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Evaluation of a Blender for HTGR Fuel Particles

D. R. Johnson

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EVALUATION OF A BLENDER FOR HTGR FUEL PARTICLES

D. R. Johnson

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ABSTRACT

An experimental blender for mixing HTGR fuel particles prior to molding the particles into fuel rods was evaluated. The blender consists of a conical chamber with an air inlet in the bottom. A pneumatically operated valve provides for discharge of the particles out the bottom of the cone. The particles are mixed by periodically levitating with pulses of air. The blender has provision for regulating the air flow rate and the number and duration of the air flow pulses. The performance of the blender was governed by the particle blend being mixed, the air flow rate, and the pulse time. Adequately blended fuel rods can be made if the air flow rate and pulse time are carefully controlled for each fuel rod composition.

INTRODUCTION

The fuel for the High-Temperature Gas-Cooled Reactor (HTGR) consists of rods 1/2—5/8 in. in diameter and 2—2 1/2 in. long. The rods contain two types of coated fuel particles, fissile and fertile, as well as graphite filler particles. The particles are bonded together in a close-packed array by a continuous carbonaceous matrix to form the fuel rods. The fuel rods are contained within prismatic graphite blocks. It is important to the performance of the fuel that the two types of fuel particles be uniformly distributed within the fuel rods; otherwise, localized temperatures become excessively high during reactor operation, resulting in premature failure of particle coatings and fission product release into the helium coolant gas.

During the remote refabrication of HTGR fuel rods, the three types of particles contained within each fuel rod must be blended prior to introduction of the fuel rod binder. However, the particles vary significantly in size and density (Table 1). The different particles naturally tend to segregate as they are loaded into a fuel rod mold; thus it is important that an effective particle blender be developed.

Table 1. Nominal Size and Density of HTGR Fuel Particles

Type	Diameter, μm	Density, g/cm^3
Fissile	660	2.25
Fertile	820	3.19
Shim	500–1100	1.9

This study was principally concerned with the testing of a single-inlet conical air blender designed by General Atomic Company (GAC). The air blender can be adjusted for best performance by varying the air flow, number of air pulses, and pulse time. A range of fuel rod compositions considered to be all-inclusive for HTGR fuel refabrication was included in the investigation.

The performance of the blender was determined by measuring a GAC-derived fuel inhomogeneity index and comparing the inhomogeneity index with the fuel specification for homogeneity. The data were also analyzed in terms of a simple maximum deviation from the mean.

EXPERIMENTAL PROCEDURE

The axial inhomogeneity of the 1/2-in.-diam fuel rods blended by the air blender was determined by mechanically separating the unbonded rods into five equal axial sections and counting the number of fissile and fertile particles in each section. Fuel particles containing normal uranium were used to model the highly enriched ^{233}U recycle particles.

The air blender used in this study was built at ORNL according to GAC's drawing PDP-2850-A. The air blender was installed on a laboratory bench with provisions for controlling air flow rate, number of air pulses, and pulse time (Fig. 1). The time between pulses (1 sec) was selected to conservatively allow sufficient time for the particles to settle to the bottom of the blender before the next pulse began.

The blender was unloaded into a specially designed 1/2-in.-diam fuel rod mold that allows the unbonded rod to be divided into five equal axial sections (Fig. 2). The position of the bottom of the mold is

