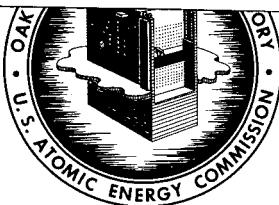




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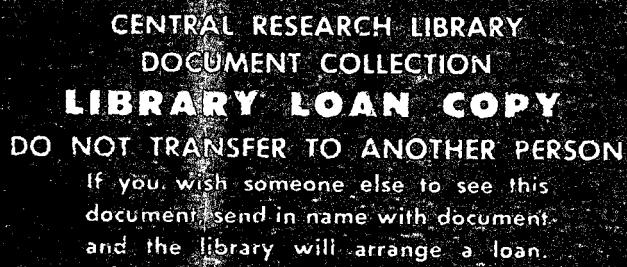
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SUMMARY REPORT OF THE REACTION OF STEAM WITH  
 LARGE SPECIMENS OF GRAPHITE FOR THE  
 EXPERIMENTAL GAS-COOLED REACTOR

R. E. Helms  
 R. E. MacPherson

— D. M. C. 1967 10-300 87



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REACTOR DIVISION

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R. E. Helms R. E. MacPherson

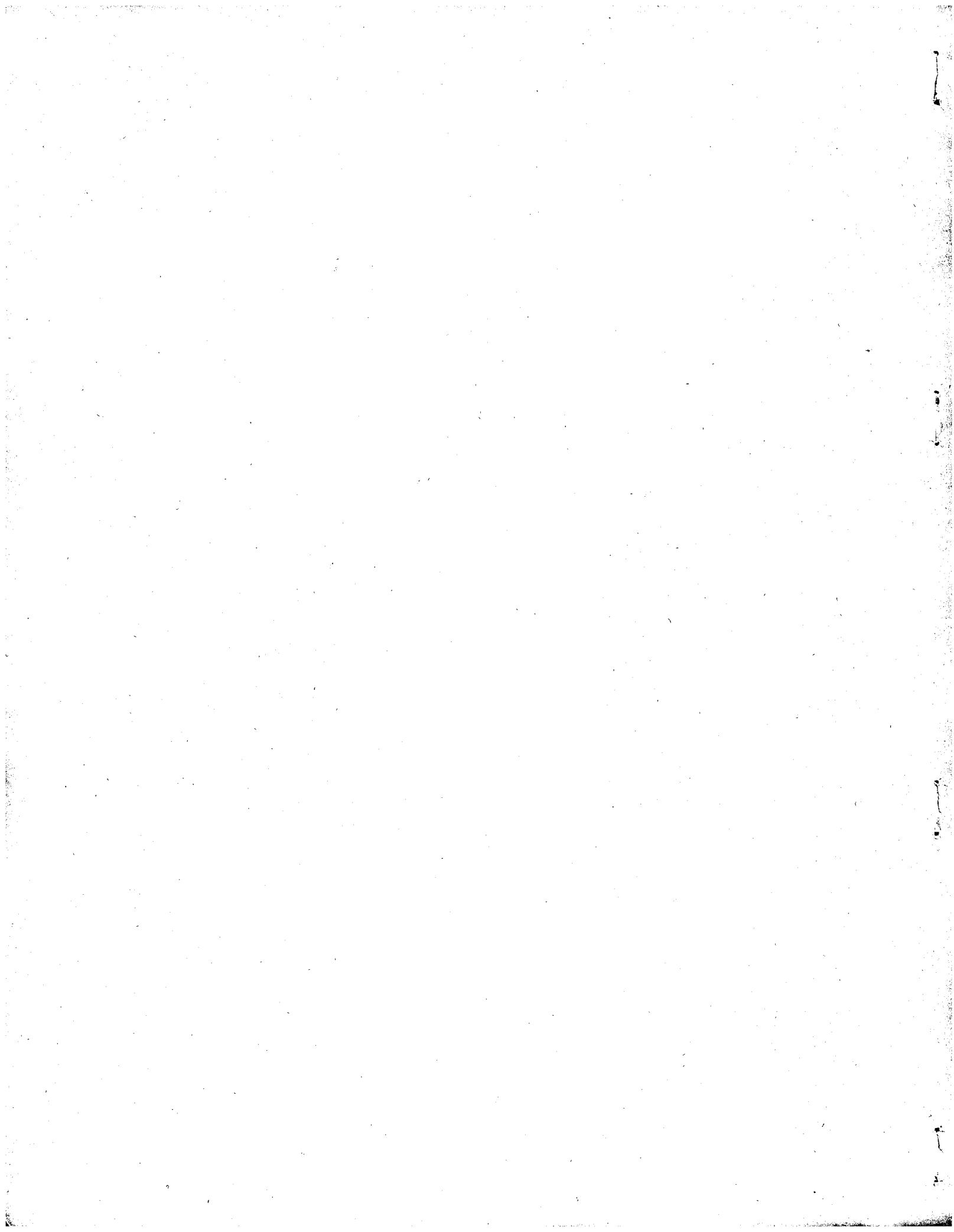
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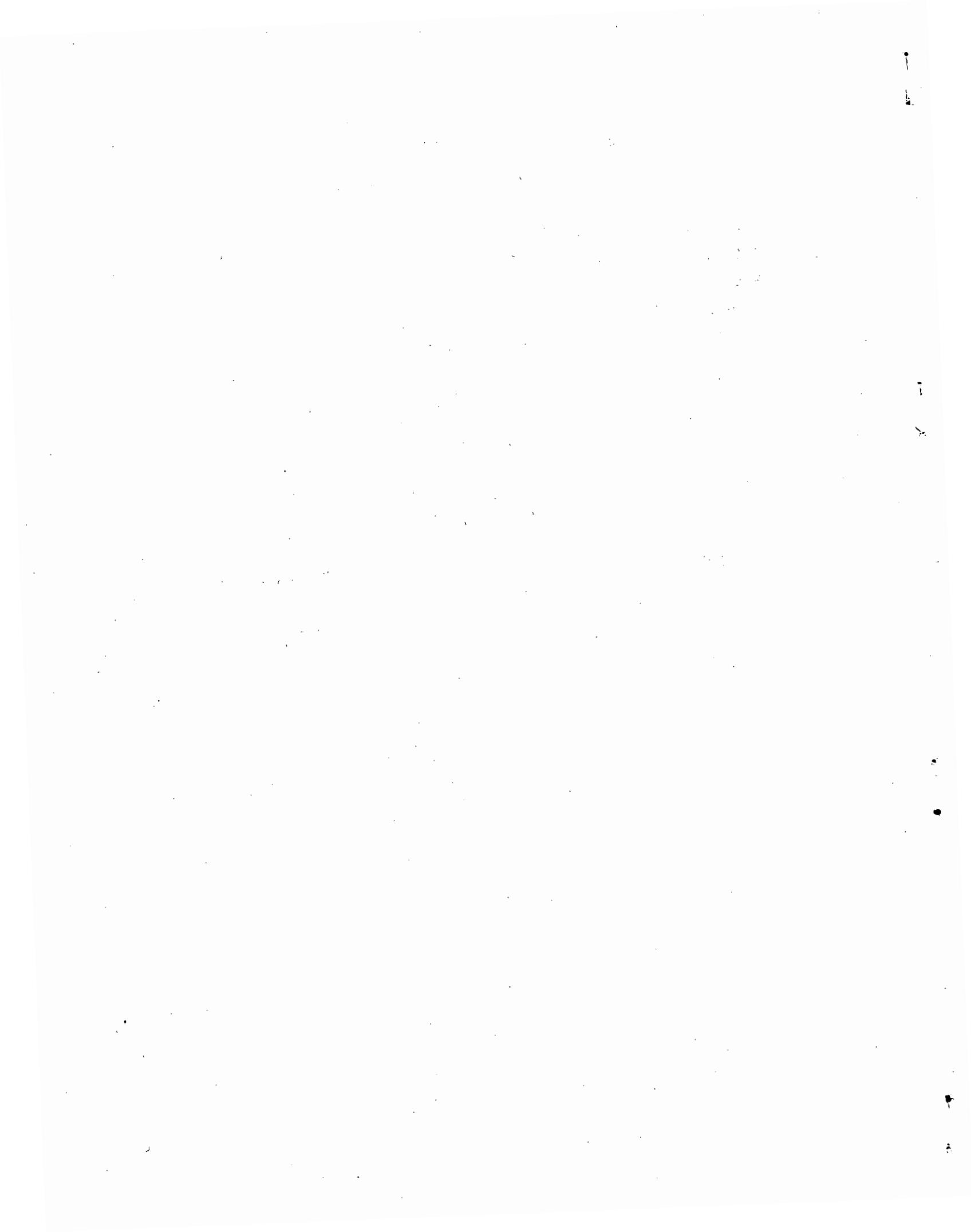


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SUMMARY REPORT OF THE REACTION OF STEAM WITH  
LARGE SPECIMENS OF GRAPHITE FOR  
THE EXPERIMENTAL GAS-COOLED REACTOR

R. E. Helms      R. E. MacPherson

Abstract

Graphite reaction rates and hydrogen generation rates have been determined for high pressure, high temperature steam flowing through a full-scale EGCR fuel element graphite sleeve (Speer 901-RYL), and a geometrically identical sleeve machined from EGCR moderator graphite (National Carbon Company).

700°C      870°C

Graphite reaction rates were measured as a function of graphite burnoff in the temperature range of 1300 to 1600°F with both types of graphite. Exposure of the graphite to steam over a period of time increases the reactive surface area. This burnoff of graphite results in an increase in the nominal reaction rate.

To determine the effect of pressure from 50 to 300 psig, test data were obtained using an EGCR fuel-element graphite sleeve. No significant effect of steam pressure on reaction rates was noted.

