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

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

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%.

Keywords: FBNR; waste treatment; environmental impact; TRISO fuel; INPRO.

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1. INTRODUCTION

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].

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 present the development of FBNR is used as an instrument in training scientists and researchers to be innovative in the light of INPRO vision and criteria.

2. MATERIALS AND METHODS

2.1 Characteristics of the FBNR

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

The FBNR is a small reactor without the need for 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.

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

It is economic with low capital investment. It can contribute to the solution of ever increasing demand for energy [25,26]. The countries that adopt FBNR will participate in the research and development of the advanced technology and become the owners of nuclear technology and not merely be the users.

2.2 Description of the Reactor

As shown in the schematic Fig. 1, the reactor has in its upper part the reactor core and a steam generator and in its lower part the fuel chamber. The core consists of a 150 cm diameter cylinder connected to a 100 Cm long cone below it where in turn it is connected to a 40 Cm diameter helical tube constituting the fuel chamber [27,28]. During the reactor operation, the 15 mm diameter spherical fuel elements are held together by the coolant flow 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 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 [32-38]. A steam generator of the shell-and-tube type is integrated in the upper part of the module. The reactor is provided with a pressurizer system to keep the coolant at a constant pressure [38-45]. The pump circulates the coolant inside the reactor moving it upward through the fuel chamber, the core and the steam generator. Thereafter, the coolant flows back down to the pump [45-47]. At a flow velocity called terminal velocity, the water coolant carries the spherical fuel elements 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 leave the core and fall back into the fuel chamber by the force of gravity. The 15 mm diameter spherical fuel elements are made of simplified TRISO micro spheres embedded in Sic and cladded by stainless steel. The simplified TRISO particle has only one layer of graphite to contain fission products. This will decrease the content of graphite in the fuel thus reduce the problem of fuel recycling.

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].

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

2.3 FBNR Fuel Element

The 15 mm 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.

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

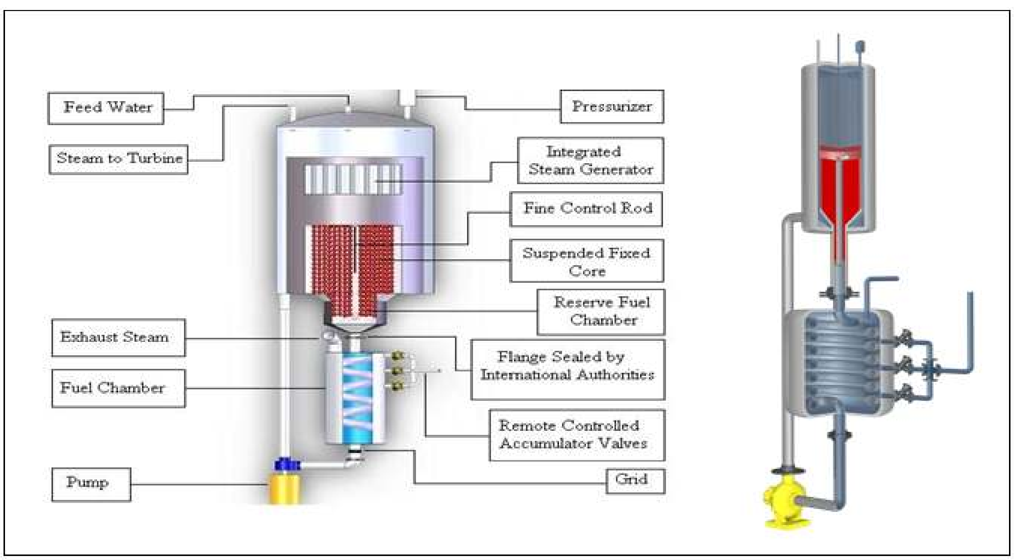

Fig. 1. Schematic design of the Fixed Bed Nuclear Reactor (FBNR)

