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GA Technologies Inc.

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Development of Improved TRISO-P Fuel Particle P-PyC Coating	☐ R&D ☒ DV&S ☐ DESIGN	APPROVAL LEVEL 2

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1.0 SCOPE

1.1 INTRODUCTION

Low defect fuels are required for the MHTGR to meet tighter fuel performance for this reactor design (Ref. 1). Exposed heavy metal (HM) contamination levels must be reduced to $\leq$ 1E-5 fraction. Particle coating breakage during the fuel compact fabrication process has been shown to be a major source of HM contamination in the final fuel compacts. Excessive forces are experienced by the coated fuel particles during matrix injection, which leads to coating failure.

Adding a sacrificial, low Young's modulus, overcoating of low density PyC in a fluidized particle bed, was shown to greatly increase the crush strength of TRISO coated fuel particles in 1986 studies (Ref. 2). The new TRISO coated fuel particle design was designated the TRISO-P coated fuel particle type. In 1987, the TRISO-P particle type was used to produce low defect fuel compacts for irradiation in the HRB-21 Capsule (Ref. 3). However, the exposed HM contamination levels for that fuel barely met the product specification limit of $\leq$ 1.0E-5. The small margin of safety between product quality and the specification limit dictated that additional process development of the TRISO-P particle design must be conducted.

1.2 PROGRAM OBJECTIVES

The TRISO-P particle design used successfully to produce in-specification fuel compacts for the HRB-21 Capsule in 1987, had two negative physical characteristics which are presented below:

1.2.1 The mean P-PyC coating thickness of 45 μm, required to reduce coating failure to an acceptable level during compact fabrication in 1987, was shown to occupy excessive volume in the fuel compacts, which will compromise the ability to meet all HM fuel loadings for the MHTGR.

1.2.2 The low P-PyC coating density (0.8 to 1.10 g/cc) required coating process conditions to be used which resulted in a high coating thickness standard deviation. Under these conditions a high mean P-PyC coating thickness was required to assure that all particles in the batch had at least a 35 μm coating. Those particles with thin P-PyC coatings were expected to have lower crush strengths than the average particle in the batch.

These effects can be minimized by allowing a higher P-PyC coating density which would mean that a lower coating thickness standard deviation could be achieved. This would allow a lower mean P-PyC coating thickness to be targeted to achieve higher metal loading.

Improved exposed HM contamination levels are required for the MHTGR over the levels obtained in the 1987 capsule fuel compact fabrication. Improving the P-PyC coating crush strength is expected to reduce fuel particle coating failure during fuel compact fabrication, leading to lower exposed HM contamination levels.

The primary objective of this program is to develop an improved TRISO-P fuel particle coating design which will minimize TRISO coated fuel particle breakage during fuel compact fabrication. The scope of this work will include optimization of the P-PyC coating process, as well as establishing the relationship between the crush strength and particle coating breakage during fuel compact fabrication.

1.3 PROGRAM JUSTIFICATION AND TECHNICAL BASIS

1.3.1 Program Justification

The exposed HM contamination product specification for the MHTGR fuel compacts is set at $\leq$ 1E-5 fraction of exposed uranium and thorium. Particle coating breakage during fuel compact fabrication is the major source of exposed HM contamination. Depositing a low modulus PyC overcoating on the TRISO coated fuel particle increases the crush strength of the material and reduces the HM contamination in the final compact. In 1987 HRB-21 Capsule fuel compacts were fabricated with the TRISO-P particle design, which demonstrated the benefits of this design in reducing particle coating breakage. However, the exposed HM contamination levels were barely within the product specification limit of 1E-5 fraction. Additional improvements in product HM contamination levels for the MHTGR are justified on this basis.

1.3.2 Technical Basis for Work

In 1986 an evaluation of ways to increase particle coating crush strengths was conducted by the author (Ref. 2). Several TRISO coating physical characteristics, such as OPyC and SiC coating thicknesses and adding a sacrificial low Young's modulus overcoating of PyC to the outside surface of the TRISO coated fuel particle were evaluated. TRISO coating crush strengths were improved by as much as a factor of 2x simply by depositing a thin layer (~ 45 μm) of low density PyC to the outside surface of the particle. The substantial increase in crush strength for the overcoated PyC particle was explained from the modeling work reported by Briggs and reported in Ref. 2. In summary, the Briggs' model states that the particle crush strength is a function of the following:

Under a given load the particle crush strength is proportional to the contact area (a). The contact area is proportional to the reciprocal of the cube root of the Young's modulus (E) of the coating ($a = 1/E^{1/3}$). For a low density PyC coating the modulus is very low when compared to a SiC coating. Therefore, the contact area is substantially larger and the crush strength is much larger under a given load.

From this model one can make some assumptions related to the nature of variables affecting crush strengths of coated fuel particles during fuel compact fabrication.

1.3.2.1 TRISO-P coated fuel particles with very thin P-PyC coating thicknesses are expected to have lower crush strengths than thicker coatings at the same PyC density.

1.3.2.2 High density P-PyC coatings have higher Young's moduli and lower crush strengths than low density P-PyC coatings of equal thickness.

