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A fool proof non-proliferation nuclear reactor concept

The non-proliferation characteristics of the Fixed Bed Nuclear Reactor (FBNR) is based on both, the extrinsic concept of sealing and the intrinsic concept of isotope denaturing. Its small spherical fuel elements are confined in a fuel chamber that can be sealed by the authorities for inspection at any time. Only the fuel chamber is needed to be transported from the fuel factory to the site and back. There is no possibility of neutron irradiation to any external fertile material. Isotopic denaturing of the fuel cycle either in the U-233/Th or Pu-239/U cycle increases the proliferation resistance substantially. Therefore, both concepts of "sealing" and "isotope denaturing" contribute to the fool proof non-proliferation characteristics of the proposed reactor.

Ein Reaktorkonzept mit Nichtverbreitungseigenschaften. *Die Nichtverbreitungseigenschaften des Festbettreaktors basieren sowohl auf dem „extrinsischen Konzept der Versiegelung" als auch auf dem „intrinsischen Konzept der Brennstoffdenaturierung". Seine kleinen Brennstoffkugeln werden in einer Brennstoffkammer eingeschlossen, die durch die Kontrollbehörde jederzeit inspiziert werden kann. Nur die Brennstoffkammer im Ganzen muss von der Fabrik zum Reaktor und zurück transportiert werden. Es gibt keine Möglichkeit externes fruchtbares Material mit Neutronen zu bestrahlen. Die isotopische Denaturierung des Brennstoffzyklus, entweder im U-233/Th- oder Pu-239/U-Zyklus, verstärkt zusätzlich die Proliferationsresistenz. Beide Konzepte, das „Versiegelungskonzept des Brennstoffs" und das „Isotopendenaturierungskonzept" bilden das Gerüst für das vorgeschlagene narrensichere Nichtverbreitungskonzept. Dieser Beitrag beschränkt sich ausschließlich auf den Nichtverbreitungsaspekt des Reaktors.*

1 Introduction

Under the present world conditions, the first priority of the governments in relation to nuclear energy is non-proliferation and safeguard of the nuclear reactors. This provides a challenge for us to come up with a fool proof nuclear reactor concept.

Small nuclear reactors without the need for on-site refuelling have greater simplicity, better compliance with passive safety systems, and are more adequate for countries with small electric grids and limited investment capabilities. The Fixed Bed Nuclear Reactor (FBNR) is thoroughly based on the Pressurized Water Reactor (PWR) technology, but incorporates the fuel of High Temperature Gas Cooled Reactor (HTGR) and the concept of a suspended fixed bed core. FBNR has an integrated primary circuit and is simple in design. It has the characteristics of being small, modular, inherently safe and passively cooled reactor with reduced adverse environmental impact. The spherical fuel elements are fixed in the suspended core by the flow of water coolant. Any malfunction in the reactor system will cut off the power to the coolant pump causing a stop in the flow. This results in making the fuel elements fall out of the reactor core by the force of gravity and become stored in the passively cooled fuel chamber under sub critical condition. For detailed information see www.rcgg.ufrgs.br/fbnr.htm.

The objective is to conceive the FBNR in such a manner that it become a fool proof reactor from non-proliferation and safeguard points of view.

2 Requirements for non-proliferation

The International Atomic Energy Agency (IAEA) through its International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) recommends that proliferation resistant features and measures should be provided in innovative nuclear energy systems to minimize the possibilities of misuse of nuclear materials for nuclear weapons. Both intrinsic features and extrinsic measures are essential, and neither should be considered sufficient by itself. Extrinsic proliferation resistance measures, such as control and verification measures will remain essential, whatever the level of effectiveness of intrinsic features. From a proliferation resistance point of view, the development and implementation of intrinsic features should be encouraged. Communication between stakeholders will be facilitated by clear, documented and transparent methodologies for comparison or evaluation/assessment of proliferation resistance. The establishment of Multilateral Fuel Cycles (perhaps on a regional basis) will be of benefit to the deployment of many advanced reactors independent of their particular type. Specifically, an option for fuel or nuclear power plant leasing coupled with an option of Multilateral Fuel Cycles may be of essential benefit for the deployment of such reactors in many developing countries that are embarking on a nuclear program without having a sufficient nuclear infrastructure [3].