Introduction

The Experimental Gas-Cooled Reactor (EGCR) is moderated by graphite and cooled by helium.<sup>1</sup> The fuel element is a seven-rod cluster of type 304 stainless steel clad fuel rods encased in a 5-in. OD x 3-in. ID graphite sleeve. Six of these fuel rod-sleeve assemblies are stacked vertically in each of the four 5 1/4-in. ID fuel channels contained in each moderator graphite column. There are 234 fuel channels in the EGCR core.

Two types of graphite are used in the EGCR. The graphite sleeve that encases the fuel elements is manufactured by the Speer Company. The moderator graphite is manufactured by the National Carbon Company.

In evaluating the hazards associated with the operation of the Experimental Gas-Cooled Reactor, it has been necessary to examine the

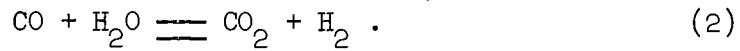
problems which arise as a result of the rupture of the steam generator and introduction of large quantities of steam into the helium coolant system. Since the steam generator operates at a higher pressure than the reactor coolant system, failure of this unit would introduce steam into the reactor coolant, thus resulting in steam-graphite and steam-metal reactions. If a rupture in the steam coolant system occurs, the overpressurization of the primary helium coolant circuit is relieved to the containment vessel. The hydrogen generated from the steam-graphite reaction may give rise to a serious explosive hazard in the event that emergency procedures accompanying a steam generator failure caused mixing of the hydrogen and air in the containment vessel.<sup>2</sup>

The production rate of gases ( $H_2$ ,  $CO_2$ ,  $CH_4$ , and  $CO$ ) and the graphite removal rate as a function of burnoff up to 50%, and the graphite removal rate as a function of temperature in the range of 1300-1600°F were determined for the EGCR fuel element graphite (Speer 901-RYL) and the EGCR moderator graphite (National Carbon Company). The reaction rate of the fuel-element graphite was determined at 50, 100, 150, 200, and 300 psig, while holding the graphite temperature constant at 1400°F. These tests were performed in the facility shown in Fig. 1.<sup>3</sup>

When steam reacts with carbon, the gaseous products are primarily carbon monoxide, hydrogen, carbon dioxide, and methane. It is now generally accepted that the gasification reaction is<sup>4,5,6</sup>

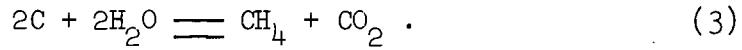


The carbon dioxide produced is attributed to the secondary water-gas shift reaction



This reaction is believed to take place predominantly on the graphite surface.<sup>7</sup>

The formation of methane is believed to be by the direct attack of steam on a carbon atom.<sup>5</sup> The methane reaction is considered to be



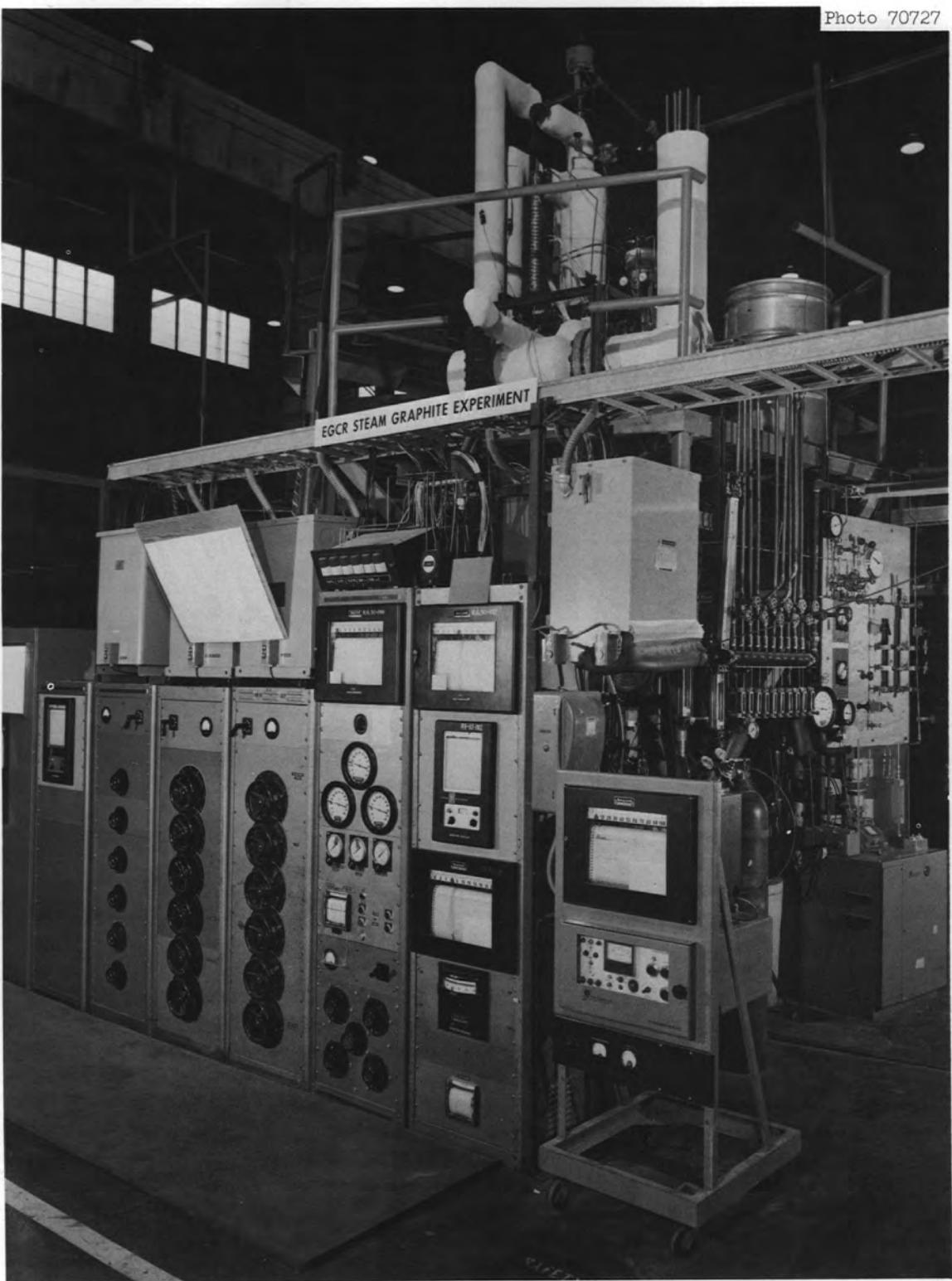


Fig. 1. Steam-Graphite Experimental Facility.

The amount of methane formed at the system pressures used for these tests was approximately .04% by volume.

The rate of reaction of graphite in these tests was calculated on the basis of the rates of appearance of carbon monoxide, carbon dioxide, and the methane in the product gases.

#### Procedure

After assembling a graphite sleeve in the test section of the experimental facility (Fig. 2), the autoclave vessel that houses the superheater, test section, and regenerator was heated to approximately 1000°F. The power to the boiler was turned on, and the cooling was applied to the condenser. The saturation temperature corresponding to the desired operating pressure level was set on the boiler temperature controller. Condenser cooling was adjusted until the desired steam flow rate was obtained. The inlet steam temperature to the test section was increased by adjusting the superheater power until the desired inlet steam temperature was obtained. Power adjustments were then made to the guard heaters around the test section to obtain an isothermal region.

Since all tests were made at essentially steady state conditions, hydrogen production rates and graphite removal rates were calculated using the data recorded over (approximately) an eight-hour period. During this time increment approximately 24 gas analyses were obtained, and eight off-gas volume determinations were recorded. The total volume of each gas component produced during this time increment was calculated by Equation 4:

$$V_x = \sum_{1 \rightarrow 8} (v_1 x_1 + v_2 x_2 + \dots + v_8 x_8) . \quad (4)$$

$V_x$  = Volume of each gas component ( $H_2$ ,  $CO_2$ ,  $CH_4$ ,  $CO$ ) produced during the total time increment,

$v_1 \rightarrow 8$  = Volume of total gas produced during each recorded time increment,

$x_1 \rightarrow 8$  = Concentration of gas component during each recorded time increment (average of three analyses).

