KT_kt100350 – 22.4.04/druckhaus köthen

F. Sefidvash

Preliminary evaluation of the fixed and fluidized bed nuclear reactor concept using the IAEA-INPRO methodology

The International Atomic Energy Agency (IAEA) through its INPRO Project has developed a methodology to evaluate the innovative nuclear reactors. Here is a preliminary application of this methodology to evaluate the Fixed and Fluidized Bed Nuclear Reactor Concept (FBNR). Some of the characteristics of the proposed reactor are: The FBNR is based on pressurized light water reactor technology. It is a small, modular, and integrated primary circuit reactor. The fuel elements of FBNR are 8 mm diameter spherical uranium dioxide pellets cladded by zircaloy or made of compacted TRISO type fuel particles. The reactor core is suspended by the flow of water coolant. The stop in flow causes the fuel elements leaves the reactor core by the force of gravity and goes to the passively cooled fuel chamber or even leaves the reactor and become deposited in the spent fuel pool. It is an inherently safe and passively cooled reactor concept. FBNR in its first phase of development is a fixed bed nuclear reactor and in its next phase will be a fluidized bed nuclear reactor. FBNR in its advanced versions can use supercritical steam or helium gas as coolant, and utilize MOX or thorium fuel.

Vorläufige Evaluation des Festbett- und Wirbelbettreaktors mit Hilfe der IAEAlNPRO Methodologie. *Die Internationale Atomenergiebehörde (IAEA) hat mit den INPROProjekt eine Methodologie entwickelt um innovative Reaktorkonzepte zu evaluieren. In diesem Beitrag wird eine vorläufige Anwendung dieser Methodologie vorgestellt, um die Konzepte des Festbett und Wirbelbettreaktors (FBNR) zu evaluieren. Einige Charakteristika sind: der FBNR basiert auf der Druckwasserreaktortechnik. Es ist ein kleiner, modular aufgebauter und primärseitig integrierter Reaktor. Die Brennelemente des FBNR bestehen aus kugelförmigen $U0_2$-Pellets mit 8 mm Durchmesser und ZirkaloyCladding oder aus kompaktierten TRISO-Partikeln. Das Wirbelbett wird durch den vertikalen Wasserdurchfluss aufrechterhalten; ihr Unterbruch verursacht das Absinken der Brennelemente durch Schwerkraft und ihr Verschwinden in passiv gekühlten Brennelementkammern. Es handelt sich um einen inhärent sicheren, passiv gekühlten Reaktor. Der FBNR ist in seiner ersten Entwicklungsphase ein Festbettreaktor und in der folgenden Phase ein Wirbelbettreaktor. In fortgeschrittenen Phasen kann er sowohl überkritischen Dampf oder Heliumgas als Kühlmittel benutzen als auch Mischoxid oder Thoriumbrennstoff enthalten.*

1 Introduction

The solution to an 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. It will not produce greenhouse gases which continue to be a major environmental concern.

The next generation of nuclear energy systems must be licensed, constructed, and operated in a manner that will provide a competitively priced supply of energy, keeping in consideration an optimum use of natural resources, while addressing nuclear safety, waste, proliferation resistance, and the public perception.

Recognizing both, the positive attributes and shortcomings of the present generations of reactor designs, there are two ongoing activities in the world to identify and help develop the innovative nuclear energy systems which are to be acceptable to the public because they are economic, safe, proliferation resistant, sustainable, and having reduced environmental impact.

One activity has been initiated by the U.S. Department of Energy's Office of Nuclear Energy, Science and Technology which has engaged governments, industry, and the research community worldwide in a wide-ranging discussion on the development of next-generation nuclear energy systems known as "Generation IV". This has resulted in the formation of the Generation-IV International Forum (GIF), a group whose member countries are interested in jointly defining the future of nuclear energy research and development. "Generation IV" refers to the development and demonstration of one or more Generation IV nuclear energy systems that offer advantages in the areas of economics, safety and reliability, sustainability, and could be deployed commercially by 2030. A Generation IV Technology Roadmap is prepared by GIF member countries which are to identify the most promising reactor system and fuel cycle concepts and the R&D necessary to advance these concepts for potential commercialization.