INPRO defines some *Basic Principles for* Proliferation Resistance (BPPR):

- BPPR 1: Proliferation resistant features and measures should be provided in innovative nuclear energy systems to minimize the possibilities of misuse of nuclear materials for nuclear weapons.
- BPPR 2: Both intrinsic features and extrinsic measures are essential, and neither should be considered sufficient by itself.

- BPPR 3: Extrinsic proliferation resistance measures, such as control and verification measures will remain essential, whatever the level of effectiveness of intrinsic features.
- BPPR 4: From a proliferation resistance point of view, the development and implementation of intrinsic features should be encouraged.
- BPPR 5: Communication between stakeholders will be facilitated by clear, documented and transparent methodologies for comparison or evaluation/assessment of proliferation resistance.

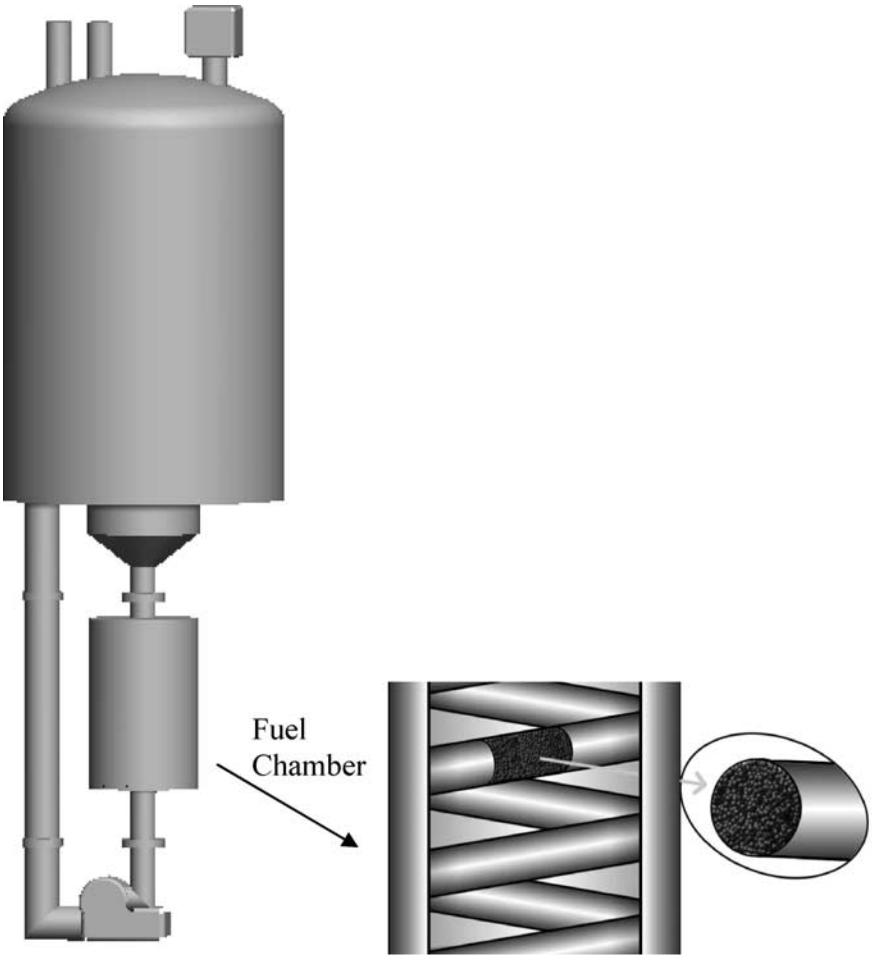
3 Reactor description

The main features of the proposed reactor are as follows: *Fuel Element*: The 15 mm diameter spherical fuel elements are made of compacted coated particles in a graphite matrix. The coated particles are similar to TRISO fuel with outer diameters about 2 mm. They consist of 1.58 mm diameter uranium dioxide spheres coated with 3 layers. The inner layer is of 0.09 mm thick porous pyrolitic carbide (PYC) with density of 1 g/cm3 called buffer layer, providing space for gaseous fission products. The second layer is of 0.02 mm thick dense PYC (density of 1.8 g/cm^3) and the outer layer is 0.1 mm thick corrosion resistant silicon carbide (SiC, density of 3.17 g/cm^3). The fuel element is cladded by 1 mm thick SiC.