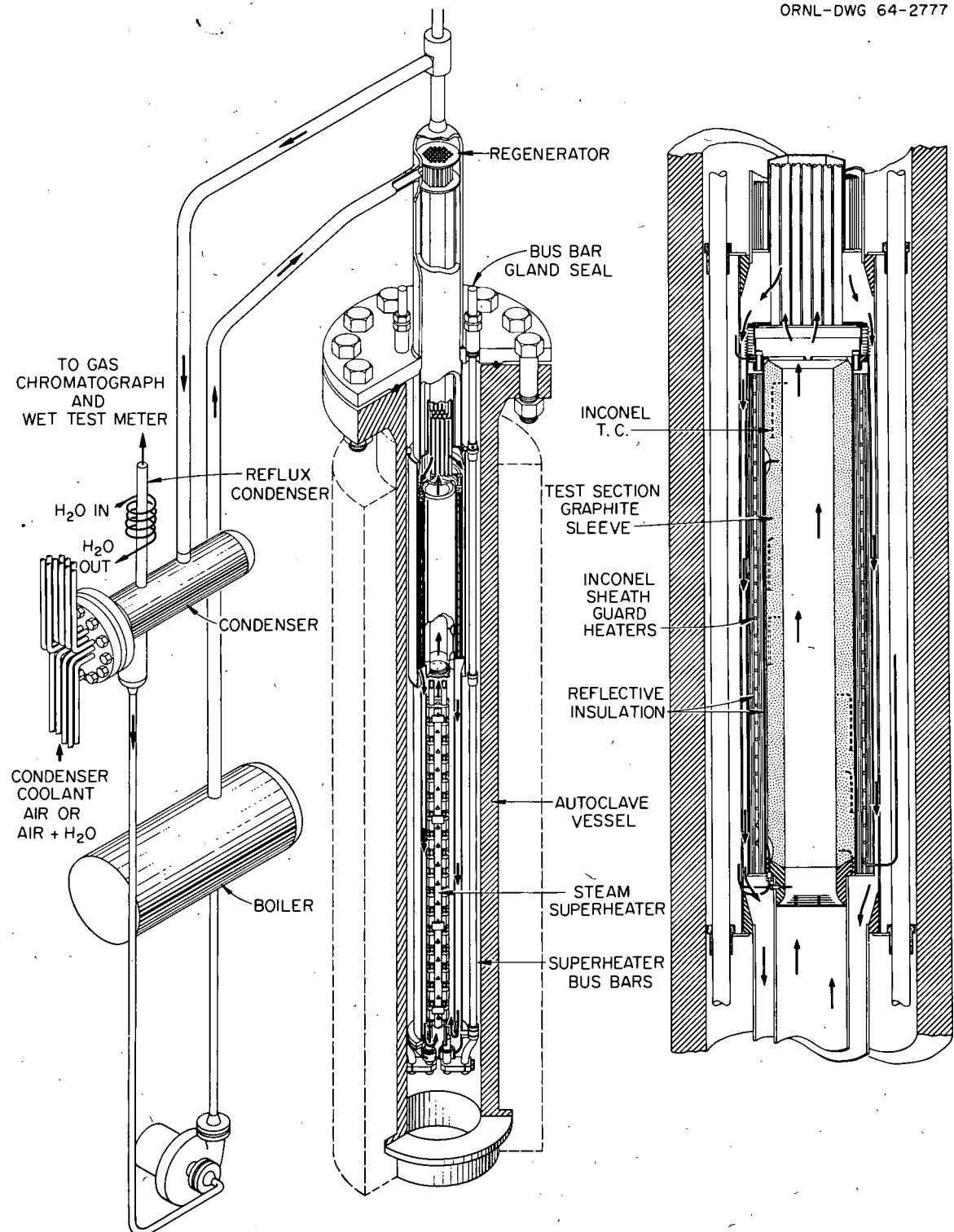


Fig. 2. Steam-Graphite Experimental Facility.

The average gas production rates were calculated by Equation 5:

$$R_x = V_x/T \quad (5)$$

$R_x$  = Average production rate of each gas component,

$V_x$  = Volume of gas component produced during total time increment,

$T$  = Total time increment.

Using the average production rate of the carbon-containing gas components CO,  $\text{CO}_2$ ,  $\text{CH}_4$ , and the internal surface area, the average carbon reaction rate was calculated using Equation 6:

$$R_{CA} = \frac{12 \text{ g of C/mole}}{22,400 \text{ CC/mole}} \frac{R_{CO} + R_{\text{CO}_2} + R_{\text{CH}_4}}{A} \quad (6)$$

$R_{CA}$  = Carbon reacting per unit of time per unit of initial surface area,

$R_{CO}$  = CO production rate at 14.7 psia and 70°F,

$R_{\text{CO}_2}$  =  $\text{CO}_2$  production rate at 14.7 psia and 70°F,

$R_{\text{CH}_4}$  =  $\text{CH}_4$  production rate at 14.7 psia and 70°F,

$A$  = Internal surface area of the test specimen.

The total carbon reacted during each data period was calculated by multiplying the average carbon reaction rate by the time increment associated with each data point. A cumulative sum of the total carbon reacted permitted the determination of the total carbon removed from the test specimen. The total carbon removed up to the time of a data point divided by the initial test specimen weight gave the fractional burnoff.

### Experimental Results

#### EGCR Fuel Element Graphite (Speer 901-RYL)

To measure the effect of pressure on the reaction of Speer 901-RYL with superheated steam, the graphite temperature was held constant at 1400°F, and the boiler temperature was changed to vary the system

pressure over the range of 50-300 psig. The CO/CO<sub>2</sub> ratio in the product gases decreased as the pressure was increased as indicated in Fig. 3.

There was no significant effect of pressure on the reaction rate. The slight variation between initial and final reaction rates at 50 psig was due to the increase in burnoff during the test period.

BUT  
WITH THE GAS  
WAS FULL  
STEAM!

To determine the reaction rate and hydrogen generation rate as a function of burnoff, other tests were made with new sleeves exposed to steam at different temperature levels. These data are shown in Figures 4 and 5 for temperature levels of 1400, 1500, 1580, and 1600°F.

To correlate this data, a modified Arrhenius equation that describes the reaction rate as a function of temperature and burnoff was derived.

The equation is of the following form:

$$K = A e^{-\Delta E/RT} = B^m e^n e^{-\Delta E/RT}$$

where

A = B<sup>m</sup> e<sup>n</sup> = frequency factor,

ΔE = Activation energy, cal/mg-mole,

R = Gas constant, 1.987 cal/°K/mg-mole,

T = Absolute temperature - °K,

K = Reaction rate - mg of carbon/hr · cm<sup>2</sup>, or

scc (H<sub>2</sub>)/hr · cm<sup>2</sup>,

B = Burnoff, %

m, n are exponents determined from experimental data.

The solid lines (Fig. 4, 5) through the data points represent the derived Arrhenius equations which best describe the complete sets of data. The carbon reaction rate as a function of temperature and burnoff is described by Equation 7, and the hydrogen production rate as a function of temperature and burnoff is described by Equation 8.

$$K (\text{mg of C/hr.cm}^2) = e^{26.0} B^{.346} e^{-55,200/RT} \quad (7)$$

$$K (\text{scc H}_2/\text{hr.cm}^2) = e^{25.3} B^{.323} e^{-53,600/RT} \quad (8)$$

An Arrhenius plot showing the carbon reaction rate versus reciprocal temperature for various levels of burnoff is shown in Fig. 6.

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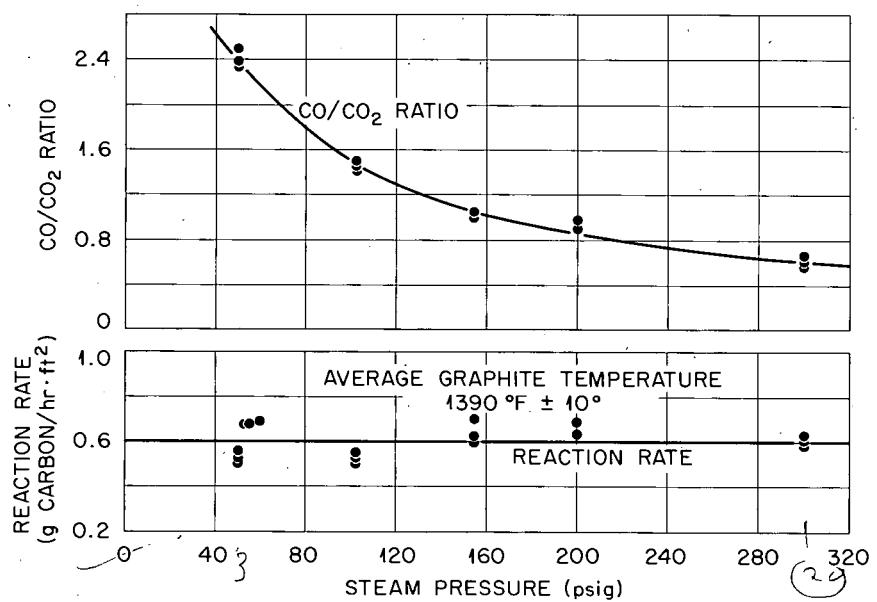


Fig. 3. Effect of Steam Pressure on Graphite Reaction Rate and CO/CO<sub>2</sub> Ratio for EGCR Fuel Element Sleeve; Speer 901-RYL.

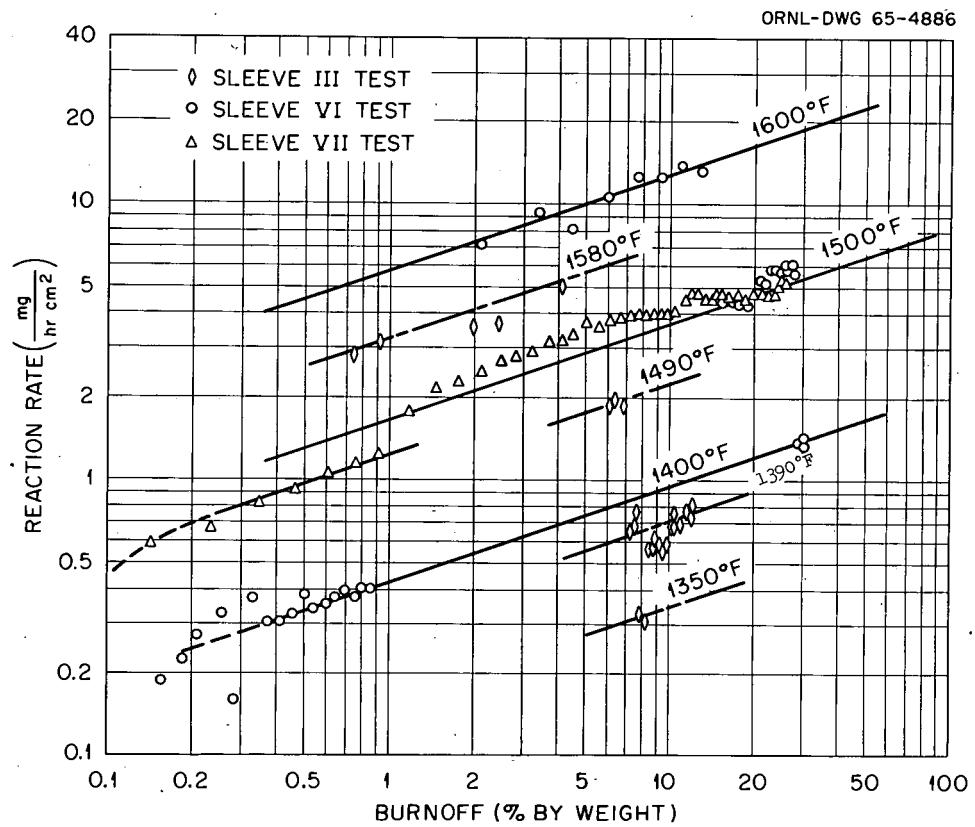


Fig. 4. Reaction Rate vs Burnoff - EGCR Fuel Element Graphite Sleeve (Speer 901-RYL).