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

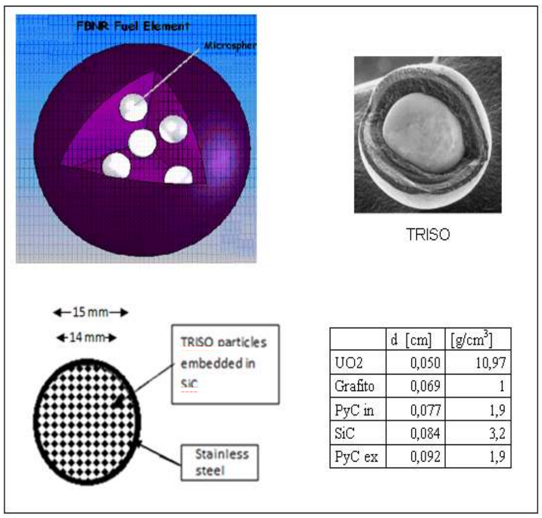

Fig. 2. FBNR fuel element

Originally, the fuel elements were composed of ordinary TRISO particles where the UO2 particles were covered by 3 graphite layers. This was chosen to simplify the implementation of design by using the "commercially available" fuel. Another reason was to create an exaggerated safety to increase acceptability of the FBNR concept adequate for an open end fuel cycle. In order to have closed end fuel cycle, one will have additionally extra carbon that is a source of radioactive C-14 problem in fuel reprocessing process. Therefore, we are proposing the use of simplified TRISO particle where the UO2 particle is covered only by one layer of 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 graphite will not be necessary and we can avoid the problem of C-14 totally. As shown in Fig. 3 for equal FBNR core height, simplified TRISO has higher amount of K-effective than original TRISO. Also at core height 200 cm and an enrichment range from 10% to 19%, simplified TRISO has higher amount of K-effective than original TRISO (Fig. 4).

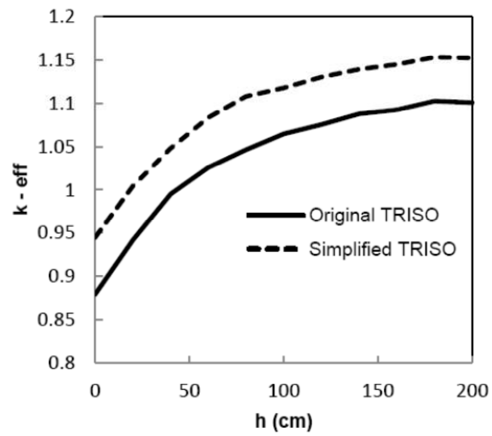

Fig. 3. K-effective with FBNR core height for original and simplified TRISO for 19% enrichment and coolant critical water

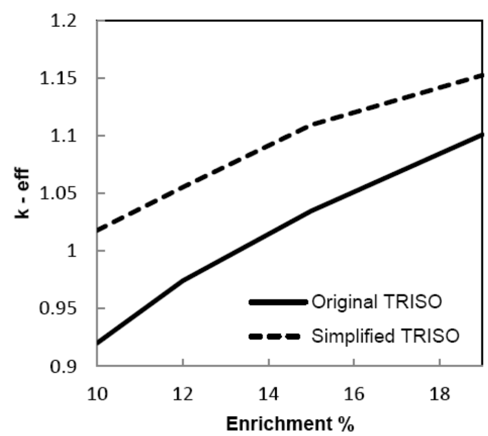

Fig. 4. K-effective with FBNR at core height of 200 cm for original and simplified TRISO in an enrichment range from 10% to 19% and coolant critical water

The reactor physics calculations show that such a choice will have additional advantage of increasing the reactivity of the reactor leading to a longer fuel cycle as seen.

