The Peaceful Investment of Nuclear Energy Resources in Jordan

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***Abstract*--The discovery of uranium in 1789 ushered in a new era of nuclear science and technology. This discovery was a turning point in history, which led to the introduction of the first chain reaction in the forties of the previous century. A tremendous amount of energy is released in this process called nuclear energy, which is obtained from the splitting of uranium atoms in a process known as nuclear fission. Although there are three ways to get a nuclear reaction; namely, fission, fusion, and decay, only energy from the first type has been harnessed. Despite its initial usage in wartime, nuclear energy has gained a great popularity amid other energy resources. Its peaceful applications are seen in several scientific fields. It has also played a remarkable role in electricity generation. Countries that are relatively poor in indigenous energy resources, and suffer from water scarcity such as Jordan, tend to turn towards nuclear energy much more intensively. Ultimately, Jordan's intention is to use nuclear energy in electrical power generation, water desalination, and applications of radiations and radioisotopes. This paper will review several factors, which make it essential for Jordan to initiate work for developing alternative sources of energy for large-scale energy production and economic development. It will also suggest a solution for the water problem based on nuclear energy utilization. However, before that, nuclear fission, fusion, and decay processes; the role of uranium in the development of the first chain reaction; the methods used in uranium enrichment; and the reasons for using nuclear energy need to be addressed. Using nuclear energy will mark the beginning of a new era in Jordan. Therefore, this paper is expected to act as an orientation to the generic person to accept this new comer.**

Keywords-nuclear energy; uranium; enrichment; safety; power generation; desalination

I. Introduction

The initial idea of putting nuclear energy to practical use was mentioned in 1914 by H. G. Wells in his famous novel, '***The World Set Free'*,** in which he speculated the possible uses of this type of energy. Leo Szilard, a Hungarian Scientist, was inspired by the idea and thought about turning it into reality. Their dream came true when Otta Hahn and Fritz Strassmann discovered nuclear fission in 1938, at the height of the Second World War. This discovery eventually led to the development of nuclear reactors and nuclear weapons. The devastating effects of such weapons led the international community to restrict them and work on utilizing nuclear energy peacefully.

According to recent studies by the International Atomic Energy Agency (IAEA), 14% of the world's electrical total generation comes from Nuclear Power Plants (NPPs). Seventy-six percent of the electricity generated in France for instance, comes from NPPs. The Jordanian government, represented by the Jordan Atomic Energy Commission (JAEC), and in cooperation with the National Electric Power Company (NEPCO), has decided to become part of this world enterprise and work on producing part of its total generated power through nuclear energy. In addition, JAEC has also considered the practical details of utilizing nuclear energy in seawater desalination for the sake of future generations.

Jordan is rich with trainable human resources, rich in uranium ore, and well placed geographically and politically; thus, it is feasible to exploit these facts to the benefit of the Kingdom. This paper will illustrate the main reasons behind such decision, and will go over the steps taken so far to initiate the aforementioned projects. For clarity reasons, the paper will delve into the three processes of nuclear energy; namely, fission, fusion, and decay. Eventually, and since human safety is the Jordanian government's ultimate concern, the nitty-gritty details of the Defense in Depth (DiD) concept will be investigated.

II. Nuclear Energy Processes

Nuclear energy is a source of energy that can provide power for hundreds of years ahead. At the end of the 19th century, scientists reached a verdict that **Maxwellian Electromagnetic** and **Newtonian Mechanics** are sufficient to explain all physical phenomena, leaving some facts unexplained, which were considered minor if compared with the great scientific achievements of the 18th and 19th centuries. The most obstinate facts that could not be explained by any of the established theoretical frameworks existing then were the wavelength distribution of the blackbody radiation, failure of Michelson- Morley experiment, and the continuous emission of radiation by uranium salts. Remarkably, each of above-mentioned facts became the precursor for a series of discoveries, which altered the face of physics. The details of these anomalies are beyond the scope of this paper, however it is enough to mention that from the first case, Max Planck postulated that the emission of electromagnetic radiation takes place in a discrete packets called Quanta and not continuous as it was thought in that era, and thus Quantum Mechanics came into being. From the failure of Michael & Morley experiment, Albert Einstein explained the Special Theory of Relativity and set his famous formula $\mathbf{E = mc^2}$. The third unexplained phenomenon however, led to the discovery of Nuclear Decay, Fission, and Fusion.