The other activity is by the International Atomic Energy Agency (IAEA). The IAEA initiated in the year 2000 the International Project on Innovative Nuclear Reactors and Fuel Cycles referred to as INPRO. The main objectives of INPRO are to (1) Help to ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner; and (2) 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 nuclear fuel cycles.

To evaluate the innovative nuclear energy systems (INS), the INPRO established basic principles (BP), user requirements (UR), and Criteria (C) in the areas of safety, economics, sustainability and environment, waste management, proliferation resistance, and cross cutting issues in order to establish the INPRO Methodology for assessment of INS.

The INPRO methodology is described in the IAEA publication TECDOC-1362.

The fundamental safety functions for nuclear reactors are to control reactivity, remove heat from the core, and confine radioactive materials and shield radiation. Safety analyses will involve a combination of deterministic and probabilistic assessments, including best estimate plus uncertainty analysis. The development of INS should be based on a holistic life cycle analysis that takes into account the risks and impacts of the integrated fuel cycle.

INPRO has set out two basic principles related to sustainability, one dealing with the acceptability of environmental effects caused by nuclear energy and the other dealing with the capability of INS to deliver energy in a sustainable manner in the future. Protection of the environment from harmful effects is seen to be fundamental to sustainability.

In the area of economics, to be competitive, all component costs, e. g., capital costs, operating and maintenance costs, fuel costs, must be considered and managed to keep the total unit energy cost competitive.

In designing INS, it is important to consider the potential for such system being misused for the purpose of producing nuclear weapons. Generally two types of proliferation resistance measures or features are distinguished: intrinsic and extrinsic. Intrinsic features result from the technical design of INS including those that facilitate the implementation of extrinsic measures. Extrinsic measures are based on governments' decisions and undertakings related to nuclear energy systems.

Issues other than technical requirements are important to potential users of INS. Many of the factors that will either facilitate or obstruct the on-going deployment of nuclear power are Cross Cutting Issues that relate to nuclear power infrastructures, international cooperation, and human resources.

2 Reactor description

The fixed and fluidized bed nuclear reactor (FBNR) concept is modular in design such that any size of reactor can be constructed from the basic module. It is an integrated primary system design. The basic module 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 25-cm-diameter tube in which, during reactor operation, the spherical fuel elements are held together in a fixed bed configuration forming a suspended core. The fuel chamber is a 10-cm-diameter tube, which is directly connected underneath the core tube. A steam generator of the shell and tube type is integrated into the upper part of the module. A neutron absorber shell slides inside the core tube, acting similarly to a control rod.

The pump circulates the coolant inside the module moving up through the fuel chamber, the core, and the steam generator and thereafter flows back down to the pump through the concentric annular passage. At the maximum or terminal fluidizing velocity, the coolant carries up the fuel elements from fuel chamber into the core. In the shut down condition, the suspended core breaks up and the fuel elements leave the core and fall back into the fuel chamber by the force of gravity.

The 8-mm-diameter spherical fuel elements are fed into the reactor core from the top of the module. The spent fuel leaves the module through a valve provided at the bottom of the fuel chamber. The valve is operated by a hydraulic system allowing the spent fuel to be discharged from the fuel chamber into a permanently cooled storage tank. The reactor is provided with a pressurizer system to maintain the module pressure a constant. There are also depressurizer valves which allow the