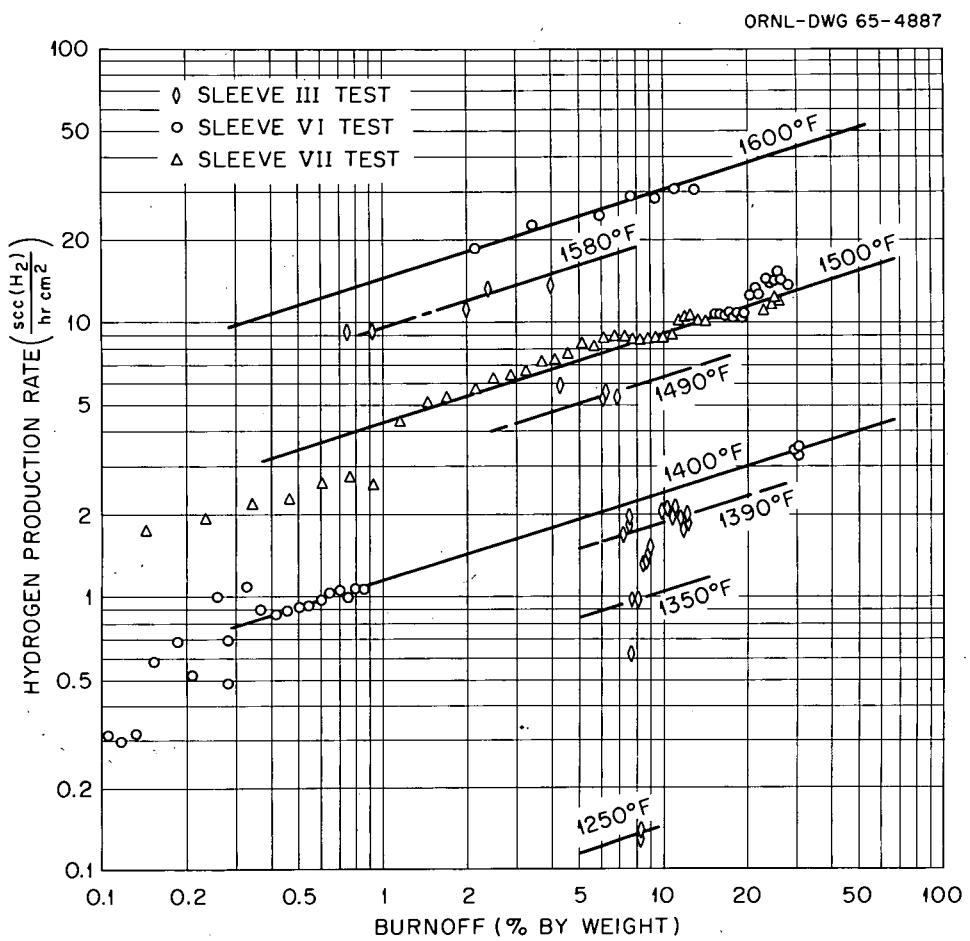


Fig. 5. Hydrogen Production Rate vs Burnoff - EGCR Fuel Element Graphite Sleeve (Speer 901-RYL).

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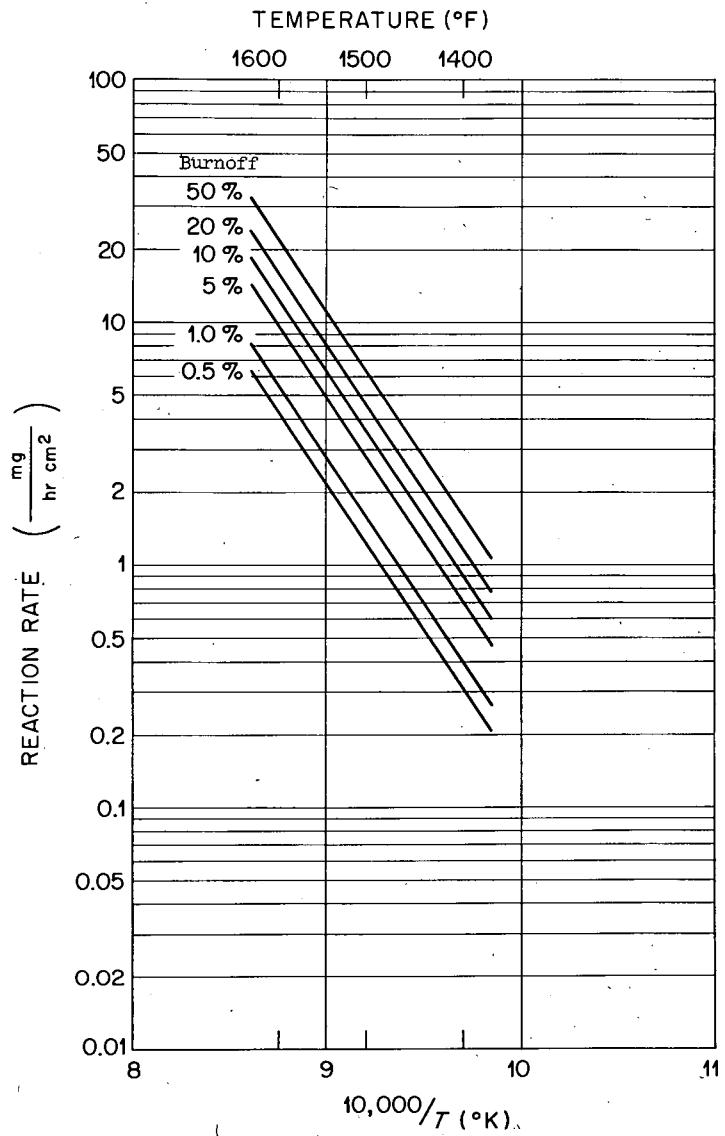


Fig. 6. Steam-Graphite Reaction Rate for EGCR Fuel Element Graphite (Speer 901-RYL).

EGCR Moderator Graphite (National Carbon Company)

The reaction rate and hydrogen generation rate as a function of burnoff were determined at 1400, 1500, and 1550°F. (For Sleeve IV, data were also taken at approximately 1300°F.) The Arrhenius equations best describing the data are shown by the solid lines through the data points in Figures 7 and 8. The carbon reaction rate as a function of temperature and burnoff is described by Equation 9, and the hydrogen production rate as a function of temperature and burnoff is described in Equation 10.

NOTE UNITS.  
DIFFER FROM  
R - [ % LOSS ]  
TIME

$$K \text{ (mg of C/hr.cm}^2) = e^{25.4} B \cdot 150 e^{-52,200/RT} \quad (9)$$

$$K \text{ (scc H}_2\text{/hr.cm}^2) = e^{24.5} B \cdot 209 e^{-48,300/RT} \quad (10)$$

~~WAS~~ ~~NOT~~ An Arrhenius plot showing the reaction rate versus reciprocal temperature for constant various burnoff levels is shown in Figure 9. The generally higher reaction rates of the moderator graphite at lower burnoff levels as compared to the fuel element graphite is a reflection of the higher permeability of the former grade. The effect can be seen to disappear at high burnup.

Conclusion

The results of these tests can be used in the hazard evaluation of the EGCR to predict the amount of hydrogen and other reaction product gases generated in case of a steam generator rupture and the reaction of steam with reactor graphite.

In using these data, conservative predictions will be obtained since the results apply directly only to the upstream end of the core. Because of the decrease in reaction rate resulting from the increase in concentration of H<sub>2</sub> and CO in the boundary layer along the flow path, overall production rates for the core would be lower.

Conclusions to be drawn based on these tests are as follows:

1. The significant variables affecting the reaction rate of steam with graphite are temperature and burnoff, which tends to increase the

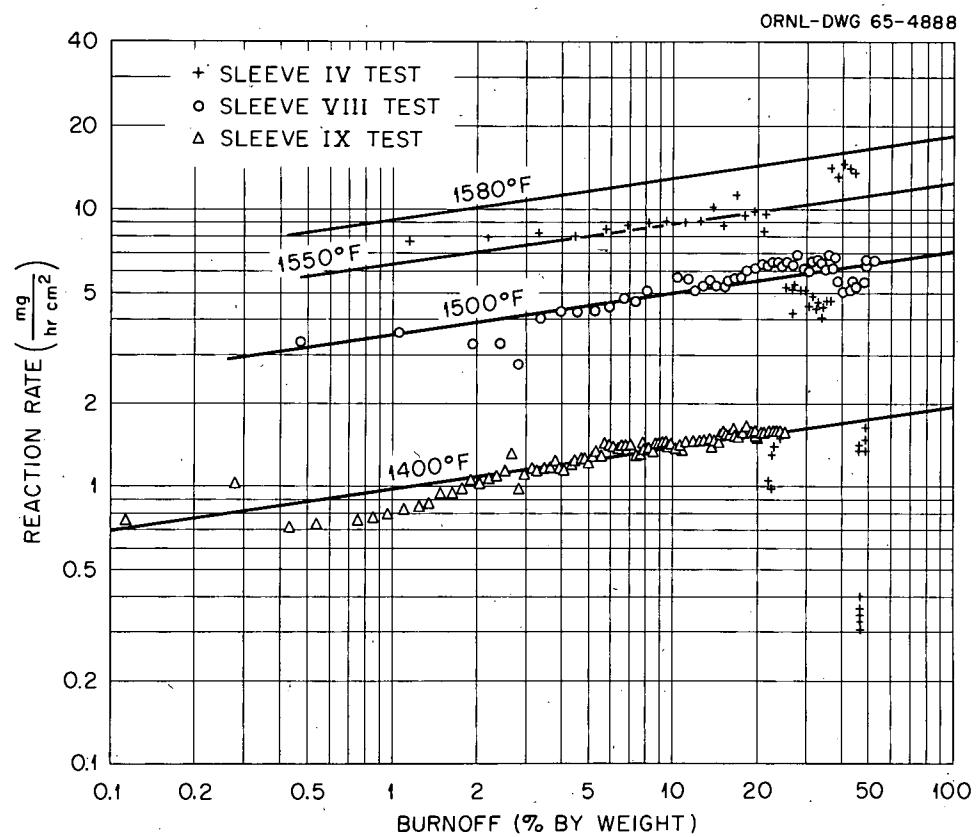


Fig. 7. Reaction Rate vs Burnoff - EGCR Moderator Graphite (National Carbon Co.).