A. Nuclear Fusion, Fission, & Decay

Nuclear fusion, fission, and decay are three different types of energy-releasing reactions. **Nuclear fusion** is the reactions of fusing two or more smaller atoms to form a new element with higher atomic number (more protons in the nucleus). These reactions are most likely Deuterium–Tritium (Hydrogen isotopes) reactions. Whereas, **nuclear fission** is the splitting of a massive nucleus into photons in the form of gamma rays, free neutrons, and other subatomic particles. The fission reaction can proceed uncontrollably and needs to be slowed down whereas the fusion reaction takes exceptional mounts of energy to speed it up and get it started. **Nuclear decay** however, occurs when small bits of the atomic nucleus are ejected from an unstable atom transforming it into a different, more stable species. An atom decays via one of three natural methods. These methods are known as alpha, beta, and gamma decays.

In all three transformations, decay, fission, and fusion, nuclear reaction is accompanied by a tiny reduction in the total mass of the components and the release of energy **[1]**. However, only energy from nuclear fission has been harnessed in which uranium plays the major role.

III. Uranium Role & Enrichment

Almost 95 % of Jordan's energy consumptions come from imported oil and natural gas. This trading costs the government 23 % of its gross domestic product annually. Hence, it is feasible to develop the existing uranium, which is estimated to be at least 80,000 metric tons, plus another 100,000 metric tons mixed in with rich phosphate deposits, which make Jordan the 11th largest deposit of uranium in the world. Being available and close to the surface, uranium in Jordan can be easily prospected, mined, and then milled, the first three stages of the fuel front-end cycle. In fact, natural uranium **(0.71% ^{235}U, 99.29% ^{238}U)** must first be enriched in ^{235}U to be used in NPPs. This is done in enrichment plants where electromagnetic separation, thermal diffusion, gaseous diffusion, gas centrifugation, or laser isotope separation is used. The last three methods are the most commonly used ones due to their special characteristics. The details of each one is beyond the scope of this paper.

The nuclear power industry has become one of the most crucial components of the modern technological era whose prosperity depends heavily on the availability of abundant energy resources. A question arises: ***Is Jordan ready to start this type of industry and will it have its own enrichment plant?*** The answer is given hereinafter.

IV. Prospects of Nuclear Power

Jordan is poor in both energy and water resources, but has uranium deposits, and is working towards introducing nuclear energy for power and desalination. It is also investigating the feasibility of mining its uranium, and has recently signed an agreement on joint exploration and mining activities. To initiate this program, and to face the controversy of nuclear power, Jordan must be prepared politically, technically, environmentally, and economically.

A. Politically: Jordan is one of the signatories to the Treaty on the **Nonproliferation of Nuclear Weapons (NPT)**. This treaty explicitly allows participants to enrich uranium for peaceful power production. Jordan has also NPT safeguards agreements, which entered into force in October 31, 1992. This fact emphasizes that Jordan is completely against the development of nuclear weapons and its worldwide spread, and fully abides by the treaty's terms.

B. Technically: Jordan has employed the general philosophy of '***Defense in Depth' (DiD)*** for the design of its future NPP. The main issue here is to keep the radioactivity, accumulated in the reactor core, from reaching the environment. One of the major implications of this philosophy is that a number of diverse and redundant backup systems need to be employed to guard against even multiple failures. It also ensures in all aspects of reactor design, manufacture, construction, operation, and maintenance that there is strict conformity to specifications and that the highest standards are maintained. Much attention is being paid to human factors and intensive efforts are being made to raise safety consciousness throughout the nuclear industry by introducing the concepts and the practices underlying the term ***Safety Culture***.

C. Environmentally: In spite of the number of barriers to impede the movement of radionuclides generated in the reactor core, it is still very difficult to reduce their release to an absolute zero level. Certainly, there will always be some leakage even during routine operation of a plant. Steps are taken to keep its level below the specified limits. One such measure is the provision of a tall stack (chimneys) to permit controlled release of radioactivity from its top, in order to enhance mixing with air and lower the ground level concentrations in the vicinity. Furthermore, unlike fossil fuel plants, NPPs do not produce any carbon dioxide or sulfur emissions, which are major contributors to the greenhouse effect and acid rain.

