Nuclear science and its Importance in Society – An Analysis

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Abstract

This paper looks at Nuclear Physics in Society. Nuclear Physics positively influences our daily lives, through advances in technology, health, and energy production, and yet is often misunderstood by the general public. Nuclear physics is ubiquitous in our lives: Detecting smoke in our homes, testing for and treating cancer, and monitoring cargo for contraband are just some of the ways that nuclear physics and the techniques it has spawned make a difference in our safety, health, and security. Many of today's most important advancements in medicine, materials, energy, security, climatology, and dozens of other sciences emanate from the wellspring of basic research and development in nuclear physics. Answers to some of the most important questions facing our planet will come from nuclear science, interdisciplinary efforts in energy and climate, and marketplace innovations. An atom consists of an extremely small, positively charged nucleus surrounded by a cloud of negatively charged electrons. Although typically the nucleus is less than one ten-thousandth the size of the atom, the nucleus contains more than 99.9% of the mass of the atom! Nuclei consist of positively charged protons and electrically neutral neutrons held together by the so-called strong or nuclear force. This force is much stronger than the familiar electrostatic force that binds the electrons to the nucleus, but its range is limited to distances on the order of a few x10-15 meters. The number of protons in the nucleus, Z, is called the atomic number. This determines what chemical element the atom is. The number of neutrons in the nucleus is denoted by N. The atomic mass of the nucleus, A, is equal to Z + N. A given element can have many different isotopes, which differ from one another by the number of neutrons contained in the nuclei. In a neutral atom, the number of electrons orbiting the nucleus equals the number of protons in the nucleus. Since the electric charges of the proton and the electron are +1 and -1 respectively (in units of the proton charge), the net charge of the atom is zero. At present, there are 112 known elements which range from the lightest, hydrogen, to the recently discovered and yet to-be-named element 112. All of the elements heavier than uranium are man made. Among the elements are approximately 270 stable isotopes, and more than 2000 unstable isotopes.The first power station to produce electricity by using heat from the splitting of uranium atoms began operating in the 1950s. Today most people are aware of the important contribution nuclear energy makes in cleanly providing a significant proportion of the world's electricity.

Not so well known are the many other ways the peaceful atom has slipped quietly into our lives, often unannounced and in many cases unappreciated. Radioisotopes and radiation have many applications in agriculture, medicine, industry and research. They greatly improve the day to day quality of our lives.

Key words: feminism, interrogation, Kashmir, women writing, regional, *religious.*

Introduction

Nuclear science and technologies contribute in many ways to the health, development and security in countries worldwide. Through its Nuclear Science Programme the IAEA carries out activities to assist and advise the IAEA Member States in assessing their needs for capacity building, research and development in the nuclear sciences, as well as in supporting the Member States' activities for deriving benefits in specific fields, such as:

- *Nuclear, atomic and molecular data;*
- *Research reactors and their effective management;*
- *Accelerators, nuclear spectrometry and allied instrumentation;*
- *Nuclear fusion and plasma physics;*
- *Coordination of cooperation with the International Centre for Theoretical Physics (ICTP) and ITER.*

The effective development of new technologies and their applications, as well as the safe and economical maintenance of existing technologies, rely on a thorough understanding of the underlying nuclear science principles, related physico-chemical processes and nuclear data.

The IAEA Nuclear Science Programme is part of the IAEA's Major Programme 1, managed by the Department of Nuclear Energy, while the Division of Physical and Chemical Sciences, located within the Department of Nuclear Sciences and Applications is responsible for implementing most parts of the Programme.

There are five sub-programmes, and the work is carried out by a staff of approximately 40 persons distributed among three sections, namely, Nuclear Data Section and Physics Section within the Division of Physical and Chemical Sciences in the Department of Nuclear Sciences and Applications; and Research Reactor Section in the Department of Nuclear Energy.

The tasks under the Nuclear Science Programme include supporting Member States' needs-based development efforts through Coordinated Research Projects, advisory missions, laboratory training and analytical services, publication of the state-of-the-art reports on specific topics and issues, preparation and provision of materials for human resources development, and assistance to the Department of Technical Cooperation on scientific and technical aspects of a large number of technical cooperation projects.

The activities address the requirements of both nuclear energy systems and non-power nuclear applications. Nuclear science and technology is the foundation for all the IAEA's activities. The Agency assists Member States with scientific advice, education, training and technical documents in many nuclear science areas, provides key nuclear data and helps them improve awareness about the wide range of applications of nuclear technology.