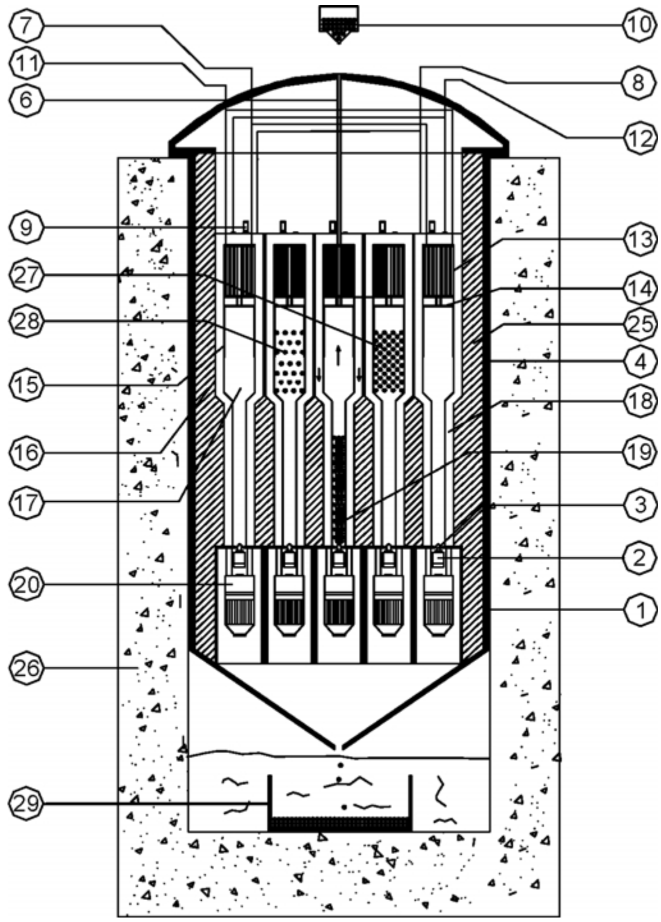

Fig. 1. Schematic design of the reactor
(1) structural support; (2) hydraulic valve opener; (3) fuel discharge valve; (4) graphite jacket; (5) reactor core; (6) level limiter shaft; (7) depressurizer; (8) steam exit; (9) level limiter drive; (10) fuel feed; (11) pressurizer; (12) water entrance; (13) steam generator; (14) level limiter; (15) absorber shell; (16) hexagonal channel; (17) fluidization tube; (18) circular channel; (19) fuel chamber; (20) distributor (21) entrance perfurations; (22) coolant entrance; (23) coolant exit; (24) primary pump; (25) reflector; (26) biological shield, (27) fixed bed core, (28) fluidized bed core, (29) spent fuel pool.

flow of steam from the modules to condenser, in order to reduce the pressure and ease the opening of fuel valves for refueling purpose.

Any hypothetical accident will cut-off power from the pump causing the fuel elements to leave the core and fall back into the fuel chamber by the force of gravity. There, they remain in a highly subcritical and passively cooled condition. The fuel chambers are cooled by natural convection transferring heat to the surrounding air or a water pool.

A detailed heat transfer analysis of the fuel elements has shown that due to a high convective heat transfer coefficient and a large heat transfer surface to volume ratio, the maximum power extracted from the reactor core is not limited to the material temperature limits, but to the maximum mass flow of the coolant.

The core tube is designed in a slightly conical shape in such a manner that the coolant velocity decreases along the height of the reactor. The slow and continuous reduction of coolant velocity has a compacting effect, thus securing a stable fixed or fluidized bed.

The proposed concept is very flexible and has the possibility of devising many types of designs. The proposal for the first stage in development is to have a "fixed" bed nuclear reactor, where the fuel elements fluidize out of the fuel chamber into the core forming a fixed bed at its lowest porosity. This will form a static "suspended core" in the upper part of the module. Therefore, in this case there would not exist any collisions between the fuel elements and eliminates the concerns about the fuel performance. The fully fluidized bed design will be implemented at a later stages when the reliability of fuel integrity in the fluidized condition has been confirmed.

Each module has independently a pump but a single refueling machine serves all the modules. A crown type header on the top of the reactor joins and connects all the modules to a common system where the entering and outgoing fluids are integrated into a unique system.

3 The fuel

There are two options are suggested for the design of fuel element for FBNR: (1) A 8 mm diameter spherical fuel element made of uranium dioxide with the density of 10.5 g/cm^3, cladded by zircaloy (2) A 8 mm diameter spherical fuel element made of compacted Micro-Fuel-Elements (MFE) with the density of 5.9 g/cm3, cladded by silicon carbide.

MFE are coated particles and are similar to TRISO fuel with outer diameters about 2 mm. They consist of 1.5–1.64 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^3 called a 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 0.07–0.1 mm thick corrosion resistant silicon carbide (SiC). Ceramic protection films, manufactured by chemical vapor deposition (CVD) method, create resistance of graphite components against water and steam at high temperatures (450–550 °C at normal operating conditions and up to 1400 °C at accidental conditions). Small fuel elements are able to confine fission products indefinitely at a temperature less than 1400 °C.

4 Design options

The FBNR concept gives the possibility of various design options to be introduced.

