The Contributions of Physics in the Emergence of the Nuclear Technology -A Review

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Abstract

This paper investigates Physics as the study of matter, energy and their interactions - targeting nuclear technology enterprise, which plays a key role in the future progress of humankind. All matter is composed of atoms: incredibly small structures that house different combinations of three particles, known as protons, neutrons, and electrons. At the center of each atom is a "nucleus" (the plural of which is "nuclei"), where neutrons and protons are bound in closeimity together. Most nuclei are relatively stable, meaning the makeup of their neutrons and protons is comparatively static and unchanging. During fission, the nuclei of certain heavy atoms split into smaller, lighter nuclei, releasing excess energy in the process. This can sometimes occur spontaneously, but can also, in certain nuclei, be induced from outside. A neutron is shot at the nucleus and is absorbed, causing instability and fission. In some elements—such as certain isotopes of uranium and plutonium—the fission process also releases excess neutrons, which can trigger a chain reaction if they're absorbed by nearby atoms. Fusion works in reverse: when exposed to extremely high temperatures and pressures, some lightweight nuclei can fuse together to form heavier nuclei, releasing energy in the process. In modern nuclear weapons, which use both fission and fusion, a single warhead can release more explosive energy in a fraction of a second than all of the weapons used during World War II combined—including Fat Man and Little Boy, the two atom bombs dropped on Japan.

All nuclear weapons use fission to generate an explosion. "Little Boy"—the first nuclear weapon ever used during wartime—worked by shooting a hollow uranium-235 cylinder at a target "plug" of the same material. Only certain isotopes of certain elements can undergo fission (an isotope is a variation of the same element with different numbers of neutrons in the nucleus). Plutonium-239 and uranium-235 are the most common isotopes used in nuclear weapons. Each piece by itself was not enough to constitute a critical mass (the minimum amount of nuclear material needed to maintain fission)—but by colliding the pieces, critical mass was reached and a fission chain reaction occurred. Modern nuclear weapons work slightly differently. Critical mass depends on the density of the material: as the density increases, the critical mass decreases. Instead of colliding two sub-critical pieces of nuclear fuel, modern weapons detonate chemical explosives around a sub-critical sphere (or "pit") of uranium-235 or plutonium-239 metal. The force from the blast is directed inward, compressing the pit and bringing its atoms closer together.

Key words: critical mass, chemical explosives, neutrons, uranium-235, plutonium-239.

Introduction

The energy released by the weapon creates a fireball that reaches several tens of million degrees—temperatures in the same range as the center of the sun (which also runs on fusion). The explosions used in thermonuclear weapons are often described as a primary (the chemical and fission explosions) and secondary (the subsequent fusion blast). Fusion weapons (also called "thermonuclear" or "hydrogen" weapons), the energy from an initial fission explosion is used to "fuse" hydrogen isotopes together. Once dense enough to reach the critical mass, neutrons are injected, initiating a fission chain reaction and producing an atomic explosion.

However, the actual mechanisms are considerably more complicated. For example, a pure fission primary is inefficient—the plutonium pit will blow itself apart before most of the plutonium-239 can fission. Instead, the reaction can be "boosted" by including hydrogen gas (consisting of the isotopes deuterium and tritium) in the center of a hollow pit. As the surrounding plutonium fissions, the hydrogen gas undergoes fusion and releases neutrons, inducing additional fission. Similarly, the secondary doesn't consist purely of fusion fuel; layered within it is a fission "spark plug," consisting of either plutonium-239 or uranium-235. As the primary explosion compresses the fuel from the outside, the spark plug material becomes supercritical and fissions, heating the hydrogen from the inside and facilitating further fusion reactions. Fusion releases neutrons. These neutrons hit a layer of uranium surrounding the fusion fuel causing atoms in it to fission; this fissioning generally contributes more than half of the weapon's total explosive yield. Thermonuclear weapons that don't include this uranium "blanket" are called neutron bombs, as the neutrons freed by fusion are released from the weapon. Neutron bombs therefore create a larger amount of radiation than a normal weapon of the same yield. During the Cold War such weapons were considered for use against tank attacks, with the goal of disabling tank crews without having to physically destroy the tank. Natural uranium must be enriched in centrifuges like these before it's usable in nuclear weapons. Photo: Nuclear Regulatory Commission Nuclear fuel While a number of elements are fissionable (meaning they can undergo fission), only a few are used in nuclear weapons. Most common are the isotopes uranium-235 and plutonium-239 (reminder: isotopes are atoms of the same element that differ only in their number of neutrons).