D. Economically: Nuclear power competitiveness depends on the economic prospects of coal, oil, and natural gas, which dominate the current and the predictable electricity generation in Jordan. The prices of these three have risen considerably in the past few years, which gave nuclear power a wide public acceptance. Note that uranium market prices have also risen; however, they have hardly affected electricity costs since uranium, unlike fossil fuel, constitutes only 5% of nuclear power generating costs. Therefore, the high prices of fossil fuels, which are expected to be permanent for they are driven largely by the energy demand growth, have put nuclear power on the Jordanian agenda [2].

V. The National Nuclear Energy Strategy

His Majesty King Abdullah the Second has been continuously emphasizing that **energy remains a top challenge that requires long-term radical solutions.** Therefore, a decision was made to secure and utilize alternative local energy resources, both traditional and renewable in order to decrease the Kingdom's reliance on energy imports. **The strategic objective is to become an energy exporting country rather than an energy importing one by exploiting our resources locally and to our own benefit [3].** JAEC and in cooperation with energy sectors in Jordan, adopted a national strategy to face the challenges that may jeopardize the future of electricity generation in the country. These challenges are:

- The ever-growing demand for energy,
- The continuous rise in energy costs and prices,
- The lack of conventional energy resources,
- The high dependence on imported resources,
- The scarcity of water resources,
- The high consumption of fossil resources,
- The environmental dreadful conditions [4].

The adopted **National Nuclear Energy Strategy**, to face the aforementioned challenges, consists of five components:

- To design energy generation plants to meet the growing demand for electric power and water desalination.
- To utilize the large quantities of uranium ore available in Jordan.
- To apply nuclear fuel cycle and process nuclear waste in accordance with international standards.
- To prepare the required studies and invest in qualifying Jordanians human resources.
- To secure the needed funds for the project without straining the treasury with any extra financial burdens.

Actually, launching a nuclear power program is a major step for a developing country like Jordan. This step requires careful planning, alertness, preparation, and investment in a healthy infrastructure that provides legal, regulatory, technological, human, and industrial support to ensure that the nuclear material is solely used for peaceful purposes and in a safe and secure manner [5]. The idea of deploying a NPP in Jordan came into being due to the drastic increase in the total population and the growing demand for electricity. Twenty years ago, the total system load was about 600 MW, while now; it is higher than 2200 MW. These two figures indicate that the demand for electricity and a secure power supply is continually rising. The need for a reliable energy source is hence inevitable.

VI. Nuclear Power for Electrical Generation

One of the major applications of nuclear energy has undoubtedly been in its role in the production of electrical power. Nowadays, there are more than 440 NPPs operating all over the world and thus capable of generating more than 350,000 megawatt of electrical power. The greatest concentration of these plants is in the industrialized countries. The extent to which this form of energy is being utilized varies considerably from one country to another. One of the major determinants however, is the sort of access that the country has to other sources of energy. Countries that are relatively poor in indigenous energy resources, such as Jordan, tend to turn towards nuclear power much more intensively. Most of the nuclear reactors are currently used in the form of nuclear power plants for electricity generation. The steps for electricity generation are given below:

- Energy is generated in the reactor core.
- The energy is then transferred to the heat exchanger by the primary coolant, which is then pumped back into the core.
- In the heat exchanger i.e., the steam generator, water coming in on the secondary side takes up the heat to be changed to steam.
- The steam is then sent to the turbine to cause its rotation, which results in electricity being generated by the attached generator, then it is fed to the grid.
- The spent steam from the turbine goes to the condenser to be condensed to water and to be pumped back to the steam generator.

In some types of NPPs, water is allowed to boil in the reactor core and the steam generated there, after some processing, is directly fed to the turbine. The need for a separate steam generator is eliminated in such systems. The disadvantage of this kind of systems is that the primary coolant, which carries some radioactivity flow through a much larger circuit. Their associated radiation problems are more difficult to handle.

