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Nuclear Energy: A clean and efficient source of energy

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ABSTRACT

As we are progressing towards a developed, industrially civilized generation, we almost totally depend on energy for our daily living. Since global warming is a challenge before us which otherwise can destroy the existence of humans. So we need to find an environment friendly, huge power generating source to meet our rising demands of energy. The purpose of this paper is to find whether nuclear energy is the solution of above problem or not. Here, various aspects of nuclear energy either positive or negative were considered by having thorough views of reports of various organization and thoughts of various analyzers and scientists.

Key points: Existence of humans, Global warming, Nuclear energy

I. INTRODUCTION

Energy is needed in every aspect of life. Since past, energy is produced by conventional energy sources such as coal, petroleum, natural gas etc. But the reserves of these sources are limited and can provide energy in future for few decades. Therefore, other source of energy is required to be explored in order to meet the energy based requirements for day to day life. Besides the large need of energy, it is evident that a major part of greenhouse gas emission comes from the production of electricity. As now climate change due to global warming is also a challenging problem so we have to find energy sources which should be clean, economic ,eco-friendly and capable to fulfill our power requirements. Nuclear energy can be a potential option for us as it can provide huge energy and also clean source. The present study is based on the potentiality of nuclear energy and its future prospects at global level emphasizing the possibilities in India.

II. PRESENT SCENARIO OF ENERGY SOURCES IN INDIA AND OTHER COUNTRIES

The utility electricity sector in India_has one National Grid with an installed capacity of 330.86 GW as on 31 December 2017. Renewable power plants constituted 31.7% of total installed capacity. During the fiscal year 2016-17, the gross electricity generated by utilities in India was 1,236.39 TWh and the total electricity generation (utilities and non-utilities) in the country was 1,433.4 TW The gross electricity consumption was 1,122 kWh per capita in the year 2016-17. India is the world's third largest producer and fourth largest consumer of electricity Electric energy consumption in agriculture was recorded highest (17.89%) in 2015-16 among all countries. The per capita electricity consumption is low compared to many countries despite cheaper electricity tariff in India. India's

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electricity sector is dominated by fossil fuels, and in particular coal, which in 2016 produced about two thirds of all electricity. However, the government is pushing for an increased investment in renewable energy. The Draft National Electricity Plan of 2016 prepared by the Government of India states that the country does not need additional non-renewable power plants in the utility sector until 2027, with the commissioning of 50,025 MW coal-based power plants under construction and achieving 275,000 MW total installed renewable power capacity [7].

