Original Research Article

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Reduction of Environmental Impact of Fixed Bed Nuclear Reactor (FBNR) Waste

ABSTRACT

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The Fix Bed Nuclear Reactor (FBNR) is a pressurized water reactor but its fuel elements are made of Tristructural-Isotropic (TRISO) type particles. Its spent fuel elements may be used as a source of radiation for irradiation purposes in medicine, industry and agriculture. Thereafter, the waste treatment problem is the same as for the fourth generation high temperature nuclear reactors using TRISO particles. It is found that using the proposed simplified TRISO particles, increases the reactivity of the reactor resulting in higher fuel burnup while in recycling of its spent fuel, the amount of radioactive carbon is reduced by 57%

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Keywords: FBNR, Waste Treatment, Environmental Impact, TRISO Fuel, INPRO

1011 **1. INTRODUCTION**

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The global warming is no longer a philosophical discussion, but is a fact adversely affecting the future of humanity. Generation of nuclear energy does not produce CO2 that is the cause of global warming. The 40 scenarios studied about the mixture of different forms of energy generation resulted that none of them can satisfy the world's demand for energy without considering the nuclear energy [1, 2]. But the present nuclear reactors are not acceptable to public opinion for energy generation [3-5].

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The International Atomic Energy Agency (IAEA) has established the INPRO project [6-8]. INPRO defines a new philosophy and criteria on how to generate nuclear energy without having the adverse effects that are of concern to the public. It is expected that a new era of nuclear energy will soon emerge in which the world will benefit from the environmental friendly and clean nuclear energy.

One proposal is the development of a new nuclear reactor concept called the Fixed Bed Nuclear Reactor (FBNR) [9-12]. At the present the development of FBNR is used as an instrument of training the scientists and researchers to be innovative in the light of INPRO vision and criteria.

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2. MATERIALS AND METHODS

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33 2.1 Characteristics of the FBNR

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The FBNR reactor type is essentially the Pressure Light Water Reactor (PWR) but its fuel elements are spheres of 15 mm in diameter containing TRISO type fuel particles embedded in SiC matrix cladded by stainless steel [13-15].

FBNR is a small reactor without the need of on-site refueling. It utilizes the PWR technology.
It has the characteristics of being simple in design, inherently safe, passive cooling,
proliferation resistant, and reduced environmental impact [16-20].

The FBNR fuel chamber is fuelled in the factory. The sealed fuel chamber is then transported to and from the site. The FBNR has a long fuel cycle time and there is no need for onsite refueling [21]. It is an integrated primary system design.

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45 FBNR Nuclear Reactor is an innovative and small nuclear reactor that meets all the INPRO 46 criteria and philosophy. Small reactors have the advantages of serving the needs of local 47 communities, need low capital investment and do not require expensive power transmission 48 system [22]. FBNR can serve as a multipurpose plant producing electricity, desalinated 49 water, industrial steam, and supply district heating simultaneously [23, 24]. The FBNR is 50 inherently safe that implies total safety and environmentally friendly. The spent fuel of FBNR 51 may not be considered nuclear waste since it can serve as a source of radiation for 52 irradiation purposes which has useful applications in agriculture, medicine and industry.

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The FBNR is a foolproof non-proliferating reactor that cannot be misused for military purposes [25, 26]. It is economic with low capital investment. It can contribute to the solution of ever increasing demand for energy. FBNR uses the well proven PWR technology. The countries that adopt FBNR will participate in the research and development of advanced technology and become the owners of nuclear technology and not merely be the users. Science may be transferred, but technology is not transferable—it is developed.