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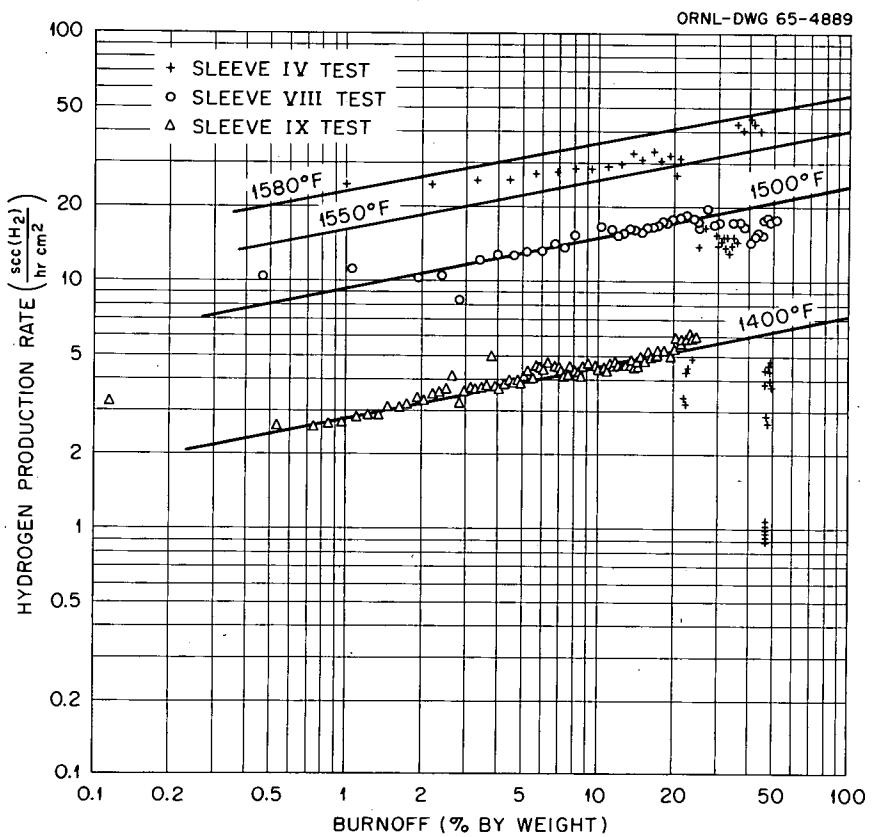


Fig. 8. Hydrogen Production Rate vs Burnoff - EGCR Moderator Graphite (National Carbon Co.).

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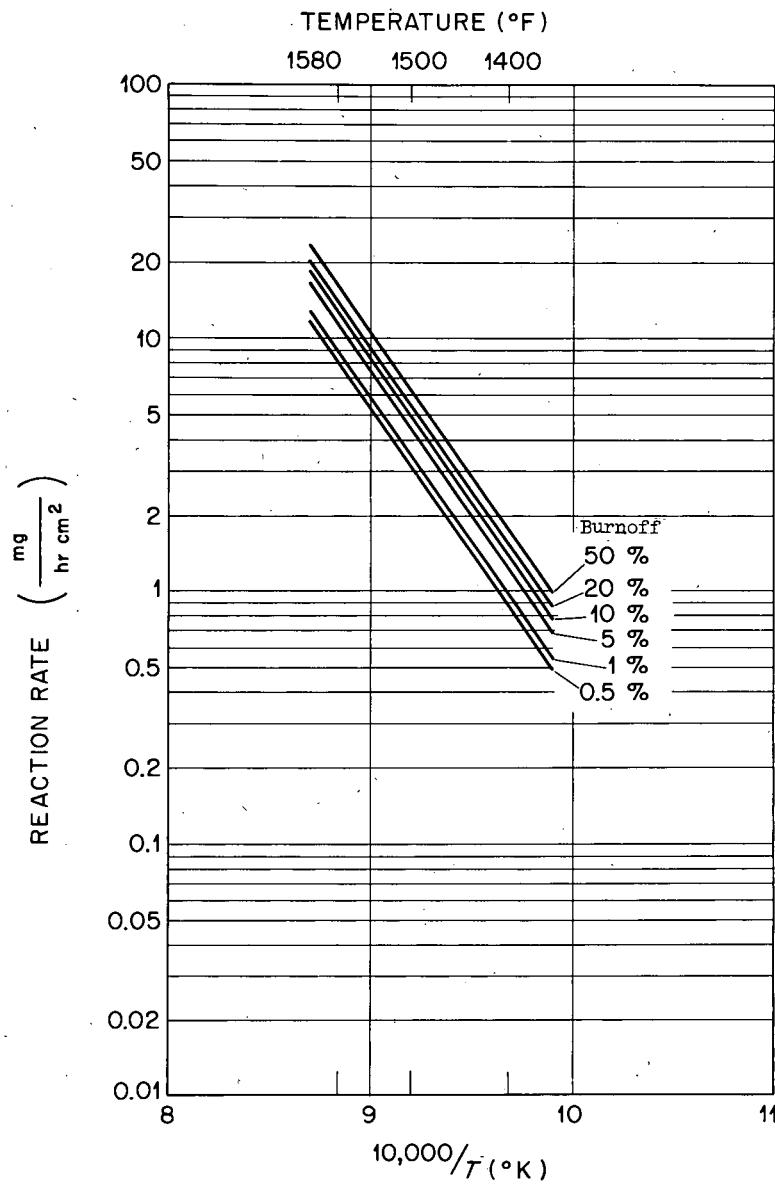


Fig. 9. Steam-Graphite Reaction Rate for EGCR Moderator Graphite  
(National Carbon Co.).

reactive surface area.

The inlet to the test section was 100% steam; however, the effect of CO and  $\text{H}_2$  concentration in suppressing the reaction rate was not noticeable by examination of the geometric surface of the specimen as shown by Figure 10 (Speer 901-RYL) and Figure 11 (National Carbon Graphite) graphite sleeves. The Speer 901-RYL graphite (Fig. 10) was exposed to steam at 1500°F and 150 psig for 430 hours for a resulting burnoff of 26%. The National Carbon Graphite (Fig. 11) was exposed to steam at 1400°F for 1011 hours for a resulting burnoff of 24.7%.

2. Reaction rate is a negligible function of system pressure in the pressure range of 30 to 300 psig as shown in Figure 3.

3. The CO/ $\text{CO}_2$  concentration ratio decreases as the steam pressure increases as shown in Figure 3.

4. The data can be correlated using a modified Arrhenius equation that describes the reaction rate as a function of temperature and burn-off.

5. The reaction of steam and graphite appears to take place by inpore diffusion with no appreciable change in the geometric dimensions as indicated by the relatively unaffected contour of the graphite sleeve shown in Figure 12.

Photo 72400



Fig. 10. EGCR Fuel Element Graphite (Speer 901-RYL) Exposed to Steam at 1500°F and 150 psig for 430 hr. 26% Burnoff.