4.1 Option 1: Fixed bed with liquid water as coolant

The reactor in its simplest form consists of a pack of spherical fuel elements forming a fixed bed. The fixed bed is suspended and is kept cooled by water which flows up in the core. Therefore, in this case there would not exist any collision between the fuel elements eliminating the concerns about the fuel performance. It is essentially a conventional pressurized water reactor with spherical fuel elements instead of cylindrical ones.

4.2 Option 2: Fixed bed with supercritical steam as coolant

The concept of a direct cycle reactor operating at supercritical pressure is attractive for improving the thermal efficiency drastically to enhance the resulting environmental protection. The reactor combines the fixed bed concept with the idea of using direct cycle reactor operating at supercritical pressure proposed by Oka [4]. The supercritical steam is used as the reactor coolant. The critical pressure of water is 221 bars. When the reactor operates at 250 bars, the supercritical water does not exhibit a change in phase and the concept of boiling does not exist. The water density decreases continuously with temperature.

The coolant entering temperature, on the lower part of the bed, is 310 °C and the exit temperature, on the upper part of the bed, is 416 °C. Therefore, the water density decreases continuously from 0.725 to 0.137 g/cm^3 along the bed. This is an important factor in causing the bed to become a more stable and having fixed core. The recommended pressure of 250 bars is due to the smooth and mild variation of density with pressure in this region resulting in stability of flow in the core. The power production is much higher in this option as the difference in inlet and outlet enthalpy is much higher than a simple pressured or even boiling reactor. The plant thermal efficiency is estimated to exceed 40 % which is about 20 % higher than the conventional pressurized water reactors. The turbines will be smaller compared with the light water reactors by adopting the supercritical steam as the coolant. The superheated steam is fed directly into the turbine. The steam-water separation is not needed for direct cycle reactor. Some other advantages of such a choice besides the high thermal efficiency, will have smaller turbine, no steam generators, and reduced waste heat.

4.3 Option 3: Fluidized bed with water as coolant

The power density may significantly be increased by fluidizing the bed. The increase in turbulence of the coolant will allow a significant increase in power generation. Such a study was related elsewhere [1–3]. In this case the effects of flow on the homogeneity of the fluidized bed porosity and physical interaction between fuel elements need to be further studied.

4.4 Option 4: Fixed bed with helium gas as coolant

In this option, the fixed bed is cooled by helium gas yielding all the advantages of a gas cooled reactor including high efficiency and utilization of direct gas turbine. In this case we have a fast nuclear reactor system. The concept of molten salt having a boiling point of 1400 °C at a low pressure may also be considered.

5 Basic principles

The INPRO methodology in evaluating the innovative nuclear reactors establishes certain basic principles which are obliged to be considered. The basic principle is a statement of a general rule that provides broad guidance for the development of an innovative design of a nuclear energy system. All basic principles shall be taken into account in all areas considered within INPRO; namely, economics, environment, safety, waste management, and proliferation resistance. Below the suggested basic principles are quoted whose basis the evaluation of FBNR are made.

5.1 Basic Principles for Economy (BPE)

BPE 1: The cost of energy from innovative nuclear energy systems must be competitive with that of alternative energy sources.
BPE 2: Innovative Nuclear Energy Systems must represent an attractive investment compared with other major capital investments.

Economic evaluation: The simplicity of design, short construction period, and the reactor being modular in design, result in much smaller capital investment compared to a conventional PWR. Also, the provision of small units match the energy needs as they arise, instead of providing large units to meet the uncertain energy requirements of the future. This will avoid the necessity of a large present investment thus simplifying the raising of the needed funds.

The total electrical energy production cost from the FBNR is estimated at 21 in $/MWh unit. The capital cost being about 16, the fuel cost 3, and the operation cost of 2. This cost value does compete well with alternative energy sources. The reactor being small, shop fabricated, requiring short construction period of about 2 years, involves relatively small investment of about 1000 $/Kw, and meets the incremental increase in energy demands, thus making it an attractive capital investment.

The inherent safety feature of the reactor allows the possibility of having it operate totally by computers without any human operator. Only an inspection and maintenance group is required to periodically do check up and maintenance of various reactors located in different localities.

The total investment requirement to design, construct, and commission the FBNR including investment during construction, is such that the necessary investment funds can easily be raised.

The risk of investment in FBNR is sufficiently low to be acceptable to investors compared to the risk of investment in other energy projects. The FBNR by its nature is a good long term investment opportunity.