61 **2.2. Description of the reactor**

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The reactor as shown in the schematic Figure 1, has in its upper part the reactor core and a 63 64 steam generator and in its lower part the fuel chamber. The core consists of a 150 cm 65 diameter cylinder connected to a 100 Cm long cone below it where in turn is connected to a 66 40 Cm diameter helical tube constituting the fuel chamber [27,28]. During the reactor 67 operation, the 15 mm diameter spherical fuel elements are held together by the coolant flow 68 in a fixed bed configuration, forming a suspended core. The coolant flows vertically upward into the core and thereafter to the steam generator [29-31]. The connecting helical tube is 69 made of high neutron absorbing alloy, which is directly connected underneath the core tube. 70 The fuel chamber consists of a helical 40 cm diameter tube flanged to the reserve fuel 71 72 chamber that is sealed by the national and international authorities. A grid is provided at the 73 lower part of the tube to hold the fuel elements within it [32-38]. A steam generator of the 74 shell-and-tube type is integrated in the upper part of the module. The reactor is provided with 75 a pressurizer system to keep the coolant at a constant pressure [38-45]. The pump 76 circulates the coolant inside the reactor moving it upward through the fuel chamber, the core, 77 and the steam generator. Thereafter, the coolant flows back down to the pump [45-47]. At a 78 flow velocity called terminal velocity, the water coolant carries the spherical fuel elements 79 from the fuel chamber up into the core [47-49]. A fixed suspended core is formed in the reactor. In the shutdown condition, the suspended core breaks down and the fuel elements 80 81 leave the core and fall back into the fuel chamber by the force of gravity. The 15 mm in 82 diameter spherical fuel elements are made of simplified TRISO micro spheres embedded in 83 SiC and cladded by stainless steel. The simplified TRISO particle has only one layer of 84 graphite to contain fission products. This will decrease the content of graphite in the fuel thus 85 reduce the problem of fuel recycling.

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Any signal from any of the detectors, due to any initiating event, will not allow the pump to operate, causing the fuel elements to leave the core and fall back into the fuel chamber under the force of gravity, where they remain in a highly subcritical and passively cooled condition. The fuel chamber is cooled by natural convection transferring heat to the water in the tank housing the fuel chamber [49-59].

93 The long-term reactivity is supplied by fresh fuel addition. A piston type core limiter adjusts 94 the core height and controls the amount of fuel elements that are permitted to enter the core 95 from the reserve chamber [60-67]. The control system is conceived to have the pump in the 96 "not operating" condition and only operates when all the signals coming from the control 97 detectors simultaneously indicate safe operation. Under any possible inadequate functioning 98 of the reactor, the power does not reach the pump and the coolant flow stops causing the 99 fuel elements to fall out of the core. The water flowing from an accumulator, which is 100 controlled by a multi redundancy valve system, cools the fuel chamber functioning as the 101 emergency core cooling system. The other components of the reactor are essentially the 102 same as in a conventional pressurized water reactor[68-77].

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Fig. 1: Schematic design of the Fixed Bed Nuclear Reactor (FBNR)

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107 2.3. FBNR Fuel Element

The 15 mm in diameter spherical fuel element is made of TRISO type particles embedded in
 SiC matrix covered by 0.5 mm thick stainless steel cladding. Consider 60% TRISO particles
 embedded in 40% SiC matrix.

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112 The conventional TRISO particle as shown in Figure 2, consists of a fuel kernel composed of 113 UO2 in the center, coated with four layers of three isotropic materials. The four layers are a 114 porous buffer layer made of carbon, followed by a dense inner layer of pyrolytic carbon (PvC), followed by a ceramic layer of SiC to retain fission products at elevated temperatures 115 and to give the TRISO particle more structural integrity, followed by a dense outer layer of 116 117 PyC. TRISO fuel particles are designed not to crack due to the stresses from processes 118 (such as differential thermal expansion or fission gas pressure) at temperatures up to and 119 beyond 1600 ℃, and therefore can contain the fuel in the worst of accident scenarios in a 120 properly designed reactor.

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Since the principle difficulty associated with the recycling of TRISO fuel particles is the presence of graphite, the simplified TRISO particle is used for FBNR where only the first layer of porous carbon is maintained. As it is embedded in SiC matrix, the fuel bed retains the fission products. This will immensely reduce the carbon content of the fuel elements

- 126 which alleviate the problem of fuel recycling. The future detailed study may allow the total
- 127 elimination of graphite.