Objective:

This paper intends to explore, how nuclear physicists can have a huge positive impact when they actively engage the public and schools with their science.

Radioactive elements that undergo radioactive decay

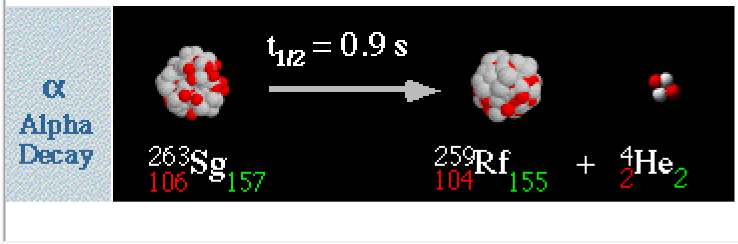
In 1896, Henri Becquerel was working with compounds containing the element uranium. To his surprise, he found that photographic plates covered to keep out light became fogged, or partially exposed, when these uranium compounds were anywhere near the plates. This fogging suggested that some kind of ray had passed through the plate coverings. Several materials other than uranium were also found to emit these penetrating rays. Materials that emit this kind of radiation are said to be radioactive and to undergo radioactive decay.

In 1899, Ernest Rutherford discovered that uranium compounds produce three different kinds of radiation. He separated the radiations according to their penetrating abilities and named them a alpha, b beta, and g gamma radiation, after the first three letters of the Greek alphabet. The a radiation can be stopped by a sheet of paper. Rutherford later showed that an alpha particle is the nucleus of a He atom, 4He. Beta particles were later identified as high speed electrons. Six millimeters of aluminum are needed to stop most b particles. Several millimeters of lead are needed to stop g rays , which proved to be high energy photons. Alpha particles and g rays are emitted with a specific energy that depends on the radioactive isotope. Beta particles, however, are emitted with a continuous range of energies from zero up to the maximum allowed for by the particular isotope.

α decay

The emission of an a particle, or 4He nucleus, is a process called a decay. Since a particles contain protons and neutrons, they must come from the nucleus of an atom. The nucleus that results from a decay will have a mass and charge different from those of the original nucleus. A change in nuclear charge means that the element has been changed into a different element. Only through such radioactive decays or nuclear reactions can transmutation, the age-old dream of the alchemists, actually occur. The mass number, A, of an a particle is four, so the mass number, A, of the decaying nucleus is reduced by four. The atomic number, Z, of 4He is two, and therefore the atomic number of the nucleus, the number of protons, is reduced by two. This can be written as an equation analogous to a chemical reaction. For example, for the decay of an isotope of the element seaborgium, 263Sg:

^{263}Sg ----> ^{259}Rf + ^{4}He

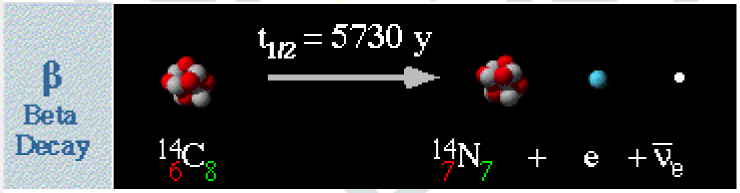


The atomic number of the nucleus changes from 106 to 104, giving rutherfordium an atomic mass of 263-4=259. a decay typically occurs in heavy nuclei where the electrostatic repulsion between the protons in the nucleus is large. Energy is released in the process of a decay. Careful measurements show that the sum of the masses of the daughter nucleus and the a particle is a bit less than the mass of the parent isotope. Einstein's famous equation, E=mc2, which says that mass is proportional to energy, explains this fact by saying that the mass that is lost in such decay is converted into the kinetic energy carried away by the decay products.

β Decay

Beta particles are negatively charged electrons emitted by the nucleus. Since the mass of an electron is a tiny fraction of an atomic mass unit, the mass of a nucleus that undergoes b decay is changed by only a tiny amount. The mass number is unchanged. The nucleus contains no electrons. Rather, b decay occurs when a neutron is changed into a proton within the nucleus. An unseen neutrino,ν, accompanies each b decay. The number of protons, and thus the atomic number, is increased by one. For example, the isotope ^{14}C is unstable and emits a β particle, becoming the stable isotope ^{14}N:

^{14}C ----> ^{14}N + e^- + ν



In a stable nucleus, the neutron does not decay. A free neutron, or one bound in a nucleus that has an excess of neutrons, can decay by emitting a b particle. Sharing the energy with the b particle is a neutrino. The neutrino has little or no mass and is uncharged, but, like the photon, it carries momentum and energy. The source of the energy released in b decay is explained by the fact that the mass of the parent isotope is larger than the sum of the masses of the decay products. Mass is converted into energy just as Einstein predicted.