The water flow from the pump drives the fuel elements from the fuel chamber into the reactor core. It forms a fixed bed suspended core. The fuel elements fall back into the fuel chamber under reactor shutdown or accident conditions. Any probable accident causes the cutting off of the power to the pump, thus the fuel elements will fall out of the core by the force of gravity and become stored in the passively cooled fuel chamber. The fuel chamber is to be sealed by the inspectors.

FBNR is a small reactor with a very long core life. Small Reactors without On-Site Refueling are defined 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. They also should ensure difficult unauthorized access to fuel during the whole period of its presence at the site and during transportation, and design provisions to facilitate the implementation of safeguards [3]. FBNR being a Small Reactor without On-Site Refueling will be factory produced and fueled and brought back to the factory for refueling after its fuel lifetime expires. FBNR modules are fabricated, fueled, and sealed in the factory under the supervision of the IAEA safeguard program. They are taken to the site and installed in the reactor and will return to the factory as sealed for refueling. This should assure the safeguard of the nuclear fuel.

Adopting a thorium cycle as an intrinsic measure will hinder the possibility of misuse of nuclear materials for nuclear weapons. The mixing of thorium with low enriched uranium or plutonium results in the production of U-233 that is diluted along with U-235 in U-238. The access to uranium-233 will only be possible through isotope separation techniques. Additionally the production of gamma emitting Tl-208 in the thorium cycle is hindrance to nuclear proliferation.



If the U-Pu cycle is applied, one can increase the Pu-238 concentration by adding Np to the fresh fuel. From a certain concentration of Pu-238 on (~ 8 %), the alpha decay heat is so strong that the metallic Pu-sphere, as well as the surrounding chemical explosives, in a nuclear device become plastic or even melts so that the fuel of the reactor at any time is not useful for weapons. Thus, the combination of sealing the reactor, as described above, and the isotopic denaturing of the irradiated fuel will additionally increase the proliferation resistance.

There are less than 300 kg of UO2 in a reactor module. There are less than 15 kg of U-235 in a module. The Pu content of the spent fuel will be calculated, but may be estimated to be less than 10 kg. There is no thorium at the initial stage of the development.

The FBNR has a very long lifetime (more than 10 years) and will not be refueled on the site. Refueling is done in the factory. The fuel elements are confined in the fuel chamber. The FBNR modules are fabricated, fueled, and sealed in the factory under the supervision of the IAEA safeguard program. They are taken to the site and installed in the reactor and the spent fuel chamber will return to its final destination as sealed. The fuel chamber is stored in a passively cooled intermediate storage at the reactor site before going to the final disposal site or to the reprocessing plant or any other future destination. This should assure the safeguard of the nuclear fuel.

The reactor core is surrounded by a jacket of downward flowing water, thus there is insufficient neutron leakage for irradiation purposes outside the pressure vessel. The reactor vessel may be cladded by neutron absorbing materials, if necessary, to eliminate the possibility of neutron irradiation to any external nuclear material. Only the fuel chamber is needed to be transported from factory to the site and return.

4 Conclusios

The proposed reactor meets the IAEA requirements for non-proliferation. The concept is based on both sealing of the fuel chamber and denaturing of the fuel itself.

The sealing of the fuel in the fuel chamber of a long life reactor, permits the control at any time from "cradle to grave" allowing the continuity of knowledge (COK) about the fuel which guarantees an effective control.

The isotopic denaturing of the fissile fuel, both in the U-233/Thorium cycle as well as for the classical Pu-239/Uranium cycle, would further increase the proliferation resistance as it will require isotope separation technology to produce weapon grade materials.

In this way both intrinsic features and extrinsic proliferation resistance measures are provided. The Continuity of Knowledge (COK) and the communication between stakeholders are facilitated due to the nature of the design. The proposed reactor can utilize variety of fuel cycles and can benefit from a Multilateral Fuel Cycle concept.

In conclusion, the FBNR can be considered as a fool proof reactor against nuclear proliferation that the present world is looking for to be assured of both safety and safeguard.

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4 For more detailed and up to date information on FBNR, visit: www.rcgg.ufrgs.br/fbnr.htm

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