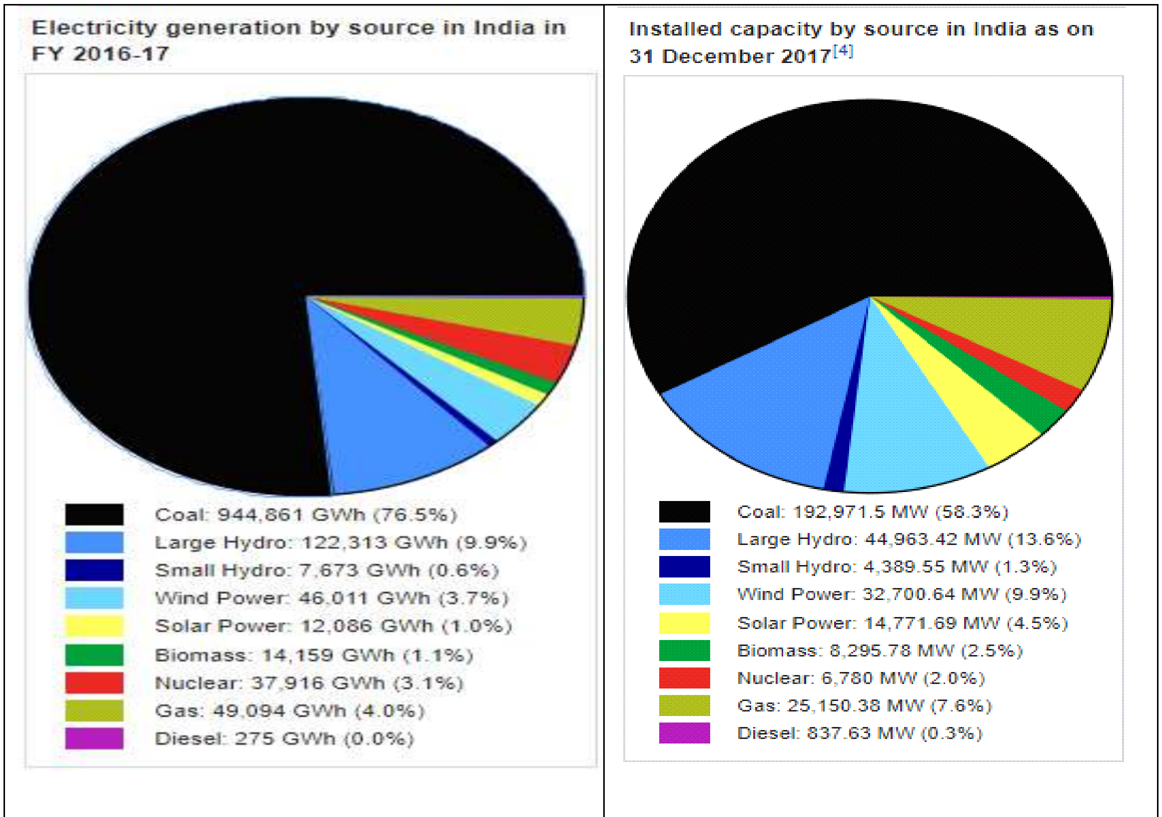

Figure: A pi-chart represented a nuclear power in India during financial year 2016 and 2017[7]

As of Mar 01, 2017 India had 6.78 GW of installed nuclear electricity generation capacity or 1.91% of total installed electricity generation capacity in India. India's Nuclear plants generated 37,835 million units in year 2014-15.. India has nuclear power plants operating in the following states: Maharashtra, Gujarat, Rajasthan, Uttar Pradesh, Tamil Nadu and Karnataka. These reactors have an installed electricity generation capacity between 100 MW and 540 MW each. India aims to supply 9% of it electricity needs with nuclear power by 2032. India's largest nuclear power plant project is planned to be implemented Jaitapur, Maharashtra in partnership with Areva, France. India's government is also developing up to 62, mostly thorium reactors, which it expects to be operational by 2025. It is the "only country in the world with a detailed, funded, government-approved plan" to focus on thorium-based nuclear power. [7].As of April 2017, 30 countries worldwide are operating 449 nuclear reactors for electricity generation and 60 new nuclear power plants are under construction in 15 countries. France produces 72.3 percent of total energy from nuclear. [13]

In 2016 U.S produces 805.3billion kWh, France 384.0kWh and china 210.5 kWh electricity from nuclear energy [12].

III. ADVANTAGES OF USING NUCLEAR ENERGY

3.1. Clean energy:

Our industrial civilization runs on energy and 85% of the world's energy is provided by the fossil fuels, coal, oil and gas. Burning fossil fuels, we inject 23 billion tons of carbon dioxide every year into the atmosphere – 730 tons per second. Half of it is absorbed in the seas and vegetation, but half remains in the atmosphere hence polluting the environment [1].Coal mining produce methane which is 84 times as powerful as CO_2 at disrupting climate. Globally coal –fired power plants are the largest single source of mercury emission. Mercury is a neurotoxin; it has harmful effects on the brain and nervous system. Particulate matter, or PM, particle pollution is possibly the most harmful emission from coal power plants. These very small unburned pollution particles released directly from coal plant smokestacks cause an estimated 800,000 premature deaths each year. When inhaled, particle pollution can have wide-ranging and harmful health effects, including asthma attacks, lung tissue damage, stroke, heart attack and premature death [14]. But nuclear power provide energy without emission of any poisonous gases representing the eco-friendly energy source.

