NUCLEAR INDUSTRY

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Contents

1. Introduction

Radioactivity is a natural phenomenon. It was discovered in 1896 by Antoine Henri Becquerel. Since the discovery, scientists have been attempting to understand and harness its power.

In 1938, fission was discovered by Lise Meitner and Otto Frisch and in 1942, the first self-sustaining nuclear chain reaction was observed by a group of engineers lead by Enrico Fermi. The discovery of radioactivity and subsequent use has helped shape the world today.

2. Mining/Milling

Uranium is ubiquitous in the environment. In order to remove uranium from the earth to make nuclear fuel, it is either mined or leached out of the ground in-situ. After it is mined, it is then milled and processed to make fuel.

If uranium is close to the surface, it is mined in an open pit mine, otherwise an underground mine is used. Open pit mining occurs when the uranium is within a few hundred meters of the surface and does not require blasting to excavate. Underground mining is required for the deeper uranium. Most of the world's mines are in Canada, USA, Australia, Russia, South Africa, Uzbekistan, Ukraine, Namibia, China, and France. In-situ leaching consists of pumping acid into the ground, which dissolves the uranium, and pumping out the leachate. A concern with this process is that if all of the acid solution is not removed, then the uranium is able to migrate through the environment very quickly.

Milling consists of grinding the uranium ore to a uniform size and dissolving it in a concentrated acid or alkaline solution. The remaining solids are called mill tailings. The mixed solvent solution is then combined with organic solvents that will attract the uranium. The solvent with the uranium is less dense and can be decanted off the top. After stripping the uranium a few times, the uranium is precipitated, filtered and dried. The resulting material is referred to as "yellow cake". One of the hazards that exists during mining and milling of uranium ore is the release of by-product radionuclides such as radon gas and ${}^{230}_{90}\mathrm{Th}$ into the air and potable water supply.

According to the United States Energy Information Administration 1999 Uranium Report, USA mined 4.5 million pounds of uranium and 4.6 million pounds of uranium concentrate in 1999. United States uranium mills produced 20% of the uranium, and in-situ leaching and by-product plants (phosphate mining, mine water and other materials) made up the other 80%. In 1999, fuel assemblies from the United States contained 58.8 million pounds of uranium. Overall, uranium activities in USA declined in 1999, including mining, milling, employment, exploration, and foreign sales. The anticipated market for uranium is predicted to be fairly constant through 2009.

3. Policies

The United States Atoms for Peace Program was established in 1953 to encourage peaceful uses of nuclear power. Information sharing was encouraged to establish industrial uses of nuclear power. The Atoms for Peace Program also discouraged nuclear weapons proliferation. Out of this paradigm shift, the International Atomic Energy Agency (IAEA) and the Non-proliferation Treaty (NPT) were established.

The IAEA was established in 1957 to oversee international operations with nuclear materials. It currently facilitates scientific and technical cooperation between governments and serves as the international inspector for civilian nuclear programs.

The NPT was ratified in 1968 to ensure that peaceful nuclear operations could be performed and to prevent the proliferation of nuclear weapons. The NPT encourages research, production and use of nuclear energy for peaceful purposes. The treaty encourages the exchange of equipment and technology between participating States. It facilitates financial support for technology exchanges regarding safe uses of nuclear materials.

Nations that did not possess nuclear weapons when the NPT was ratified promised not to obtain them. In May 2000, the five nuclear weapon states, China, France, USA, Russia, and the United Kingdom, pledged to completely disarm under strict and effective international controls. No timeline for achieving this goal was set at that time. The remaining 182 States that are party to the Treaty have legally committed to not receive, manufacture, or acquire nuclear weapons or explosive devices. The five nuclear weapon states are bound not to aid in the non-nuclear states acquirement of nuclear weapons or explosive devices. As of May 2000, Cuba, India, Israel and Pakistan were not members of the treaty.

In 1991, the IAEA published an inventory of radionuclides that have been dumped in the marine environment. In 1993, the inventory was updated to include dumping by the Former Soviet Union and the Russian Federation. According to the IAEA, approximately 94% of the Low-Level Radioactive Waste (LLW) dumped at sea went into the North-East Atlantic Ocean. Dumping operations ceased in 1982 and are unlikely to resume under the current political climate. Studies have been underway to determine the effect of the radioactivity on humans and biota.