3. RESULTS AND DISCUSSION

3.1 Useful Applications of Spent Fuel

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

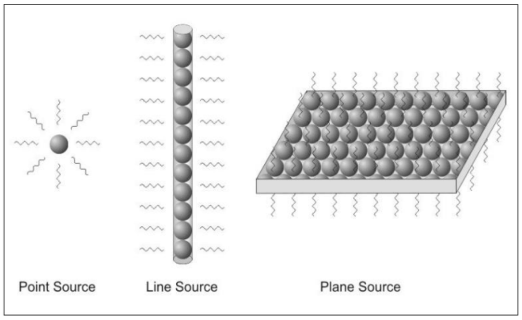

Fig. 5. FBNR spent fuel for radiation applications

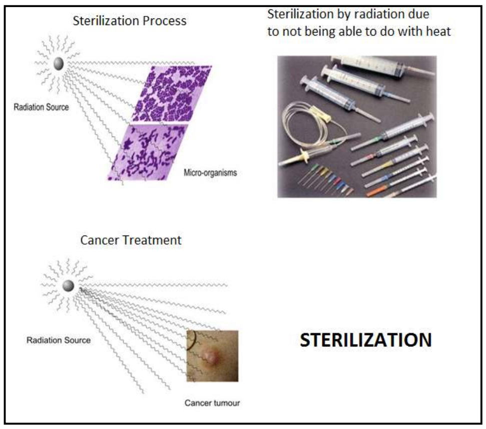

Fig. 6. Radiation applications in medicine

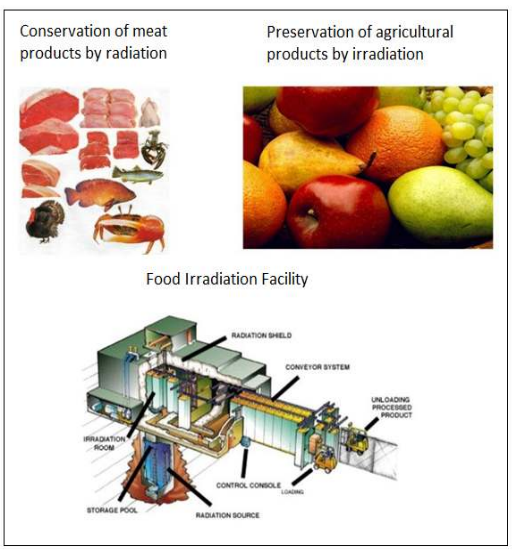

Fig. 7. Radiation applications in Food

3.2 Waste Treatment Problem

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-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 materials presents special problems.

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. The primary disadvantage of this method is the need to capture and sequester the 14C-containing CO2.

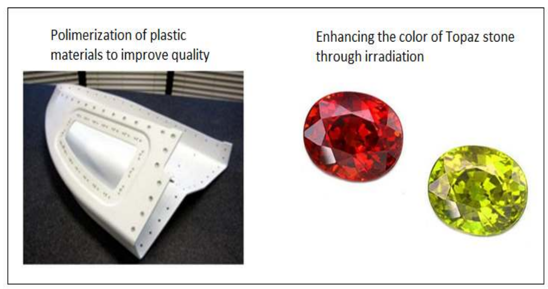

Fig. 8. Radiation applications in industry

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.

4. CONCLUSION

The used 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.

The FBNR spent fuel after serving as a source of radiation and after some years of decaying, can 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 that of the fourth generation high-temperature reactors using TRISO particles; while it has the advantage that the problem of radioactive carbon is much reduced or may not exist. The cost of fabrication and recycling of such fuel are greatly reduced.

Supplementary Video Links

http://www.youtube.com/watch?v=P8dnbEdqvoQ&authuser=0

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

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

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sefidvash F. Nuclear energy for the next century. 2nd European Congress on Economics and Management of Energy in Industry. April 5-9. Estoril; 1994.
2. Sefidvash F. Sustainability and Fixed Bed Nuclear Reactor (FBNR). Sustainability (Basel). 2012;4:1683-1710. DOI: 10.3390/su4081683.
3. Sefidvash F, Thong HV, Hiep DX, Nguyet Minh DT. Some characteristics of the fixed bed nuclear reactor. 4th International Conference on Nuclear & Renewable Energy Resources. October 26-29. Antalya; 2014.
4. Sefidvash F. Fixed bed suspended core nuclear reactor concept. Kerntechnik. 2003;68:56-59.
5. Sahin S, Al-Kusayer TA, Sefidvash F. A pathway to initiate nuclear power technology in developing countries. 5th International Conference on Advances in Mechanical Engineering and Mechanics ICAMEM2010. December 20-22. Hammamet; 2010.
6. Sefidvash F. Preliminary evaluation of the fixed bed nuclear reactor concept using iaea-inpro methodology. 12th International Conference of Nuclear Engineering. April 25-29. Arlington; 2004.
7. Sefidvash F. Fixed bed nuclear reactor concept. International Conference on Innovative Technologies for Nuclear Fuel Cycles and Nuclear Power. June 23-26. Vienna; 2003.
8. Sefidvash F. Preliminary evaluation of the fixed and fluidized bed nuclear reactor concept using iaea-inpro methodology. Kerntechnik. 2004;69(3):127-131. DOI: 10.3139/124.100200.
9. Sefidvash F. Fluidized bed nuclear reactor proposed for the generation iv reactor. International Conference on the New Frontiers of Nuclear Technology: Reactor Physics, Safety and High-Performance Computing. October 7-10. Seoul; 2002.
10. Sahin S, Sahin HM, Acir A. Criticality and burn up evolutions of the Fixed Bed Nuclear Reactor with alternative fuels. Energy Conversion and Management. 2010;51(9).
11. Sahin S, Sefidvash F. The fixed bed nuclear reactor for decentralized energy needs. International Symposium on Peaceful Applications of Nuclear Technologies in the GCC Countries. November 3-5. Jeddah; 2008.
12. Sahin S, Sefidvash F. The fixed bed nuclear reactor concept. Energy Conversion and Management. 2008;49(7).
13. Thong HV, Sefidvash F, Nguyet Minh DT. Some advantages of nuclear fuel under spherical form for nuclear power plant. international Journal of Nuclear Energy, Science and Technology. 2007;3(4):135.
14. Sefidvash F. Thermal hydraulics of the fixed bed nuclear reactor concept. Kerntechnik. 2006;71(3):144-148. DOI: 10.3139/124.100287
15. Sefidvash F. Fluidized bed nuclear reactor proposed for the generation iv reactor. International Atlantic Conference. Aug,11-16. Rio de Janeiro; 2002.
16. Sefidvash F. Preliminary neutronics calculations of the fixed bed nuclear reactor FBNR - Status of Small Reactor Designs without On-site Refuelling. CD-ROM. IAEA-TECDOC-1536. Vienna; 2007.
17. Sahin S, Al-Kusayer TA, Sefidvash FA. Sustainable new nuclear reactor for emerging nuclear countries. The 9th International Conference on Sustainable Energy Technology. August 24-27, (invited paper). Shanghai; 2010.