1.3.3.3 TRISO-P coated fuel particles with higher crush strengths will experience less breakage during the fuel compact fabrication process.

The work to be conducted in this program will evaluate the key P-PyC coating attributes affecting crush strength. The optimium TRISO-P coated fuel particle coating thickness and density will be determined to produce the highest crush strength for MHTGR fuel particles possible within the HM loading and other considerations. Fuel compacts will be fabricated from the optimium TRISO-P fissile and fertile particles. Exposed HM contamination levels for these fuel compacts will be measured by the HCl Gaseous Leach Method and the data will be compared to the MHTGR product specification requirements.

1.4 EXPERIMENTAL WORK

1.4.1 P-PyC Coating Parameters to be Evaluated

TRISO-P coated UCO and ThO_2 fuel particles will be fabricated to MHTGR product specification as the target for all attributes through the OPyC coating layer. The batches will be composited and split into equal batch sizes on which the P-PYC and the ≤ 5 µm outer seal layers will be deposited.

1.4.1.1 Fissile and Fertile P-PyC Coating Batches

Table 1 lists the mean P-PyC coating attributes that will be used for the test batches:

Table 1

Batch Numbers and Mean P-PyC Coating Attributes*

Batch No.	P-PyC Thickness µm	P-PyC Density g/cc
1	35	1.0
2	40	1.0
3	45	1.0
4	to be determined	1.0
5	35	1.2
6	40	1.2
7	45	1.2

*The fissile particles will use 350 µm ThO_2 as the coating substrate for these coating runs.

The QC properties, such as P-PyC thickness, thickness standard deviation and density, will be determined prior to use in the crush strength evaluations.

1.4.1.2 TRISO-P Fissile and Fertile Crush Strength Evaluations

The crush strengths for the TRISO-P fissile and fertile particles prepared will be determined as a function of the P-PyC coating thickness and density of the particle breakage measurement apparatus. For those materials which show high crush strengths a standard 0.5" diameter by 2" long cylinder fitted with a calibrated load cell will be used to determine the percentage increase in particle coating breakage as a function of the applied load. The exposed particle test samples will be HCl gas leached to determine the fractions of breakage as a function the increasing applied load.

1.4.1.3 Fuel Compacts Containing TRISO-P Fissile and Fertile Particle Evaluations.

Fuel compacts containing TRISO-P UCO and ThO_2 particles fabricated to the P-PyC coating thickness and density showing the greatest crush strengths as per the results obtained above, will be fabricated and high temperature heat-treated. Depleted 350 µm UCO kernels produced on the UCO kernel line and recovered ThO_2 kernels will be used as coating substrate for fuel compact fabrication. Fuel compacts will be fabricated to the highest uranium and thorium HM loading for the MHTGR core design. High temperature 1500°C HCl gaseous leach analyses of the heat-treated fuel compacts will be conducted.

2.0 DOCUMENTATION REQUIREMENTS

The documentation requirements are laboratory notebooks containing records of coating and test data and a test report (RTE) of data and analysis at the completion of the work. The report shall include the optimized P-PyC coating thickness and density range for acceptable ability to avoid crushing during compact production.

3.0 RESPONSIBILITY

C. C. Adams is the responsible engineer for the work, with technical assistance from E. B. Merriweather and K. E. Partain. The work will be conducted as one of the FY-88 tasks of the Fuel Development Branch, O. M. Stansfield, Manager.

4.0 QUALITY ASSURANCE REQUIREMENTS

The quality assurance requirements on this work are in accordance with 10CFR50 Appendix B, as defined in the GA Quality Assurance Program Document (QAPD) 6300 (2/26/88).

5.0 SCHEDULE

The schedule for this program, showing the major milestones, is presented in Table 2 below:

Table 2

Optimized Protective Coating Design Schedule

Milestone	March	April	May	June	July	August
1) Issue Test Specification	------>	4/29/88				
2) Fabricate P-PyC Fissile & fertile Particles		------>	5/13/88			
3) Complete Part. Crush Strength Tests		------>	5/20/88			
4) Fabricate Fuel Compacts			------>	6/10/88		
5) Complete Parameter Evaluations of Coating Attributes Versus Crush Strengths			------>	6/24/88		
6) Complete HM Contamination Analyses				------>	7/1/88	
7) Issue Draft Test Report (RTE)				------>	7/15/88	
8) Issue Final Test Report (RTE)				------>	7/29/88	

6.0 REFERENCES

1) Scheffel, W. J., "HTGR Fuel Product Specification For MHTGR", GA Doc. No. 901588 Issue E, Sept. 26, 1986.

2) Briggs, A., R. W. Davidge, C. Padgett and S. Quickenden, "Crushing Behaviour Of High Temperature Reactor Coated Fuel Particles," Journal of Nuclear Material 61 (1979) 233-242, North-Holland Publishing Co., 1976.

3) Scheffel, W. J., D. T. Goodin and B. F. Myers, "Capsule HRB-21 Preirradiation Report", GA Doc. No. 909551 Issue N/C, March 21, 1988.