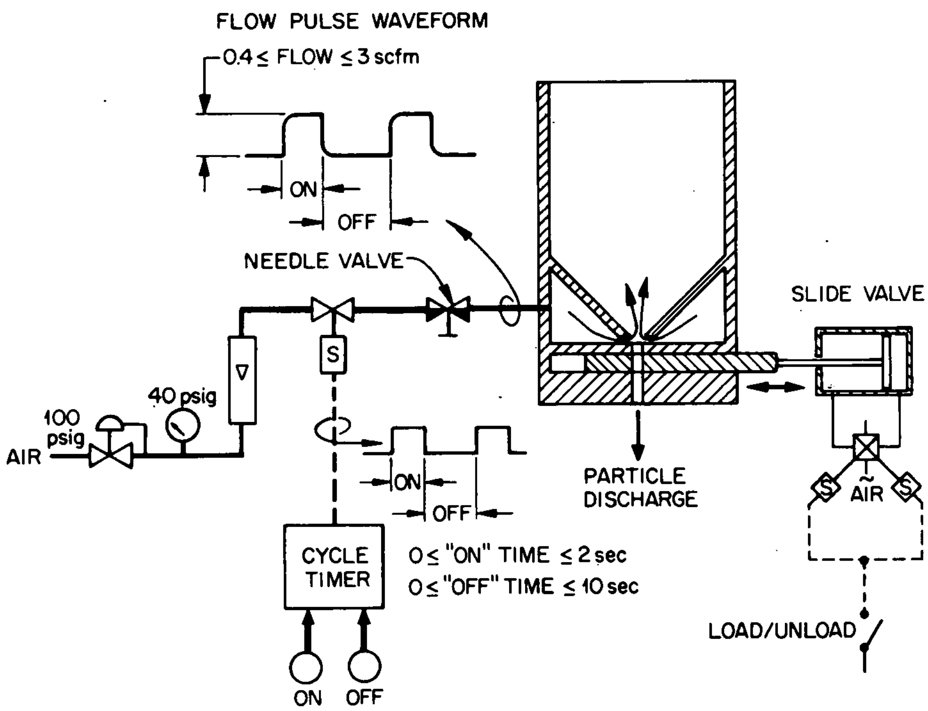

Fig. 1. Experimental HTGR Fuel Particle Blender.

adjustable via a micrometer. Once a blended charge had been loaded into the mold, the height of the column of particles was accurately determined with the micrometer. The bottom of the mold was then raised a vertical distance equal to one-fifth the height of the column of particles. No visible rearrangement of the particles occurred as the particle stack was moved in the mold. The top one-fifth of the particles was thus elevated into a cavity in a Teflon slide. The slide was repositioned to discharge the particles through a conical hole into a sample bottle. The procedure was repeated to accurately divide each particle stack into five equal axial segments.

The graphite shim particles were separated from the fissile and fertile particles in each sample via a shape spearation device.[1] The shim particles were discarded, after which the number of fissile

[1]F. J. Furman, J. T. Meador, and J. D. Sease, *Microsphere Handling Techniques*, ORNL-TM-2782 (March 1970).