18. Sefidvash F. A new advanced safe nuclear reactor concept. 15th Brazilian Congress of Mechanical Engineering. Águas de Lindóia; 1999.
19. Sefidvash F. A fixed bed nuclear reactor concept. IAEA Technical Meeting. June 7-11. Vienna; 2004.
20. Sefidvash F. Fixed bed nuclear reactor concept. Innovative Small and Medium Sized Reactors: Design Features, Safety Approaches and R&D Trends. IAEA-TECDOC-1451.Vienna; 2005.
21. Sefidvash F, Petry VJ, Bortoli AL. Passive cooling of a fixed bed nuclear reactor. 4th International Conference on Computational Heat and Mass Transfer. May 17-20, Paris-Cachan; 2005.
22. Sahin S, Sahin HM, Sefidvash F, Al-Kusayer TA. Fixed bed nuclear reactor for electricity and desalination needs of middle-east countries. Proccedings of the 1st International Nuclear and Renewable Energy Conference (INREC10). March, 21-24. Amman; 2010.
23. Sahin S, Sahin HM, Al-Kusayer TA, Sefidvash F. An innovative nuclear reactor for electricity and desalination. International Journal of Energy Research. 2011;35(2):92-102.
DOI: 10.1002/er.1772
24. Sefidvash F. Water desalination by fluidized bed nuclear reactor. Kerntechnik. 1999;64:1-5.
25. Sefidvash FA. Proliferation resistant nuclear reactor concept. Nuclear Atlantic Conference. Aug. 28 - Sept. 2. Santos; 2005.
26. Sefidvash F, Seifritz W. A fool proof non-proliferation nuclear reactor concept. Kerntechnik. 2005;70(4):243-245.
DOI: 10.3139/124.100252
27. Sahin S, Acir A, Sahin HM. Performance analysis of 233U for Fixed Bed Nuclear Reactor. Kerntechnik. 2010;75(5):243-247.
DOI: 10.3139/124.110097
28. International Atomic Energy Agency. Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles. IAEA-TECDOC-1362. Vienna; 2003.
29. Sefidvash F, Mohamad AA. Passive cooling characteristics of the fluidized bed nuclear reactor. 1st International Conference on Applications of Porous Media. June 02-08. Jerba; 2002.
30. Sefidvash F, Mohamad AA. Passive cooling characteristics of the fluidized bed nuclear reactor. 10th International on Emerging Nuclear Energy Systems. Petten; 2000.
31. Sefidvash F, Oliveira CI. Análise térmica do reator nuclear a leito fluidizado. International Atlantic Conference. Aug, 11-16. Rio de Janeiro; 2002.
32. Sefidvash F, Seifritz W. An energy amplifier fluidized bed nuclear reactor concept. Kerntechnik. 2001;66:59-61.
33. Sefidvash F, Laan FV, Cornelius V. An experimental study of fluidized behavior using flow visualization and image. Brazilian Congress of Thermal Engineering and Sciences. October 3-6. Porto Alegre; 2000.
34. Sahin S, Sahin HM, Acir A, Al-Kusayer TA. Criticality investigations for the fixed bed nuclear reactor using thorium fuel mixed with plutonium or minor actinides. Annals of Nuclear Energy. 2009;36(8):1032-1038.
DOI: 10.1016/j.anucene.2009.06.003
35. Sefidvash F. The fluidized bed nuclear heat reactor concept. International Conference and Exhibition on Industrial Heat Engineering. May 24-30. Kiev; 1999.
36. Sefidvash F, Laan FV, Borges V, Cornelius V. Estudo do comportamento de Fluidização usando Método de Visualização do Fluxo. XII Encontro Nacional de Física de Reatores e Termohidráulica. Rio de Janeiro; 2000.
37. Sefidvash F. A high efficiency fluidized bed nuclear reactor cooled by super criticalsteam. XI Encontro Nacional de Física de Reatores e Termohidráulica. August 18-22. Poços de Caldas; 1997.
38. Seifritz W, Sefidvash F. An energy amplifier using fluidized bed nuclear reactor concept. Conference on Nuclear Applications of Accelerator Technology. November 16-20. Albuquerque; 1997.
39. Sefidvash F. Advancement in the fluidized bed nuclear reactor concept. 8th International Conference on Emerging Nuclear Energy Systems. June 24-28. Obninsk; 1996.
40. Sefidvash F. Status of the small modular fluidized bed light water nuclear reactor concept. Nuclear Engineering Design. 1996;167:203-214.
41. Sefidvash F, Borges V. Reator Nuclear a Leito Fluidizado como formador de pessoal. VI Congresso Geral de Energia Nuclear. October 27 - November1. Rio de Janeiro; 1996.