Uranium is found throughout the world and can be mined from mineral deposits (it can also be extracted from seawater, but doing so is currently much more expensive). However, only a small fraction (less than one percent) of naturally occurring uranium is uranium-235. Producing usable uranium requires a process of "enrichment," in which different uranium isotopes are separated and concentrated (usually using centrifuges, which operate like salad spinners). This is extremely costly, difficult, and time-consuming, and is one of the central barriers to constructing a nuclear bomb. Plutonium can also be used, but only occurs naturally in trace amounts.

Objective:

This paper intends to explore Feminist ideology as revealed in Kashmiri women writings.

Nuclear fuel & Nuclear power

Nuclear power, can be produced as a fission byproduct in nuclear reactors, then separated by a process called "reprocessing. " Plutonium separation is easier than uranium enrichment—it involves separating different elements, not different isotopes of the same element—but it's a highly radioactive process that requires heavily shielded facilities with remote-handling equipment. The United States was the first country to develop nuclear weapons, detonating the first fission device in 1945. Seven years later the United States successfully tested the first hydrogen bomb during "Operation Ivy" (physicist Richard Garwin helped build that device, and today serves on the board of the Union of Concerned Scientists). As of 2014, the United States had an estimated 6,500 nuclear warheads, including retired (awaiting dismantlement), stored, and deployed weapons. The Soviet Union first developed nuclear capabilities in 1949. Russia's modern day arsenal includes an estimated 7,000 warheads. France (~300 warheads), China (~260), the United Kingdom (~215), Pakistan (~130), and India (~120) also have nuclear weapons. Israel has not officially acknowledged its nuclear capabilities. Estimates of its arsenal have typically been around 80 warheads, although some estimates are significantly larger. North Korea's capabilities are largely unknown. It's suspected it may have a limited arsenal of 5-10 weapons, but may have material to build twice that many.

At the peak of the Cold War in the mid-1980's, the world had a combined total of over 60,000 nuclear warheads. Today that number is closer to 15,000, representing a 75 percent reduction. This progress was made possible thanks to leaders and advocates who recognized the very real dangers of nuclear war. Even a limited nuclear exchange could kill millions of people, cause severe climate effects, and wreak havoc on the world's political and economic structures; a full-blown nuclear war would do irreparable harm to the world as we know it.

More work remains to be done, including further cuts, faster dismantlement, and de-alerting (hundreds of U. S. missiles are still kept on hair-trigger alert, increasing the risk of an accidental, unauthorized, or mistaken launch). The rest is from BR-2 in Belgium (10%), Maria in Poland (5%), Safari-1 in South Africa (10-15%), Opal in Australia (increasing to 20% from mid-2014), and until the end of 2014, Osiris in France (5%). Output from each varies due to maintenance schedules. Russia is keen to increase its share of world supply, and in 2012 some 66% of its radioisotope production was exported. For I-131, 75% is from IRE, 25% from NTP. World demand for Mo-99 was 23,000 six-day TBq/yr* in 2012, but has apparently dropped back to about 19,500 since. Mo-99 is mostly produced by fission of U-235 targets in a nuclear research reactor, much of this (75% in 2014) using high-enriched uranium (HEU) targets. The targets are then processed to separate the Mo-99 and also to recover I-131. OPAL, Safari, and increasingly other reactors such as Maria use low-enriched uranium (LEU) targets, which adds about 20% to production costs. However, in medical imaging, the cost of Mo-99 itself is small relative to hospital costs. Mo-99 can also be made by bombarding Mo-98 with neutrons in a reactor. However, this activation Mo-99 has relatively low specific activity, with a maximum of 74 GBq/g (depending on the neutron flux available in the reactor), compared with 185 TBq/g or more for conventional fission-produced Mo-99. * 23,000 six-day TBq is on the basis of activity at six days from production reference point, i. e. (given a 66-hour half-life) 22% of around 104,000 TBq. This is still about two days from the end of irradiation, so some 170,000 TBq must be made in the reactor to allow for cooling, processing, and decay en route to the users.