Actually, NPPs resembles other electrical generating facilities. For instance, in fossil-fueled power plant heat converts boiled water into steam, it is then piped into the turbine. Once in turbine, the steam passes through the blades, which spins the electrical generator, thus producing electricity. After leaving the turbine, the steam is converted back into water in the condenser. The water is then pumped back to the boiler to be reheated and converted back into steam.

However, in a NPP, a Nuclear Steam Supply System (NSSS) replaces the steam boiler. The NSSS consists of a nuclear reactor and all necessary components needed to produce high-pressure steam, which will be used to turn the turbine for the electrical generator [6].

The demand for energy in Jordan is expected to rise by at least 50% over the next twenty years. Consequently, Jordan decided to invest approximately 872 million dollars in power generation, and a further 386 million dollars in electricity transmission, between now and 2014. Most of Jordan's energy is currently generated from fossil fuels, 95% of which is imported from neighboring Arab countries at a cost of 20% of its gross domestic product. In order to reduce its dependence on oil, Jordan decided to build its first NPP, which hopes to have it up and running by 2015, with the aim of increasing the nuclear power contribution to 30% of all energy generation by 2030. The first NPP is decided to be a 1,100-megawatt nuclear reactor in the initial stage with several reactors to follow with equal capacity. Jordan's ultimate goal is to expand its production and to acquire the capacity to export extra energy in the future **[7]**.

VII. Water Desalination

Although the water scarcity problem is not any of NEPCO's specialties, it was found necessary to address it briefly in this document for it is an urging problem. Water scarcity is the most important natural constraints to the economical growth and development. Due to the rapid increase in population, agriculture, and industrial development, a heavy demand on water resources has been placed. A recent study conducted by the Water Authority, Ministry of Environment, and the Royal Scientific Society of Jordan, showed that the water quality is drastically deteriorating. Their final draft indicated that:

- About 70% of spring water is contaminated.
- Surface water suffers from high fecal coliform counts.
- Water resources have a high level of toxicity.
- Industrial charges are improperly treated.
- Over-abstraction of ground water for irrigation has reduced the water level by five meters in some aquifers and tripled salinity.
- Improper application of fertilizers and pesticides has increased the nitrates and phosphorous level in water supply.

Thus, it is about time to move forward and consider a water desalination technique to overcome this dilemma noting that Jordan has a water deficit of about 1.4 million m^3 per day **[8]**.

A reliable technique would be to deploy a nuclear reactor and a desalination plant. In some cases, a nuclear system may be designed to produce both heat and electricity as products. The most common types of reactors used for water desalination are either Light Water Reactors (LWR) or Pressurized Heavy Water Reactors (PHWR). Such reactors can be either heat-only reactors, providing low temperature heat directly for use in thermal desalination processes, or cogeneration reactors providing both electricity and heat. Liquid Metal Reactors (LMR) and Gas Cooled Reactors (GCR) can also be considered for desalination, but are more likely to be used in other heat applications where high temperatures are required **[9]**.

JAEC has recently announced the Red-Dead Canal Project for the establishment of four nuclear plants in the southern region, two near Aqaba and two near Karak around the southern shores of the Dead Sea. These four NPPs are expected to provide almost 750 MW of energy for desalination and water pumping. Eventually, the project aims at generating much of the needed water to end-users, and saving the Dead Sea, which has been falling at the rate of one meter/year.

VIII. Applications of Radiation & Radioisotopes

In addition to electricity generation and water desalination, Jordan is seeking to develop and promote applications of radioisotopes and radiation technology in all three major aspects of our socio-economic structure: industry, agriculture, and medicine. Radionuclides and nuclear radiations have some characteristics that enable them to be used extensively in many applications, amongst them are:

- Nuclear radiations can penetrate through matter and interact with it in various ways.
- Several detecting systems, which are sensitive to extremely low levels of radiation, can distinguish between different types and energies of radiation.
- Each radionuclide has a set of characteristics, such as its half-life and the spectrum of its emitted radiation that enables us to identify and quantify its presence by studying the radiation emitted by it.
- Radionuclides can be tailored with the desired physical, chemical, and biological properties for a particular application.

These characteristics allowed the humanity to benefit in many ways as progressively more potential problems are identified.

