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Data Compilation for AGR-2 UCO Variant Coated Particle Batch G73J-14-93073A

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Coated particle fuel batch G73J-14-93073A 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-14-93073A 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-B7958 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 0.41 ml/m^2. One possible SiC soot inclusion was found in a sample of 4729 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-14-93073A
Coated particle composite description:	AGR-2 Variant particle batch

Property	Measured Data			k or t value	Specification INL SPC-923	Acceptance Criteria	Acceptance Test Value	Pass or fail	Data Records
	Mean (x)	Std. Dev. (s)	# measured (n)						
IPyC anisotropy (BAFo equivalent)	1.0349	0.0012	10	1.833	mean ≤ 1.045	$B = x + ts/\sqrt{n} \leq 1.045$	1.036	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	$D = x + ks < 1.06$	1.040	pass	
OPyC anisotropy (BAFo equivalent)	1.0263	0.0011	10	1.833	mean ≤ 1.035	$B = x + ts/\sqrt{n} \leq 1.035$	1.027	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	$D = x + ks < 1.06$	1.031	pass	

Comments

John Thomas — **QC Supervisor**

10-07-08 — **Date**

Accept coated particle composite (Yes or No):	Yes

M. C. Pan — **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:	M08082801
Sample ID:	NP-B7958-B01
Sample Description:	G73J-14-93073A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08090201\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0122	0.0018	0.0005	1.0366	0.0054	0.0015
2	4,5	0.0117	0.0018	0.0005	1.0351	0.0054	0.0015
3	4,6	0.0113	0.0021	0.0005	1.0339	0.0063	0.0015
4	5,4	0.0116	0.0020	0.0005	1.0348	0.0060	0.0015
5	5,5	0.0116	0.0021	0.0005	1.0348	0.0063	0.0015
6	5,6	0.0112	0.0021	0.0005	1.0336	0.0063	0.0015
7	6,4	0.0121	0.0020	0.0005	1.0363	0.0060	0.0015
8	6,5	0.0118	0.0020	0.0005	1.0354	0.0060	0.0015
9	6,6	0.0120	0.0018	0.0005	1.0360	0.0054	0.0015
10	5,7	0.0109	0.0017	0.0005	1.0327	0.0051	0.0015
Average		0.0116	0.0019	0.0005	1.0349	0.0058	0.0015

Mean of average BAFo per particle:	1.0349
Standard deviation of average BAFo per particle:	0.0012

Comments

G. E. Jellison — Operator

9/02/08 — 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:	M08082801
Sample ID:	NP-B7958-B01
Sample Description:	G73J-14-93073A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08090201\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0089	0.0016	0.0005	1.0267	0.0048	0.0015
2	4,5	0.0090	0.0017	0.0005	1.0270	0.0051	0.0015
3	4,6	0.0089	0.0018	0.0005	1.0267	0.0054	0.0015
4	5,4	0.0092	0.0017	0.0005	1.0276	0.0051	0.0015
5	5,5	0.0091	0.0020	0.0005	1.0273	0.0060	0.0015
6	5,6	0.0082	0.0019	0.0005	1.0246	0.0057	0.0015
7	6,4	0.0083	0.0016	0.0005	1.0249	0.0048	0.0015
8	6,5	0.0082	0.0018	0.0005	1.0246	0.0054	0.0015
9	6,6	0.0089	0.0018	0.0005	1.0267	0.0054	0.0015
10	5,7	0.0089	0.0017	0.0005	1.0267	0.0051	0.0015
Average		0.0088	0.0018	0.0005	1.0263	0.0053	0.0015

Mean of average BAFo per particle:	1.0263
Standard deviation of average BAFo per particle:	0.0011

Comments

G. E. Jellison
Operator

9/02/08
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:	M08082801
Sample ID:	NP-B7958-B01
Sample Description:	G73J-14-93073A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08090201\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0122	0.0018	0.0005	1.0247	0.0037	0.0010
2	4,5	0.0117	0.0018	0.0005	1.0237	0.0037	0.0010
3	4,6	0.0113	0.0021	0.0005	1.0229	0.0043	0.0010
4	5,4	0.0116	0.0020	0.0005	1.0235	0.0041	0.0010
5	5,5	0.0116	0.0021	0.0005	1.0235	0.0043	0.0010
6	5,6	0.0112	0.0021	0.0005	1.0227	0.0043	0.0010
7	6,4	0.0121	0.0020	0.0005	1.0245	0.0041	0.0010
8	6,5	0.0118	0.0020	0.0005	1.0239	0.0041	0.0010
9	6,6	0.0120	0.0018	0.0005	1.0243	0.0037	0.0010
10	5,7	0.0109	0.0017	0.0005	1.0220	0.0035	0.0010
Average		0.0116	0.0019	0.0005	1.0236	0.0040	0.0010