5.2 Basic Principles for Environment (BPEV)

BPEV1: Acceptability of Environmental Effects; The expected (best estimate) adverse environmental effects of the innovative nuclear energy system must be well within the performance envelop of current nuclear energy systems delivering similar energy products.
BPEV2: Fitness for Purpose; The innovative nuclear energy system must be capable of contributing to energy needs in the future while making efficient use of non-renewable sources.

Environmental evaluation: The inherent safety feature and smallness of FBNR make it impossible to have a large release of radioactivity to the environment. However, the envisaged simple underground containment will, as a defense-in-depth measure, protect the environment against any possible adverse event. The FBNR is in this respect much superior to the conventional nuclear energy systems.

The various options for FBNR make the utilization of all types of fissile and fertile materials such as uranium, plutonium, and thorium possible. This allows that besides uranium one uses plutonium resulting from the dismantling of nuclear weapons and the enormous quantity of thorium available in countries like Brazil and India. Therefore, the fuel resources for FBNR are sufficient for centuries if not for thousands of years.

5.3 Basic Principles for Safety (BPSN)

BPSNI1: Innovative nuclear reactors and fuel cycle installations shall incorporate enhanced defense-in-depth as a part of their fundamental safety approach and the levels of protection in defense-in-depth shall be more independent from each other than in current installations.
BPSNI2: Innovative nuclear reactors and fuel cycle installations shall prevent, reduce or contain releases (in that order of priority) of radioactive and other hazardous material in construction, normal operation, decommissioning and accidents to the point that these risks are comparable to that of industrial facilities used for similar purposes.
BPSNI3: Innovative nuclear reactors and fuel cycle installations shall incorporate increased emphasis on inherent safety characteristics as a part of their fundamental safety approach.
BPSNI4: Innovative nuclear reactors and fuel cycle installations shall include associated RD&D work to bring the knowledge of plant characteristics and the capability of computer codes used for safety analyses to at least the same confidence level as for the existing s.
BPSSNI5: Innovative nuclear reactors and fuel cycle facilities shall include a holistic life-cycle analysis encompassing the effect on people and on the environment of entire integrated fuel cycle.

Safety evaluation: The fuel elements in FBNR, due to the flow of coolant, form a suspended core, thus any motivation for an accident will cut the power from the coolant pump. Consequently, the fuel elements fall out of the core, by the force of gravity, back into the highly subcritical and passively cooled fuel chamber. As a further measure of defense-in depth, the opening of fuel valve allows the fuel elements leave the fuel chamber and fall, again through the force of gravity, into the permanently cooled fuel storage pool without any human intervention.

The FBNR fuel elements are much more robust than that of a PWR. They are simply loosely packed spherical fuel elements compared to the PWR fuel assemblies which are delicately designed and fabricated structures involving grids and thimble rods.

The FBNR the fuel elements consist of small spheres where each one contain less than 0.25 % of uranium dioxide fuel that exists in a single fuel rod of a conventional PWR, any leakage from such a fuel element is of insignificant consequence. It is very difficult to imagine a scenario causing a major release of radioactivity. Should there occur any accident, the spherical fuel elements can easily be moved out of the reactor into a permanently cooled storage pool, there is no need for any human relocation or evacuation measures.

The FBNR utilizes the PWR technology, thus all the safety basis for it has already been well established by the IAEA and most national nuclear organizations. The computer codes to analize the FBNR are the modified versions of those used for the design and analysis of the conventional pressurized light water reactors. A variety of such codes are available which have been successfully applied to the conventional PWR. Here, only the model of equivalence between a spherical and cylindrical fuel element needs to be verified.

This experimental verifications can simply be done by testing on a single module. The test module simply consists of a pump and a 25 cm diameter tube which is partially filled with 8 mm diameter spherical fuel pellets. It is put in a PWR test facility and the necessary experiments and verifications are made. The pilot plant will consist of a single module reactor which can easily be built at a relatively low cost.

Transportation of the FBNR is much simpler than that of the PWR fuel assemblies. They are simply small spherical pellets instead of being 4 m long fuel assemblies. The decommissioning of FBNR is relatively a simple job, because being modular in design, all parts are small in size and weight. There is no heavy pressure vessel.

A holistic life-cycle analysis of FBNR encompassing the effect on people and on the environment of entire integrated fuel cycle is easily performed. The inherent safety and passive cooling nature of the reactor before hand shows the safe results no matter what scenario is used.