The Convention for the Protection of the Marine Environment of the North-East Atlantic, “OSPAR Convention”, was ratified by Belgium, Denmark, the Commission of the European Communities, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, the United Kingdom, Luxembourg and Switzerland in 1998 to provide an international regulatory council for control of pollution to international waters. The OSPAR Convention was drafted by the Oslo and Paris Commissions in 1992. The Oslo and Paris Conventions were created to control pollution to international waters and to protect the ecosystem. The OSPAR Convention was to combine the Oslo and Paris Conventions and to expand in the areas of protection and conservation of ecosystems and biological diversity, hazardous substances, radioactive substances, and eutrophication. The area covered by the OSPAR Convention is the North-East Atlantic Ocean, excluding the Baltic or Mediterranean seas; the Helsinki and Barcelona Conventions apply in these sea areas respectively. The OSPAR Strategy commits to achieving negligible radioactive discharges, emissions, and losses by the year 2020.

4. Use of Radionuclides

Radionuclides are used and are generated in numerous applications in a number of different areas, including academia, federal agencies, industrial applications, mining, medical facilities and utilities. In many cases, radionuclides have beneficial uses.

4.1 Industrial

Many industrial activities utilize radionuclides. They are used for non-destructive-testing operations, such as radiography and lead-based paint testing. Non-destructive testing enables a manufacturer to evaluate critical welds and steel parts for flaws as well as to determine the appropriate thickness or quantity used in a manufacturing process. Radioactivity is also used by cigarette manufacturers to gage the amount of tobacco in each cigarette. Radionuclides are used to gauge the moisture content of soil for construction. Tritium ($^{3}_{1}H$) can be used to make something glow in the dark, like luminous watch dials or gun sights. Smoke detectors in homes and offices use $^{241}_{95}Am$. X-ray machines are used in airports to ensure passenger safety.

4.2 Academic/Medical

Academic institutions, such as university medical and non-medical research facilities, utilize radioactive tracers. By spiking samples with radionuclides such as $^{32}_{15}P$, $^{14}_{12}C$, $^{137}_{55}Cs$, $^{51}_{24}Cr$, $^{57}_{27}Co$, and $^{3}_{1}H$, beneficial research is conducted. Medical facilities such as hospitals and clinics, research facilities, and private medical offices also benefit from the use of radionuclides. Approximately 112 million medial procedures that utilize radionuclides are performed annually. Radionuclides will attach to compounds that naturally accumulate or flow through bodily systems or organs. This allows physicians to evaluate the proper functioning of a system or organ. These procedures are very effective in evaluating the heart, brain, lung, kidney, liver, bone formation, cellular functions, spleen and blood circulation. The radionuclide most commonly used is $^{99m}_{43}Tc$ because of its short half-life and gamma radiation penetrating capabilities. Cancer patients are exposed to a beam of gamma radiation to destroy uncontrolled cell generation via a teletherapy unit. Physicians can also implant radioactive “seeds” inside tumors to better irradiate the area; this is called brachytherapy. In addition, surgical instruments are sterilized using $^{60}_{27}Co$.

4.3 Science

There are varieties of scientific uses for radionuclides. NASA has powered more than 20 spacecraft with plutonium since 1972. Radionuclides are also used for navigational, communication and weather satellites. In addition, forensic scientists use activation analysis to aid in criminal investigations. By irradiating samples, trace quantities of metals, poisons, gunpowder, tape and glass can be determined.

“Carbon dating” uses naturally occurring radioactive carbon, $^{14}_{12}C$, to date archeological finds. Scientists also use $^{14}_{12}C$ as an organic tracer in biological and agricultural research and to ensure new drugs are metabolized properly. Radionuclides are used in pollution control to evaluate emissions to the environment via air, water and soil. Museums use radionuclides to detect forged paintings.

4.4 Agriculture/Food

Agriculture uses radionuclides to research superior food crops and to sterilize insects to control the population of undesirable insects. The Mediterranean fruit fly, screw worms and mosquitoes have been successfully controlled by sterilization of the insect using radionuclides. Tracers have been used to optimize fertilizer application. Nuclear density gauges are used to determine if sufficient water is available for a crop.

