

## *FBNR Letter*

# **FIXED BED NUCLEAR REACTOR – FBNR**

<http://www.rcgg.ufrgs.br/fbnr.htm>

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Dear coworkers and potential coworkers around the world,

As the number of coworkers is increasing, we are issuing a circular letter to communicate about the matters of general interest to the FBNR project. Please consider this as a personal letter to yourself. Those who are not involved in the project as yet may participate at any appropriate moment. The project has manifold aspects including scientific, technological, economical, political, and sociological.

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 21<sup>st</sup> 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.”- IAEA-TECDOC-1362.

The objective is to develop an innovative nuclear reactor to be inherently safe, passively cooled, small, modular, and simple in design with integrated primary circuit. Safety is achieved by design, and has reduced adverse impact on environment. It is to meet the requirements of GEN IV and IAEA-INPRO as being economic, safe, proliferation resistant and sustainable.

The FBNR may be called People’s Reactor. It is intended to be developed by the peoples for the peoples of the world in the spirit of cooperation and service to humanity. It is intended to be a near term deployment project. Let us form an international consortium to develop this reactor where all members are stakeholders.

An IAEA Coordinated Research Project (CRP) includes FBNR in its program.

**Participate in the project**

*FBNR is meant to be a fool proof non-proliferation nuclear reactor. Take it as a challenge to prove or disprove this claim!*

Dear coworker or potential coworker,

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.

You and your friends are invited to participate in a brainstorm type discussion in order to help reach this objective. Please participate with your critical mind making comments and asking questions.

Thanking you in advance for your active participation and contributions,

Farhang Sefidvash

## **Non-Proliferation & Safeguard of the Fixed Bed Nuclear Reactor (FBNR)**

[www.rcgg.ufrgs.br/fbnr.htm](http://www.rcgg.ufrgs.br/fbnr.htm)

### ***INVITATION TO CHALLENGE A FOOL PROOF REACTOR***

This is a record of informal discussions in order to develop a fool-proof reactor concept from the safeguard and non-proliferation points of view. Some of the IAEA experts are participating in this discussion. Others from around the world are kindly invited to participate. After the completion of the discussion, the names of the participants who should allow will be announced. This is to make the participants feel free to express their opinions in the spirit of brainstorming. Please pass on this invitation to any one that you think can make a contribution by his critical analysis and evaluation.

### ***LIST OF THE PARTICIPANTS***

The participants in the discussion presently are the followings. The new ones will be added to the list as the process of discussion develops.

- EXP1 – an IAEA Expert on safeguard whose name will be revealed on the completion of the discussion should he permit.
- EXP2 – an IAEA Expert on safeguard whose name will be revealed on the completion of the discussion should he permit.
- FS – Farhang Sefidvash

- Other participants (with name or anonymous) will be added to the list as the process of discussion develops.

#### STATEMENTS ON FBNR BY FS

1. 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. See details in [www.rcgg.ufrgs.br/fbnr.htm](http://www.rcgg.ufrgs.br/fbnr.htm)
2. 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 2mm. They consist of 1.58 mm diameter uranium dioxide spheres coated with 3 layers. The inner layer is of 0.09 mm thick porous pyrolytic carbide (PYC) with density of 1 g/cm<sup>3</sup> 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<sup>3</sup>) and the outer layer is 0.1 mm thick corrosion resistant silicon carbide (SiC, density of 3.17 g/cm<sup>3</sup>). The fuel element is clad by 1mm thick SiC.
3. The IAEA-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”- (IAEA-TECDOC-1362).
4. FBNR is a small reactor with a very long core life. IAEA says, “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.” FBNR being a Small Reactor without On-Site Refueling will be factory produced and fuelled 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.
5. IAEA says, “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.”

6. 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 will only be possible through isotope separation techniques. The high Pu-238 to Pu-239 ratio and the production of gamma emitting Tl-208 in the thorium cycle are hindrances to nuclear proliferation.
7. There are less than 500 Kg of UO<sub>2</sub> in a reactor module. There are less than 30 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 3 Kg. There is no thorium at this initial stage of development.
8. The water flow from the pump drives the fuel elements from the fuel chamber into the reactor 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 IAEA inspectors.
9. 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 will return to the factory as sealed for refueling. This should assure the safeguard of the nuclear fuel.
10. The reactor vessel is clad by neutron absorbing materials 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.
11. For schematic design, dimensions and material compositions see FBNR Letters no.8 and 14: <http://www.rcgg.ufrgs.br/fbnr.htm>
12. See the paper published in Kerntechnik entitled, “Evaluation of FBNR using IAEA-INPRO Methodology. [www.rcgg.ufrgs.br/kerntechnik.pdf](http://www.rcgg.ufrgs.br/kerntechnik.pdf) . A few items extracted from the paper are as follows:
  - a. INPRO defines some *basic Principles for Proliferation Resistance (PRPR)*

