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OPTIMUM UTILIZATION OF NUCLEAR FUEL WITH GAS AND VAPOR CORE REACTORS

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ABSTRACT

Gas and Vapor Core Reactors (G/VCR) are externally reflected and moderated nuclear energy systems fueled by stable uranium compound in gaseous or vapor phase. In G/VCR systems the functions of fuel and coolant are combined and the reactor outlet temperature is not constrained by solid fuel-cladding temperature limitations. G/VCRs can potentially provide the highest reactor and cycle temperature among all existing or proposed fission reactor designs. Furthermore, G/VCR systems feature a low inventory and fully integrated fuel cycle with exceptional sustainability and safety characteristics. With respect to fuel utilization, there is practically no fuel burn-up limit for gas core reactors due to continuous recycling of the fuel. Owing to flexibility in nuclear design characteristics of cavity reactors, a wide range of conversion ratio from almost solely a burner to a breeder is achievable. The continuous recycling of fuel in G/VCR systems allows for continuous burning and transmutation of actinides without removing and reprocessing of the fuel. The only waste product at the backend of the gas core reactors' fuel cycle is fission fragments that are continuously separated from the fuel. As a result the G/VCR systems do not require spent fuel storage or reprocessing.

G/VCR systems also feature outstanding proliferation resistance characteristics and minimum vulnerability to external threats. Even for comparable spectral characteristic, gas core reactors produce fissile plutonium two orders of magnitude less than Light Water Reactors (LWRs). In addition, the continuous transmutation and burning of actinides further reduces the quality of the fissile plutonium inventory. The low fuel inventory (about two orders of magnitude lower than LWRs for the same power generation level) combined with continuous burning of actinides, significantly reduces the need for emergency planning and the vulnerability to external threats. Low fuel inventory, low fuel heat content, and online separation of fission fragments are among the key constituent safety features of G/VCR systems.

KEYWORDS

MHD; Magnetohydrodynamic; Brayton; Rankine

1. INTRODUCTION

Gas and Vapor Core Reactors (G/VCR) are externally reflected and moderated nuclear energy systems fueled by stable uranium compounds in gaseous or vapor phase. A gas core reactor with a condensable fuel such as uranium tetrafluoride (UF_4) or a mixture of UF_4 and other metallic fluorides (BeF_2, LiF, KF, etc.) is commonly referred to as a Vapor Core Reactor (VCR). The single most relevant and unique feature of gas/vapor core class reactors is that the reactor outlet temperature is not constrained by solid fuel-cladding temperature limitations, and is only constrained by the vessel limits, which is far less restrictive. It combines the functions of fuel and coolant into one. Therefore, G/VCRs can potentially provide the highest reactor and cycle temperature among all existing or proposed fission reactor designs.

Gas and vapor fuel reactors feature a low inventory and fully integrated fuel cycle with exceptional sustainability and safety characteristics. With respect to fuel utilization, there is no fuel burn-up limit for gas core reactors due to continuous recycling of the fuel. Owing to the flexibility in nuclear design characteristics of cavity reactors, a wide range of conversion ratio from completely burner to breeder is achievable. The continuous recycling of fuel in G/VCR systems allow for complete burning of actinides without removing and reprocessing of the fuel. The only waste product at the backend of the gas core reactors' fuel cycle is fission fragments that are continuously separated from the fuel. As a result the G/VCR systems do not require spent fuel storage or reprocessing. Due to very low fuel inventory and continuous burning and transmutation of actinides, gas core reactors minimize the environmental impact and stewardship burden.

G/VCR systems also feature outstanding proliferation resistance characteristics and minimum vulnerability to external threats. Even for comparable spectral characteristic, gas core reactor production of fissile plutonium is two orders of magnitude less than Light Water Reactors (LWRs). In addition, the continuous recycling and burning of actinides further reduces the quality of the fissile plutonium inventory. The low fuel inventory (about two orders of magnitude lower than LWRs for the same power generation level) combined with continuous burning of actinides significantly reduces the need for emergency planning and vulnerability to external threats. Low fuel inventory, low fuel heat content, and online separation of fission fragments are among robust features that improve the safety performance and reliability of G/VCR systems under normal operation and abnormal operational transients in compare with other fission power systems.

Due to circulation of fuel in gas core reactors, the entire operation is remote and robotically controlled. Continuous separation of fission products from fuel reduces the delayed source of radiation (after reactor shut down) to a bare minimum. These factors result in significant reduction in the probability of worker radiation overdose during normal operation. Any loss of system pressure, core damage, or fuel leakage result in loss of reactivity that is needed to keep the reactor critical. Because the fuel is in gaseous phase the core damage would be limited to pressure vessel and reflector damage that are not at the same level of severity with any other solid fuel reactor.

2. FUEL CYCLE AND DESIGN CHARACTERISTICS

There are two designs employing a combined power cycle type arrangement for extracting as much electricity from the high quality G/VCR nuclear heat source. The near term, low end, scheme operates at core maximum temperatures of about 1800K and employs a high temperature gas turbine, developed by Siemens-Westinghouse, in a Brayton cycle, with a bottoming superheated steam Rankine heat recovery cycle. In this concept the released nuclear energy is processed and used to power the combined gas turbine and superheated Rankine cycle, achieving conversion efficiency close to 60%. A schematic is shown in **Fig. 1**.

An advanced GCR-MHD concept utilizes closed magnetohydrodynamic (MHD) power generation cycle to directly process and convert fission power at temperatures of 1800-2500K. The rejected heat from the MHD power cycle is used to power single or multiple gas turbine and/or superheated steam cycles. The magnetohydrodynamic generator extracts energy directly from the gas core fluid at the highest possible quality, with sufficient heat left over to drive two heat recovery cycles