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A SMALL SAFE NUCLEAR POWER REACTOR

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Abstract

There is a re-emerging interest in small and medium size nuclear power plants, particularly in the developing countries. At the same time, especially since the Three Mile Island accident, there has grown a greater concern about the safety of the present day nuclear power reactors. These have caused the emergence of many new nuclear reactor concepts. Here a new nuclear reactor design based on the fluidized bed concept is proposed. This reactor concept is simple in design and is especially suited as a small reactor with a high inherent safety.

1. Introduction

The Three Mile Island accident senario was unknown. No one had the nightmare about China Syndrome. No one spoke of Anticipated Transient Without Scram. No one imagined of the Brown Ferry type fire accident. There were few safety regulations. Hundereds of safety issues and problems were unknown. This was the world in which the first commercial nuclear power reactors were born into.

Although safety has always been serious consideration in reactor design, but the reactor concepts were not chosen because they were intrinsically the safest reactors. Most of the present objections to the use of nuclear power have their roots in the reactor safety issue. The approach taken to safety the escalating safety concerns has resulted in excessively complex and expensive plant designs while have not succeeded to create public confidence.

There are many proposals made to remedy the problem that presently nuclear energy is facing, but surprisingly the one and the most direct way out of the difficulties; namely, a new reactor concept has been least emphasized. The reason is that many thought that the water reactors are to be used only for a relatively short period of time, since the breeder was expected to take over soon to solve the supposed problem of the limitations of uranium resources. Now the situation has completely changed. It is generally recognized that large scale application of the breeder is not likely until well into the next century. The new resources of uranium and thorium whichhave been discovered have changed the question of how long uranium resources will last to the question that will they be used in the safe manner or not.

Since the Three Mile Island accident, the reactor safety has been the central issue of the nuclear energy, and the nuclear technologists have been chalanged to come up with a new reactor that is "totally safe". The Kraftwerk Union Comany of West Germany has cume up with "The Modular High-Temperature Reactor" [1], and the General Atomic Company of The United States is proposing, "A new HTGR Plant Concept with Inherently Safe Features Aimed at Small Energy Users Needs" [2]. The Asea-Atom of Sweden offers the concept of the PIUS reactor [3].

A reactor design based on the fluidized bed concept has been also proposed by others [1, 2]. Any size of reactor may be designed from the basic module. The cost of the development, design, fabrication and licensing will therefore be associated to the basic standard module which is consequently reduced.

The proposed reactor concept avail itself especially as a small reactor. The developing countries with a small electrical grids or with the need for water desalination and some industrial countries where small additions to their grids are now being considered or urban and process heating are being planned, are showing a great interest in the small reactors. A scale down of the presently large reactors have shown uneconomical and the necessity for a new reactor concept which alters the traditional scaling laws has become necessary.

The reactor is simple in design such that even the developing countries with modest industrial infrastructures can develop, design and finally construct such a reactor.

Presently the reactor concept is being developed on the basis of slightly enriched uranium being moderated and cooled by light water under pressure. The future studies will include the use of organic coolants with thorium fuel cycle. Of much interest will also be the use of natural uranium with heavy water.

The proposed reactor fulfils the objectives of simplicity in design, inherent safety, economy, standardization, shop fabrication, easy transportability, and the high availability of the reactor.

2. The Reactor Description

The reactor is modular in design; therefore, any size of reactor can be made from the basic module. The total number of modules of the reactor is equal to $3 (n + 1) + 1$ where n is the number of ring of modules surrounding the central module. The reactor uses the fluidized bed concept.

As shown in figure 1, the upper part of the reactor module which include the core and the steam generator consists of a 25 cm diameter fluidizing tube being circumscribed by a hexagonal channel. The lower part of the module consist of a 10 cm diameter fuel storage tube surrounded by a circular channel which in turn is covered by a graphite jacket. The bottom part of the fuel storage tube perforated to allow coolant flow from circular channel to the storage tube. The bottom end of the storage tube is provided with a fuel discharge valve. The valve is opened and closed by a hydraulic jack with a force sufficient to press the valve should it get stucked. In the upper part of the module, a movable sieve acting as a fluidized bed level limiter separates the core from the steam generator. A cylindrical neutron absorber shell connected to the sieve moves along with it. The fresh fuel pellets are fed into the reactor core through the hollow shaft of the level limiter. The once through steam generator tubes fill the upper part of the reactor module. A small pump located immediately on the top of the module circulates the coolant. The module is provided with a depressurizer valve which leads the steam to the condenser. A pressurizer system regulates the module pressure. A graphite reflector surrounds the whole reactor. A pool of water is constructed below the reactor which canbe flooded to a level to cover the valves and certain height of the fuel storage tube.

The fuel pellets are made of 7 mm diameter Uranium dioxide spheres cladded by 0.5 mm zircaloy. The preliminary calculations show the thicknesses of the fluidized tube and the hexagonal channel to be 2 mm and 15 mm respectively.

