A PATHWAY TO INITIATE NUCLEAR POWER TECHNOLOGY IN DEVELOPPING COUNTRIES

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ABSTRACT

The main energy source of GCC Countries is based on indigent oil. However, oil resources are time limited. On the other hand, **oil is a prime material for the petrochemical industry and so too precious to be wasted as fuel**. Also, both electricity generation and desalination processes with oil are expensive. A sound way to initiate nuclear power research programme in GULF Countries will be to start graduate studies in the regional Universities. For that purpose, multi-disciplinary Institutes for Nuclear Science and Engineering should be opened for graduate studies (MS and PhD) for the graduates of divers engineering departments, physic and mathematics with strong experimental & practical content. For that purpose, following steps could be strongly advisable: ① Purchase of a research reactor to train and prepare manpower. ② Actively participate on the development of a small innovative reactor in order to move gradually from a key turn costumer to a technology holder. The Fixed Bed Nuclear Reactor (FBNR) is being developed under the International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) on Small Reactors (40 to 70 MW_{el}) without On-site Refueling (SRWOSR). They are defined by IAEA "As reactors which have a capability to operate without refueling and reshuffling of fuel for a reasonably long period consistent with the plant economics and energy security, with no fresh and spent fuel being stored at the site outside the reactor during its service life. The reactor is evaluated by the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Methodology in respect to safety and non-proliferation aspects. The inherent safety and fool proof non-proliferation characteristics of the reactor are demonstrated. GULF Countries have the will and financial possibilities. They should be encouraged to participate in the research and development of an innovative future nuclear reactor and become a technological stakeholder in such a project. While implementing its nuclear program according to the Milestone guidelines, it can involve itself in the R&D of non-nuclear components of an innovative nuclear reactor concept. The only way that they can have the technology is by their active participation in its development. The fact is that science may be transferred, but technology is not transferable - it is developed.

KEYWORDS: Small innovative nuclear reactor, inherent safety, passive cooling, proliferation resistance, water desalination.

1. INTRODUCTION

The world needs to produce energy for its development without producing gases that cause global warming.

The solution to the ever increasing demand for energy to satisfy the needs of growing world population and improving its standard of living lies in the combined utilization of all forms of energy. Nuclear energy produced safely and economically has an important role in solving the world energy problem. The public objections to nuclear energy most often expressed are reactor safety, cost and nuclear waste disposal. The proposed reactor concept is to meet the requirements of a modern reactor.

At the end of 2000, 438 nuclear power reactors were in operation in 31 countries around the world, generating electricity for nearly 1 billion people. They account for approximately 17 percent of worldwide installed base capacity for electricity generation.

About 30% of the world's primary energy consumption is used for electricity generation, about 15% is used for transportation, and the remaining 55% is converted into hot water, steam and heat. Non-electric applications include desalination, hot water for district heating, and heat energy for petroleum refining, for the petrochemical industry, and for the conversion of hard coal or lignite. For non-electric applications, the specific temperature requirements vary greatly. Hot water for district heating and heat for seawater desalination require temperatures in the 80 to 200 C range, whereas temperatures in the 250 to 550 C range are required for petroleum refining processes and about 800 C are necessary for coal gasification processes.

2. INNOVATIVE NUCLEAR REACTORS

Recently, international cooperation activities, such as the Generation IV International Forum (GIF) initiated by US Department of Energy and the International Project of Innovative Nuclear Reactors and Fuel Cycles (INPRO) initiated by IAEA, have motivated the nuclear scientists and technologists around the world to search for a new generation of innovative nuclear reactors. These reactors are to be totally safe, resistant to proliferation, environmental friendly and economic.

Thus, a new era of nuclear energy is emerging. The International Atomic Energy Agency has committed itself to "Help to ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner; and to bring together both technology holders and technology users to consider jointly the international and national actions required to achieve desired innovations in nuclear reactors and fuel cycles."

The International Atomic Energy Agency through its INPRO Program is creating a new paradigm in nuclear energy. The nuclear energy in the future will be generated by innovative nuclear reactors that will meet a new set of requirements. The public perception of nuclear energy will change and thus a new era of nuclear energy will emerge.

