to3 years)	25	32	42	0.25
Neonates (birth to 1 month)	12.5	16	21	0.125

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Emergency planning

The emergency plan should guarantee that the potentially affected public:

- is provided with general information about possible accidents at planned or existing nuclear sites. This should include the nature and extent of radiological risk, and potential effects on human health; and/or the environment, including property;
- is provided with timely information on the appropriate behaviour and safety measures they should adopt in the event of an accident involving radionuclides or other hazardous substances. Other information that may be needed to understand the nature of the possible effects of an accident (such as information on radionuclides or other hazardous substances capable of causing serious off-site damage) should be available, and most importantly, information about being able to contribute effectively, as appropriate, to decisions concerning hazardous installations and the development of community emergency preparedness plans.