3.2. Manageable waste

Nuclear waste is correspondingly about a million times smaller than fossil fuel waste, and it is totally confined. In the USA and Sweden, spent fuel is simply stored away. Elsewhere, spent fuel is reprocessed to separate out the 3% of radioactive fission products and heavy elements to be vitrified (cast in glass) for safe and permanent storage. The remaining 97% plutonium and uranium – is recovered and recycled into new fuel elements to produce more energy. Nuclear waste is to be deposited in deep geological storage sites; it does not enter the biosphere. Its impact on the ecosystems is minimal. Nuclear waste spontaneously decays over time while stable chemical waste, such as arsenic or mercury, lasts forever. [1]

3.3. Compact

A nuclear power station is very compact, occupying typically the area of a football stadium and its surrounding parking lots. Solar cells, wind turbine farms and growing biomass, all require large areas of land. The land needed in square miles for 1000 MW electricity production by wind,solar and nuclear sources are 260-300,45-75and 1.3 respectively. [15]

3.4. Capable of huge power

The energy produced by 1 ton Uranium (U-235) is approximately equal to energy produced by 30 lakh ton coal or 120 lakh barrel petroleum. So nuclear energy is capable of providing power to growing civilized society [9].

3.5. Availability of nuclear fuel

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The 26th edition of the joint IAEA-OECD/NEA publication Uranium 2016: Resources, Production and Demand, also referred to as the "Red Book", was published in November. It reported that, as of 1 January 2015, the annual world uranium production of 55 975 ton of uranium provided about 99% of current annual world reactor requirements, with the remainder supplied by previously mined uranium. The uranium resource base is considered to be more than adequate to meet projected requirements for the foreseeable future [3].

IV. DISADVANTAGES OF USING NUCLEAR ENERGY

4.1. Risk due to misuse and bad understanding of technology

If more nuclear power plants are built in developing countries with little experience of operating a reactor, or bordering a region where terrorism is a concern, or without sufficient financial resources to import state of the art technology, then the chance of a major nuclear accident hitting the developing world will loom large in the coming decades. Pakistan, a volatile country prone to terrorist activity, has received less safe and more easily proliferated nuclear generators, and China is building new reactors without new safety standards. Both of these situations could easily lead to malfunctions or meltdowns of the reactors .Without proper training, countries will be unable to probably use the nuclear technology. This could result in them not meeting their energy needs or a malfunction of the equipment because they do not know how to use the equipment safely [2].

4.2. Nuclear radiations

Nuclear power plants release radiation. Normally, innate radiation engender about 1% of cancers; however, 0.002% ascension caused by nuclear technology makes the 1%, 1.002%. This decreases, furthermore, the life of humans. Radiation can also be caused from uranium mining. For example, radioactive gas, radioactive powder or other radioactive materials can be released from mining. What is more, by not taking rigorous measures, many miners died as yet and it is increasing also [4].

4.3. Expensive

The cost of a nuclear facility commonly is comprised of four individual costs: capital or construction costs, back-end costs or the cost of decommissioning an old nuclear plant, fuel costs, and Operations and Maintenance (O&M) costs, which are costs related to the management and upkeep of a nuclear plant . The exorbitantly expensive cost is one of the main issues facing the expansion of nuclear power [2].

4.4. Nuclear accidents as disaster to humans

There are more than 100 nuclear accidents all over the world. Effects of such accidents is not a short term problem but a problem for long time. The most severe are the following three which cause dangers to not only property but also to human life:

4.4.1 Fukushima Nuclear Disaster

In March 2011, the Fukushima Daiichi Nuclear Power Plant failed after Japan experienced an earthquake and a subsequent tsunami. On March 11, 2011, a 9.0 magnitude earthquake shook Japan causing structural damage and the loss of many lives. The earthquake also caused a fifteen meter tsunami to crash onto the shores of the already devastated island. The reactors that were in use shut down immediately when the earthquake hit like they were designed to do, however, they were vulnerable to the tsunami. The massive wave disabled twelve of the thirteen back-up generators that were on site at the plant; it also disabled the power supply to the cooling systems for three of the reactors causing the melting of their cores. A high amount of radioactive release occurred in the following four to six days. Over 100,000 people had to be evacuated from their homes in the surrounding areas that were affected by the radioactive exposure. The air, water, and land all suffered from contamination of radioactive materials (World Nuclear Association, 2014) [2].

4.4.2 The Chernobyl disaster

It was a major accident at the Chernobyl Nuclear Power Plant on April 26, 1986, with an explosion at the plant and later radioactive contamination of the surrounding area. It is so far the worst nuclear accident in the history of nuclear power. A plume of radioactive fallout drifted over parts of the western Soviet Union, Eastern and Western Europe, Scandinavia, the UK, Ireland and Eastern North America. Large areas of Ukraine, Belarus, and Russia were badly damaged, forcing the people in charge to have to evacuate and resettle more than 336,000 people. About 60% of the radioactive fallout landed in Belarus, according to official post-Soviet data [6]. The accident caused the death of 30 people, 28 of them were subjected to radiation and finally the accident was the reason for thousand of cancer-related deaths [4].

