OAK RIDGE
NATIONAL LABORATORY
MANAGED BY UT-BATTELLE
FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2008/135

Data Compilation for AGR-2 UCO Variant Coated Particle Batch G73J-14-93074A

John D. Hunn
October 2008

UT-BATTELLE
ORNL-27 (4-00)

Data Compilation for AGR-2 UCO Variant Coated Particle Batch G73J-14-93074A

John D. Hunn
Oak Ridge National Laboratory

Coated particle fuel batch G73J-14-93074A was produced by the Babcock and Wilcox Company (B&W) for possible selection as UCO variant fuel for the Advanced Gas Reactor Fuel Development and Qualification Program's AGR-2 irradiation test. Batch G73J-14-93074A is a single batch of TRISO-coated 425 μm nominal diameter 14% low enrichment uranium oxide/uranium carbide kernels (LEUCO). The TRISO-coatings consist of a ~50% dense carbon buffer layer (100 μm nominal thickness) followed by a dense inner pyrocarbon layer (40 μm nominal thickness) followed by a SiC layer (35 μm nominal thickness) followed by another dense outer pyrocarbon layer (40 μm nominal thickness). For this variant, argon was added to the hydrogen fluidization gas during SiC deposition.

The AGR-2 Fuel Specification (INL SPC-923) provides the requirements necessary for acceptance of the fuel manufactured for the AGR-2 irradiation test. The bulk of the kernels and coated particle acceptance testing was performed at B&W and is not contained in this report. Sample NP-B7979 was sent to ORNL for supplemental characterization. The procedures for the limited characterization and qualification of the particles performed at ORNL are outlined in ORNL product inspection plan AGR-CHAR-PIP-09. The BAFo equivalent optical anisotropies of the inner and outer pyrocarbon layers are reported on Inspection Report Form IRF-09, with a determination as to whether the particle batch satisfied the specified parameters for this property. The batch was found to satisfy the AGR-2 Fuel Specification SPC-923, Rev. 1 for IPyC and OPyC anisotropy.

Also provided in this data package are data on the true BAFo, average particle weight, OPyC open porosity, and SiC soot inclusion defect fraction. True BAFo is calculated as (1+N)/(1-N), where N is the diattenuation. This differs from equivalent BAFo = 1+3N, which is the calculation used by the fuel specification to allow comparison to historical measurements. Average OPyC open porosity was determined using a single sample to be 0.27 ml/m^2. One SiC soot inclusion was found in a sample of 4746 particles. This corresponds to <1E-3 defect fraction at 95% confidence.

Inspection Report Form IRF-09: AGR-2 Coated Particles

Procedure:	AGR-CHAR-PIP-09 Rev. 0
Coated particle composite ID:	G73J-14-93074A
Coated particle composite description:	AGR-2 Variant particle batch

Property	Measured Data				Specification	Acceptance Criteria	Acceptance Test Value	Pass or fail	Data Records
	Mean (x)	Std. Dev. (s)	# measured (n)	k or t value	INL SPC-923				
IPyC anisotropy (BAFo equivalent)	1.0338	0.0007	10	1.833	mean ≤ 1.045	B = x + ts/√n ≤ 1.045	1.034	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.037	pass	
OPyC anisotropy (BAFo equivalent)	1.0248	0.0015	10	1.833	mean ≤ 1.035	B = x + ts/√n ≤ 1.035	1.026	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.031	pass	