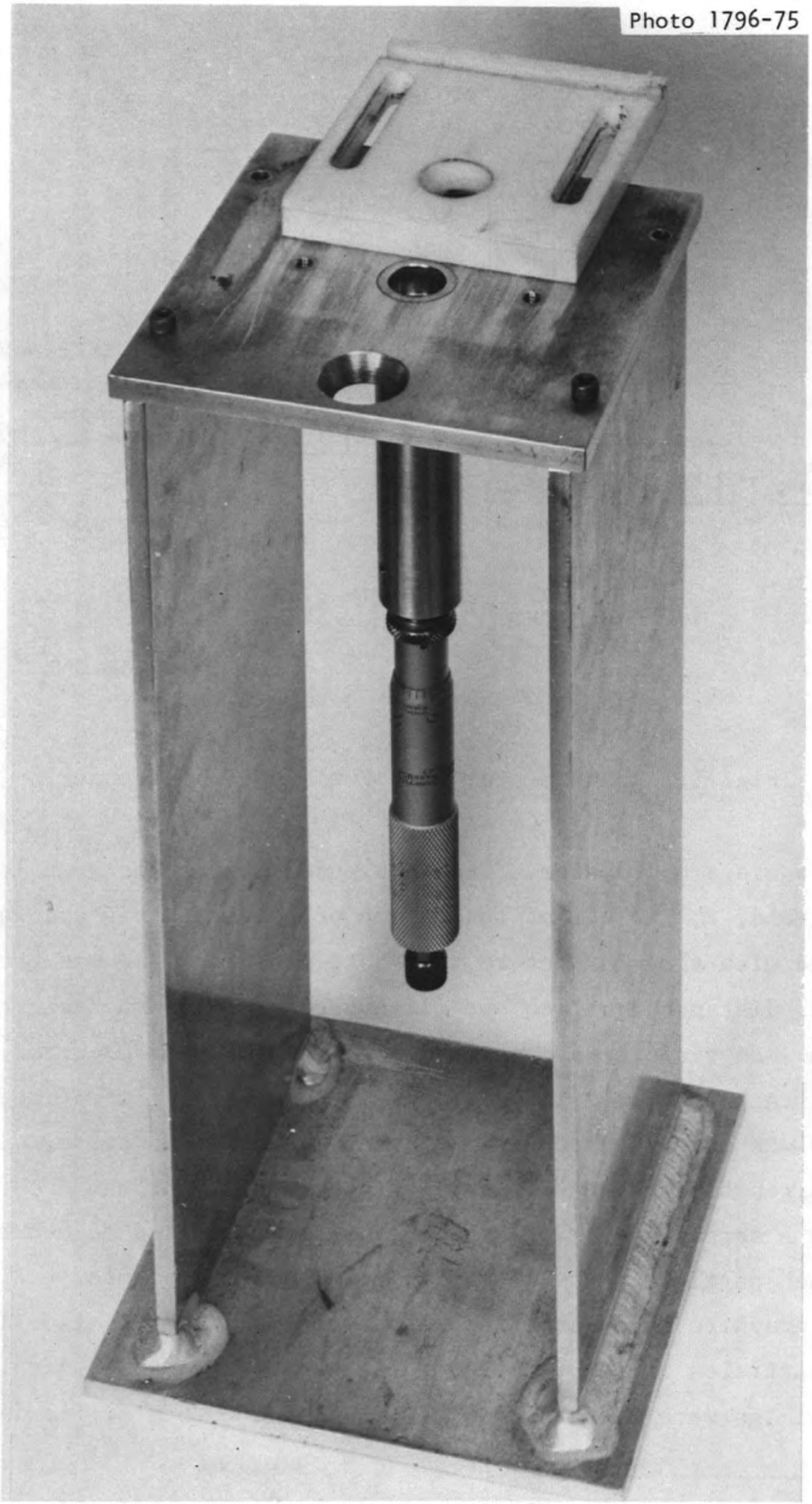

Fig. 2. Special HTGR Fuel Rod Mold for Evaluating Blenders.

and fertile particles in each sample were counted. The particles were counted automatically on a particle size analyzer that is described elsewhere.[2] The difference in size of the two types of particles allowed the separate counting of each type. The particle size distributions (Fig. 3) did not significantly overlap, thus allowing the unambiguous determination of fertile and fissile particles in each one-fifth rod segment.

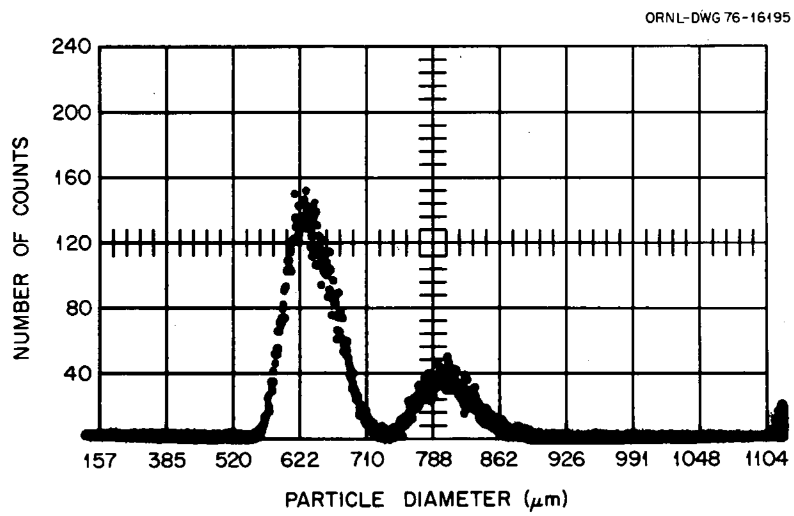

Fig. 3. Cathode-Ray Tube Display From Particle Size Analyzer Showing Particle Size Distributions for Fertile and Fissile Particles. Note that the particle diameter scale is nonlinear.