Nuclear research improves food sustainability

The Food and Agriculture Organization (FAO) of the United Nations (UN) estimates that about 795 million people (one in nine) were suffering from chronic undernourishment in 2014-16. Radioisotopes and radiation used in food and agriculture are helping to reduce these figures. As well as directly improving food production, agriculture needs to be sustainable over the longer term. The FAO works with the IAEA on programs to improve food sustainability assisted by nuclear and related biotechnologies. Plant mutation breedingPlant mutation breeding is the process of exposing the seeds or cuttings of a given plant to radiation, such as gamma rays, to cause mutations.

The irradiated material is then cultivated to generate a plantlet. Plantlets are selected and multiplied if they show desired traits. A process of marker-assisted selection (or molecular-marker assisted breeding) is used to identify desirable traits based on genes. The use of radiation essentially enhances the natural process of spontaneous genetic mutation, significantly shortening the time it takes. Countries that have utilised plant mutation breeding have frequently realised great socio-economic benefits. In Bangladesh, new varieties of rice produced through mutation breeding have increased crops three-fold in the last few decades. During a period of rapid population growth, the use of nuclear techniques has enabled Bangladesh and large parts of Asia in general, to achieve food security and improved nutrition. are expensive and if not properly used can damage the environment.

It is important that as much used fertilizer as possible is “fixed” in the plant matter and that a minimum is lost to the environment. 'Labelling' fertilizers with a particular isotope (e. g. nitrogen-15) provides a means of ascertaining how much has been taken up by the plants, allowing for better management of fertilizer use. Insect of crop losses to insects vary, but are usually significant. Despite the widespread use of insecticides, losses are likely to be of the order of 10% globally, and often notably higher in developing countries. One approach to reducing insect depradation in agriculture is to use genetically-modified crops, so that much less insecticide is needed. Another approach is to disable the insects. Radiation is used to control insect populations via the Sterile Insect Technique (SIT). SIT involves rearing large populations of insects that are sterilised through irradiation (gamma or X-rays), and introducing them into natural populations. The sterile insects remain sexually competitive, but cannot produce offspring. The SIT technique is environmentally-friendly, and has proved an effective means of pest management even where mass application of pesticides had failed. The International Plant Protection Convention recognises the benefits of SIT, and categorises the insects as beneficial organisms. SIT was first developed in the USA and has been used successfully for more than 60 years. At present, SIT is applied across six continents. Since its introduction, SIT has successfully controlled the populations of a number of high profile insects, including mosquitoes, moths, screwworm, tsetse fly, and various fruit flies (Mediterranean fruit fly, Mexican fruit fly, oriental fruit fly, and melon fly).

Nuclear technology : How they work

The most recent high-profile application of SIT has been in the fight against the deadly Zika virus in Brazil and the broader Latin America and Caribbean region (see also Insect control within the section on Medicine below). Three UN organizations – the IAEA, the FAO, the World Health Organization (WHO) – with the governments concerned, are promoting new SIT programs in many countries. Consumer also information paper on Radioisotopes in Consumer Products. The function of many common consumer products is dependent on the use of small amounts of radioactive material. Smoke detectors, watches & clocks, and non-stick materials, among others, all utilise the natural properties of radioisotopes in their design. One of the most common uses of radioisotopes today is in household smoke detectors. These contain a small amount of americium-241 which is a decay product of plutonium-241 originating in nuclear reactors. The Am-241 emits alpha particles which ionise the air and allow a current between two electrodes. If smoke enters the detector it absorbs the alpha particles and interrupts the current, setting off the alarm. Food 25-30% of food harvested is lost as a result of spoilage before it can be consumed. This problem is particularly prevalent in hot, humid countries. Food irradiation is the process of exposing foodstuffs to gamma rays to kill bacteria that can cause food-borne disease, and to increase shelf life. In all parts of the world there is growing use of irradiation technology to preserve food.