- i. *BPPR1: 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.*
- ii. *BPPR2: Both intrinsic features and extrinsic measures are essential , and neither should be considered sufficient by itself.*
- iii. *BPPR3: Extrinsic proliferation resistance measures, such as control and verification measures will remain essential, whatever the level of effectiveness of intrinsic features.*
- iv. *BPPR4: From a proliferation resistance point of view, the development and implementation of intrinsic features should be encouraged*
- v. *BPPR5: Communication between stakeholders will be facilitated by clear, documented and transparent methodologies for comparison or evaluation/assessment of proliferation resistance.*

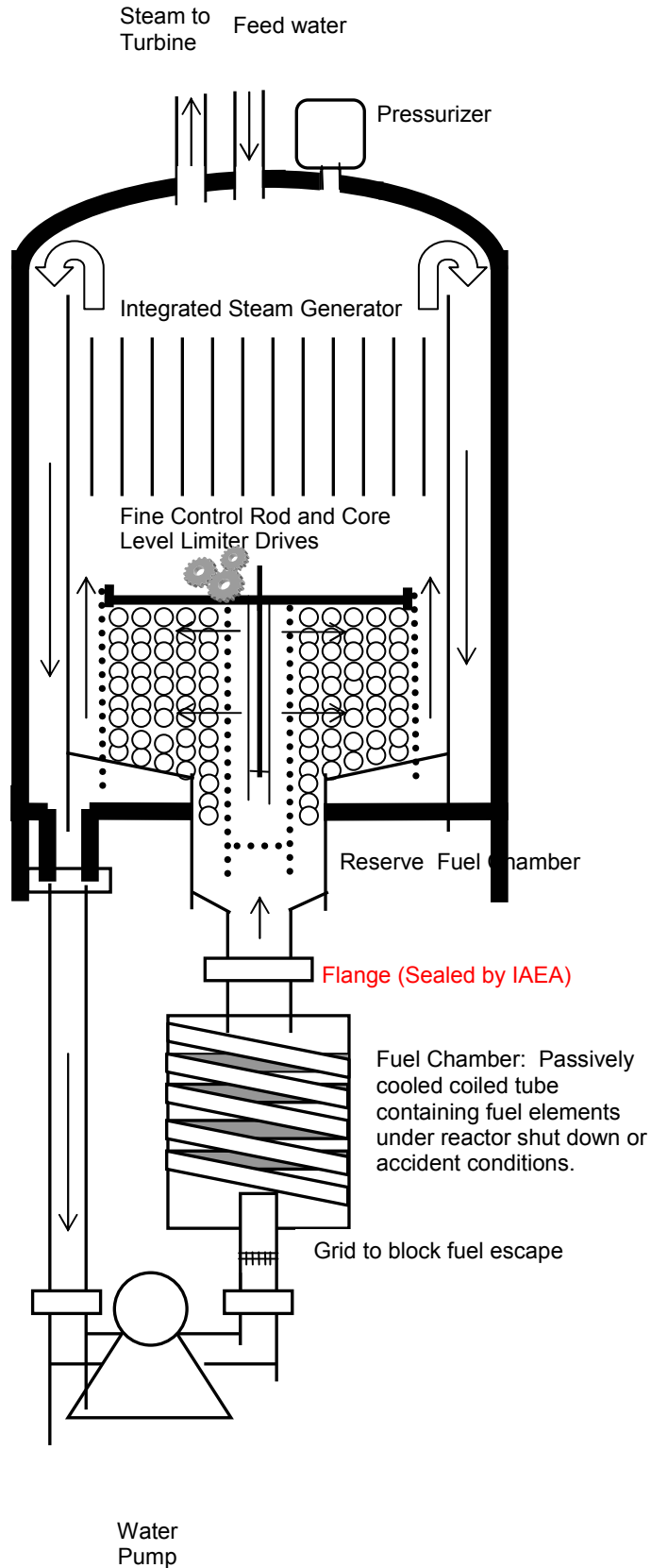
***Proliferation Resistance Evaluation:***

Item 6: 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 which is diluted along with U-235 in U-238. The access to uranium will only be possible through isotope separation techniques. The high Pu-238 to Pu-239 ratio and the production of gamma emitting Tl-208 in the thorium cycle are hindrances to nuclear proliferation.

The proposed World Nuclear Energy Company (WONEC), an international consortium responsible for the development and deployment of FBNR will operate closely and faithfully under the auspices of IAEA to eliminate the problem of proliferation.