A. Nuclear Radiation

Nuclear radiation is widely used in oil, gas, chemical, petrochemical, steel, mining, paper, mineral, and automobile industries. It is also used in agriculture and medicine.

A. Industry: Many industries nowadays require strict controls over quality. Large industries products would not be competitive in the world market unless quality assurance and quality control become an integral part of the process. Nuclear radiations play an essential role in this field all over the world. For instance, Jordan can make use of nuclear radiation by employing gamma radiography to obtain images of the interior structure of mechanical components, so that any hidden structural faults may be revealed. One can think of it as being analogous to X-ray images of the human body. Gamma radiography is a sealed source type of application, which is on-line, nondestructive, and noninvasive. In this type of application, the radioisotope remains permanently sealed within the source capsule and makes no contact either with the plant or the process material**.**

B. Agriculture: In the field of agriculture, Jordan can make use of nuclear radiation in several ways, such as:

- The development of new strains of crops with favorable qualities.

- Increasing the shelf-life of agricultural products,
- Control of agricultural pests without toxic chemicals
- Study of plant metabolism.
- Dealing with the problem of water logging and salinity.
- Tracing the movement of underground water.

C. Medicine: While a radiation dose can increase the probability of contracting cancer, this very agent can also retard the progress of this inexorable disease. Radiotherapy has been one of the most widely used weapons in the desperate war against cancer. It is playing a vital role in relieving human suffering. Nuclear radiation can also be used to obtain detailed information about the state of various organs and systems of the body for diagnostic purposes.

B. Radioisotopes

Radioisotopes find numerous uses in different areas such as medicine, chemistry, biology, archaeology, agriculture, industry, and engineering. Radioisotopes are frequently used as tracers or tagged atoms in various fields. In tracer technique, a radioactive isotope is added to the reactants and its movement is studied by measuring radioactivity in different parts. The two most common factors of tracer applications are the high degrees of specificity and of sensitivity that can be attained.

IX. NUCLEAR WASTE PRODUCTS

The management of spent fuel from nuclear power plants is a major policy issue for almost every nuclear power program in the world. For the nuclear industry in Jordan, finding sufficient capacity for storage and processing or disposal of spent fuel is essential if NPP is to be allowed to continue to operate. Likewise, the options chosen for spent fuel management can greatly influence the political controversies, proliferation risks, environmental hazards, and economic costs of the nuclear fuel cycle.

The initial plan of launching a nuclear power program in Jordan needs to account for radioactive waste management and disposal. As far as the high-level waste (HLW) is concerned, the external supplier is to be responsible for repatriating spent fuel following a period of initial storage close to the NPP. This necessitates the construction of an interim storage for the spent fuel, not a long-term repository. Therefore, an agreement should be made with the external supplier to repatriate spent fuel. This agreement will eventually minimize the disposal demands on the recipient and will generate international confidence in nonproliferation. Another option would the construction of a national disposal site, which could be rather costly for small nuclear program. The quantity of low-level waste (LLW) produced by a nuclear reactor is highly dependent on the type of reactor and the way that waste is treated **[10]**. LLW generally include radioactively contaminated protective clothing, tools, filters, rags, medical tubes, and many other items. These items according to the USNRC can be stored on-site by licensees, either until it has decayed away and can be disposed of as ordinary trash, or until amounts are large enough to be shipped in approved containers to a low-level waste disposal site. As part of this project, Jordan Nuclear Regulatory Commission (JNRC) was established for regulation, safety, and safeguard purposes.

X. SAFETY & DEFENSE IN DEPTH

The primary objective of nuclear safety is to protect individuals, society, and the environment from radiological hazards that may arise from nuclear power usage. Radiation protection, accident prevention, and mitigation serve this primary objective. The following three Fundamental Safety Functions (FSFs) accomplish the aforementioned objective:

- Control of the reactivity
- Removal of heat from the fuel
- The confinement of radioactive materials and control of operational discharges.