Mean of average BAFo per particle:	1.0236
Standard deviation of average BAFo per particle:	0.0008

Comments

A. E. Jellison
Operator

9/02/08
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:	M08082801
Sample ID:	NP-B7958-B01
Sample Description:	G73J-14-93073A AGR-2 Variant batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08090201\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0089	0.0016	0.0005	1.0180	0.0033	0.0010
2	4,5	0.0090	0.0017	0.0005	1.0182	0.0035	0.0010
3	4,6	0.0089	0.0018	0.0005	1.0180	0.0037	0.0010
4	5,4	0.0092	0.0017	0.0005	1.0186	0.0035	0.0010
5	5,5	0.0091	0.0020	0.0005	1.0184	0.0041	0.0010
6	5,6	0.0082	0.0019	0.0005	1.0165	0.0039	0.0010
7	6,4	0.0083	0.0016	0.0005	1.0167	0.0033	0.0010
8	6,5	0.0082	0.0018	0.0005	1.0165	0.0037	0.0010
9	6,6	0.0089	0.0018	0.0005	1.0180	0.0037	0.0010
10	5,7	0.0089	0.0017	0.0005	1.0180	0.0035	0.0010
Average		0.0088	0.0018	0.0005	1.0177	0.0036	0.0010

Mean of average BAFo per particle:	1.0177
Standard deviation of average BAFo per particle:	0.0008

Comments

G. E. Jellison
Operator

9/02/08
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-B7958
Particle Lot Description:	From G73J-14-93073A AGR-2 Variant Batch
Filename:	\\mc-agr\AGR\ParticleWeight\W08082901_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.1593	0.1380	0.1353	0.1489	0.1203
Number of particles:	155	135	133	145	117
Average weight/particle (g):	1.028E-03	1.022E-03	1.017E-03	1.027E-03	1.028E-03

Mean average weight/particle (g):	1.024E-03
Standard error in mean average weight/particle (g):	2.09E-06

Dixie Barker
Operator

8-29-08
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-B7958-D01
Batch Description:	From G73J-14-93073A AGR-2 Variant batch
Thermocouple Expiration Date:	5/15/09
Penetrometer Expiration Date:	7/10/08
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S08091101\S08091101_DRF31R1.xls

Mean average weight/particle (g):	1.02E-03
Standard error in mean average weight/particle (g):	3.87E-06

Weight of particles (g):	3.8113
Approximate number of particles:	3722
Uncertainty in number of particles:	14
Total envelope volume of sample (cc):	1.276
Average envelope volume/particle (cc):	3.43E-04
Sample envelope density (g/cc):	2.988

Average particle diameter (microns):	8.68E+02
Average surface area/particle (cm2):	2.37E-02
Total sample surface area (cm2):	8.82E+01
Intruded mercury volume from 250-10,000 psia (cc):	3.60E-03
Open porosity (ml/m2):	4.08E-01

Comments

S. D. Nunn
Operator

9/11/08
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-B7958-E01
Sample Description:	From G73J-14-93073A AGR-2 Variant Batch
Folder containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090803\
DRF filename:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090803_DRF32R0.xls

Mean average weight/particle (g):	1.02E-03
Uncertainty in average weight/particle (g):	2.09E-06
Weight of sample of particles (g):	4.842
Approximate number of particles in sample:	4729
Uncertainty in number of particles in sample:	10

Number of particles with SiC soot inclusion defects:	1

Comments

1/4729 corresponds to <1E-3 defect fraction at 95% confidence.
The one defect identified looked like it may be a chip in the SiC at the IPyC interface. Initial polish on mount 4 resulted in 5 particles with SiC gouges. These were removed by additional polishing, except for the deep one at the IPyC/SiC interface, which was identified as a defect.
Overall, the SiC/OPyC surface looks rough and is probably a strong interface.

Fred C. Montgomery — Operator

10-14-08 — Date

From frame 43, mount 4 of NP-B7958-E01, G73J-14-93073A AGR-2 Variant batch.

This is the only particle out of 4729 identified with a bright field anomaly in the SiC. The defect appears to be a relatively large and deep chip at the IPyC interface. This may be related to a weakened region caused by a soot inclusion. However, normally a soot inclusion will extend over a greater arc.