4.4.3 The Three Mile island accident

This hazardous accident halted the development of the U.S. nuclear power industry for 30 years. On March 28, 1979, a cooling circuit malfunctioned, allowing the primary coolant to overheat. The reactor shut down immediately. The release valve opened for ten seconds. That allowed enough coolant to escape to reduce pressure and heat. But it got stuck in the open position. As a result, all the coolant was released. There wasn't an instrument that could have alerted engineers that this had happened. New coolant rushed into the tank, but the engineers now thought that there was too much. They reduced the flow. The remaining coolant turned to steam. The fuel rods overheated, melting the protective coating. It released radioactive material into the coolant. When the steam was released, the radioactive contaminant was released into the surrounding area. Fortunately, the amount released was not enough to harm local food supplies, animals, or people. It took 12 years and cost $973 million to decontaminate to low levels of radiation. There were 10.6 megalitres of radioactive coolant that were processed, stored, and safely evaporated [7].

V. POSSIBILITIES OF NUCLEAR ENERGY IN INDIA

5.1. Availability of future fuel

Although India has only around 1–2% of the global uranium reserves, thorium reserves are bigger; around 12–33% of global reserves, according to IAEA and US Geological Survey. Several in-depth independent studies put Indian thorium reserves at 30% of the total world thorium reserves. As per official estimates shared in the country's

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Parliament in August 2011, the country can obtain 846,477 ton of thorium from 963,000 ton of ThO_2, which in turn can be obtained from 10.7 million ton of monazite occurring in beaches and river sands in association with other heavy metals. Indian monazite contains about 9–10% ThO_2. About 225,000 ton of thorium metal is available for nuclear power program. [8].

5.2. India's three-stage nuclear power programme

It was formulated by Homi Bhabha in the 1950s to secure the country's long term energy independence, through the use of uranium and thorium reserves found in the monazite sands of coastal regions of South India. The ultimate focus of the programme is on enabling the thorium reserves of India to be utilised in meeting the country's energy requirements. Thorium is particularly attractive for India, as it has only around 1–2% of the global uranium reserves, but one of the largest shares of global thorium reserves at about 25% of the world's known thorium reserves. However, thorium is not economically viable because global uranium prices are much lower.

5.2.1. Stage I – Pressurised Heavy Water Reactor

In the first stage of the programme, natural uranium fuelled pressurised heavy water reactors (PHWR) produce electricity while generating plutonium-239 as by-product. PHWRs was a natural choice for implementing the first stage because it had the most efficient reactor design in terms of uranium utilisation. India correctly calculated that it would be easier to create heavy water production facilities (required for PHWRs) than uranium enrichment facilities (required for LWRs). Natural uranium contains only 0.7% of the fissile isotope uranium-35. Most of the remaining 99.3% is uranium-238 which is not fissile but can be converted in a reactor to the fissile isotope plutonium-239. Heavy water (deuterium oxide, D_2O) is used as moderator and coolant [8].

5.2.2. Stage II – Fast Breeder Reactor

In the second stage, fast breeder reactors (FBRs) would use a mixed oxide (MOX) fuel made from plutonium-239, recovered by reprocessing spent fuel from the first stage, and natural uranium. In FBRs, plutonium-239 undergoes fission to produce energy, while the uranium-238 present in the mixed oxide fuel transmutes to additional plutonium-239. Thus, the Stage II FBRs are designed to "breed" more fuel than they consume. Once the inventory of plutonium-239 is built up thorium can be introduced as a blanket material in the reactor and transmuted to uranium-233 for use in the third stage. The uranium in the first stage PHWRs that yield 29 EJ of energy in the once-through fuel cycle, can be made to yield between 65 and 128 times more energy through multiple cycles in fast breeder reactors. Indian government has already allotted Rs.250 crore for pre-project activities for two more 500 MW units, although the location is yet to be finalized [8].