The radial and axial inhomogeneity indexes H_R' and H_A' are defined in the fuel specifications as follows: the fuel rod is separated into ten equal volumes, five axial layers with each layer divided into an inner core and an outer annular ring; then

$$\text{the radial inhomogeneity index} = H_R' = \frac{L_i' - L_o'}{L_s} , \tag{1}$$

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[2] W. H. Pechin, "Sample Inspection — 2107 (ORNL Lead)," *Gas-Cooled Reactor Programs Annu. Prog. Rep. Dec. 31, 1973*, ORNL-4975, pp. 53–55.

$$\text{the axial inhomogeneity index} = H_A' = \frac{L_i' + L_o'}{2L_s} - 1 , \tag{2}$$

$$L_i' = \frac{L_i + 0.2\ [L_i\ (\text{above}) + L_i\ (\text{below})]}{1.4} , \tag{3}$$

$$L_o' = \frac{L_o + 0.7\ [L_o\ (\text{above}) + L_o\ (\text{below})]}{2.4} , \tag{4}$$

where

L_i = measured uranium or thorium loading in the inner core of rod in an axial slice,

L_o = measured uranium or thorium loading in the outer ring of rod in an axial slice,

L_s = specified uranium or thorium loading,

L_i (above), L_o (above) = L_i, L_o at axial level above axial level under consideration, and

L_i (below), L_o (below) = L_i, L_o at axial level below axial level under consideration.

To evaluate L_i' or L_o' at either end of the rod, it should be assumed that there are homogeneous rods above and below. For each segment of a fuel rod, H_R' and H_A' are calculated. The reported values for a rod are the numerical maxima.

These expressions are for the 5/8-in.-diam fuel rods designed for the large HTGR. There is presently no specification for radial inhomogeneity in the 1/2-in.-diam Fort St. Vrain fuel rods considered in this study. The axial inhomogeneity for 1/2-in. rods was calculated from the above expressions by assuming perfect radial homogeneity. With that assumption, the expression for the axial inhomogeneity reduced to the following:

$$H_A' = \frac{(0.5655)L + 0.2173\ (L_{over} + L_{under})}{\text{mean}} - 1 , \tag{5}$$

where

L = number of particles, and

mean = average L for the five rod segments.

For an end segment, mean is used for L_{over} and L_{under}.

The expression is evaluated separately for the fissile and fertile particles. In general, the inhomogeneity indexes for the two particle types may be independent. For example, it is possible for the fertile particles to be uniformly distributed, while the fissile particles are segregated at one end of the rod and the shim at the other. In this blending study the contribution of variations in fuel dispensing to rod performance were not considered. Thus, the actual rod loading (i.e., the mean of the five segments) is used in Eq. (5) rather than the specified rod loading.

The ^{233}U fissile particles generate approximately twice as much heat in the HTGR as the fertile particles. Thus, the uranium inhomogeneity should be given twice as much weight as the thorium inhomogeneity. For this reason and to simplify the interpretation of results, only the fissile data were analyzed. That is, the effectiveness of the blender was judged via the uranium inhomogeneity.

In addition to the uranium inhomogeneity index, a simple maximum deviation from the mean, K, was calculated and analyzed. The K index was defined for each rod segment as the absolute value of the deviation from the mean expressed as a percentage of the mean $\overline{L}$:

$$K = \left| \frac{L - \overline{L}}{\overline{L}} \right| \times 100 \ . \tag{6}$$

The numerical maximum of the five segments for each rod is reported as the K index.

In the investigation of the air blender, the following variables were considered:

fissile particle loading: 0.5, 1.25, 2.0, 2.75, 3.5 g;

fertile particle loading: 4.0, 5.0, 6.0, 7.0, 8.0 g;

air flow rate: 0.189, 0.260, 0.354, 0.486, and 0.66 std liter/sec
(0.40, 0.55, 0.75, 1.03, and 1.4 scfm)

number of pulses: 5, 7, 10, 14, 20;

pulse time: 0.15, 0.24, 0.39, 0.62, 1.00 sec.

The range of rod loadings is thought to accommodate any anticipated rod loading for a refabricated (or fresh) rod. A sufficient quantity of shim was added to each composition to make the rods 1.975 in. (5.017 cm) long. The required shim for each composition was calculated as follows: the 4-g fertile — 2-g fissile loading was mixed by shaking in a jar, and poured into a mold; then the height of the column of particles was measured. The procedure was repeated with shim added in 1/2-g increments. A calibration curve of length change vs weight shim was plotted. For the other compositions, the rod length with spherical fuel particles only was calculated using a previously determined packing factor of 0.5725. The shim required to increase the rod length to 1.975 in. (5.017 cm) was then determined from the calibration curve.