Approximately 37 countries irradiate up to 40 food products. The United States Food and Drug Administration authorized the use of radiation for food in 1963. Initially it was used for sprout inhibition and to delay ripening. In 1997, food irradiation was authorized to control pathogens, such as E-coli, in pork, lamb and red meats. Prior to 1997, the FDA approved irradiation of poultry, spices, seasonings and dry enzymes to control pathogens, as well as irradiation of fruits, vegetables and grains to control insects. The food is considered safer to eat after irradiation since it does not contain harmful microorganisms. The UN World Health Organization and the American Medical Association generally endorse this process.

4.5 Closure

It is important to emphasize that exposure of materials to radiation, as discussed above, does not cause the materials to become radioactive. Gamma radiation penetrates a material but does not cause the elements to become radioactive. High doses of radiation can change the material's properties to make them more durable in some cases, like flooring, but gamma-irradiated materials will not expose humans to radiation. Neutron radiation, on the other hand, can cause a material to become radioactive. Details about this phenomenon may be found in section 7, Nuclear Reactor Theory**.**

The nuclear applications listed above are only some of the numerous applications of nuclear materials in today's world. Undoubtedly, more beneficial uses will be discovered in the future.

5. Military Uses

If it were not for Germany and USA's race for nuclear weapons in the 1940s, nuclear science may not have been developed as rapidly as it was in the twentieth century. The military has always played a large role in the development and proliferation of nuclear materials. In USA, it began with the Manhattan Project. Premier scientists, under Enrico Fermi, were gathered in Chicago to study the concept of nuclear fission. In December 1942, the first man-made nuclear chain reaction was accomplished. The group moved to Los Alamos, New Mexico, and a top-secret community was created to support the development of the first nuclear weapon. These nuclear weapons were later dropped on Nagasaki and Hiroshima, Japan, in August 1945 to end World War II. Los Alamos continues to operate as a government nuclear research facility.

Military uses for nuclear technology include bombs and nuclear power plants in surface ships and submarines. The military also uses depleted uranium (DU) for munitions and tank armor. The benefit of using DU is its strength, high density and penetration capabilities. The drawback is that LLW is generated in the manufacture, testing and use of DU munitions. Depleted uranium has caused controversy because radioactive contamination has been found where the munitions have been used. Studies are underway to predict the fate and effects of the radionuclides, including plant uptake and assimilation of DU, the natural and artificial degradation of DU and its by-products, and the potential exposure to humans in the future.

The first nuclear submarine to become operable was the USS Nautilus in 1955. This was the beginning of a new generation of nuclear powered warships. Nuclear reactors are used in submarines, aircraft carriers and other surface ships. Some of the benefits of nuclear propulsion are quieter operation and reduced refueling requirements.

The Cold War was a period in history of unprecedented growth of the world's arsenal of nuclear arms. The USA and the USSR, primarily, were in a technological race to prove military superiority. Nuclear weapons played a key role in the Cold War. Each government was keenly aware that at a moment's notice a nuclear weapon could be launched.

6. Nuclear Physics

The elements identified in the periodic table are made up of atoms, which are composed of a nucleus surrounded by electrons. The nucleus of an atom contains neutrons and protons. Strong, short-range forces bind neutrons and protons together in the nucleus. Elements in the periodic table are arranged according to the number of protons that they contain, called the atomic number (A). Because electrons have very little mass, the mass of an atom, called the atomic mass number (Z), is essentially the sum of an atom's protons and neutrons. In symbolic form, the atomic mass number is placed to the top-left of the element abbreviation and the atomic number to the bottom left, i.e. ${}^{Z}_{A}\mathrm{U}$ or ${}^{235}_{92}\mathrm{U}$.

The number of neutrons in the atomic nucleus can vary. Stable nuclides have a fixed ratio of neutrons to protons. Elements with higher atomic mass numbers have higher ratios of neutrons to protons. Atoms of an element that contain different numbers of neutrons are called isotopes. Isotopes of an element can be stable or unstable. Unstable isotopes can undergo radioactive decay, which results in the formation of a new isotope. Natural radioactive decay occurs by emission of alpha, beta or gamma radiation. Unstable isotopes may also change atomic mass numbers by ejecting neutrons. Radioactive decay occurs until a stable isotope is formed.