Comments

John Thorn — **QC Supervisor**

10-07-08 — **Date**

Accept coated particle composite (Yes or No):	Yes

M. C. [illegible] — **QA Reviewer**

10/14/08 — **Date**

Data Report Form DRF-18A: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - IPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08090201
Sample ID:	NP-B7979
Sample Description:	From G73J-14-93074A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R080090501\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0115	0.0021	0.0006	1.0345	0.0063	0.0018
2	4,5	0.0114	0.0023	0.0006	1.0342	0.0069	0.0018
3	4,6	0.0112	0.0021	0.0006	1.0336	0.0063	0.0018
4	5,4	0.0114	0.0022	0.0006	1.0342	0.0066	0.0018
5	5,5	0.0111	0.0023	0.0005	1.0333	0.0069	0.0015
6	6,4	0.0113	0.0022	0.0005	1.0339	0.0066	0.0015
7	6,5	0.0116	0.0019	0.0006	1.0348	0.0057	0.0018
8	6,6	0.0109	0.0021	0.0006	1.0327	0.0063	0.0018
9	4,7	0.0113	0.0021	0.0005	1.0339	0.0063	0.0015
10	5,7	0.0110	0.0024	0.0006	1.0330	0.0072	0.0018
Average		0.0113	0.0022	0.0006	1.0338	0.0065	0.0017

Mean of average BAFo per particle:	1.0338
Standard deviation of average BAFo per particle:	0.0007

Comments

G. E. Jellison
Operator

9/08/08
Date

Data Report Form DRF-18B: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - OPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08090201
Sample ID:	NP-B7979
Sample Description:	From G73J-14-93074A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R080090501\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0076	0.0020	0.0006	1.0228	0.0060	0.0018
2	4,5	0.0078	0.0020	0.0006	1.0234	0.0060	0.0018
3	4,6	0.0084	0.0022	0.0005	1.0252	0.0066	0.0015
4	5,4	0.0091	0.0023	0.0006	1.0273	0.0069	0.0018
5	5,5	0.0083	0.0023	0.0006	1.0249	0.0069	0.0018
6	6,4	0.0088	0.0021	0.0005	1.0264	0.0063	0.0015
7	6,5	0.0079	0.0022	0.0006	1.0237	0.0066	0.0018
8	6,6	0.0079	0.0024	0.0005	1.0237	0.0072	0.0015
9	4,7	0.0081	0.0022	0.0005	1.0243	0.0066	0.0015
10	5,7	0.0087	0.0021	0.0006	1.0261	0.0063	0.0018
Average		0.0083	0.0022	0.0006	1.0248	0.0065	0.0017

Mean of average BAFo per particle:	1.0248
Standard deviation of average BAFo per particle:	0.0015

Comments

G. E. Jellison
Operator

09/08/08
Date

Data Report Form DRF-18A: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - IPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08090201
Sample ID:	NP-B7979
Sample Description:	From G73J-14-93074A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R080090501\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0115	0.0021	0.0006	1.0233	0.0043	0.0012
2	4,5	0.0114	0.0023	0.0006	1.0231	0.0047	0.0012
3	4,6	0.0112	0.0021	0.0006	1.0227	0.0043	0.0012
4	5,4	0.0114	0.0022	0.0006	1.0231	0.0045	0.0012
5	5,5	0.0111	0.0023	0.0005	1.0224	0.0047	0.0010
6	6,4	0.0113	0.0022	0.0005	1.0229	0.0045	0.0010
7	6,5	0.0116	0.0019	0.0006	1.0235	0.0039	0.0012
8	6,6	0.0109	0.0021	0.0006	1.0220	0.0043	0.0012
9	4,7	0.0113	0.0021	0.0005	1.0229	0.0043	0.0010
10	5,7	0.0110	0.0024	0.0006	1.0222	0.0049	0.0012
Average		0.0113	0.0022	0.0006	1.0228	0.0044	0.0012

Mean of average BAFo per particle:	1.0228
Standard deviation of average BAFo per particle:	0.0005

Comments

Gerald E Jellison
Operator

09/08/08
Date

Data Report Form DRF-18B: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - OPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08090201
Sample ID:	NP-B7979
Sample Description:	From G73J-14-93074A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R080090501\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0076	0.0020	0.0006	1.0153	0.0041	0.0012
2	4,5	0.0078	0.0020	0.0006	1.0157	0.0041	0.0012
3	4,6	0.0084	0.0022	0.0005	1.0169	0.0045	0.0010
4	5,4	0.0091	0.0023	0.0006	1.0184	0.0047	0.0012
5	5,5	0.0083	0.0023	0.0006	1.0167	0.0047	0.0012
6	6,4	0.0088	0.0021	0.0005	1.0178	0.0043	0.0010
7	6,5	0.0079	0.0022	0.0006	1.0159	0.0045	0.0012
8	6,6	0.0079	0.0024	0.0005	1.0159	0.0049	0.0010
9	4,7	0.0081	0.0022	0.0005	1.0163	0.0045	0.0010
10	5,7	0.0087	0.0021	0.0006	1.0176	0.0043	0.0012
Average		0.0083	0.0022	0.0006	1.0167	0.0044	0.0011