The combination of values of the experimental variables chosen for testing was according to a published experimental plan.[3] This experimental plan, *a central composite design*, was carefully chosen to yield maximum information from a limited number of experimental tests (Table 2). The order in which the tests were run (Table 2) was determined by a random selection process to eliminate any systematic bias in the results.

RESULTS AND DISCUSSION

The data from this experiment (Table 3) indicate that in nearly every case the bottom (fifth) rod segment is deficient in fissile particles but contains a corresponding excess of fertile particles. Apparently the denser fertile particles have a tendency to systematically settle to the bottom of the blender and thus are concentrated in the bottom of the fuel rod mold.

Run 21 (Table 3) gave an anomalous result. The lowest air flow rate, 0.189 liter/sec was used in this run. The inhomogeneity resulting from this lowest flow rate is approximately four times as high as from any other conditions investigated. The air flow rate effect apparently makes a discontinuous change at a critical flow rate required to levitate the particles. The 0.189 liter/sec flow would appear to be below the critical

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[3]W. H. Cochran and G. M. Cox, Plan 8A.2, p. 371, in *Experimental Designs*, 2nd ed., John Wiley and Sons, Inc., New York, 1957.

Table 2. Experimental Conditions for Evaluation of Air Blender

Run	Particle Loading, g			Air Flow (std liter/sec)	Number Pulses	Pulse Time (sec)
	Fissile	Fertile	Shim			
1	1.25	7.00	1.44	0.260	7	0.24
2	2.00	6.00	1.34	0.354	10	0.39
3	2.75	5.00	1.24	0.486	7	0.62
4	2.00	6.00	1.34	0.66	10	0.39
5	1.25	7.00	1.44	0.486	7	0.62
6	2.00	6.00	1.34	0.354	10	0.15
7	2.00	6.00	1.34	0.354	5	0.39
8	1.25	5.00	2.30	0.486	7	0.24
9	2.00	6.00	1.34	0.354	20	0.39
10	2.75	7.00	0.38	0.486	7	0.24
11	1.25	7.00	1.44	0.486	14	0.24
12	2.00	8.00	0.48	0.354	10	0.39
13	1.25	7.00	1.44	0.260	14	0.62
14	2.75	7.00	0.38	0.260	14	0.24
15	2.75	5.00	1.24	0.260	7	0.24
16	1.25	5.00	2.30	0.486	14	0.62
17	2.75	7.00	0.38	0.486	14	0.62
18	1.25	5.00	2.30	0.260	14	0.24
19	2.00	6.00	1.34	0.354	10	0.39
20	2.00	6.00	1.34	0.354	10	1.00
21	2.00	6.00	1.34	0.189	10	0.39
22	2.75	5.00	1.24	0.260	14	0.62
23	1.25	5.00	2.30	0.260	7	0.62
24	2.75	7.00	0.38	0.260	7	0.62
25	2.00	4.00	2.20	0.354	10	0.39
26	3.50	6.00	0.28	0.354	10	0.39
27	2.00	6.00	1.34	0.354	10	0.39
28	2.00	6.00	1.34	0.354	10	0.39
29	2.00	6.00	1.34	0.354	10	0.39
30	2.00	6.00	1.34	0.354	10	0.39
31	0.50	6.00	2.40	0.354	10	0.39
32	2.75	5.00	1.24	0.486	14	0.24