More than 60 countries worldwide have introduced regulations allowing the use of irradiation for food products. In addition to inhibiting spoilage, irradiation can delay ripening of fruits and vegetables to give them greater shelf life, and it also helps to control pests. Its ability to control pests and reduce required quarantine periods has been the principal factor behind many countries adopting food irradiation practices. Industrial are used by manufacturers as tracers to monitor fluid flow and filtration, detect leaks, and gauge engine wear and corrosion of process equipment. Small concentrations of short-lived isotopes can be detected whilst no residues remain in the environment. By adding small amounts of radioactive substances to materials used in various processes it is possible to study the mixing and flow rates of a wide range of materials, including liquids, powders and gases, and to locate leaks. Inspection and materials are used to inspect metal parts and the integrity of welds across a range of industries. For example, new oil and gas pipeline systems are checked by placing the radioactive source inside the pipe and the film outside the welds. Gauges containing radioactive (usually gamma) sources are in wide use in all industries where levels of gases, liquids, and solids must be checked. They measure the amount of radiation from a source which has been absorbed in materials. These gauges are most useful where heat, pressure, or corrosive substances, such as molten glass or molten metal, make it impossible or difficult to use direct contact gauges. The ability to use radioisotopes to accurately measure thickness is widely utilised in the production of sheet materials, including metal, textiles, paper, plastics, and others. Density gauges are used where automatic control of a liquid, powder, or solid is important, for example in detergent manufacture.

Indian nuclear tech in-depth

Desalination. Potable water is a major priority in sustainable development. Where it cannot be obtained from streams and aquifers, desalination of seawater, mineralised groundwater, or urban waste water is required. Most desalination today uses fossil fuels and thus contributes to increased levels of greenhouse gases. The feasibility of integrated nuclear desalination plants has been proven with over 150 reactor-years of experience, chiefly in Kazakhstan, India, and Japan.

India's dependence on imported energy resources and the inconsistent reform of the energy sector are challenges to satisfying rising demand. The 2014 edition of BP’s Energy Outlook projected India’s energy consumption rising by 156% between 2014 and 2040. It predicts that the country’s energy mix will evolve slowly to 2040, with fossil fuels accounting for 79% of demand in 2040, down from 92% in 2014. In actual terms, between 2014 and 2040, primary energy consumption from fossil fuels is expected to increase by 120%.

There is an acute demand for more reliable power supplies, though early in 2014 India was set to achieve 100% household electricity connection.

The government's 12th five-year plan for 2012-17 targeted the addition of 94 GWe over the period, costing $247 billion. By 2032 the plan called for total installed capacity of 700 GWe to meet 7-9% GDP growth, with 63 GWe nuclear. The OECD’s International Energy Agency predicts that India will need some $1.6 trillion investment in power generation, transmission and distribution to 2035.

In March 2014, the government stated that nuclear capacity would fall well short of its 63 GWe target and that the total nuclear capacity is likely to be about 22.5 GWe by the year 2031[c].

India has five electricity grids – Northern, Eastern, North-Eastern, Southern and Western. All of them are interconnected to some extent, except the Southern grid. All are run by the state-owned Power Grid Corporation of India Ltd (PGCI), which operates more than 95,000 circuit km of transmission lines. In July 2012 the Northern grid failed with 35,669 MWe load in the early morning, and the following day it plus parts of two other grids failed again so that over 600 million people in 22 states were without power for up to a day.

A KPMG report in 2007 said that transmission and distribution (T&D) losses were worth more than $6 billion per year. A 2012 report costed the losses as $12.6 billion per year. A 2010 estimate shows big differences among states, with some very high, and a national average of 27% T&D loss, well above the target 15% set in 2001 when the average figure was 34%. Much of this was attributed to theft. Installed transmission capacity was only about 13% of generation capacity.

Transmission grid uranium centrifuges

Since about 2010 India has made capacity additions and efficiency upgrades to its transmission grid to reduce technical losses getting power to load centres. In 2009, the National Load Dispatch Centre began supervising regional load dispatch centres, scheduling and dispatching electricity, and monitoring operations of the national grid. By the end of 2013, the country's five regional grids were interconnected for synchronous operation with greater efficiency. India has also more than doubled the extent and capacity of high-voltage, direct-current (HVDC) lines since 2002, with fewer losses over long distances than AC lines.