5.4 Basic Principles for Waste Management (BPW)

BPW1: Radioactive waste shall be managed in a such a way as to secure an acceptable level of protection for human health.
BPW2: Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
BPW3: Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
BPW4: Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
BPW5: Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
BPW6: Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
BPW7: Generation of radioactive waste shall be kept to a minimum practicable.
BPW8: Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
BPW9: The safety facilities for radioactive waste management shall be appropriately assured during their lifetime.

Waste management evaluation: The spent fuel from FBNR is in a form and size that can directly be used as a source of radiation for irradiation purposes in agriculture and industry. Therefore, the spent fuel elements from FBNR may not be considered as waste since it can perform a useful function. At a later stage, they can be reprocessed similar to that of the LWRs. Should reprocessing not be allowed, the unwanted fuel elements can easily be vitrified in the modules and deposited directly in a waste repository.

5.5 Basic Principles for Proliferation Resistance (PRPR)

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

Proliferation resistance evaluation: 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.

5.6 Cross cutting issues

The existing nuclear power infrastructures and legal institutions can be used in deploying the proposed reactor concept. The reactor fulfills the objectives of electricity generation, steam production for industrial applications and water desalination.

It is desirable that a World Nuclear Energy Company (WONEC) be formed to become a catalyst in organizing and coordinating the world-wide existing and to-be-created scientific, technological and industrial elements in order to supply the world with clean and safe nuclear energy. WONEC can supply the world with the proposed inherently safe nuclear reactors and will be responsible for its entire fuel cycle. It is to function as a commercial as well as scientific venture with highest international standard. Its shares can be freely traded in the international financial market. WONEC is to operate under auspices of the International Atomic Energy Agency (IAEA). WONEC by the nature of its policies, compositions, and adopted legal and ethical values will have the conditions and credibility to supply nuclear energy and create public confidence in nuclear energy.

The research and development needed are to be performed by the participation of all the interested companies and research organizations of the world. It is to be done in a true spirit of international cooperation and service to humanity. Nuclear technology no longer is a monopoly of any single or group of nations and to various degrees most nations posses them. A new method of consultation and decision making process will be applied in order to safeguard the interest of all. The participants will not need to control WONEC to have their interests guaranteed.

The developing countries are expected to show great interest in participating in WONEC since in this way they will acquire nuclear power without the fear of being exploited by the vendors or making very large investments for an independent national nuclear program. The industrialized countries are expected to support the idea as well, since by participation in WONEC they will benefit from the sales of their technologies to WONEC and partake in a very large nuclear reactor sales market worldwide. Also the problem of nuclear proliferation which is of their great concern will be under control. The WONEC is to operate in the spirit of the new era providing the citizens of the world with clean and safe nuclear energy.

Acknowledgement

The author would like to acknowledge the continuous interest and collaboration of Prof. *Walter Seifritz* with the development of the fluidized bed nuclear reactor concept.

(Received on 1 December 2003)

References

1 *Sefidvash, F.:* A Fluidized Bed Nuclear Reactor Concept. Nuclear Technology 71 (1985) 527

2 *Sefidvash, F.:* Status of the Small Modular Fluidized Bed Light Water Nuclear Reactor Concept. Nuclear Engineering Design 167 (1996) 203
3 *Sefidvash, F.:* A Preliminary Thermal-Hydraulic Study of the Fluidized Bed Nuclear Reactor Concept. Kerntechnik 60 (1995) 48
4 *Oka, Y. et al.:* Systems Design of Direct-Cycle Supercritical Water-Cooled Fast Reactors. Nuclear Technology 109 (1995) 1
5 *Sefidvash, F.:* Fixed Bed Suspended Core Nuclear Reactor Concept. Kerntechnik 68 (2003) 56
6 Visit http://www.rcgg.ufrgs.br/fbnr_ing.ht. about the fluidized bed nuclear reactor and the list of publications see
7 Visit: http://www-pub.iaea.org/MTCD/publications/PDF/te_1362_web.pd about the IAEA-TECDOC-1362: Guidance for the evaluation of innovative nuclear reactors and fuel cycles

The author of this contribution

Prof. *Farhang Sefidvash*, Nuclear Engineering Department, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
E-Mail: farhang@ufrgs.br