42. Seifritz W, Sefidvash F. Non-linear Noise Theory for the Fluidized Bed Light Water Reactor. Kerntechnik. 1997;62(4):178-183.
43. Sefidvash F. A direct cycle fluidized bed nuclear reactor operating at supercritical pressure. Technologies for Energy Efficiency and Environmental Protection Conference. Cairo. 1995;47-50.
44. Sefidvash F. A preliminary thermal-hydraulic study of the fluidized bed nuclear reactor concept. Kerntechnik.1995;60(1): 48-51.
45. Sefidvash F, Elbern A. The study of transients in the fluidized bed nuclear reactor by linkage and fuzzy methods. 3rd International Conference on Nuclear Engineering. April 23-27. Kyoto; 1995.
46. Borges V, Vilhena MT. dynamical stability of a fluidized bed nuclear reactor. Nuclear Technology.1995;111(2):251-259.
47. Sefidvash F. Un reator nuclear simple y seguro al servicio de la Humanidad. Ecologia y Unidad Mundial. 1994;7:23.
48. Sefidvash F. A Small modular fluidized bed nuclear reactor. International European Nuclear Society Topical Meeting Towards the Next Generation of Light Water Reactors. April 25-28. The Hague; 1993.
49. Sefidvash F. An experimental method to study the porosity of a fluidized bed using gamma ray transmission technique. 45° Reunião Anual da Sociedade Brasileira para o Progresso da Ciência. 1993;1:203.
50. Sefidvash F. Preliminary thermal hydraulic analysis of a fluidized bed nuclear reactor concept. ASME/AIChE/ANS/AIAA National Heat Transfer Conference. 1993;7:378-38.
51. Sefidvash F. The structural design needs of a small modular fluidized bed nuclear reactor. 12th Conference on Structural Mechanics in Reactor Technology. Vol. SD-1, August 15-20. Stuttgart. 1993;261-266.
52. Sefidvash F, Borges V. Métodos operacionais do reator nuclear a leito fluidizado. IX Encontro Nacional de Física de Reatores e Termohidráulica. Outubro 25-29. Caxambu; 1993.
53. Sefidvash F, Borges V. Termohidráulica do reator nuclear a leito fluidizado. IX Encontro Nacional de Física de Reatores e Termohidráulica Outubro 25-29. Caxambu; 1993.
54. Sefidvash F. The future of nuclear energy. 4° Congresso Geral de Energia Nuclear. Julho 5-10. Rio de Janeiro, 1992;2:879-883.
55. Sefidvash F. nuclear energy and the new era. International Specialists Meeting on Potential of the Small Nuclear Reactor for Future Clean and Safe Energy Sources. October 23-25. Tokyo; 1991.
56. Borges V, Vilhena MT. A Fluidized bed nuclear cell calculation. Kerntechnik. 1990; 55(5):315-317.
57. TúlioVilhena M, Sefidvash F. Solution of the heat conduction equation for a Fluidized Bed Nuclear Reactor. Kerntechnik. 1990;55(2):108-111.
58. Sefidvash F, Borges V. Método de cálculos neutônicos de uma célula esférica equivalente a uma cilíndrica, para utilização de códigoscomputacionais para reatores a água leve no reator nuclear a leito fluidizado. VII Encontro Nacional de Física de Reatores. Abril 26-28. Recife; 1989.
59. Sefidvash F. An inherently safe small nuclear reactor concept. American Nuclear Society International Topical Meeting on Safety of Next Generation Power Reactors. May 1-5. Seattle; 1988.
60. Sefidvash F. Um novo conceito de reator nuclear. 39° Reunião Anual da Sociedade Brasileira para o Progresso da Ciência. Julho 12-18. Brasília; 1987.
61. Sefidvash F, Vilhena MT, Streck E, Borges V, Johansson M. State of art of the fluidized bed nuclear reactor concept. IV Congresso Brasileiro de Energia. Agosto 17-21. Rio de Janeiro; 1987.
62. Vilhena MT, Sefidvash F. Análise de transferência de calor em regime transiente em reator nuclear a leito fluidizado utilizando a transformada de laplace. I Simpósio Brasileiro de Transferência de Calor e Massa. Julho 1-3. Campinas; 1987.
63. Sefidvash F. Transient heat transfer in a fluidized bed nuclear power reactor. II Congresso Latinoamericano de Transferência de Calor e Matéria. Maio 12-15. São Paulo; 1986.
64. Sefidvash F. Um Conceito de reator nuclear a leito fluidizado. I Congresso Geral de Energia Nuclear. Março. Rio de Janeiro. 1986;1:333.
65. Sefidvash F, Schaeffer L. Fabricação de revestimento dos elementos de combustível para o reator nuclear a leito fluidizado. III Congresso Brasileiro de

