Title and keywords immediately orient reader to focus of proposed work

Research Statement

High Fluence Studies for the Advancement of Breed-and-Burn Reactor Design

Keywords: breed-and-burn reactor, neutron fluence, fuel cladding, silicone carbide

Labeled sub-headings show that all pieces of research proposal are included

Abstract

Breed-and-burn (B&B) reactor design is currently limited by a lack of knowledge of material properties under high neutron fluence. For my graduate research, I propose to study properties of materials commonly used as fuel cladding at neutron fluences similar to those that will be found in B&B reactors. I plan to conduct this research at the Massachusetts Institute of Technology, where breed and burn reactor design has been pioneered by Professor Mujid Kazimi and many others, in collaboration with the facilities at Oak Ridge National Labs, where the High Flux Isotope Reactor (HFIR) provides the highest steady-state neutron flux capacity of any research reactor in the US.

Noting who you would like to work with and using what resources shows forethought

Introduction

Introduce reader to the space that you will be discussing

The nuclear infrastructure in the United States, and much of the rest of the world, is based on a once-through light water reactor (LWR) cycle that is costly in terms of both money and uranium resources. The byproducts, depleted uranium and spent fuel, pose environmental and proliferation risks. One alternative is a fast breeder reactor (FBR) cycle, as used in France, that has the ability to produce more mixed-oxide fuel than it consumes fissile uranium; however, the fuel reprocessing in this cycle poses an even more significant proliferation risk.

What is the impact of the problem you propose to study?

A new type of reactor design and infrastructure has been proposed as the next generation of safer and more efficient nuclear reactors: the B&B reactor in a limited separation fuel cycle. Using a high neutron flux in the core, a B&B reactor can be fueled with natural or depleted uranium. This fertile fuel is bred into fissile plutonium, which is then burned directly in the same core, removing the need for chemical fuel reprocessing. However, the high sustained neutron flux comes with a cost; B&B reactor design is currently limited as a result of a lack of knowledge of material properties under high neutron fluence [1].

Clearly define the knowledge gap you hope to address

Objectives

Two main goals will be pursued in this study. First, the properties of cladding materials commonly used in FBRs and LWRs, stainless steel and zirconium alloys, will be studied at high neutron fluence levels [1, 2]. Currently, data has been collected for cladding materials for a fast, > .1 MeV, neutron fluence of about 10^{23} neutrons/cm^2, which corresponds to a damage level of ~200 displacements per atom (dpa). I propose to study materials subjected to ~400dpa; this is the level of damage expected from the neutron fluence necessary to operate a B&B reactor at minimum burnup with natural uranium [1].

Quantifiable objective with justification

The second objective of this study is to explore the possibility of using silicon carbide as a fuel cladding material for these types of reactors. SiC is of interest in this type of reactor because, although it requires higher fuel burnup, it has been shown to soften the neutron spectrum and reduce the required fast fluence [1]. If found structurally stable under these conditions, SiC has the possibility of increasing the allowed operational temperature of B&B reactors, which can lead to an overall performance increase.

Specific impact of possible result

Method

Methods are clearly delineated, showing step-by-step how the study will be carried out

1) Prioritize, acquire and machine samples to specifications for HFIR testing. SiC, as one of the least studied materials at these exposure levels, will be the first type of material to be tested. Then, steel alloys found promising in previous studies will be considered in turn [1].

2) Conduct preliminary analysis of material properties. Initial measurements of shape, volume, stiffness, ductility and other material properties will be carried out using an international standard [2, 3].

3) Irradiate materials at the HFIR at Oak Ridge National Labs. Incremental testing of these materials will be necessary to safely characterize them up to damage levels of ~400dpa.

4) Hot test material properties after irradiation. Large-scale testing of the samples immediately after exposure can be completed at the Irradiated Materials Examination and Testing (IMET) Hot Cell Facility at Oak Ridge. This facility includes all of the necessary equipment and is designed specifically for the testing of irradiated alloys and ceramics.

What special or specific facilities are needed to make this study possible?

5) Re-test material properties after reduction in radiation levels. Smaller samples will be transported back to MIT and analyzed over a longer period of time using the containment facilities on campus.

6) Analyze data and model material properties. Expected results include significant swelling, an increase in tensile strength and a severe reduction in ductility in metallic samples. Accurate determination of these properties is necessary before structural design of B&B reactor cores can be completed.

Impacts

Direct call to broader impacts, both of you and your work

In my previous experience at MIT, I worked closely with public school teachers from underprivileged sections of Boston. While pursuing my study, I hope to be able to work with them to educate young students about nuclear technology. Beginning the scientific and cultural education of the next generation at a young age in the areas surrounding energy and climate change, I am confident, will be the most effective way to truly bring change about.

Possible impacts facilitated by your experience and and location of graduate work

The results of this research have the ability to make a lasting impact on the nuclear energy industry. If these cladding materials prove stable under high burnup conditions, then we will be one step closer to a commercial scale B&B reactor. These types of reactors have many advantages: removing the cost and necessity of uranium enrichment, lowering the proliferation risk normally associated with fuel reprocessing, and potentially allowing more regions of the world to utilize nuclear power. In total then, my research will promote the advancement of a safer and more accessible type of nuclear reactor. Our world is currently faced with intertwined problems of energy demand and climate change. With the reduced fuel costs and proliferation risks in a B&B reactor infrastructure, I believe that nuclear can be a viable option to meet the world's increasing energy needs while gradually reducing its dependence on fossil fuels.

Large-scale, forward-looking impact statement with analysis showing intellectual merit of proposal

References

[1] Robert C. Petroski. *General Analysis of Breed-and-Burn Reactors and Limited-Seperations Fuel Cycles.* PhD thesis, Massachusetts Institute of Technology, February 2011.

[2] S. Murgan et. al. Irradiation testing of structural materials in fast breeder test reactor. In *Research Reactor Application for Materials under High Neutron Fluence.* IAEA, 2011.

[3] Yutai Katoh et al. Thermophysical and mechanical properties of near-stoichiometric fiber cvi sic/sic composites after neutron irradiation at elevated temperatures. *J. Nucl. Mater.*, 403, August 2012.

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