INPRO has developed requirements to be met by the new innovative nuclear reactors. It has also developed a methodology described in TECDOC-1434 [1] to evaluate such reactors. It sets new philosophy and criteria in respect to the economics, safety, environment, waste management, and proliferation resistance in such a manner that the nuclear energy of the future will be completely different from what it is today. There is a rebirth of nuclear energy in the horizon.

3. IMPORTANCE OF NUCLEAR REACTORS FOR GULF COUNTRIES

The main energy source of GCC Countries is based on indigent oil. However, oil resources are time limited. On the other hand, **oil is a prime material for the petrochemical industry and so too precious to be wasted as fuel**. Also, both electricity generation and desalination processes with oil are expensive.

A sound way to initiate nuclear power research programme in GULF Countries will be to start graduate studies in the regional Universities. For that purpose, multi-disciplinary Institutes for Nuclear Science and Engineering should be opened for graduate studies (MS and PhD) for the graduates of divers engineering departments, physic and mathematics with strong experimental & practical content. In that respect, Turkish and some other universities with their respectable source of very high qualified academician of international reputation in nuclear sciences and technology can give great support to develope nuclear technology in GULF Countries. For that purpose, following steps could be strongly advisable for consideration:

- Purchase of a research reactor to train and prepare manpower.

Among other alternatives, one may consider, for the reason of simplicity, a TRIGA research reactor, which is a pool-type reactor that can be installed without a containment building, and is designed for use by scientific institutions and universities for purposes such as undergraduate and graduate education, private commercial research, non-destructive testing and isotope production.

- Actively participate on the development of a small innovative reactor in order to move gradually from a key turn costumer to a technology holder.

GULF Countries have the will and financial possibilities. They should be encouraged to participate in the research and development of an innovative future nuclear reactor and become a technological stakeholder in such a project. While implementing its nuclear program according to the Milestone guidelines, it can involve itself in the R&D of non-nuclear components of an innovative nuclear reactor concept. GULF countries do not need to be merely the buyer of nuclear reactors. They can be participants in the technology development. The only way that they can have the technology is by their active participation in its development. The fact is that science may be transferred, but technology is not transferable - it is developed.

4. THE FIXED BED NUCLEAR REACTOR

The Fixed Bed Nuclear Reactor (FBNR) is being developed under the International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) on Small Reactors (40 to 70 MW_{el}) without On-site Refueling (SRWOSR). They are defined by IAEA "As reactors which have a capability to operate without refueling and reshuffling of fuel for a reasonably long period consistent with the plant economics and energy security, with no fresh and spent fuel being stored at the site outside the reactor during its service life. The reactor is evaluated by the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Methodology in respect to safety and non-proliferation aspects. The inherent safety and fool proof non-proliferation characteristics of the reactor are demonstrated.