## Schematic Design of FBNR Concept

See a more detailed scheme in <http://www.rcgg.ufrgs.br/FBNRLetterNo.14.pdf>



13. EXP1 writes: For example I would suggest to start with you need some sort of table giving the basic parameters of safeguards interest:
- a. - approximate size and physical design of a fuel pellet.
    - i. [FS: Spherical with 15 mm in diameter, See item 2 ]
  - b. - ditto for a fuel assembly or fuel unit
    - i. [FS: There is no fuel assembly. See item 2 ]
  - c. - amounts (kg) of U, U235, Thorium or other nuclear material in each fresh fuel unit.
    - i. [FS: ~30 Kg U-235, no Th. See item 6 &7 ]
  - d. - typical weights of U, U235, Pu etc. in a spent fuel assembly (unit) at discharge.
    - i. [FS: Need to be calculated. May be ~3 Kg of Pu. See item 7 ]
  - e. -approximate Pu isotopics at discharge (not very important at the early stages but enough to give some idea of the grade of Pu) - the most important parameter is the amount of Pu as this defines the inspection regime. However, another important point in your favour is that I assume your fuel will be extremely difficult to reprocess)
    - i. [FS: The thorium cycle will be introduced at a later stage. See item 6]
  - f. - some sort of review of the life cycle of a fuel unit including cooling period and where it will be stored.
    - i. [FS: The sealed fuel chamber, after an adequate cooling period, will be taken to the factory and stored under the IAEA supervision. See item 9 ]
  - g. - the physical design of the fuel unit now becomes important as this would define the containment and where you could design something that provides complete confidence in continuity of knowledge (COK).
    - i. [FS: The fuel elements are in the fuel chamber that is sealed by the IAEA. See item 9 ]
  - h. Also important is that you have a scheme for refuelling that will ensure COK. This is easier said than done. Ideally you will have to design a fuel unit that could be verified and sealed by the Agency when fresh. This would

mean that they can determine to reasonable accuracy the amount of U and U235 present in the fuel unit. There are many sophisticated gamma and even neutron interrogation methods available in principle, but for a new design of fuel something may have to be developed (usually the USA pays for such development project and they are done in liaison with Los Alamos). The problem always comes with ensuring COK during its time in the reactor and particularly from the moment after the fuel unit has left the reactor. If you could design, for example, a foolproof 'cradle to grave' seal (many have tried and failed). (It would be a great MSc project for a student to read up all the IAEA and other literature on this subject and then make such a design.)

i. [FS: The fuel chamber is about 1 m<sup>3</sup> in volume containing spherical fuel elements blocked in the bottom by grid and sealed on the top by the IAEA such that can not be violated. See item 9 ]

i. REXP2 writes: The technical objective of safeguards in agreements concluded under the NPT is defined as "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection" (INFCIRC/153, Part II, para.28).

14. EXP2 writes: The following traditional safeguards detection goals would be applicable to the FBNR:

a. Detection of unrecorded production of Pu or U-233, using declared or undeclared target material.

i. [FS: The fuel chamber is sealed and is under the control of the IAEA. See item 9 ]

b. Detection of diversion of 1 SQ of irradiated fuel (8 kg Pu or U-233) within 3 months.

i. [FS: The fuel chamber is sealed and is under the control of the IAEA. See item 9 ]

c. Detection of diversion of 1 SQ of fresh fuel (75 kg U-235) within 12 months.

i. [FS: The fuel chamber is sealed and is under the control of the IAEA. See item 9 ]

15. EXP2 writes: Since IAEA safeguards do not constitute a physical security system, [ FS: Does this mean that IAEA will not do the sealing of the fuel chamber ? ] a State can physically remove (divert) any nuclear material that is present at any facility in

that State, in any quantity and in any manner, subject only to basic physical restrictions (size, weight, etc.) and the requirements of nuclear and radiation safety. Basic diversion strategies at a FBNR facility could be:

- a. Irradiation of undeclared target material in or around the core, for the purpose of producing Pu or U-233.
    - i. [FS: The pressure vessel is clad by neutron absorbing materials; therefore, there is no neutron leakage from the reactor to be used for irradiation purposes. See item 10 ]
  - b. Removal of fresh fuel, with or without substitution with dummy items.
    - i. [FS: This can not be done since the fuel chamber is sealed and is under the control of the IAEA. See item 9 ]
  - c. Removal of core fuel, with or without falsification of operating records.
    - i. [FS: The fuel chamber is sealed and is under the control of the IAEA. See item 9 ]
  - d. Removal of spent fuel, with or without substitution with dummy items and/or falsification of operating records.
    - i. [FS: The fuel chamber is sealed and is under the control of the IAEA. See item 9 ]
16. EXP2 writes: The following design features, if applicable, should be taken into account in formulating the inspection goals for the FBNR:
- a. The fresh fuel pebbles are not identifiable as items (the FBNR could probably be considered a bulk-handling facility).
    - i. [FS: It is ~1 m<sup>3</sup> spiral tube in a cylindrical tank. See the figure ]
  - b. The possibility for undeclared irradiation of target material exists.
    - i. [FS: No, there is no way to do this. See item 10 ]
  - c. The core fuel will remain inaccessible for safeguards verification during the operating life of the FBNR.
    - i. [FS: Its seal can be verified at any time. See item 9 ]
  - d. The core fuel inventory may only be accounted for by monitoring the load-discharge fuel operation and reactor operational parameters.

- i. [FS: IAEA can check the seal at any time. See item 9 ]
- e. EXP2 writes: One immediate comment would be that sealing FBNR modules would probably not safeguard against "diversion" of neutrons, i.e., provide a detection capability for unrecorded production of Pu or U-233, using declared or undeclared target material.
  - i. [FS: There is no neutrons available for irradiation. See item 10.]

17. Your analysis, criticisms, comments, and contributions.