Isotopes are different forms of an atom of the same chemical element. They have identical chemical properties but different relative atomic masses. While the number of protons is the same, the number of neutrons in the nucleus differs.

Some isotopes are referred to as 'stable' and unchanging, while others are 'unstable' since their nucleus changes over time – from milliseconds to millennia – as they emit charged particles or waves, making them 'radioactive'. It is the radioactive nature of these unstable atoms, usually referred to as '**radioisotopes**', which gives them so many applications in modern science and technology. Their radioactivity means that they can be used as a tag to follow the movement of some material incorporating them.

George de Hevesy

The first practical application of a radioisotope was made by George de Hevesy in 1911. At the time de Hevesy was a young Hungarian student working in Manchester with naturally radioactive materials. Not having much money he lived in modest accommodation and took his meals with his landlady. He began to suspect that some of the meals that appeared regularly might be made from leftovers from the preceding days or even weeks, but he could never be sure. To try and confirm his suspicions de Hevesy put a small amount of radioactive material into the remains of a meal. Several days later when the same dish was served again he used a simple radiation detection instrument - a gold leaf electroscope - to check if the food was radioactive. It was, and de Hevesy's suspicions were confirmed.

History has forgotten the landlady, but George de Hevesy went on to win the Nobel prize in 1943 and the Atoms for Peace award in 1959. His was the first use of radioactive tracers - now routine in environmental science.

Scientists continue to find new and beneficial ways of using nuclear technology to improve our lives. In our daily life we need food, water and good health. Radioisotopes play an important part in technologies that provide us with these basic needs. The UN's International Atomic Energy Agency (IAEA) is a base for international cooperation in hundreds of development projects.

Food and Agriculture

At least 800 million of the world's seven billion inhabitants are chronically malnourished, and tens of thousands die daily from hunger and hunger-related causes. Radioisotopes and radiation used in food and agriculture are helping to reduce these tragic figures.

As well as directly improving food production, agriculture needs to be sustainable over the longer term. The UN's Food and Agriculture Organisation (FAO) works with the IAEA on programs to improve food sustainability assisted by nuclear and related biotechnologies.

Fertilisers

Fertilisers are expensive and if not properly used can damage the environment. Efficient use of fertilisers is therefore of concern to both developing and developed countries. It is important that as much of the fertiliser as possible finds its way into plants and that a minimum is lost to the environment.

Fertilisers 'labelled' with a particular isotope, such as nitrogen-15 and phosphorus-32 provide a means of finding out how much is taken up by the plant and how much is lost, allowing better management of fertiliser application. Using N-15 also enables assessment of how much nitrogen is fixed from the air by soil and by root bacteria in legumes.

Increasing Genetic Variability

Ionising radiation to induce mutations in plant breeding has been used for several decades, and some 1800 crop varieties have been developed in this way. Gamma or neutron irradiation is often used in conjunction with other techniques, to produce new genetic lines of root and tuber crops, cereals and oil seed crops.

New kinds of sorghum, garlic, wheat, bananas, beans and peppers are more resistant to pests and more adaptable to harsh climatic conditions. In Mali, irradiation of sorghum and rice seeds has produced more productive and marketable varieties.

Insect Control

Crop losses caused by insects may amount to more than 10% of the total harvest worldwide, - in developing countries the estimate is 25-35%. Stock losses due to tsetse in Africa and screwworm in Mexico have also been sizeable. Chemical insecticides have for many years been the main weapon in trying to reduce these losses, but they have not always been effective. Some insects have become resistant to the chemicals used, and some insecticides leave poisonous residues on the crops. One solution has been the use of sterile insects.

The Sterile Insect Technique (SIT) involves rearing large numbers of insects then irradiating their eggs with gamma radiation before hatching, to sterilise them. The sterile males are then released in large numbers in the infested areas. When they mate with females, no offspring are produced. With repeated releases of sterilised males, the population of the insect pest in the project area is drastically reduced.

Major SIT operations have been conducted in Mexico, Argentina and northern Chile against the Medfly (Mediterranean fruit fly) and in 1981 this was declared a complete success in Mexico. In 1994-95 eradication was achieved in two fruit-growing areas of Argentina and 95% success in another, as well as in Chile. The program has been extended to all of southern South America and to Africa. Meanwhile the EU is financing a 'fly factory' on Portugal's Madeira island to produce up to 100 million sterile male Medflies per week.

