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Low Power Fusion Driven -Subcritical Thorium Fission Reactor Concept

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Abstract:

The present study introduces a novel approach to the next generation of fission reactor controlled by a DDμ fusion, addressing the demand for enhanced safety, reduced size, and minimized radioactive waste.

1. Introduction

E. Fermi and others, in 1942, devised a method for controlling atomic reactors by mechanically withdrawing control materials (rods) that were pre-inserted into a supercritical state reactor to maintain criticality. To halt the reaction, the control rods would be inserted mechanically in reverse. This method involves inserting negative reactivity by the control rods absorbing excess neutrons. Reactors of this design have potential risks of exceeding criticality if control is lost. Therefore, multiple measures are implemented to ensure the safety of the reactor. However, the Chernobyl accident is believed to have occurred in this manner, and public opinion remains skeptical of this approach.

In contrast, subcritical reactors only become critical when additional neutrons are introduced from the outside. If the input of external neutrons is halted, the reactions decrease exponentially, and a runaway reaction is fundamentally impossible. This concept should be apparent to anyone with a little thought.

Why, then, since 1942, haven't reactors utilized nuclear fusion for starting up? The reason is that nuclear fusion requires configurations significantly different from reactors, such as large confinement magnetic fields or laser systems, and it demands a different topology and size. Additionally, achieving break-even in fusion still requires a considerable period of research.

2. Muon Catalyzed Fusion

Muon-catalyzed fusion experiments, demonstrating the generation of fusion neutrons, were already conducted in the 1980s. In recent years, precise theoretical analyses have been published [1]. This sequence of experiments and theories indicates that the average free path (approximately the distance traveled) of muons diffusing is comparable to that of high-density neutral gas molecules. From an engineering perspective, the core size of a muon-catalyzed fusion reactor can be determined based on this distance. If the convergence radius of the muon beam can be narrowed down to 25mm, the fusion core could be about the size of a chicken egg. The possibility exists to drive a reactor by inserting a muon-catalyzed fusion core into a subcritical post-modern reactor and generating neutrons. ^{240}Pu and MA to 1/100,000 and 1/1,000,000, respectively. Nuclear reactors using such a Th series as fuel were only implemented at the United States' Shippingport Atomic Station during the 1977-82 period.

3. High-level radioactive waste

Replacing reactor fuel with ^{233}U-2^{32}Th can reduce the probabilities of generating This reactor, which generated an average of 60MW of power, was the first to supply electricity to the commercial power grid. The reactor was safely dismantled, and its spent fuel underwent precise analysis, meticulously investigating burn-up levels, damages, and other factors. Detailed reports have been published. There were no incidents of melting or damage, and the increase in contaminations of Pu and MA remained below analytical limits.

4. Fusion-Driven Subcritical Fission Reactor Concept

A pioneering fission reactor design emerges from the Shippingport Thorium Reactor model. It integrates a core blanket, the "Seed," and an outer cylindrical blanket, the "Sheath." Loaded with radioactive ^{233}U within ^{232}Th, these blankets maintain subcritical conditions. Fusion neutrons, introduced externally, regulate the fission reactor, sustaining it just below criticality.

Neutron interactions within dictate the multiplication factor. Two fusion core arrangements are studied. The first, placing a core at the Seed's center[fig1a], increases neutron gradient, reducing k_{eff}. The second aligns fusion cores at the Seed's boundary[fig.1b], enhancing k_{eff} by saving neutron loss.

Real reactor complexity hinders analytical solutions. A virtual reactor via supercomputer modeling, inspired by Shippingport, captures neutron flow through diffusion equations. Fuel distribution validity is ensured by comparing spent fuel changes with real data. Using this, a novel Low Power Fusion-Driven Subcritical Thorium Fission Reactor aims for completion by 2033.

References
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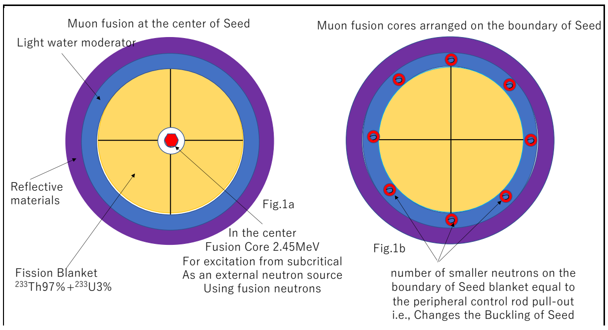

Figure 1. muon fusion neutron sources arrangements