3. The Reactor Operation

The pump drives the coolant down through the jacket space between the hexagonal channel and the fluidizing tube and thereafter flowing through the annular space between circular channel and the storage tube, passes the perforations at the bottom and flows upward through the fluidizing tube. The coolant velocity in the storage tube, having a smaller diameter, is higher than in the fluidizing tube. Therefore after a certain flow velocity is reached the fuel pellets become transported into the fluidizing tube where there will be at low porosity fluidized state. The fluidized bed height and porosity will directly increase with the flow velocity. Therefore the fluidized bed level is controlled by the pump velocity. The reactor becomes critical at a critical bed height. The reactor physics calculations as performed in detail show that the reactivity of the reactor increases with the bed height to a maximum and thereafeter decreases. The level limiter is set at a certain distance away from the critical height where it defines the maximum reserve reactivity. The level limiter also prevents the escape of fuel pellets from the module in the case of a flow excursion due to a loss of coolant accident. Should the level of the bed increases beyond the absorber cylindrical shell position, the reactivity decreases as the reactor faces a situation similar to control rod insertion.

The coolant removes the heat from the fuel pellets in the core and after passing the level limiter sieve, transfers it to the steam generator before becoming recirculated. In a shutdown state the fuel pellets, due to their weights, participate and become stored in the storage tube where they are in a subcritical state. The decay heat may be removed by a small coolant flow or even by natural convection. In the most severe accident of loss of water from both the storage tube and the water jacket, the graphite jackete has the sufficient heat capacity to absorb most of the decay heat produce. Finally the decay heat is transfered to the pool water coming into contact with the reactor bottom after being flooded. Always the option of opening the fuel discharge valve and removing the fuel pellets exist.

The refuelling may be done while the reactor is in power. All the fuel pellets in a module is changed at a time. The procedure involves depressurizing the module and the opening the fuel discharge valve so the spent fuel pellets may leave the reactor core to be stored in a permanently cooled spent fuel storage tank, or in the pool of water which is provided under the reactor.

4. Conclusion

The feasibility studies of this reactor which have been performed and others which are under study, have shown a great promise for the success in its development. The Atomic Energy Commission of Brazil after having made a detailed analysis of the proposed concept, on December 22, 1983, gave its verdict in favor and support of the continuation of the research and development of this reactor concept.

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3) Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS).

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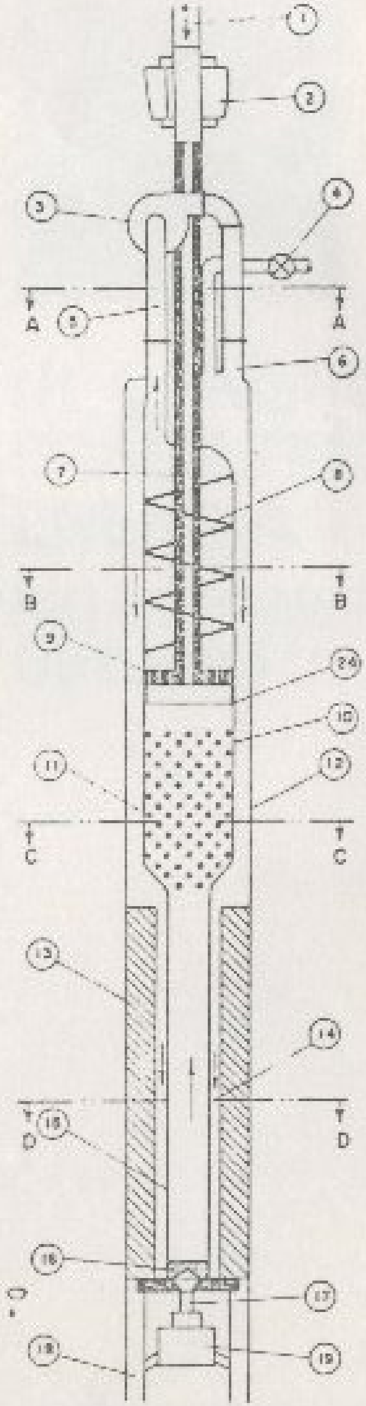
The Legends

Figure 1: (a) The front view of the reactor module, (b) the top view of the 19 module reactor.
(1) Fuel feed, (2) Level limiter drive, (3) Primary pump, (4) Depressurizer valve, (5) Coolant exit, (6) Coolant entrance (7) Level limiter shaft, (8) Steam generator, (9) Level limiter, (10) Fluidization tube, (11) Reactor core, (12) hexagonal channel, (13) Graphite, (14) Circular channel, (15) Fuel storage tube, (16) Entrance perfurations, (17) Fuel discharge valve, (18) Structural support, (19) Hydraulic valve opener, (20) Pressurizer tube, (21) Condenser entrance, (22) Steam exit, (23) Graphite reflector, (24) Absorber shell.



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