5.2.3 Stage III – Thorium Based Reactors

A Stage III reactor or an Advanced nuclear power system involves a self-sustaining series of thorium-232-uranium-233 fuelled reactors. This would be a thermal breeder reactor, which in principle can be refueled – after its initial fuel charge – using only naturally occurring thorium. According to the three-stage programme, Indian nuclear energy could grow to about 10 GW through PHWRs fueled by domestic uranium, and the growth above that would have to come from FBRs till about 50GW. The third stage is to be deployed only after this capacity has been achieved [8].

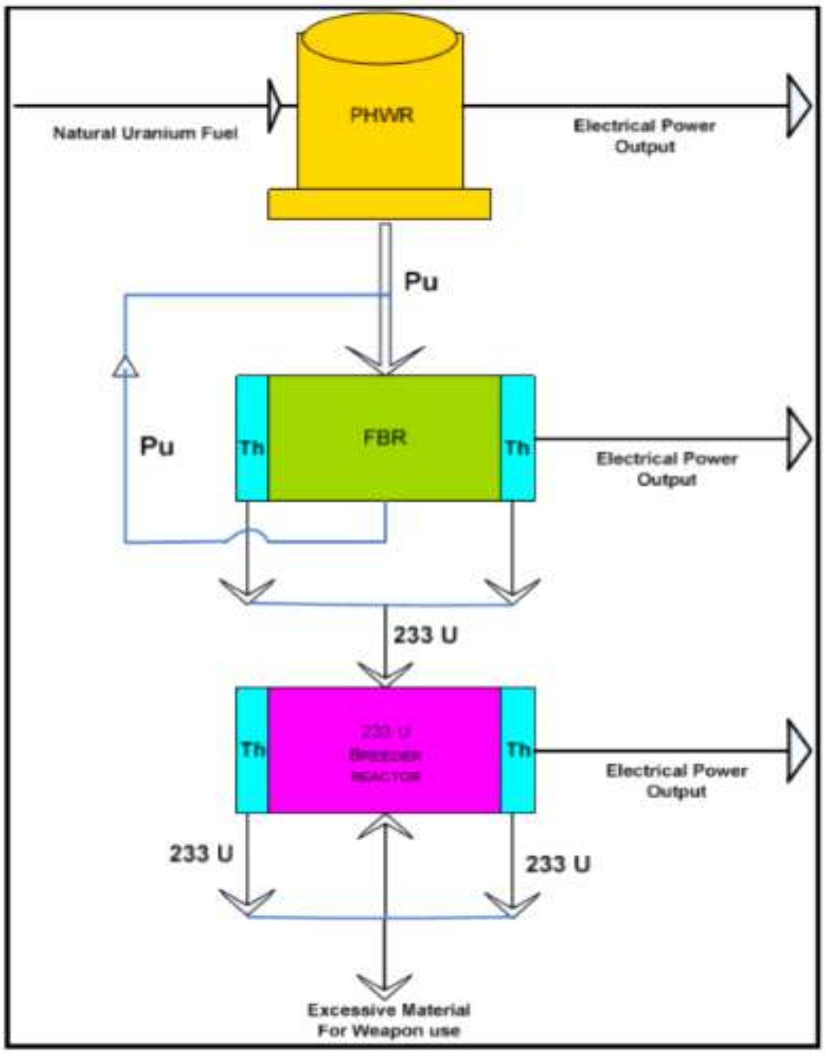

Figure: 3-stage Nuclear Power Program of India

5.3. Future proposed technology in India

As there is a long delay before direct thorium utilisation in the three-stage program, the country is looking at reactor designs that allow more direct use of thorium in parallel with the sequential three-stage program. Three options under consideration are as follows:

5.3.1 Accelerator driven system

India's Department of Atomic Energy and Fermi Lab. of the USA are designing unique first-of-it's-kind accelerator driven systems. No country has yet built an Accelerator Driven System for power generation. Dr Anil Kakodkar, former chairman of the Atomic Energy Commission called this a mega science project and a "necessity" for humankind [8].

5.3.2 Indian Molten Salt Breeder Reactor (IMSBR)

The Indian Molten Salt Breeder Reactor (IMSBR) is under development. Studies on conceptual design of the Indian Molten Salt Breeder Reactors (IMSBR) have been initiated [8].