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Fig. 2: FBNR fuel element

132 Originally the fuel elements were composed of ordinary TRISO particles where the UO2 133 particles were covered by 3 graphite layers. This was chosen to simplify the implementation of design by using the "commercially available" fuel. Also was to create an exaggerated 134 135 safety to increase acceptability of the FBNR concept adequate for an open end fuel cycle. In 136 order to have closed end fuel cycle, one will have additionally extra carbon that is a source 137 of radioactive C-14 problem in fuel reprocessing process. Therefore, we are proposing the 138 use of simplified TRISO particle where the UO2 particle is covered only by one layer of 139 graphite to contain fission products and will be supported by robust SiC matrix. This reduces the graphite content in the fuel by 57%. In the future, we may find that this one layer of the 140 graphite will not be necessary and we can avoid the problem of C-14 totally. As shown in 141 142 Figure 3 for equal FBNR core height, simplified TRISO has higher amount of K-effective than 143 original TRISO. Also at core height 200cm and an enrichment range from 10% to 19%, 144 simplified TRISO has higher amount of K-effective than original TRISO (Figure 4).



146 147 Fig. 3: K-effective with FBNR core height for original and simplified TRISO for 19% enrichment and coolant critical water 148 149



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Fig. 4: K-effective with FBNR at core height of 200 cm for original and simplified TRISO in an enrichment range from 10% to 19% and coolant critical water

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increasing the reactivity of the reactor leading to a longer fuel cycle as seen. 155

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3. RESULTS AND DISCUSSION 157

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159 **3.1 Useful Applications of Spent Fuel**

The spent fuel elements of FBNR before being reprocessed can serve as the source of 160 radiation for irradiation purposes for many years. As shown in Figure 5, all types of point, 161 line, and plane sources can be manufactured and utilized in the irradiators. Figures 6~8 162 163 show some various areas of application for the spent fuel.

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The reactor physics calculations show that such a choice will have additional advantage of





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Fig. 8: Radiation applications in industry

3.2 Waste Treatment Problem 178

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180 The FBNR is a pressurized water reactor but its fuel elements are made of TRISO particles. Therefore, the waste treatment problem is the same as the fourth generation high 181 182 temperature nuclear reactors. Because only a relatively small amount of fuel in a great amount of carbon will contain 14C after burn up, processing these fuels to recover the fissile 183 184 materials presents special problems.

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Historical approaches to processing TRISO-coated fuel involved crushing and burning
operations, which would reduce the fuel elements size (thereby increasing the surface area),
breach the SiC layer, oxidize the metal carbide, and remove the carbon components from
the fuel as gaseous carbon dioxide. The fuel is then easily separated from the remaining SiC
fragments by dissolution in nitric acid.1 The primary disadvantage of this method is the need
to capture and sequester the 14C-containing CO2.

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The crush-leach process may be used as a method to treat GEN IV TRISO-coated reactor
fuels. The method retains the bulk of the carbon components in elemental form, which is
favorable for achieving waste reduction goals.

- 197 4. CONCLUSION
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The use fuel elements made of simplified TRISO particle will produce 57% less radioactive
carbon compared to advanced high temperature reactors which is a source of problem in
fuel reprocessing.

The FBNR spend fuel elements may not be considered as nuclear waste since they serve useful purpose as the source of radiation for irradiation purposes.

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The FBNR spent fuel after serving as source of radiation after some years decaying the fission products may be able to be reused in the reactor since the neutron absorbing isotopes may have decayed out.

At the end of the cycle the reprocessing is done using the same procedure as will be used by the fourth generation high temperature reactors using TRISO particles with the advantage that for FBNR the problem of radioactive carbon is much reduced or may not exist. The cost of fabrication and recycling of such fuel are greatly reduced.

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216 **Supplementary video links**

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218 <u>http://www.youtube.com/watch?v=P8dnbEdqvoQ&authuser=0</u>

219 <u>http://www.youtube.com/watch?v=2w4JZ5tT5vY&authuser=0</u>

220 <u>http://www.youtube.com/watch?v=-g0vh5m25y8&authuser=0</u>

221 http://www.youtube.com/watch?v=XnXcjpGc7N4&authuser=0

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