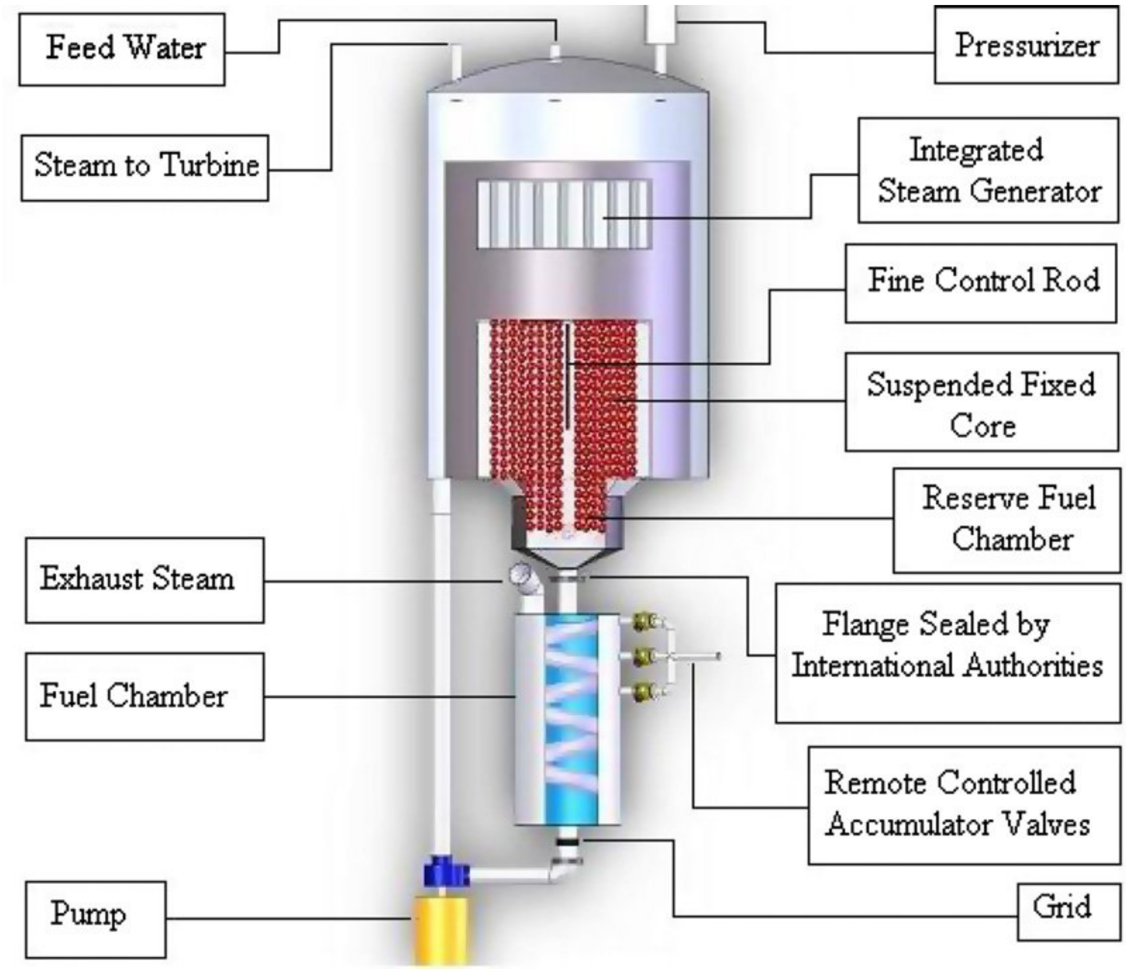

Fig. 1: Schematic design of the main components of FBNR

The core of a water moderated Fixed Bed Nuclear Reactor (FBNR), possessing, for instance, an electrical power of 40 MW, consists of 1.35 million fuel pellets (9.5t) with a diameter of 1.5 cm each. The low enriched uranium fuel is made of TRISO type microspheres used in the HTGR, embedded in a graphite matrix and cladded by a shell of 1mm SiC. Fig. 1 shows the main components of the FBNR.

The reactor has in its upper part the reactor core and a steam generator, and in its lower parts the fuel chamber. The core is placed between two concentric perforated zircaloy tubes of 31 cm and 171 cm in diameters, inside which, during the reactor operation, the spherical fuel

elements are held together by the coolant flow in a fixed bed configuration, forming a suspended core. The coolant flows vertically up into the inner perforated tube and then, passing horizontally through the fuel elements and the outer perforated tube, enters the outer shell where it flows up vertically to the steam generator. The reserve fuel chamber is a 60 cm diameter tube made of high neutron absorbing alloy, which is directly connected underneath the core tube. The fuel chamber consists of a helical 40 cm diameter tube flanged to the reserve fuel chamber that is sealed by the national and international authorities. A grid is provided at the lower part of the tube to hold the fuel elements within it. A steam generator of the shell-and-tube type is integrated in the upper part of the module. A control rod can slide inside the centre of the core for fine reactivity adjustments. The reactor is provided with a pressurizer system to keep the coolant at a constant pressure. The pump circulates the coolant inside the reactor moving it up through the fuel chamber, the core, and the steam generator. Thereafter, the coolant flows back down to the pump through the concentric annular passage. At a flow velocity called terminal velocity, the water coolant carries the 15 mm diameter spherical fuel elements from the fuel chamber up into the core. A fixed suspended core is formed in the reactor. In the shut down condition, the suspended core breaks down and the fuel elements leave the core and fall back into the fuel chamber by the force of gravity.

Under any thinkable operational condition the fuel temperature will be below 400 C whereas its stability limit is at about 1600 C. The first characteristic of the FBNR is, therefore, its robust fuel under relatively "cold" operating conditions and – due to the outer SiC – shell layer – the freedom from any hydrogen production.