A very successful SIT campaign was screwworm eradication in southern USA, Mexico and nearby. By 1991 the screwworm eradication had yielded some US$ 3 billion in economic benefits due to healthier livestock, not to mention humans. The Mexican plants and equipment were then applied to infestations in Libya, Jamaica and Central America, providing 20 million sterile pupae per week.

SIT has been effective on the Medfly in southern Africa and is now being applied to Codling Moths which damage citrus crops. The IAEA and FAO are assessing the potential of using SIT against Sugarcane Borers on sugarcane, as well as consolidating Codling Moth management to support the apple and pear export industries.

A number of the most fertile parts of Africa cannot be farmed because of the tsetse fly which carries the parasite trypanosome that causes the African sleeping sickness disease and the cattle disease Nagana. Economic losses due to this are estimated by FAO at US$ 4 billion per year. However, SIT in conjunction with conventional pest controls is starting to change all this. Zanzibar was declared tsetse-free in 1997 and Nigeria has also benefited. In southern Ethiopia a major tsetse SIT program is under way, with a million sterile males per month being produced in a 'fly factory' at Addis Ababa and then released.

Screwworm flies are major pests in some parts of the world. Females lay eggs into animal wounds and on soft tissues, the larvae then burrow through the flesh creating serious bacterial infections that attract more egg-laying females and are often fatal. Using SIT, screwworm has been eradicated from North and Central America, and also Libya. South America, most of Africa, and south Asia through to Melanesia remain a challenge.

Three UN organizations - the IAEA, the FAO, the World Health Organisation (WHO), with the governments concerned, are promoting new SIT programs in many countries.

Food Preservation

Some 25-30% of the food harvested in many countries is lost as a result of spoilage by microbes and pests. In a hungry world we cannot afford this. The reduction of spoilage due to infestation and contamination is of the utmost importance. This is especially so in countries which have hot and humid climates and where an extension of the storage life of certain foods, even by a few days, is often enough to save them from spoiling before they can be consumed. Some countries lose a high proportion of harvested grain due to moulds and insects.

In all parts of the world there is growing use of irradiation technology to preserve food. In over 40 countries health and safety authorities have approved irradiation of more than 60 kinds of food, ranging from spices, grains and grain products to fruit, vegetables and meat. It can replace potentially harmful chemical fumigants to eliminate insects from dried fruit and grain, legumes, and spices.

Following three decades of testing, a worldwide standard was adopted in 1983 by a joint committee of WHO, FAO and IAEA. In 1997 another such joint committee said there was no need for the earlier recommended upper limit on radiation dose to foods.

As well as reducing spoilage after harvesting, increased use of food irradiation is driven by concerns about food-borne diseases as well as growing international trade in foodstuffs which must meet stringent standards of quality. On their trips into space, astronauts eat foods preserved by irradiation.

Food irradiation means that raw foods are exposed to high levels of gamma radiation which kills bacteria and other harmful organisms without affecting the nutritional value of food itself or leaving any residue. It is the only means of killing bacterial pathogens in raw and frozen food. Of course, irradiation of food does **not** make it radioactive!

Food irradiation applications

Low dose (up to 1 kGy)	Inhibition of sprouting	Potatoes, onions, garlic, ginger, yam
	Insect and parasite disinfestation	Cereals, fresh fruit, dried foods
	Delay ripening	Fresh fruit, vegetables
Medium dose (1-10 kGy)	Extend shelf life	Fish, strawberries, mushrooms
	Halt spoilage, kill pathogens	Seafood, poultry, meat
High dose (10-50 Gy)	Industrial sterilisation	Meat, poultry, seafood, prepared foods
	Decontamination	Spices, etc

Radiation is also used to sterilise food packaging. In the Netherlands, for example, milk cartons are freed from bacteria by irradiation.

Water Resources

Adequate potable water is essential for life. Yet in many parts of the world fresh water has always been scarce and in others it is becoming scarcer. Yet for any new development, whether agricultural, industrial or human settlement, a sustainable supply of good water is vital.

Isotope hydrology techniques enable accurate tracing and measurement of the extent of underground water resources. Such techniques provide important analytical tools in the management and conservation of existing supplies of water and in the identification of new, renewable sources of water. They provide answers to questions about origin, age and distribution of groundwater, as well as the interconnections between ground and surface water and aquifer recharge systems. The results permit planning and sustainable management of these water resources.

