Fabrication and Characterization Methodology of Transformational Challenge Reactor Fuel Form‡

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INTRODUCTION

The Transformational Challenge Reactor (TCR) is a unique advanced gas cooled reactor concept with an advanced manufactured reactor core [1,2]. By exploiting advanced manufacturing, the TCR demonstration targets implementation of advanced in-situ monitoring methods that are expected to immensely reduce the financial and temporal burden of the current nuclear qualification and licensing process while enhancing its rigor.

The fuel form for TCR consists of conventionally fabricated UN-TRISO [3] contained in an advanced manufactured silicon carbide (SiC) matrix. These integrated fuel forms are fabricated using advanced manufacturing methods (3D printing and chemical vapor infiltration methods) [4].

Work described herein gives an overview of the current fuel fabrication and characterization methodology adopted for the successful design, deployment, and operation of this unique microreactor.

DESCRIPTION OF THE WORK

Fabrication Methodology Overview

The TCR fuel consists of stackable modular 3D-shaped compacts that can be massed up into manageable assemblies. The fuel compacts consist of a homogenized SiC matrix in which conventionally fabricated UN-TRISO particles are dispersed at high packing fractions. The homogenized SiC matrix is fabricated using two advanced manufacturing methods: binder jet 3D printing and chemical vapor infiltration (CVI). A typical conventionally fabricated UN-TRISO and a graphic of the integrated fuel form are shown in Figure 1 and 2 respectively.

The fuel fabrication methodology is divided into three discrete serial steps: 1. Fabrication of the matrix exoskeleton using 3D binderjet printing, 2. TRISO fuel loading, 3. Final densification via CVI.

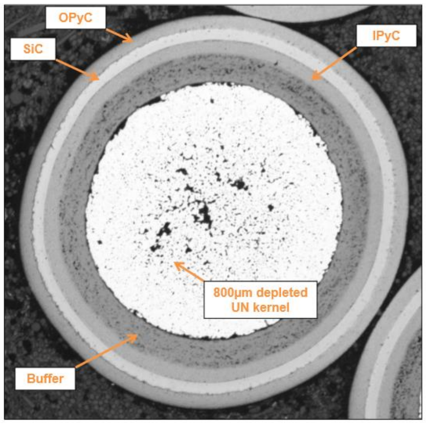

Figure 1: Typical conventionally fabricated UN-TRISO used in TCR fuel compacts, adopted from ref. [5].

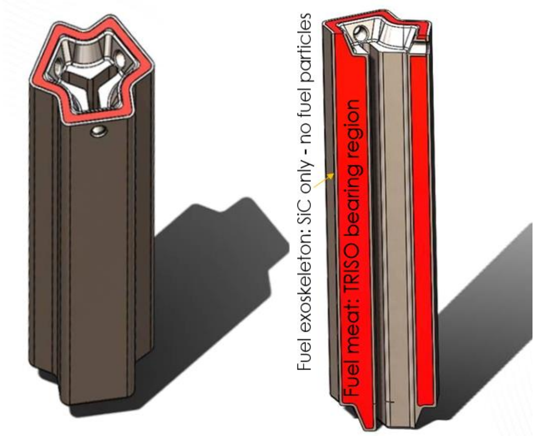

Figure 2: An example of a modular fuel form geometry relevant to the TCR concept.

Binder jetting [6] offers huge advantages in fabricability of complex green components from a refractory ceramic such as SiC which facilitates

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unique design of fuel compacts that would otherwise be extremely difficult to fabricate using traditional methods like hot-pressing and sintering [7]. The current TCR compact exo-skeleton (also known as cannister) is printed in the green state using pure SiC microparticles (400-450 mesh size) and an organic binder on an ExOne's Innovent binder jetting system. The cannister is then filled with conventionally-fabricated UN-TRISO particles and high purity SiC to achieve an exceptionally high TRISO particle packing fraction of 62-65%. An example of a Y-shaped fuel compact being readied for chemical vapor infiltration is shown in Figure 3.

Figure 3: A Y-shaped fuel compact with built-in coolant pathways just before the final chemical vapor infiltration step

As a last step this filled cannister is fully densified using chemical vapor infiltration with MTS precursor. Currently various fuel compact geometries are being studied to evaluate the design and scale-up feasibility. The TCR core is expected to comprise hundreds of modular fuel compacts, all requiring precise quality control during fabrication.

To ensure that nuclear QA and other licensing requirements are met, fabrication parameters at each of these steps is constantly evaluated and documented to help in early detection of flaws that adversely impact fuel behavior.