5.3.3 The advanced heavy-water reactor (AHWR)

This is the latest Indian design for a next-generation nuclear reactor that burns thorium in its fuel core. It is slated to form the third stage in India's three-stage fuel-cycle plan. This phase of the fuel cycle plan is supposed to be built starting with a 300MW prototype in 2016.The proposed design of the AHWR is that of a heavy-water-moderated nuclear power reactor that will be the next generation of the PHWR type. It is being developed at Bhabha Atomic Research Centre (BARC), in Mumbai, India and aims to meet the objectives of using thorium fuel cycles for commercial power generation. The AHWR is a vertical pressure tube type reactor cooled by boiling light water under natural circulation. A unique feature of this design is a large tank of water on top of the primary containment vessel, called the gravity-driven water pool (GDWP). This reservoir is designed to perform several passive safety functions [10].

The overall design of the AHWR is to utilize large amounts of thorium. The AHWR is much like that of the Pressurized heavy water reactor (PHWR), in that they share similarities in the concept of the pressure tubes and calandria tubes, but the tubes' orientation in the AHWR is vertical**,** unlike that of the PHWR. The AHWR's core is 3.5 m long and has 513 lattice locations in a square pitch of 225 mm. The core is radially divided into three burn up regions. The burn up decreases as it moves toward the external surface of the core. Fuel is occupied by 452 lattice locations and the remaining 37 locations are occupied by shutdown system-1. This consists of 37 shut-off rods, 24 locations are for reactive control devices which are consisted of 8 absorber rods (AR's), 8 shim rods (SR's), and 8 regulating rods (RR's). By boiling light water at a pressure of 7 MPa**,** heat is then removed. The main focus with this model is to get the total power and a coarse spatial power distribution within the core to be within certain degree of accuracy.

The reactor design incorporates advanced technologies, together with several proven positive features of Indian pressurized heavy water reactors (PHWRs). These features include pressure tube type design, low pressure moderator, on-power refueling, diverse fast acting shut-down systems, and availability of a large low temperature heat sink around the reactor core. The AHWR incorporates several passive safety features. These include: Core heat removal through natural circulation; direct injection of emergency core coolant system (ECCS) water in fuel; and the availability of a large inventory of borated water in overhead gravity-driven water pool (GDWP) to facilitate sustenance of core decay heat removal. The emergency core cooling system (ECCS) injection and containment cooling can act (SCRAM) without invoking any active systems or operator action.

The reactor physics design is tuned to maximize the use of thorium based fuel, by achieving a slightly negative void coefficient. Fulfilling these requirements has been possible through the use of PuO_2-ThO_2 MOX, and ThO_2-$^{233}UO_2$ MOX in different pins of the same fuel cluster, and the use of a heterogeneous moderator consisting of amorphous carbon (in the fuel bundles) and heavy water in 80–20% volume ratio [10].

5.3.3.1 Some Distinctive Features of AHWR:

• Elimination of high-pressure heavy water coolant resulting in reduction of heavy water leakage losses, and eliminating heavy water recovery system. Recovery of heat generated in the moderator for feed water heating.

• Elimination of major components and equipment such as primary coolant pumps and drive motors, associated control and power supply equipment and corresponding saving of electrical power required to run these pumps.

• Shop assembled coolant channels, with features to enable quick replacement of pressure tube alone, without affecting other installed channel components. Replacement of steam generators by simpler steam drums and Higher steam pressure than in PHWRs.

• Production of 500 m3/day of demineralized water in Multi Effect Desalination Plant by using steam from LP Turbine, Hundred year design life of the reactor. A design objective of requiring no exclusion zone on account of its advanced safety features.

5.3.3.2. Safety innovation

One of the top security measures for a meltdown is containment of radioactivity from escaping the reactor. The Defense in Depth (DiD) is a method which is used in reactors by providing a list of provisions and required equipment in order to retain the radioactivity in the core. The Defense in Depth method sets regulations that must be followed in order to reduce human error incidents and machine malfunctions [10].