Engenharia e Ciências de Materiais. Dezembro 10-12. Florianópolis; 1986.
66. Sefidvash F. A fluidized bed nuclear reactor concept. Nuclear Technology. 1985;71(3):527-534.
67. Sefidvash F. A simple, small, safe nuclear reactor for developing countries. II Course International on Nuclear Physics and Reactor. February.Bogotá; 1985.
68. Haroon MR, Haroon MR, Sefidvash F. Reactor physics study of organic moderated fluidized bed nuclear reactor. Journal of Natural Science and Mathematics. 1984;24(1):129-146.
69. Sefidvash F. A small safe nuclear power reactor. III Congresso Brasileiro de Energia. Outubro. Rio de Janeiro; 1984.
70. Sefidvash F, Mattos JRL, Eberle LMM, Vilhena MTMB, Schaeffer L, Degrazzia LF, Silvia EZ, Ramsy JEM, Machado ABP. Relatório do progresso alcançado na pesquisa e desenvolvimento de um reator nuclear a leito fluidizado. IV Encontro Nacional de Física de Reatores. Novembro. Itaipava; 1983.
71. Sefidvash F. A nuclear power reactor for developing countries. 1st International Course of Reactor Physics for Developing Countries. Bogotá; 1983.
72. Sefidvash F. Loss of coolant accident in the fluidized bed nuclear power reactor. Atomkernenergie/Kerntechnik. 1983;42(2): 125-126.
73. Sefidvash F. heat transfer in a fluidized bed nuclear power reactor. I Congresso Latinoamericano de Transferência de Calor y Materia. 31 de Octubreal 4 de Noviembro. La Plata; 1982.
74. Sefidvash F. physics and thermal and hydraulic of the fluidized bed nuclear power reactor. II Encontro Nacional de Física de Reatores. Dezembro 12-14. Itaipava; 1982.
75. Sefidvash F. Preliminary thermal design calculation of the fluidized bed nuclear power reactor. Atomkernenergie/ Kerntechnik. 1982;41(1):45-49.
76. Sefidvash F. A nuclear power reactor concept for brazil. Revista Brasileira de Tecnologia.1980;11(3):145-158.
77. Sefidvash F, Haroon MR. Preliminary Reactor Physics calculations of the Fluidized Bed Nuclear Reactor concept. Atomkernenergie/Kerntechnik. 1980;35 (3):191-195.

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