CHARACTERIZATION OVERVIEW

Post fabrication characterization currently includes non-destructive X-ray tomography examination of the compacts to ascertain the distribution of UN-TRISO particles, porosity, and the packing fraction (Figures 4 & 5). Highly skewed fuel particle distributions could impact the temperature and stress distributions across the compact and even impact core physics. Therefore, control and tailoring of fuel particle distribution is an important fabrication specification.

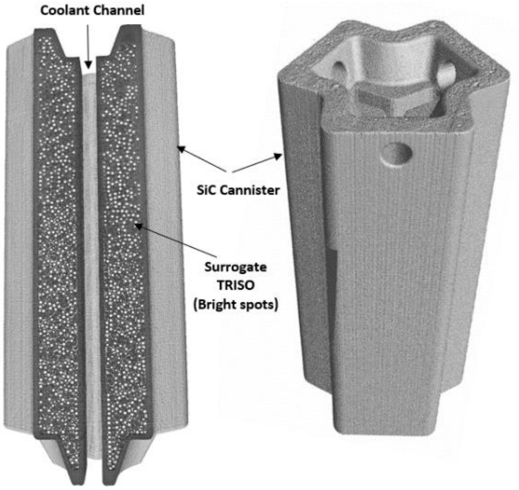

Figure 4: X-ray computed tomography images of Y-shaped fuel compact showing high level of matrix infiltration and compaction

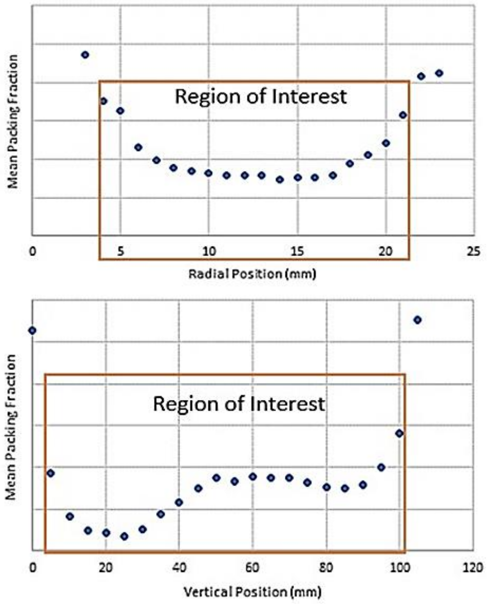

Figure 5: Relative radial and Axial calculated packing fraction in fully compacted Y-shaped compacts from XCT analysis.

IRRADIATION EXPERIMENTS OVERVIEW

Since majority of the components for TCR are to be fabricated using non-traditional, advanced manufacturing methods, there is little available experimental data on the behavior of these components under neutron irradiation. Although the current state of knowledge in radiation effects allows experts to predict the behavior of advanced manufactured material structures in displacement damage inducing neutron irradiation environments, some data is necessary for the purpose of verification.

In order to provide confirmatory data for the TCR program and build a boarder database on advanced manufactured materials for the nuclear energy community, full-fledged irradiation campaigns are ongoing under the TCR program. Fuel irradiation test articles produced by the chosen advanced manufacturing methods will be irradiated in the Nuclear Reactor at the Massachusetts Institute of Technology (MITR) for steady state and the Transient Test Reactor (TREAT) facility at the Idaho National Laboratory for postulated reactivity excursion events. Geometric forms currently being fabricated for irradiation experiments at MITR and TREAT are shown in Figure 7. Although articles are scaled down to suit the planned test requirements, miniaturization is being carefully engineered to maintain accurate coupling of thermo-mechanical stresses between the test articles and scaled compacts intended for use in TCR.

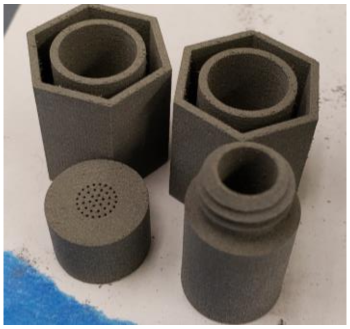

Figure 7: Green hexagonal compacts and Salt-Shaker Capsules for TREAT and MITR irradiations fabricated via Binderjet 3D printing

SUMMARY

Significant effort is currently underway to specify and qualify properties of an optimal fuel compact composed of conventionally-fabricated UN TRISO particles and advanced manufactured SiC matrix, that fits all the operational and safety criteria for the deployment of the TCR. Synergistic efforts include characterization and fine-tuning of the interface between fabrication, documentation and monitoring to assist in mitigating large variations in advanced manufactured compacts that will assist in accelerated licensing.

ACKNOWLEDGEMENTS

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