Table 3. Air Blender Evaluation Data

Run	Rod Segment: Fissile Particles/Fertile Particles					H_a'	K
	1	2	3	4	5		
1	805/1160	801/1323	864/1449	877/1532	695/1657	0.055	14.0
2	1557/876	1241/1186	1334/1270	1312/1340	1111/1412	0.095	18.8
3	1729/1003	1631/1087	1826/1046	1969/963	1868/981	0.062	9.6
4	1180/1123	1270/1244	1501/1144	1551/1178	1128/1381	0.103	14.9
5	735/1320	718/1488	866/1476	925/1421	878/1425	0.094	12.9
6	1524/1049	1215/1260	1349/1255	1315/1284	1279/1314	0.060	14.0
7	1544/1049	1371/1139	1295/1216	1297/1309	1030/1404	0.113	21.2
8	747/987	706/1065	847/1038	981/1008	801/994	0.118	20.2
9	1154/1116	1290/1193	1273/1219	1349/1249	1047/1353	0.053	14.4
10	1971/1286	1709/1496	1791/1447	1939/1410	1652/1470	0.037	8.8
11	786/1352	702/1470	881/1452	953/1360	770/1501	0.097	16.5
12	1423/1465	1350/1664	1442/1616	1296/1652	1061/1751	0.112	19.3
13	920/1050	791/1350	832/1461	790/1644	730/1619	0.069	13.2
14	2134/1103	1849/1409	1752/1520	1726/1527	1559/1567	0.109	18.3
15	1922/821	1803/1020	1855/1048	1783/1079	1648/1142	0.038	8.6
16	757/1019	722/1004	797/1054	913/1004	896/1013	0.082	11.8
17	1876/1290	1653/1492	1774/1493	2010/1416	1701/1447	0.049	11.5
18	847/751	725/966	807/1067	863/1139	794/1172	0.036	10.2
19	1491/1018	1277/1155	1374/1218	1282/1307	1139/1381	0.071	13.6
20	1221/1216	1181/1250	1379/1200	1402/1188	1281/1263	0.060	8.7
21	1413/70	2319/504	1075/1673	940/1893	764/1986	0.422	78.1
22	1739/883	1784/985	1910/1052	1822/1041	1780/1133	0.041	5.7
23	816/797	763/982	872/993	826/1151	843/1145	0.019	7.4
24	2093/1274	1749/1420	1810/1442	1721/1510	1661/1482	0.083	15.8
25	1393/721	1270/804	1396/760	1307/827	1176/976	0.031	10.1
26	2282/1238	2287/1198	2352/1116	2389/1187	2010/1337	0.036	11.2
27	1355/1136	1260/1255	1438/1153	1345/1238	1136/1170	0.055	13.1
28	1468/1160	1351/1176	1402/1180	1277/1274	1100/1356	0.069	16.6
29	1453/1108	1393/1169	1387/1188	1306/1290	1021/1373	0.074	22.2
30	1467/1089	1259/1174	1394/1201	1360/1280	1118/1398	0.053	15.3
31	350/1058	324/1221	342/1249	331/1278	287/1334	0.038	12.2
32	1945/943	1747/1038	1937/976	1968/1029	1578/1096	0.037	14.0

value. The one datum (Run 21) was therefore deleted from the quantitative analysis of the results. The resulting analysis will obviously be valid only for flow rates greater than 0.189 liter/sec.

A multiple regression analysis was done to evaluate the results of this work. The analysis of variance for the data along with a regression equation that can be used for predicting the inhomogeneity coefficient are given in Table 4. The analysis indicates that at the 95% confidence level the inhomogeneity of fuel rods blended by the air blender depends only on the rod loading (fissile and fertile particle content) and air flow rate. Within the ranges investigated, pulse time and the number of pulses did not significantly influence the results. One might interpret this to mean that five pulses of 0.15 sec are adequate and that longer times or more pulses offer no advantages.

The air flow rate effect depends on the fissile and fertile particle loading of the rods. This effect can be seen in Table 5, in which the inhomogeneity index H_a' is calculated for a range of compositions and air flow rates. The predicted inhomogeneity index was claculated using the multiple regression equation in Table 4:

$$H_a' = 0.0717 - 0.0085\ X11 + 0.0138\ X2 + 0.0099\ X3 - 0.0180\ X13 - 0.0134\ X23\ . \qquad (7)$$

For most compositions, an increase in the air flow rate apparently causes an increase in H_a'. However, the rods with virtually no shim, that is, those with less than 0.5 g exhibit a reversal in the flow rate effect. For the essentially unshimmed rods, an increase in the flow rate results in a decreased inhomogeneity index. An additional multiple regression analysis was done in which the shim content was considered a variable. The effect of shim alone or in conjunction with the fissile or fertile particle loading could not be shown to be statistically significant. Probably this means that shim is not a significant continuous variable, that is, shimmed rods behave differently from unshimmed rods, but the quantitative shim content alone is not otherwise significant. Statistically it would be advantageous to consider shim a class (qualitative) variable.

