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NATIONAL LABORATORY

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FOR THE DEPARTMENT OF ENERGY



ORNL-27 (4-00)

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## **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  $\mu\text{m}$  nominal diameter 14% low enrichment uranium oxide/uranium carbide kernels (LEUCO). The TRISO-coatings consist of a ~50% dense carbon buffer layer (100  $\mu\text{m}$  nominal thickness) followed by a dense inner pyrocarbon layer (40  $\mu\text{m}$  nominal thickness) followed by a SiC layer (35  $\mu\text{m}$  nominal thickness) followed by another dense outer pyrocarbon layer (40  $\mu\text{m}$  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.

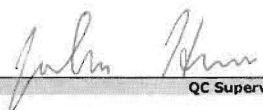
Also provided in this data package are data on the true BAFO, average particle weight, OPyC open porosity, and SiC soot inclusion defect fraction. True BAFO is calculated as  $(1+N)/(1-N)$ , where N is the diattenuation. This differs from equivalent BAFO =  $1+3N$ , which is the calculation used by the fuel specification to allow comparison to historical measurements. Average OPyC open porosity was determined using a single sample to be 0.27 ml/m<sup>2</sup>. 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 |

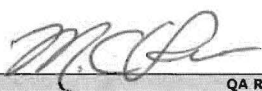
| Property                          | Measured Data |               |                |              | Specification                    | Acceptance Criteria              | Acceptance Test Value | Pass or fail | Data Records |
|-----------------------------------|---------------|---------------|----------------|--------------|----------------------------------|----------------------------------|-----------------------|--------------|--------------|
|                                   | 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 $\leq 1.045$                | $B = x + ts/\sqrt{n} \leq 1.045$ | 1.034                 | pass         | DRF-18       |
|                                   |               |               |                | 3.981        | dispersion $\leq 0.01 \geq 1.06$ | $D = x + ks < 1.06$              | 1.037                 | pass         |              |
| OPyC anisotropy (BAFo equivalent) | 1.0248        | 0.0015        | 10             | 1.833        | mean $\leq 1.035$                | $B = x + ts/\sqrt{n} \leq 1.035$ | 1.026                 | pass         | DRF-18       |
|                                   |               |               |                | 3.981        | dispersion $\leq 0.01 \geq 1.06$ | $D = x + ks < 1.06$              | 1.031                 | pass         |              |

|                 |
|-----------------|
| <b>Comments</b> |
|                 |

  
 QC Supervisor

10-07-08  
 Date

|   |     |
|---|-----|
| Accept coated particle composite (Yes or No): | Yes |
|---|-----|

  
 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

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|  |
|--|

*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 BA <sub>Fo</sub> = 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 BA <sub>Fo</sub> per particle:               | 1.0248 |
| Standard deviation of average BA <sub>Fo</sub> 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

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*G. E. Jellison*

Operator

*09/08/08*

Date

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

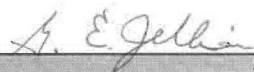
|                         |   |
|-------------------------|---|
| Procedure:              | AGR-CHAR-DAM-18 Rev. 1                  |
| Operator:               | G. E. Jellison                          |
| Mount ID:               | M08090201                               |
| Sample ID:              | 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

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|  |
|--|



Operator



Date

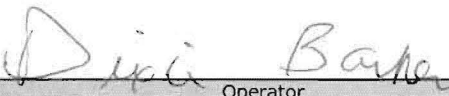


## Data Report Form DRF-22: Estimation of Average Particle Weight

|                           |   |
|---------------------------|---|
| 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  |

  
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 (cm <sup>2</sup> ):  | 2.39E-02 |
| Total sample surface area (cm <sup>2</sup> ):      | 9.07E+01 |
| Intruded mercury volume from 250-10,000 psia (cc): | 2.40E-03 |
| Open porosity (ml/m <sup>2</sup> ):                | 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 identified 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.