Alpha radiation occurs when an unstable parent nucleus emits a helium nucleus as illustrated in the following example:

$${}^{235}_{92}\mathrm{U} \rightarrow {}^{231}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} \qquad (1)$$

The total mass of the progeny is less than that of the parent. In addition, the progeny may also be unstable and undergo decay reactions. Beta (-) radiation is emitted when a neutron is converted into a proton. The mass and charge of a beta particle are equal to that of an electron. Positrons are emitted from an unstable nucleus when a proton is converted into a neutron, called beta (+) radiation. Positrons have the mass of an electron and the charge of a proton. Beta radiation results in a change in the atomic number but not in the atomic mass number. Gamma radiation is emitted by an excited nucleus. In this case, there is no change in the atomic number or the atomic mass number.

The mass of an atom's nucleus is less than the sum of the mass of its protons and neutrons. The difference in mass is called the mass defect. Albert Einstein's famous equation relates the speed of light (c) and the conversion of mass (m) to energy (E):

$E = mc^2$

The binding energy that holds the nucleus of an atom together is not the same for all atoms. Figure 1 illustrates a sketch of binding energy per nucleon as a function of mass number. As illustrated in Figure 1, atoms with an atomic mass number circa 60 have the greatest binding energy and therefore exhibit the greatest mass defect. Heavier atoms such as uranium and lighter atoms such as helium have lower binding energies. This phenomenon is the basis for nuclear fission and fusion. In fission, energy is released when an unstable nucleus splits into smaller fragments. A generic fission reaction can be expressed as follows:

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U^{*} \rightarrow F_1 + F_2 + {}^{1}_{0}n\text{'s} + \gamma\text{'s} \quad (2)$$

Where,

$^{1}_{0}n$ = neutrons
F_1 and F_2 = fission fragments
γ = gamma radiation
$*$ = unstable

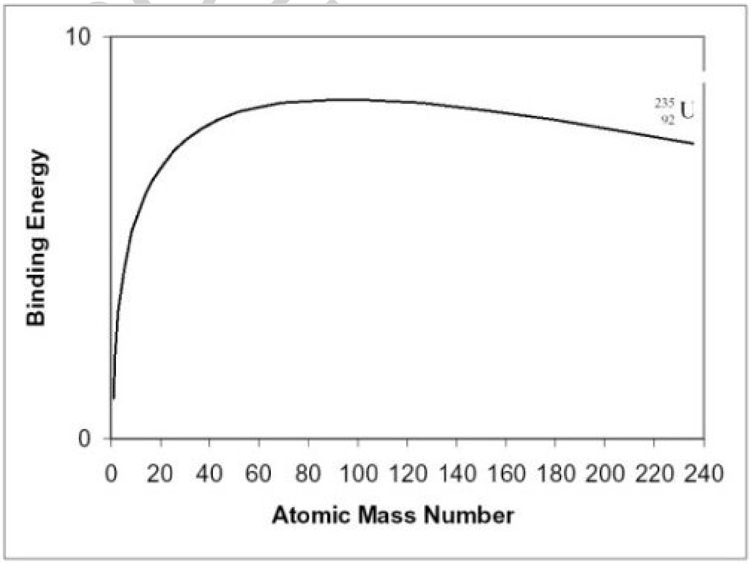

Figure 1. Binding Energy

Upon absorbing a neutron, $^{235}_{92}U$ becomes unstable. The unstable $^{236}_{92}U^{*}$ atom then splits into fission fragments. According to Figure 1, the sum of the fission fragments and neutrons that are formed will have a total mass that is less than the original $^{235}_{92}U$ atom. Consequently, energy will be released. This release of energy is typically in the form of kinetic energy possessed by fission fragments. Fission fragments are usually unstable and release additional energy via radioactive decay. Neutrons are released in nuclear fission because lighter elements have a lower neutron to proton ratio. Moreover, fission fragments may also eject neutrons for the same reason. Under specific conditions, these neutrons can generate additional fission reactions, leading to a nuclear chain reaction.

Nuclear fusion occurs when two small atoms are combined to form a heavier atom. The sum of the two lighter atoms is greater than the mass of the product atom. Consequently, the mass defect results in the release of energy.

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