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Radioactive Elements and their use in Reactors for Power generation and their utility over Fossil Fuels

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ABSTRACT

In radioactive processes, particles or electromagnetic radiation are emitted from the nucleus. The most common forms of radiation emitted have been traditionally classified as alpha (a), beta (b), and gamma (g) radiation. Nuclear radiation occurs in other forms, including the emission of protons or neutrons or spontaneous fission of a massive nucleus.

I. INTRODUCTION

Certain elements that compose matter emit particles and radiations spontaneously. This phenomenon is referred to as ***'radioactivity',*** it cannot be altered by application of heat, electricity or any other force and remains unchangeable. Three different kinds of rays, known as alpha, beta and gamma rays are associated with radioactivity. The alpha rays consist of particles (nuclei of helium atoms) carrying a positive charge, beta rays particles have negative charge (streams of electrons) and gamma rays are chargeless electromagnetic radiation with shorter wavelengths than any X-rays. These 'rays' can penetrate living tissues for short distances and affect the tissue cells. But because they can disrupt chemical bonds in the molecules of important chemicals within the cells, they help in treating cancers and other diseases. Every element can be made to emit such rays artificially, if such radioactive elements are placed in the body through food or by other methods, the rays can be traced through the body. This use of tracer elements is extremely helpful in monitoring life processes. Geologists use radioactivity to determine the age of rocks. As atoms lose particles as heavy as nuclei of helium, they become atoms of some other element. That is, the elements change or 'transmute' into other elements until the series ends with a stable element.[1, 2] Radioactive elements decay at different rates. Rates are measured as half-lives – that is, the time it takes for one half of any given quantity of a radioactive element to disintegrate. The longest half-life is that of the 'isotope' 238U of uranium. It is 4.5 billion years. Some isotopes have half-lives of years, months, days, minutes, seconds, or even less than millionths of a second.[3,4]

Measurement units and permissible dosages Radioactivity is measured in Becquerel (Bq) units. 1 Bq = 1 decay or disintegration per second. Curie (Ci) was used earlier and 1 Ci = 37 billion Bq (3.7 ´ 1010 disintegrations per second) or 37 Bq = 1 nano-Ci. To measure the health risk through ionization, in the US the most commonly used unit is rem or mrem (millirem). In Europe, the most commonly used measuring unit for this purpose is Sv (Sievert) or mSv (milli-Sv). Conversion of rem to Sieverts: 1 rem = 0.01 Sv = 10 mSv.

Coal is largely composed of organic matter, but it is the inorganic matter in coal—minerals and trace elements— that have been cited as possible causes of health, environmental, and technological problems associated with the use of coal. Some trace elements in coal are naturally radioactive. These radioactive elements include uranium (U), thorium (Th), and their numerous decay products, including radium (Ra) and radon (Rn). Although these elements are less chemically toxic than other coal constituents such as arsenic, selenium, or mercury, questions have been raised concerning possible risk from radiation. In order to accurately address these questions and to predict the mobility of radioactive elements during the coal fuel-cycle, it is important to determine the concentration, distribution, and form of radioactive elements in coal and fly ash.

II. Types of Radioactivity

2.1 Natural Radioactivity

It is somewhat surprising that nature has been a large producer of radioactive waste. Over the eons, the surface of the Earth and the terrestrial crust happens to be an enormous reservoir of primordial radioactivity. Small amounts of radioactive materials are contained in mineral springs, sand mounds and volcanic eruptions. Essentially all substances contain radioactive elements of natural origin to some extent or the other. The second source of radioactive waste is a part of industrial mining activity where, during mineral exploration and exploitation, one excavates the primordial material from the Earth that contains radioactivity, uses part of it and rejects the radioactive residues as waste. [5, 6] These are referred to as Naturally Occurring Radioactive Materials (NORMs) and are ubiquitous as residual wastes in processing industries that cover fertilizers, iron and steel, fossil fuel, cement, mineral sands, titanium, thorium and uranium mining as well as emanations and waste from coal and gas-fired power plants.

2.2 Artificial Radioactivity

Radioactivity was discovered about a hundred years ago. Following the Second World War and discovery of the fission process, human activity added radioactivity artificially to the natural one. Two main sources have been: (a) the civilian nuclear programs, including nuclear power production, medical and industrial applications of radioactive nuclides for peaceful purposes, and (b) the military nuclear program, including atmospheric[7] and underground nuclear-weapon testing and weapon production (see Box 2 for the nature of artificial radioactive isotopes produced).

III. Detection of Radioactivity

Becquerel discovered radioactivity because it left marks on photographic film as a means of detecting radiation. However, there are more definitive means commonly used by scientists and technicians who study and work with radiation. The equipment utilized for the detection and measurement of radiation commonly employs some type of a substance or material that responds to radiation. Many common methods use either an ionization process or molecular excitation process as a basis. Remember that we stated earlier that radiation interacts with matter. For detection and measurement purposes the process of ionization is the most commonly employed technique, based on the principle of charged particles producing ion pairs by direct interaction. These charged particles may collide with electrons, which remove them from their parent atoms, or transfer energy to an electron by interaction of electric fields.