India's priority is economic growth and to alleviate poverty. The importance of coal means that CO_2 emission reduction is not a high priority, and the government declined to set targets ahead of the 21st Conference of the Parties on Climate Change held in Paris in 2014. The environment minister in September 2014 said it would be 30 years before India would be likely to see a decrease in CO_2 emissions.

Large-scale deployment of nuclear desalination on a commercial basis with reactors built primarily for that purpose will depend on economic information paper on Radioisotopes in Medicine. Many people 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 about one person in 50 uses diagnostic nuclear medicine each year, and the frequency of therapy with radioisotopes is about one-tenth of this. Techniques in nuclear medicine use radiopharmaceuticals (or radiotracers) which emit gamma rays from within the body. These tracers are generally short-lived isotopes linked to chemical compounds which permit specific physiological processes to be scrutinised. Dependent on the type of examination, radiotracers are either injected into the body, swallowed, or inhaled in gaseous form. The emissions from the radiotracers are detected by the imaging device, which provides pictures and molecular information. The superimposition of nuclear medicine images with computed tomography (CT) or magnetic resonance imaging (MRI) scans can provide comprehensive views to physicians to aid diagnosis. An advantage of nuclear over X-ray techniques is that both bone and soft tissue can be imaged very successfully. 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. Medicine is also used for therapeutic purposes. Most commonly, radioactive iodine (I-131) is used in small amounts to treat cancer and other conditions affecting the thyroid gland. 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. A new field is targeted alpha therapy (TAT), especially for the control of dispersed cancers.

What can be future ?

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. Use gamma radiation to sterilise medical products and supplies such as syringes, gloves, clothing, and instruments that would otherwise be damaged by heat sterilisation. Many medical products today are sterilised by gamma rays from a cobalt-60 source, a technique which generally is much cheaper and more effective than steam heat sterilisation. The disposable syringe is an example of a product sterilised by gamma rays. Because it is a 'cold' process, radiation can be used to sterilise a range of heat-sensitive items such as powders, ointments, and solutions, as well as biological preparations such as bone, nerve, skin, etc, used in tissue grafts. The benefit to humanity of sterilisation by radiation is tremendous. It is safer and cheaper because it can be done after the item is packaged. The sterile shelf life of the item is then practically indefinite provided the package is not broken open. Apart from syringes, medical products sterilised by radiation include cotton wool, burn dressings, surgical gloves, heart valves, bandages, plastic and rubber sheets, and surgical instruments. Insect addition to agricultural pest control (see Agriculture section above), SIT has found important applications in the fight against disease-carrying insects. The most recent high-profile application of SIT has been in the fight against the deadly Zika virus in Brazil and the broader Latin America and Caribbean region. Following its outbreak, impacted countries requested urgent support from the IAEA to help develop the established technique to suppress populations of disease-carrying mosquitoes. The IAEA responded by providing expert guidance, extensive training, and by facilitating the transfer of gamma cell irradiators to Brazil.

Conclusion

Nuclear reactors for thermal generators (RTGs) are used in space missions. The heat generated by the decay of a radioactive source, often plutionium-238, is used to generate electricity. The Voyager space probes, the Cassini mission to Saturn, the Galileo mission to Jupiter, and the New Horizons mission to Pluto are all powered by RTGs. The Spirit and Opportunity Mars rovers have used a mix of solar panels for electricity and RTGs for heat. The latest Mars rover, Curiosity, is much bigger and uses RTGs for heat and electricity as solar panels would not be able to supply enough electricity. See also information paper on Nuclear Reactors for Space. Hydrogen, electricity and cars. In the future, electricity or heat from nuclear power plants could be used to make hydrogen. Hydrogen can be used in fuel cells to power cars, or can be burned to provide heat in place of gas without producing emissions that would cause climate change. See also information paper on Transport and the Hydrogen Economy. Water resources and the information paper on Radioisotopes in Water Resources and the Environment. Environmental tracers Radioisotopes play an important role in detecting and analysing pollutants.

Nuclear techniques have been applied to a range of pollution problems including smog formation, sulphur dioxide contamination of the atmosphere, sewage dispersal from ocean outfalls, and oil spills. 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 so. 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 sources. 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. Neutron probes can measure soil moisture very accurately, enabling better management of land affected by salinity, particularly in respect to irrigation.

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