Table 4. Analysis of Air Blender Evaluation Results — Inhomogeneity Index

Source[a]	Degrees of Freedom	Sum of Squares	Mean Square
		Analysis of Variance	
Regression	20	0.02090471	
X1	1	0.00068267	
X2	1	0.00459267[b]	
X3	1	0.00222887[b]	
X4	1	0.00056067	
X5	1	0.00006017	
X11	1	0.00213630[b]	
X22	1	0.00000026	
X33	1	0.00015056	
X44	1	0.00029078	
X55	1	0.00023826	
X12	1	0.00015625	
X13	1	0.00518400[b]	
X14	1	0.00000400	
X15	1	0.00013225	
X23	1	0.00286225[b]	
X24	1	0.00070225	
X25	1	0.00006400	
X34	1	0.00057600	
X35	1	0.00007225	
X45	1	0.00021025	
Error	10	0.00324471	0.0032447
TOTAL	30		
		Alternate Analysis	
Regression	5	0.01700409	0.00340082
X11	1	0.00241559[b]	
X2	1	0.00459267[c]	
X3	1	0.00194958[b]	
X13	1	0.00518400[c]	
X23	1	0.00286225[b]	
Error	25	0.00714532	0.00028581
TOTAL	30		

Regression equation: $\hat{H_a} = 0.0717 - 0.0085\ X11 + 0.0138\ X2 + 0.0099\ X3 - 0.0180\ X13 - 0.0134\ X23$.

Multiple correlation coefficient, r^2: 70.4%.

[a]X1 = [fissile particle loading (g) — 2]/0.75
X2 = [fertile particle loading (g) — 6]
X3 = [ℓn (air flow rate, scfm) + 0.288]/0.312
X4 = [ℓn (number pulses) — 2.30]/0.345
X5 = [ℓn (pulse time) + 0.942]/0.475
XIJ = XI * XJ

[b]Significant at 95% level.

[c]Significant at 99% level.

Table 5. Predicted Values of Fuel Rod Inhomogeneity for Various Fissile/Fertile/Shim Weight Ratios

Air Flow (std liter/sec)	Predicted H_a'	Tolerance Limit for H_a'	
		95,85	95,99
	0.5/6.0/2.40		
0.260	<0		
0.354	0.04	0.07	0.09
0.486	0.08	0.11	0.13
0.66	0.13	0.16	0.18
	1.25/5.0/2.30		
0.260	0.01	0.04	0.06
0.354	0.05	0.08	0.10
0.486	0.09	0.12	0.14
0.66	0.13	0.16	0.18
	1.25/7.0/1.44		
0.260	0.06	0.09	0.11
0.354	0.08	0.11	0.13
0.486	0.09	0.12	0.14
0.66	0.11	0.14	0.16
	2.0/4.0/2.20		
0.260	0.01	0.04	0.06
0.354	0.04	0.07	0.09
0.486	0.08	0.11	0.13
0.66	0.12	0.15	0.17
	2.0/6.0/1.34		
0.260	0.06	0.09	0.11
0.354	0.07	0.10	0.12
0.486	0.08	0.11	0.13
0.66	0.09	0.12	0.14
	2.0/8.0/0.48		
0.260	0.12	0.15	0.17
0.354	0.10	0.13	0.15
0.486	0.08	0.11	0.13
0.66	0.07	0.10	0.12
	2.75/5.0/1.24		
0.260	0.04	0.07	0.09
0.354	0.05	0.08	0.10
0.486	0.05	0.08	0.10
0.66	0.06	0.09	0.11
	2.75/7.0/0.38		
0.260	0.10	0.13	0.15
0.354	0.08	0.11	0.13
0.486	0.06	0.09	0.11
0.66	0.03	0.06	0.08
	3.5/6.0/0.28		
0.260	0.06	0.09	0.11
0.354	0.04	0.07	0.09
0.486	0.01	0.04	0.06
0.66	<0		