Mean of average BAFo per particle:	1.0167
Standard deviation of average BAFo per particle:	0.0010

Comments

G. E. Jellison
Operator

09/08/08
Date

Data Report Form DRF-22: Estimation of Average Particle Weight

Procedure:	AGR-CHAR-DAM-22 Rev. 1
Operator:	Dixie Barker
Particle Lot ID:	NP-B7979
Particle Lot Description:	From G73J-14-93074A AGR-2 Variant Batch
Filename:	\\mc-agr\AGR\ParticleWeight\W08082802_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.1413	0.1454	0.1358	0.1447	0.1647
Number of particles:	136	139	131	139	159
Average weight/particle (g):	1.039E-03	1.046E-03	1.037E-03	1.041E-03	1.036E-03

Mean average weight/particle (g):	1.040E-03
Standard error in mean average weight/particle (g):	1.83E-06

Dixie Barker
Operator

8-28-08
Date

Data Report Form DRF-31: Measurement of Open Porosity using a Mercury Porosimeter

Procedure:	AGR-CHAR-DAM-31 Rev. 1
Operator:	S. D. Nunn
Coated particle batch ID:	NP-B7979-D01
Batch Description:	From G73J-14-93074A AGR-2 Variant batch
Thermocouple Expiration Date:	5/15/09
Penetrometer Expiration Date:	7/10/08
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S08091001\S08091001_DRF31R1.xls

Mean average weight/particle (g):	1.04E-03
Standard error in mean average weight/particle (g):	1.83E-06

Weight of particles (g):	3.9551
Approximate number of particles:	3803
Uncertainty in number of particles:	7
Total envelope volume of sample (cc):	1.318
Average envelope volume/particle (cc):	3.47E-04
Sample envelope density (g/cc):	3.001

Average particle diameter (microns):	8.71E+02
Average surface area/particle (cm2):	2.39E-02
Total sample surface area (cm2):	9.07E+01
Intruded mercury volume from 250-10,000 psia (cc):	2.40E-03
Open porosity (ml/m2):	2.65E-01

Comments

S. D. Nunn
Operator

9/10/08
Date

Data Report Form DRF-32: Counting of Particles with SiC Soot Inclusion Defects by Visual Inspection

Procedure:	AGR-CHAR-DAM-32 Rev. 0
Operator:	Fred Montgomery
Sample ID:	NP-B7979-E01
Sample Description:	From G73J-14-93074A AGR-2 Variant Batch
Folder containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090804\
DRF filename:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090804_DRF32R0.xls

Mean average weight/particle (g):	1.04E-03
Uncertainty in average weight/particle (g):	1.83E-06
Weight of sample of particles (g):	4.936
Approximate number of particles in sample:	4746
Uncertainty in number of particles in sample:	8

Number of particles with SiC soot inclusion defects:	1

Comments

1/4746 corresponds to <1E-3 defect fraction at 95% confidence.
The one defect identified was marginal. It was just a few spots chipped out at about the same radius. It was, however, associated with the presence of several darkfield bands, and probably indicates a region of weaker SiC.

Fred C Montgomery — Operator

10-14-08 — Date

From frame 66, mount 4 of NP-B7979-E01, G73J-14-93074A AGR-2 Variant batch.

This is the only particle out of 4746 identifed with a bright field anomaly in the SiC. The defect is not severe. It was, however, associated with the presence of several darkfield bands, and probably indicates a region of weaker SiC.