Table 1 : Showing list of Radio active Elements
Radioactive Elements

Element	Most Stable Iso-tope	Half-life of Most Stable Istope
Technetium	Tc-91	4.21 x 10^6 years
Promethium	Pm-145	17.4 years
Polonium	Po-209	102 years
Astatine	At-210	8.1 hours
Radon	Rn-222	3.82 days
Francium	Fr-223	22 minutes
Radium	Ra-226	1600 years
Actinium	Ac-227	21.77 years
Thorium	Th-229	7.54 x 10^4 years
Protactinium	Pa-231	3.28 x 10^4 years
Uranium	U-236	2.34 x 10^7 years
Neptunium	Np-237	2.14 x 10^6 years
Plutonium	Pu-244	8.00 x 10^7 years
Americium	Am-243	7370 years
Curium	Cm-247	1.56 x 10^7 years
Berkelium	Bk-247	1380 years
Californium	Cf-251	898 years
Einsteinium	Es-252	471.7 days
Fermium	Fm-257	100.5 days
Mendelevium	Md-258	51.5 days
Nobelium	No-259	58 minutes
Lawrencium	Lr-262	4 hours
Rutherfordium	Rf-265	13 hours
Dubnium	Db-268	32 hours
Seaborgium	Sg-271	2.4 minutes
Bohrium	Bh-267	17 seconds
Hassium	Hs-269	9.7 seconds
Meitnerium	Mt-276	0.72 seconds
Darmstadtium	Ds-281	11.1 seconds
Roentgenium	Rg-281	26 seconds
Copernicium	Cn-285	29 seconds
Ununtrium	Uut-284	0.48 seconds
Flerovium	Fl-289	2.65 seconds
Ununpentium	Uup-289	87 milliseconds
Livermorium	Lv-293;	61 milliseconds
Ununseptium	Unknown	
Ununoctium	Uuo-294	1.8 milliseconds

IV. SIGNIFICANCE OF NUCLEAR FUELS

- Nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels.
- Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants and much greater than those for gas-fired plants.
- Providing incentives for long-term, high-capital investment in deregulated markets where short-term price signals present a challenge in securing a diversified and reliable electricity supply system.
- In assessing the economics of nuclear power, decommissioning and waste disposal costs are fully taken into account.

Assessing the relative costs of new generating plants utilizing different technologies is a complex matter and the results depend crucially on location. Coal is, and will probably remain, economically attractive in countries such as China, the USA and Australia with abundant and accessible domestic coal resources as long as carbon emissions are cost-free. Gas is also competitive for base-load power in many places, particularly using combined-cycle plants, though rising gas prices have removed much of the advantage.

Nuclear power plants are expensive to build but relatively cheap to run. In many places, nuclear energy is competitive with fossil fuels as a means of electricity generation. Waste disposal and decommissioning costs are included in the operating costs. If the social, health and environmental costs of fossil fuels are also taken into account, the economics of nuclear power are outstanding.[8]

Significance of Nuclear Energy over Fossil fuels

The fossil fuels, which include oil, natural gas and coal, are the traditional energy source and of limited supply.("International Energy Statistics", 2012) The fossil fuel was formed by decomposing plants over millions of years ago. It would take millions of year to form and we are using them in a rate faster than ever. ("How Fossil Fuels were Formed", 2013) The world oil consumption is about half a thousand million tons per year in 1950, rises to over 4 thousands million tons in 2005.("Global Fossil Fuel Consumption Surges", 2005) In addition, burning fossil fuel is not environmental friendly as well. A lot of CO2 are generated in the burning oil and it will fasten the global [9] warning.("Greenhouse Gases, Climate Change, and Energy", 2004) The situation is especially bad in coal, it will give out other harmful gases such as sulfur dioxide, which can lead to an array of adverse respiratory effects.("Sulfur dioxide", 2012) Also, coal mining can destroy the land and mountain.("Mining: Destroying mountain", n.d.)According to Hansen(2009), "the trains carrying coal to power plants are death trains, coal-fired power plants are factories of death".[10]

Nuclear energy is comparable to the renewable energy sources like solar, wind, biomass energy. It is environmental friendly and can last for a very long time. Nuclear energy makes use of the nuclear fission to generate heat and electricity.("How Nuclear Power Works", 2003) The radioactive substance called Uranium is used as fuel, it is a fairly common element in Earth's crust, as common as tin.("Uranium (revised)", 2006) "The energy in one uranium fuel pellet (about the size of the tip of your little finger) is the equivalent of 17,000 cubic feet of natural gas, 1,780 pounds of coal or 149 gallons of oil". [11,12] (Ebright, 2011) The scientists estimated that the reserves of uranium can be lasted for several thousand years. (Sims & Sherlock, 2007) Unlike burning oil and coal, nuclear power plant operations emit almost no greenhouse gases, it is considered as a clean-air energy. According to CAS Energy Coalition, nuclear energy has perhaps the lowest impact on the environment than any other energy source, providing more than 70 percent of the United States' emission-free power. "In 2004, U.S. nuclear power plants prevented 3.43 million tons of sulfur dioxide, 1.11 million tons of nitrogen oxide and 696.6 million metric tons of carbon dioxide from entering the earth's atmosphere"(Tagare, 2011) [13]