The predicted values of H'_a are the *average* values expected for a large number of rods made under the given conditions. But the homogeneity specification gives the acceptable range of inhomogeneity as follows:

$$H'_a = \begin{cases} <0.10 & 85\% \text{ of fuel rods} \\ <0.20 & 100\% \text{ of fuel rods} \end{cases}$$

Therefore, the 95,85 and 95,99 tolerance limits for the predicted value of H'_a were calculated (Table 5). These parameters are the values of H'_a below which 85 and 99%, respectively, of the fuel rods would be with a 95% confidence level. The tolerance limits were calculated from published tables[4] with the error variance in Table 4. One might reasonably then apply the $H'_a < 0.10$ specification to the 95,85 tolerance limit and the $H'_a < 0.20$ specification to the 95,99 tolerance limit.

For each composition an air flow rate can be found that results in acceptable homogeneity (Table 5). There is one exception — the 2.0-g fissile, 8.0-g fertile composition — but even in this case it would appear that an extrapolation of air flow rate to higher values will produce acceptable fuel blends.

From analysis of the K index (maximum deviation from the mean) data (Table 6) results similar to those from the H'_a data would be expected. However, K was shown to be dependent on pulse time and the square of pulse time as well as composition and air flow rate, whereas H'_a was not dependent on pulse time. An increase in pulse time results in a lower (i.e., better) K index. Presumably the divergence of the behavior of the two homogeneity parameters is due to the way in which H'_a was defined. Even though the H'_a data indicate no dependence on pulse time, it seems prudent to maximize the pulse time, consistent with production schedule limitations, as suggested by the K data.

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[4]D. B. Owen, *Factors for One-Sided Tolerance Limits and for Variables Sampling Plans*, Sandia Corporation Monograph SCR-607 (March 1963).

Table 6. Analysis of Air Blender Evaluation Results — Maximum Deviation from the Mean

Source	Degrees of Freedom	Sum of Squares	Mean Square
		Analysis of Variance	
Regression	20	426.8983	21.3449
X1	1	10.5338	
X2	1	73.1504[a]	
X3	1	10.6373	
X4	1	3.9204	
X5	1	46.2038[a]	
X11	1	42.0562[a]	
X22	1	7.0778	
X33	1	20.6925	
X44	1	3.7700	
X55	1	56.5849[a]	
X12	1	5.6406	
X13	1	27.8256	
X14	1	5.6406	
X15	1	4.5156	
X23	1	77.8806[a]	
X24	1	9.1506	
X25	1	12.7806	
X34	1	0.0306	
X35	1	1.3806	
X45	1	7.4256	
Error	10	86.7301	8.6730
TOTAL	30	513.6284	
		Alternate Analysis	
Regression	5	302.9086	60.5817
X11	1	44.6301[a]	
X2	1	73.1504[b]	
X5	1	46.2038[a]	
X23	1	77.8806[b]	
X55	1	61.0429[a]	
Error	25	210.7198	8.4288
TOTAL	30	513.6284	

Regression equation: $K = 15.85 - 1.36\ X11 + 1.75\ X2 - 1.39\ X5 - 2.21\ X23 - 1.45\ X55$.

Multiple correlation coefficient, r^2: 59%.

[a]Significant at 95% level.

[b]Significant at 99% level.

These results indicate that the GAC air blender will likely produce acceptably homogeneous fuel blends for all expected fuel rod compositions when the air flow rate is adjusted for the fissile and fertile particle loading of the fuel rods.

CONCLUSIONS

The performance of the conical air blender depended on the particle blend to be mixed, the air flow rate, and the pulse time. The effect of the air flow rate was discontinuous; whereas flows of 0.260 liter/sec and higher usually resulted in good blending, a flow of 0.189 liter/sec was apparently insufficient to levitate the particles, so little or no blending occurred. The effect of air flow was diametrically opposite for shimmed and unshimmed rods. An increase in the air flow rate improved the blending of unshimmed rods but was detrimental to shimmed rods. Within the range of 5–20 pulses investigated, the number of air pulses had little effect. The pulse time did not affect the axial inhomogeneity index, but had a strong effect on a simple maximum deviation from the mean. An increase in the pulse time apparently resulted in better blending. The results of this investigation indicate that the conical air blender will produce adequately blended HTGR fuel if the air flow rate is adjusted for the desired composition.

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