Photo 72395

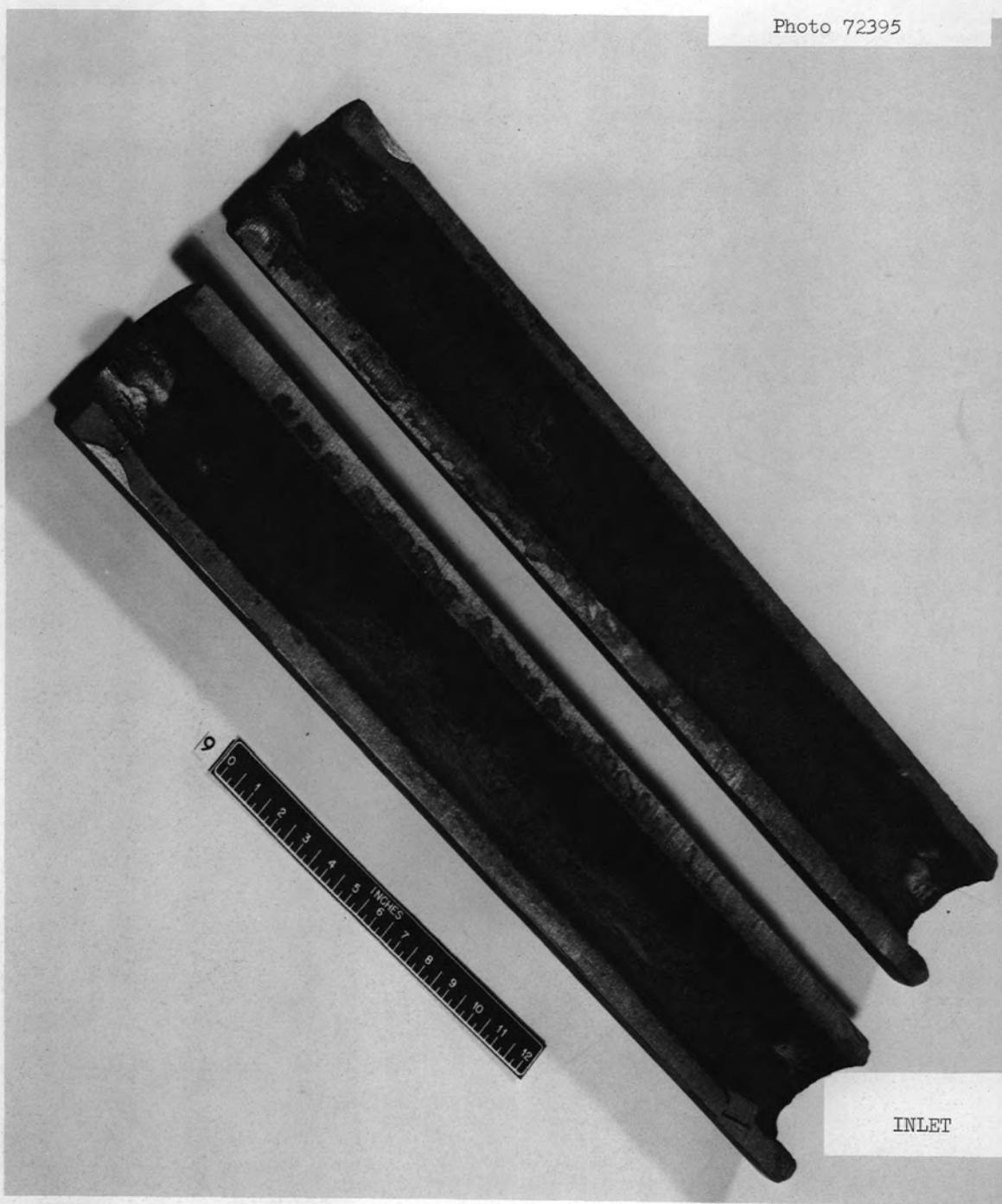


Fig. 11. EGCR Moderator Graphite (National Carbon Co.) Exposed to Steam at 1400°F for 1011 hr - 24.7% Burnoff.



Fig. 12. EGCR Moderator Graphite (National Carbon Company) Exposed to Steam at 1500°F for Approximately 550 hrs. Total burnoff 52.6%.

Acknowledgments

The author gratefully acknowledges the contributions of the Reactor Division Design Department for assistance in designing the test facility, of D. L. Clark who designed the boiler control; of J. E. Attrell and A. S. Meyer, Jr., of the Analytical Chemistry Division, who adapted the gas chromatograph for on-line analysis; of Dr. J. F. Bailey, R. B. Knight, Dr. Frank Anderson, and W. B. Cottrell for their technical assistance; of J. E. Wolfe for his assistance in collecting test data; and of the many Y-12 craft personnel who helped build the test facility.

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APPENDIX A. Test Data for EGCR Fuel Element Graphite Sleeve -  
Speer 901-RYL



## EGCR FUEL ELEMENT GRAPHITE - SLEEVE III (Speer 901-RYL)

Original Weight of Sleeve - 10,270 grams  
 Final Weight of Sleeve - 8,880 grams

25

Data Point	Timer		Test Section			Average Gas Production Rate at STP					Reaction Rate		(g)	Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (NRe)	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr·cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr·cm <sup>2</sup>	% Burn Off			
3.1	53.0	73.1	155	--	--	--	--	--	--	--	--	--	.34	--	
3.2	141.0	148.7	49.6	1192	1.75	.08	.03	.05	--	--	--	--	1.13	.59	
3.3	148.7	166.2	49.6	1192	1.67	.10	.03	.04	--	--	--	--	1.23	.42	
3.4	189.2	193.5	39.7	1580	270.6	70.40	1.58	82.97	2.83	9.24	.75	76.8	1.18		
3.5	193.5	197.0	(2030)	39.7	1581	274.0	79.60	1.70	91.20	3.15	9.36	.93	95.9	1.14	
3.6	197.0	214.0	155	35.7	1580	326.3	91.50	3.03	111.60	3.67	11.14	2.00	205.6	1.22	
3.7	214.0	219.4	(1730)	33.7	1580	388.8	108.10	2.58	142.50	4.63	13.28	2.43	249.9	1.31	
3.8	219.4	238.3	155	35.7	1574	404.3	119.90	3.03	150.70	5.00	13.81	4.05	416.9	1.26	
3.9	238.3	245.0	45.7	1492	174.2	50.30	1.20	64.20	2.11	5.95	4.36	447.8	1.28		
3.10	245.0	309.3	53.6	1482	154.9	45.20	.95	56.60	1.87	5.29	6.10	627.0	1.25		
3.11	309.3	316.3	53.6	1476	163.9	45.10	1.20	61.70	1.97	5.59	6.34	651.3	1.36		
3.12	316.3	335.6	(2900)	53.6	1477	157.2	42.20	.99	59.04	1.87	5.37	6.96	714.8	1.40	
3.13	335.6	357.6	155	59.6	1391	49.5	16.0	.25	19.12	.65	1.69	7.25	745.6	1.19	
3.14	357.6	382.3	(3400)	59.6	1392	53.6	16.30	.28	20.80	.68	1.83	7.55	775.5	1.28	
3.15	382.3	387.3	(3270)	57.6	1398	57.8	19.10	.33	22.70	.76	1.97	7.61	781.8	1.19	
3.16	387.3	406.3	155	61.6	1292	12.6	3.76	.05	4.55	.15	.43	7.67	787.9	1.21	
3.17	406.3	410.9	61.6	1292	18.1	5.38	.07	6.50	.21	.62	7.69	789.6	1.21		
3.18	410.9	432.9	59.6	1340	28.5	7.37	.12	10.40	.32	.97	7.81	802.0	1.41		
3.19	432.9	506.6	506.6	57.6	1353	28.7	7.15	.12	9.19	.30	.98	8.20	842.1	1.28	
3.20	506.6	573.6	(3970)	63.6	1251	3.8	.41	.01	1.06	.02	.13	8.35	858.1	2.61	
3.21	623.0	647.1	155	63.6	1252	4.1	.81	.01	.84	.03	.14	8.38	861.4	1.04	
3.21A	647.1	670.6	27.5	39.2	1410	38.3	7.37	.15	23.15	.55	1.31	8.56	879.5	3.14	
3.22	670.6	695.4	51	47.4	1396	38.9	8.89	.17	21.67	.56	1.33	8.73	897.5	2.50	
3.23	695.4	700.8	506.6	46.0	1396	39.9	9.29	.17	22.12	.57	1.36	8.79	902.6	2.38	
3.24	700.8	718.8	51	46.8	1397	41.6	9.83	.17	23.12	.60	1.42	8.97	921.8	2.35	
3.25	718.8	755.9	101	53.2	1382	44.1	12.68	.19	18.95	.58	1.50	9.28	953.9	1.49	
3.26	755.9	787.9	53.2	1382	41.1	12.42	.18	17.63	.55	1.40	9.59	985.0	1.42		
3.27	787.9	815.4	101	53.2	1382	43.0	12.98	.18	19.24	.59	1.46	9.86	1013.6	1.48	
3.28	815.4	841.1	200	62.2	1387	60.1	18.97	.28	18.69	.69	2.05	10.11	1039.1	.98	
3.29	841.1	863.1	200	62.6	1391	61.6	21.56	.30	19.47	.75	2.10	10.40	1068.4	.90	
3.30	868.4	887.8	300	68.7	1378	62.2	22.11	.32	14.40	.67	2.12	10.62	1091.3	.65	
3.31	887.8	910.8	(3821)	66.4	1380	57.5	21.79	.30	13.30	.64	1.96	10.88	1117.5	.61	
3.32	910.8	917.1	290	46.4	1383	59.2	23.31	.31	13.92	.68	2.02	10.91	1121.0	.59	
3.33	917.1	983.8	300	45.4	1383	56.7	21.48	.29	12.47	.63	1.93	11.63	1194.8	.58	
3.34	983.8	1030.7	56	32.7	1401	54.9	12.65	.27	28.20	.75	1.87	11.73	1205.6	2.23	
3.35	1030.7	1047.7	56	33.9	1399	52.5	12.50	.27	27.25	.73	1.79	11.95	1227.4	2.18	
3.36	1047.7	1071.8	(3780)	66.2	1392	54.8	12.51	.27	27.66	.73	1.87	12.16	1249.6	2.21	
3.37	1071.8	1075.8	55.5	65.2	1399	58.9	13.76	.50	30.66	.81	2.01	12.22	1255.4	2.22	