Nuclear energy is economical friendly to consumers as well. The economics of nuclear energy involved considerations in 3 aspects: capital cost, plant operation cost and external cost.("The Economics of Nuclear Power", 2013) A huge startup investment is needed to build a safety nuclear power plant, so the capital cost is higher. However, the fuel is a great reduction in cost. Uranium is abundant and widely available.[14, 15] Also, it can be easily and cheaply transported as quantities needed are much less than coal or oil.("The Economics of Nuclear Power", 2013) For the external cost, it is mainly related to dealing with the health and environmental problem. As nuclear energy is emission free, it does not require paying the emission trade. Thus, the external cost is pretty low. In 2008, the US electricity production cost for oil is 18 cents/ KWh, but for nuclear, it is only 2 cents/KWh. ("The cost of energy", 2011)

Nuclear energy has already achieved success in some countries. Approximately 16% of the world's electricity is supplied by nuclear energy, 21 out of 30 countries with nuclear power plants obtain 15% or more of their electricity from nuclear energy.(Krivit, Lehr & Kingery, 2011) In France, Nuclear energy is the primarily source of energy, about 76% of electricity produced in France came from nuclear energy in 2009.("Energy in Sweden facts and figure", 2011) France also leads the head of the world in nuclear power and success in both environmental and economic aspects. It has the lowest CO_2 production per unit of GPD among the industrialize nation in the world. (CO_2 Emissions from Fuel Combustion, 2012) Moreover, France's electricity price to both industrial consumers and household customers is the 7th cheapest amongst the 27 members of European Union("fuel price", 2013) Not only France, America, Germany and other advance countries are increasing the proportion of nuclear energy in order to provide cleaner and cheaper energy.("Operational & Long-Term Shutdown Reactors", 2013) [16]

After the Three Mile Island, Chernobyl and Fukushima Daiichi disaster, safety becomes the first concern of nuclear energy. [17-19] The public and mass media oppose nuclear energy mainly due to the safety problem. However**,** ***nuclear energy is in fact very safe.*** About 85% of the radiation humans receive comes from natural sources such as cosmic rays from space, the remainder of our annual radiation dose comes from artificial sources such as medical x-rays. Less than 1% comes from the nuclear industry.("Radiation & its source", n.d.) A 2hours flight on the airplane gets more radiation than lived next door to a nuclear power plant for a year. Historically, no nuclear worker dies from nuclear radiation and no single public has been exposed to large dose of radiation.(Tabak, 2009) Nuclear power, in terms of lives lost per unit of electricity delivered, is lower than many renewable energy sources.(Markandya & Wilkinson, 2007)

The nuclear plant design is very sophisticated and the location is well considered to prevent accidents. The nuclear reactor is covered by a series of physical barriers, including 30cm thick steels wall and 1.8m thick concrete wall, to prevent the core expose to outer environment. Even in Fukushima disaster, there are still 2 layers of barrier left to protect the reactor. And there is a set of redundant and diverse systems to control reactor, it can be shut down within 30s if any accidents happen. In both the Three Mile Island and Fukushima accidents, the problems started after the reactors were shut down("Safety of Nuclear Power Reactors", 2013). In addition, the plants are always located along coastal and rural. Just in case there is an accident, there is enough cooling water and causes fewer causalities. According to The Nuclear Debate(2013) in World Nuclear Association, "the nuclear industry has an excellent safety record, with some 14,800 reactor years of operation spanning five decades. Even a major accident and meltdown as at Fukushima in 2011 would not endanger its neighbours."(2013)

V. Nuclear Power is Safe

The three major reactor accidents have shown the industry that even among the worst accidents, few and far between, there is little loss of life, as compared to other fuels.[20] In addition, nuclear power producers are constantly assessing safety upgrades, in an effort to protect the public from any pollution or harm. We are living in a energy-demanding world which will continue to increase its need. [21, 22] The proposed shift to electric cars is just one example. Nothing is risk-free, but risk can be minimized through constant review, upgrade and new designs. Nuclear generated power meets all these criteria, and more.[23]

VI. Conclusion

The remarkable advantage of nuclear power plants is they generate electricity without emitting any air pollution. The clouds billowing from cooling towers are nothing but harmless steam. Nuclear power does take a toll on the environment, however. Mining uranium destroys natural habitats, and the activity involved in both mining and processing uranium produces greenhouse gases. Another concern is waste falling into the wrong hands, giving terrorists material for weapons. In recent years, dozens of nations have decided the benefits are worth the risks and are forging ahead. They're touting nuclear power as the way of the future – just as it was 60 years ago.

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