To operate the reactor the fuel pellets are pumped by a flow of water from below into the core regions where they form a stable fixed bed of about 4 cubic meter and become critical for energy production heating the outlet water to about 330 C (at 160 bar) which feeds a steam generator.

The new safety feature is now the following:

In case of any abnormality (e.g. external power failure, overheating etc.) the circulating pump stops and – due to gravity – the fuel pellets fall automatically out of the core region into a helical "fuel chamber" underneath the core where their decay heat is transferred passively by natural circulation to a water tank housing the fuel chamber. The safety principle, applied here, is: The loss of an active component (circulating pump) induces a self-controlled, passively working shut-down maneuvre accompanied by a foolproof decay heat removal without any emergency power system or any human interaction.

The fuel chamber is sealed and is transported as the only reactor component to and from the reactor site. There is no possibility to irradiate fertile fuel, too. For a long-life core (more than a 10 years cycle time) the fuel can either be poisond by gadolinium-oxide or by a piston type core limiter adjusting the height and controlling thereby the number of the fuel pellets in the active core region. Refueling is done only by changing the fuel chamber allowing also the use of this foolproof light water reactor in countries without a perfect nuclear infrastructure. Detailed technical information about FBNR can be found in refs. [2-6].

The fuel elements are made of UO_2 micro spheres embedded in zirconium and cladded by zircaloy. Figure 2 shows a typical CERMET fuel element for the FBNR. UO_2 contents in each fuel element is 23.9 volume %. Fuel element is divided into two regions: The inner region consists of coated fuel particles (kernels) embedded in a zirconium matrix. The outer region of the fuel element is made of a 0.3 mm thick protective Zircaloy cladding. The dimension of the coated UO_2 kernels (0.5 mm) is significantly smaller than the neutron mean free path in the fuel so that the inner region can be homogenized for numerical calculations. The core contains approximately 1.62×10^6 fuel elements. Total uranium charge is 11.5 tons.

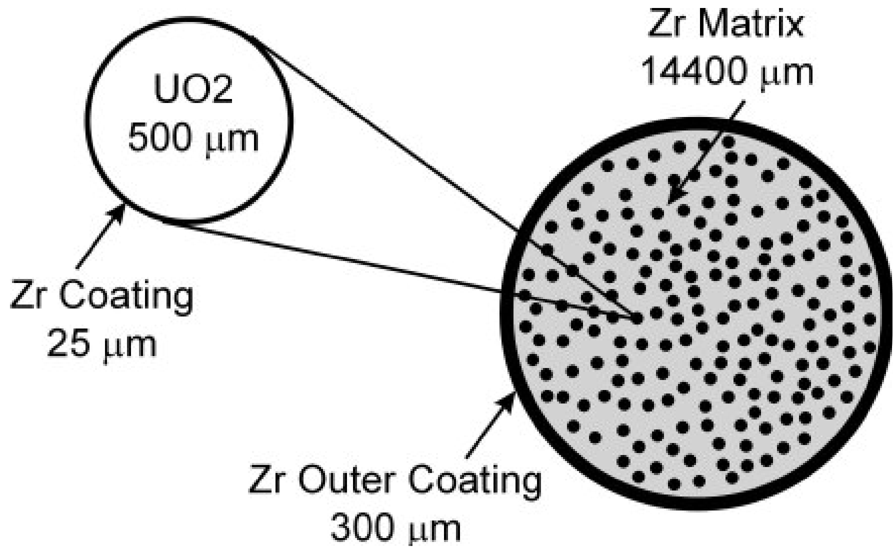

Fig. 2: Cross sectional sketch of the FBNR CERMET fuel
(outer diameter = 15 mm)

The inherent safety and passive cooling characteristics of the reactor eliminate the need for containment. However, an underground containment is envisaged for the reactor to mitigate any imagined adverse event, but mainly to help with the visual effects by hiding all reactor components and the industrial equipments underground and presenting the **nuclear plant as a beautiful garden** compatible with the environment acceptable to the public, see figure 3.

Figure 3. FBNR Underground Containment Building.

In a conclusion, FBNR being a completely new pressurized water reactor, based on a robust fuel and a purely passively working decay heat removal system can turn out to an excellent opportunity of the nuclear technology development in gulf countries. aside from electricity production in the realm of 40-70 mw_{el} it can also be used for water desalination and space heating purposes.

5. REFERENCES

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