## EGCR FUEL ELEMENT GRAPHITE - SLEEVE VI (Speer 901-RYL)

Original Weight of Sleeve - 10,270 grams  
 Final Weight of Sleeve - 7,370 grams

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		% Burn Off	(g) Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CRA</sub> mg/hr.cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr.cm <sup>2</sup>			
6.1	3.8	11.8	158	55.61	1400	17.23	1.26	.060	.55	.03	.58	.00	.48	.43
6.2	11.8	19.8	153		1400	11.33	1.17	.035	.85	.03	.38	.00	.96	.73
6.3	19.8	27.8	154			9.38	1.41	.039	1.12	.04	.32	.01	1.62	.79
6.4	27.8	35.8	154			8.20	1.51	.041	1.28	.05	.28	.02	2.35	.85
6.5	35.8	43.8	154			6.78	1.39	.037	1.26	.04	.23	.02	3.05	.90
6.6	43.8	51.8	161			6.36	1.41	.037	1.32	.05	.22	.03	3.76	.93
6.7	51.8	59.8	161			6.49	1.54	.041	1.48	.05	.22	.04	4.54	.96
6.8	59.8	69.8	158			7.42	1.84	.049	1.83	.06	.25	.05	5.74	.99
6.9	69.8	77.9	158			9.54	2.49	.063	2.53	.09	.32	.06	7.04	1.01
6.10	77.9	85.8	160			10.18	2.64	.068	2.81	.09	.34	.08	8.38	1.06
6.11	85.8	93.8	157			7.98	2.06	.053	2.30	.07	.27	.09	9.50	1.11
6.12	93.8	101.8	159			9.22	2.36	.064	2.74	.09	.31	.10	10.83	1.16
6.13	101.8	109.8	159			8.74	2.40	.062	2.68	.09	.29	.11	12.15	1.11
6.14	109.8	117.8	160			9.31	2.48	.062	2.93	.10	.31	.13	13.55	1.18
6.15	117.8	125.9	158			17.16	4.64	.119	5.59	.18	.58	.15	16.22	1.20
6.16	125.9	133.8	152			20.14	5.43	.146	6.72	.22	.68	.18	19.34	1.23
6.17	133.8	141.8	155			15.02	4.18	.108	5.11	.17	.51	.21	21.76	1.22
6.18	141.8	150.8	156			29.00	7.62	.210	10.03	.32	.99	.26	26.92	1.31
6.19	150.8	158.8	158			14.20	3.70	.106	5.02	.16	.48	.28	29.19	1.35
6.20	158.8	166.8	156	55.61		32.20	8.67	.245	11.58	.37	1.09	.33	34.46	1.33
6.21	166.8	174.8	158	54.61		26.10	7.00	.198	9.60	.30	.89	.37	38.78	1.37
6.22	174.8	182.8	158	55.61		25.37	7.17	.196	9.48	.30	.86	.42	43.10	1.32
6.23	182.8	190.8	156	55.61		26.35	7.59	.202	10.05	.32	.89	.46	47.68	1.32
6.24	190.8	198.8	156	54.61		26.5	7.45	.201	10.20	.38	.90	.51	52.28	1.36
6.25	198.8	206.8	156	54.61		27.18	7.71	.208	10.60	.34	.92	.55	57.05	1.37
6.26	206.8	214.8	155	55.61		28.33	7.93	.218	11.27	.35	.96	.60	62.04	1.42
6.27	214.8	222.9	157	52.63		29.94	8.40	.233	12.06	.37	1.02	.65	67.36	1.43
6.28	222.9	230.8	156	54.61		30.68	8.79	.237	12.47	.39	1.04	.71	72.82	1.41
6.29	230.8	238.8	156	54.61		28.97	8.16	.226	11.89	.37	.98	.76	77.97	1.45
6.30	238.8	246.8	156	51.64		31.25	8.79	.242	12.86	.40	1.06	.81	83.53	1.46
6.31	246.8	254.8	157	54.64	1400	31.27	8.76	.245	13.11	.40	1.06	.87	89.15	1.49
6.32	254.8	262.8	157	53.62	1400-1600	129.1	41.0	1.26	54.92	.17	4.40	1.11	113.8	1.33
6.33	262.8	270.8	159	50.64	1600	548.5	181.3	6.60	239.10	7.80	18.73	2.16	222.2	1.32
6.34	274.8	278.8	158	51.64		660.7	215.1	8.27	293.10	9.44	22.57	3.44	353.3	1.36
6.35	278.8	286.8	156	50.64		--	--	--	--	8.02	--	4.53	465.8	--
6.36	286.8	294.8	158	51.64		725.8	234.2	9.62	341.80	10.70	24.79	6.00	616.2	1.46
6.37	294.8	302.8	156	51.64		847.0	269.7	11.27	402.90	12.51	28.93	7.71	792.0	1.49
6.38	302.8	310.8	158	49.65		832.9	267.9	11.22	395.90	12.34	28.45	9.40	965.5	1.48

## EGCR FUEL ELEMENT GRAPHITE - SLEEVE VI (Speer 901-RYL) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g) Total Carbon Burned	$\frac{CO}{CO_2}$	
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr.cm <sup>-2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr.cm <sup>-2</sup>			
6.39	310.8	318.8	159	49.65	↓	902.6	292.2	12.13	.423.4	13.31	30.83	11.2	1152 1.44	
6.40	318.8	326.8	156	49.65	1600	888.3	292.2	12.01	.415.5	13.16	30.34	13.0	1337 1.42	
6.41	326.8	335.9	158	50.64	1600-1500	747.7	246.0	9.98	.347.6	11.05	.25.54	14.7	1514 1.41	
6.42	335.9	343.8	156	50.64	1500	313.6	99.1	3.71	.155.4	.4.72	.10.71	15.4	1579 1.56	
6.43	343.8	351.8	156	51.64	↑	313.8	99.5	3.62	.152.8	.4.67	.10.72	16.0	1645 1.53	
6.44	351.8	359.8	156	51.64		307.2	96.5	3.45	.149.6	.4.56	.10.49	16.6	1709 1.55	
6.45	359.8	367.8	157			320.6	100.4	3.35	.145.0	.4.54	.10.95	17.2	1773 1.44	
6.46	367.8	376.8	156			305.8	88.8	3.58	.144.5	.4.33	.10.44	17.9	1842 1.62	
6.47	376.8	384.8	156			314.6	91.6	3.47	.148.6	.4.45	.10.74	18.5	1904 1.62	
6.48	384.8	392.8	157			307.4	89.7	3.73	.140.5	.4.28	.10.50	19.1	1965 1.56	
6.49	392.8	400.8	155			318.3	92.9	3.74	.144.9	.4.41	.10.87	19.7	2027 1.55	
6.50	400.8	410.8	159			366.8	103.4	3.06	.153.6	.4.75	.12.53	20.5	2110 1.48	
6.51	410.8	418.8	158			388.6	118.6	3.24	.171.4	.5.36	.13.27	21.3	2186 1.44	
6.52	418.8	427.0	157			373.2	116.3	3.02	.167.1	.5.24	.12.75	22.1	2269 1.44	
6.53	427.0	434.8	157			--	--	--	--	--	--	22.8	2344 --	
6.54	434.8	442.8	158			420.7	129.2	3.55	.188.4	.5.87	.14.37	23.6	2427 1.45	
6.55	442.8	450.8	156			411.6	128.7	3.53	.186.3	.5.82	.14.06	24.4	2509 1.45	
6.56	450.8	458.8	157			412.4	129.0	3.45	.181.7	.5.74	.14.08	25.2	2589 1.40	
6.57	458.8	466.8	157			445.5	138.3	3.63	.196.5	.6.19	.15.21	26.1	2676 1.42	
6.58	466.8	474.8	157			415.9	131.3	3.41	.183.8	.5.82	.14.20	26.8	2758 1.40	
6.59	474.8	482.8	158			--	136.5	3.68	.190.3	.6.04	--	27.7	2843 1.39	
6.60	482.8	490.8	158			1500	403.1	127.1	3.31	.176.6	.5.62	.13.77	28.4	2922 1.39
6.61	490.8	498.8	157			1400	368.6	115.4	2.97	.161.5	.5.11	.12.59	29.1	2994 1.40
6.62	498.8	514.9	159				102.8	28.9	.66	.47.0	.1.40	.3.51	29.5	3033 1.63
6.63	514.9	522.8	157				99.5	28.2	.61	.45.9	.1.36	.3.40	29.7	3052 1.64
6.64	522.8	530.9	156				97.2	27.3	.58	.44.8	.1.33	.3.32	29.9	3071 1.64
6.65	530.9	538.9	157				96.1	27.5	.57	.44.0	.1.32	.3.28	30.1	3090 1.60
6.66	538.9	546.8	158	51.64			102.8	29.7	.62	.46.5	.1.40	.3.51	30.3	3109 1.56
6.67	546.8	554.9	157	50.64			101.7	29.4	.61	.46.1	.1.39	.3.47	30.4	3129 1.56
6.68	554.9	562.8	157	49.65			104.1	30.4	.61	.47.2	.1.42	.3.55	30.6	3149 1.55
6.69	562.8	570.8	157	55.23			1400	104.9	.63	.46.8	.1.42	.3.58	--	--

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## EGCR FUEL ELEMENT GRAPHITE - SLEEVE VII (Speer 901-RYL)