These are achieved by a strategy known as the Defense in Depth. The ***DiD*** concept is a key characteristic of both the design and the operation of a nuclear reactor. Effective and safe operation of an NPP needs a well-developed safety culture, that is, the personal dedication and the accountability of all involved personnel. Appropriate attitudes can be developed only if:

- The safety policy of the organization and all individual responsibilities are clearly defined.
- An adequate mechanism for implementing the policy and monitoring its effectiveness is present.
- The policy and the management structure enable managers to demonstrate their commitment to safety culture.
- The responsibilities of the governments, regulatory agencies, operators, and advisory bodies are clearly defined, and all parties must accept their responsibilities.
- The Regulatory agencies act independently, and to be protected from unnecessary external pressure.

If enough time and information are available to the person in charge, he will be able to react constructively in critical situations that cannot be controlled by automatic actions. Defense is on average jeopardized by human errors Therefore, to ensure a successful human action and a safe operation, a high level of qualification and training is required **[11].**

XI. HUMAN RESOURCES DEVELOPMENT

Upgrading the employee level in all fields of science and management has always been one of NEPCO's top priorities. Nuclear Science and technology was one of these critical fields that NEPCO dispatched a number of its employees, in the nineties of the previous century, to the Center for Nuclear Studies (CNS) in Islamabad, Pakistan to receive Master of Science Degrees in Systems Engineering. Courses like reactor dynamics, operation, and control; neutron absorption and scattering cross sections; nuclear fuel cycle, both front-end and backend; heterogeneous and homogeneous types of reactors; reactor accidents; criticality attainment; and uranium enrichment plants and methods were taught as part of the Systems Engineering curriculum This fact reflects NEPCO's alertness and vigilance. That was a leap ahead of time from NEPCO's side to elevate the capabilities of its employees in such field even before the idea of harnessing nuclear power in Jordan came into being.

In addition, and in order to sustain and further develop the nuclear power program in the country, the Jordan University of Science and Technology (JUST) has recently introduced an undergraduate Nuclear Engineering program to cater to this need. This is definitely a major step for developing the country's nuclear infrastructure, and introducing nuclear power as part of its energy mix to fulfill growing electrical demands, water desalination, and hydrogen production. The aim here is to enhance nuclear knowledge in Jordan and produce a new generation of qualified nuclear engineers that will assist in designing, building, and running the first NPP **[12]**.

Finally, the operation of the first NPP requires people with different educational background, not only nuclear engineers but also Systems Engineers, Electrical Engineers, Computer Engineers, Technical Operators, Project Manager, and others. NEPCO is rich with qualified people who are apt to learn. Therefore, training them in nuclear science related fields will strengthen their background, enhance their knowledge, and consolidate their nuclear engineering capabilities; thus, maximizing their contribution to this maiden Jordanian technology.

XII. Conclusion

The modern era has witnessed significant developments in science and technology. Nuclear science is one of those fields, which grew up rapidly and outstandingly. The list of countries utilizing nuclear energy to the benefit of its people has extended to include Jordan. Countries that are relatively poor in natural energy resources, such as Jordan, tend to turn towards nuclear power much more intensively taking into consideration that Jordan is rich in uranium ore. This fact should facilitate the implementation of the first Jordanian NPP, which is planned to operate by 2015.

Nuclear energy has undoubtedly played a vital role in the production of electrical power, water desalination, and in many industrial, agricultural, and medical applications. The reasons why this form of energy needs to be utilized vary from one country to another. For Jordan, the reasons are:

- The lack of available indigenous energy resources,
- The desire to reduce dependence upon imported energy,
- The need to increase the diversity of energy resources,
- The need for nuclear desalination to overcome water shortages,
- The increasing demand for electricity
- The high cost of fossil fuel

Moreover, it has studied and carefully scrutinized the political, technical, environmental, and economical effects of such a program on the Kingdom. Subsequently, a five-component National Nuclear Energy Strategy was adopted to tackle the challenges mentioned above. It has also taken several actions to build up the Human resources needed for this step. In addition to the undergraduate program at JUST, a master's degree program in Applied Nuclear Physics was launched in 2006 at Al-Balqa Applied University. A similar program was established a year later at Jordan University. Such programs were launched by JAEC in cooperation with the Ministry of Higher Education. Likewise, NEPCO worked on upgrading a number of its employees in this field by sending them to CNS, a nuclear reactor school, in the nineties of the previous century by offering them Systems Engineering Scholarships. These actions reflect the awareness of the Jordanian government represented by JAEC and NEPCO and its preparedness to this new comer.

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