VI. FUTURE PROSPECTS OF NUCLEAR ENERGY IN OTHER COUNTRIES

6.1. In USA

Small modular reactors or SMR's designs are a major asset for this new technology both in terms of safety and cost. There are some benefits of using SMR which are as follows:

6.1.1 Safe and Small in size

The first benefit is that SMR's are inherently safer than large conventional nuclear reactors. Firstly, the designs of the SMR's rely on battery power in order to maintain safety operations; this feature lessens or potentially makes obsolete the need for electrical or back-up generators in case of an emergency. The second safety aspect of SMR's is that they are better able to withstand earthquakes. This is achieved though "containment and reactor vessels in a pool of water underground" The third safety feature in SMR's that minimizes susceptibility or damage that could occur with nuclear energy is the large underground pool storage for spent fuel which prevent the chance of leaking of radioactive waste. SMRs are also small which allows them to be placed in remote locations where large reactors could not be located. This aspect of its design is helpful for military operations when temporary bases need energy quickly. Its size also means that there is less fuel within the apparatus so if there was ever a malfunction with the equipment, it would affect less land area than a conventional reactor.

6.1.2 Waste management

SMRs also provide for a better waste management strategy than conventional reactors. The cheaper cost is due to the simplicity of the design as well as reduced sitting and building costs.Another positive aspect of SMRs is their ability to desalinate water because they commonly have a weaker infrastructure and a smaller electrical grid.

6.1.3 Decentralization of grid

SMRs allow for the grid to be decentralized which would mean that any attack on it would be localized instead of knocking down the entire grid. Decentralizing the grid greatly benefits the Department of Defense by solving their vulnerabilities of being connected to the civilian grid. The second advantage to a decentralized grid is the security of the economy from a cyber-attack.

6.1.4 Commercialization of SRMs

Empirically, SMRs have failed in the past due to the large up-front costs of building such a reactor. They are unable to generate enough revenue to cover the costs of its infrastructure like larger plants have succeeded [2].

6.2. Nuclear fusion in Japan and Germany

The 26th IAEA Fusion Energy Conference, held in October in Kyoto, Japan, attracted about 1000 participants — the highest number of attendees in the Conference's history. The Agency continued to lead the coordination of global Demonstration Fusion Power Plant (DEMO) related activities in 2016, including through the fourth DEMO Program Workshop, held in November in Germany [3].

6.3. Nuclear fusion in United Kingdom

Britain's newest fusion reactor has been fired up and taken the world one step further towards generating electricity from the power of the stars. The new reactor was built at Milton Park, Oxfordshire, by Tokamak Energy, a private company pioneering fusion power in the UK. It is Tokamak Energy's third upgraded reactor and represents the latest step in a five-stage plan to bring fusion power to the national grid by 2030. Fusion involves placing hydrogen atoms under high heat and pressure until they fuse into helium atoms .When deuterium and tritium nuclei - which can be found in hydrogen - fuse, they form a helium nucleus, a neutron and a lot of energy. This is down by heating the fuel to temperatures in excess of 150 million °C, forming a hot plasma. Strong magnetic fields are used to keep the plasma away from the walls so that it doesn't cool down and lost it energy potential. These are produced by superconducting coils surrounding the vessel, and by an electrical current driven through the plasma. For energy production. Plasma has to be confined for a sufficiently long period for fusion to occur [11].

6.4. Programmers for growth of nuclear energy

SCIENTIFIC FORUM 'Nuclear Technology for the Sustainable Development Goals' was the theme of the 2016 Scientific Forum, held at the Agency's Headquarters. Leading experts, academics and industrial representatives outlined many of the ways that nuclear technology can be used to help achieve the Sustainable Development Goals[3].

In 2016, IAEA conducted 92 security related training activities — 39 at the international or regional level and 53 at the national level — providing training to more than 1400 partcipants . [3].

The Agency's UDEPO (World Distribution of Uranium Deposits) database provides reliable, up-to-date information on the technical, geographical and geological characteristics of uranium deposits around the world. [3].

VII. CONCLUSIONS

The qualities of nuclear energy as a large capacity power source and free from emission of greenhouse gases makes it suitable for solving the problem of energy needs and global warming. But at the same time we cannot ignore the horrible long lasting effects of nuclear accidents which costs so much to get over it. So we need advanced technology to make effective use of thorium and other efficient reserves and to minimize the risk of nuclear accidents. So if we adopt a positive attitude and promote research in this field to make current technology more advanced and economic so that we can be successful in future to make nuclear energy as an important contribution to our total energy needs.

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