For surface waters they can give information about leakages through dams and irrigation channels, the dynamics of lakes and reservoirs, flow rates, river discharges and sedimentation rates. From Afghanistan to Zaire there are some 60 countries, developed and developing, that have used isotope techniques to investigate their water resources in collaboration with IAEA.

Neutron probes can measure soil moisture very accurately, enabling better management of land affected by salinity, particularly in respect to irrigation.

Medicine

Many of us are aware of the wide use of radiation and radioisotopes in medicine particularly for **diagnosis** (identification) and**therapy** (treatment) of various medical conditions. In developed countries (a quarter of the world population) about one person in fifty uses diagnostic nuclear medicine each year, and the frequency of therapy with radioisotopes is about one tenth of this.

Over 10,000 hospitals worldwide use radioisotopes in medicine. In the USA there are over 20 million nuclear medicine procedures per year among 315 million people, and in Europe about 10 million among 500 million people. The use of radiopharmaceuticals in diagnosis is growing at over 10% per year.

Diagnosis

Radioisotopes are an essential part of medical diagnostic procedures. In combination with imaging devices which register the gamma rays emitted from within, they can study the dynamic processes taking place in various parts of the body. An advantage of nuclear over x-ray techniques is that both bone and soft tissue can be imaged very successfully.

In using radiopharmaceuticals for diagnosis, a radioactive dose is given to the patient and the activity in the organ can then be studied either as a two dimensional picture or, with a special technique called tomography, as a three dimensional picture.

The most widely used diagnostic radioisotope is technetium-99m*, with a half-life of six hours, and which gives the patient a very low radiation dose. Such isotopes are ideal for tracing many bodily processes with the minimum of discomfort for the patient. They are widely used to indicate tumours and to study the heart, lungs, liver, kidneys, blood circulation and volume, and bone structure.

* Technetium generators, a lead pot enclosing a glass tube containing the radioisotope, are supplied to hospitals from the nuclear reactor where the isotopes are made. They contain molybdenum-99, with a half-life of 66 hours, which progressively decays to technetium-99. The Tc-99 is washed out of the lead pot by saline solution when it is required. After two weeks or less the generator is returned for recharging.

Technetium (Tc-99) is employed in some 40 million diagnostic procedures per year, of which almost one quarter are in Europe, half in North America, almost one quarter in Asia/Pacific (particularly Japan), and a few in other regions. The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest.

Another major use of radioisotopes for diagnosis is in radio-immuno-assays for biochemical analysis in a laboratory. They can be used to measure very low concentrations of hormones, enzymes, hepatitis virus, some drugs and a range of other substances in a sample of the patient's blood. The patient never comes in contact with the radioisotopes used in the diagnostic tests. In the USA alone it is estimated that some 40 million such tests are carried out each year, and in Europe, about 15 million.

Therapy

The uses of radioisotopes in therapy are comparatively few, but important. Cancerous growths are sensitive to damage by radiation, which may be external - using a gamma beam from a cobalt-60 source, or internal - using a small gamma or beta radiation source. Short-range radiotherapy is known as brachytherapy, and this is becoming the main means of treatment. Many therapeutic procedures are palliative, usually to relieve pain.

Iodine-131 is commonly used to treat thyroid cancer, probably the most successful kind of cancer treatment, and also for non-malignant thyroid disorders. Iridium-192 wire implants are used especially in the head and breast to give precise doses of beta rays to limited areas, then removed. A new treatment uses samarium-153 complexed with organic phosphate to relieve the pain of secondary cancers lodged in bone.

A new field is Targeted Alpha Therapy (TAT), especially for the control of dispersed cancers. The short range of very energetic alpha emissions in tissue means that a large fraction of that radiative energy goes into the targeted cancer cells, once a carrier such as a monoclonal antibody has taken the alpha-emitting radionuclide to exactly the right places.

Conclusion

From the moment we get up in the morning, until we go to sleep, we benefit unknowingly from many ingenious applications of radioisotopes and radiation. The water we wash with (origin, supply assurance), the textiles we wear (manufacture control gauging), the breakfast we eat (improved grains, water analysis), our transport to work (thickness gauges for checking steels and coatings on vehicles and assessing the effects of corrosion and wear on motor engines), the bridges we cross (neutron radiography), the paper we use (gauging, mixing during production processes), the drugs we take (analysis) not to mention medical tests (radioimmunoassay, perhaps radiopharmaceuticals), or the environment which radioisotope techniques help to keep clean, are all examples that we sometimes take for granted.

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