Original Weight of Sleeve - 10,190 grams  
 Final Weight of Sleeve - 7,200 grams

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		% Burn Off	(g) Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr·cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr·cm <sup>2</sup>			
7.1	5.0	13.2	155			47.7	15.55	.22	9.5	.46	1.63	.06	6.5	.61
7.2	13.2	21.1	155			50.7	18.75	.26	13.5	.59	1.73	.14	14.7	.72
7.3	21.1	29.1	153			56.1	18.52	.30	17.8	.67	1.91	.23	24.2	.96
7.4	29.1	37.1	153			64.0	21.09	.35	23.1	.81	2.18	.34	35.6	1.09
7.5	37.1	45.1	152			67.1	22.37	.38	26.8	.90	2.29	.47	48.4	1.19
7.6	45.1	53.1	152			75.1	24.36	.43	31.6	1.03	2.56	.61	62.8	1.29
7.7	53.1	61.1	152			80.0	26.02	.47	35.1	1.12	2.73	.77	78.6	1.34
7.8	61.1	69.0	152			73.7	27.95	.50	38.8	1.23	2.52	.93	95.8	1.38
7.9	69.0	77.2	154			121.8	39.39	.73	55.6	1.75	4.16	1.18	121.0	1.41
7.10	77.2	85.1	155			148.2	47.13	.96	69.0	2.14	5.06	1.47	150.7	1.46
7.11	85.1	93.0	153			155.1	50.02	1.03	73.8	2.28	5.29	1.79	182.4	1.47
7.12	93.0	101.2	154			168.5	53.88	1.14	80.5	2.47	5.75	2.14	218.0	1.49
7.13	101.2	109.1	153			180.7	57.11	1.24	87.6	2.66	6.17	2.50	255.2	1.53
7.14	109.1	117.0	153			188.7	59.42	1.31	91.8	2.79	6.45	2.88	293.9	1.54
7.15	117.0	125.1	154			193.5	61.12	1.36	95.7	2.89	6.61	3.28	335.1	1.56
7.16	125.1	133.1	154			210.8	67.01	1.52	103.6	3.14	7.20	3.72	379.3	1.54
7.17	133.1	141.1	153			212.9	67.29	1.54	105.2	3.18	7.27	4.16	424.1	1.56
7.18	141.1	149.1	155			223.9	70.33	1.62	109.8	3.32	7.65	4.62	470.8	1.56
7.19	149.1	158.0	154			244.8	78.58	1.82	120.8	3.68	8.36	5.18	528.4	1.54
7.20	158	166.1	150			238.2	75.77	1.75	117.7	3.57	8.13	5.68	579.2	1.55
7.21	166.1	174.2	152			254.7	81.09	1.61	124.7	3.79	8.69	6.22	633.7	1.54
7.22	174.2	182.2	152			260.4	82.31	1.97	128.1	3.88	8.89	6.75	688.3	1.55
7.23	182.2	190.2	150			256.1	82.29	1.89	125.7	3.84	8.74	7.28	742.2	1.52
7.24	190.2	198.0	154			256.8	84.32	1.93	126.1	3.88	8.77	7.80	795.5	1.50
7.25	198.0	206.1	152			250.1	83.88	1.67	122.7	3.81	8.54	8.33	849.0	1.46
7.26	206.1	214.1	153			253.7	85.93	1.89	124.4	3.88	8.66	8.87	904.2	1.45
7.27	214.1	222.0	154			256.5	88.06	1.90	125.2	3.93	8.76	9.40	958.8	1.42
7.28	222	230.0	153			252.9	86.33	1.90	122.2	3.85	8.64	9.94	1013	1.41
7.29	230	237.1	154			262.2	90.30	1.97	127.1	4.01	8.95	10.43	1063	--
7.30	237.1	249.0	154			295.3	103.6	2.25	140.0	4.49	10.08	11.35	1157	1.35
7.31	249.0	257.0	154			308.7	107.6	2.37	146.2	4.68	10.54	12.00	1223	1.35
7.32	257	265.1	154			309.4	108.8	2.39	145.5	4.69	10.56	12.65	1289	1.34
7.33	265.1	277.0	154			293.7	105.1	2.22	136.5	4.45	10.03	13.57	1383	--
7.34	277	285.0	153			294.8	107.0	2.25	135.7	4.48	10.06	14.20	1446	1.26
7.35	285	293.1	155			308.4	112.2	2.32	140.5	4.66	10.53	14.85	1512	1.25
7.36	293.1	301.1	153			308.4	111.4	2.33	139.4	4.63	10.53	15.48	1577	1.25
7.37	301.1	309.3	152			315.8	114.6	2.43	144.7	4.79	10.78	16.16	1646	--
7.38	309.3	317.0	153			299.6	105.5	3.00	131.2	4.38	10.23	16.76	1708	1.24
7.39	317	325.0	153			311.1	112.8	3.04	137.1	4.62	10.62	17.41	1773	1.21
7.40	325	333.2	153			307.9	109.9	3.02	136.5	4.56	10.51	18.02	1836	1.24

The average graphite temperature is 1500°F for all data points.  
 (7.1 through 7.52)

The average steam flow rate was 52 lb/hr for all data points.

## EGCR FUEL ELEMENT GRAPHITE - SLEEVE VII (Speer 901-RYL) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		% Burn Off	(g) Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr.cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr.cm <sup>2</sup>			
7.41	333.2	341.2	154			301.4	107.6	2.90	132.9	4.45	10.29	18.63	1899	1.23
7.42	341.2	349.1	154			313.8	112.8	3.06	137.7	4.64	10.71	19.26	1963	1.22
7.43	349.1	357.0	154			311.5	113.2	2.99	136.7	4.62	10.64	19.90	2028	1.21
7.44	357	365.0	152			313.9	114.7	3.03	137.7	4.67	10.72	20.54	2094	1.20
7.45	365	373.1	153			318.1	116.9	3.04	138.9	4.73	10.86	21.20	2161	1.19
7.46	373.1	381.2	153			318.4	115.6	3.08	138.5	4.70	10.87	21.86	2228	1.19
7.47	381.2	389.1	153			--	113.2	3.03	135.5	4.60	--	22.48	2292	1.19
7.48	389.1	397.0	152			321.1	118.1	3.09	138.8	4.75	10.97	23.13	2357	1.18
7.49	397	405.3	153			316.3	118.1	3.05	136.6	4.71	10.80	23.81	2426	1.16
7.50	405.3	413.1	156			341.8	237.7	3.27	146.2	5.07	11.67	24.50	2496	1.14
7.51	413.1	421.1	152			354.2	132.3	3.38	151.5	5.25	12.09	25.20	2569	1.14
7.52	421.1	430.2	152			347.8	129.9	3.33	148.8	5.16	11.88	26.00	2652	1.15

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APPENDIX B. Test Data for EGCR Moderator Graphite Sleeve -  
National Carbon Company.



## EGCR MODERATOR GRAPHITE - SLEEVE IV (National Carbon Company)

Original Weight of Sleeve - 9,994 grams

Final Weight of Sleeve - 5,050 grams

Data Point	Timer		Test Section			Average Gas Production Rate at STP					Reaction Rate		(g)	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr·cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr·cm <sup>2</sup>	% Burn Off	Total Carbon Burned	
4.1	79	87		62.3	1553	708.8	229.4	4.28	188.5	7.72	24.21	1.08	108.5	.82
4.2	87	95		62.3	1553	718.9	240.8	4.45	193.5	8.02	24.55	2.21	221.4	.80
4.3	95	103		64.9	1552	739.4	246.4	4.61	199.7	8.25	25.25	3.37	337.4	.81
4.4	103	111		61.6	1553	737.2	239.4	4.61	196.1	8.05	25.18	4.50	450.4	.82
4.5	111	119		62.6	1551	782.6	251.2	4.97	209.1	8.51	26.72	5.70	570.1	.83
4.6	119	127		59.3	1554	815.4	263.9	5.09	213.5	8.82	27.85	6.90	694.1	.81
4.7	127	135		55.2	1556	835.9	270.2	5.28	213.0	8.93	28.55	8.20	819.7	.79
4.8	135	143		60.8	1551	823.9	273.0	5.20	216.5	9.05	28.14	9.47	946.9	.80
4.9	143	153		60.2	1554	858.5	275.3	4.77	220.7	9.15	29.32	11.0	1107	.75
4.10	153	162		50.9	1555	866.4	282.5	4.44	212.0	9.13	29.59	12.5	1252	.77
4.11	162	170		59.2	1555	942.3	313.5	5.75	241.9	10.26	32.18	13.9	1396	.78
4.12	170	178		58.1	1557	896.0	266.0	4.62	206.7	8.73	30.60	15.1	1519	.78
4.13	178	186		65.9	1548	977.8	341.0	5.66	266.0	11.21	33.39	16.8	1676	.77
4.14	186	194		70.0	1547	879.0	291.0	4.95	226.0	9.55	30.02	18.1	1811	.77
4.15	194	201.1		68.5	1544	928.0	303.0	5.90	234.0	9.93	31.69	19.4	1935	.75
4.16	201.1	209		65.0	1548	785.0	257.0	4.95	193.0	8.33	26.81	20.6	2065	.78
4.17	209	215.1		63.6	1547	901.9	292.0	5.58	228.3	9.61	30.80	21.6	2168	.97
4.18	220	228		73.0	1402	97.7	28.5	.47	27.8	1.04	3.34	22.3	2228	.91
4.19	228	236		67.8	1408	92.7	28.3	.47	25.8	.99	3.16	22.4	2242	.87
4.20	236	244		66.3	1414	115.7	37.2	.58	32.4	1.28	3.95	22.6	2261	.93
4.21	244	252		69.5	1414	125.0	37.1	.63	34.7	1.32	4.27	22.8	2279	.87
4.22	252	260		72.1	1413	128.8	40.6	.65	35.2	1.40	4.39	23.0	2299	.73
4.23	260	268		52.2	1416	55.4	16.5	.24	12.2	--	--	23.1	2306	.84
4.24	268	276		68.5	1405	231.4	65.1	1.04	54.8	--	--	23.4	2337	.82
4.25	276	284		73.9	1394	89.8	29.3	.42	24.2	--	--	23.5	2351	.85
4.26	284	293		72.7	1426	148.9	46.8	.75	39.8	--	--	23.8	2377	.83
4.27	293	301		68.7	1396	107.7	34.9	.51	29.2	--	--	23.9	2393	.84
4.28	301	309		66.5	1396	49.8	15.6	.20	13.2	--	--	24.0	2400	.87
4.29	309	312.5		64.4	1389	141.6	43.9	.48	38.2	1.50	4.83	24.1	2410	.70
4.30	316	324		58.6	1502	485.9	165.7	2.87	117.3	5.23	16.59	25.0	2502	.77
4.31	324	332		57.0	1501	409.0	132.2	2.43	101.8	4.32	13.97	25.6	2563	.74
4.32	332	340		57.4	1502	476.1	161.1	2.81	118.9	5.17	16.26	26.4	2636	.74
4.33	340	348		58.8	1500	488.6	167.2	2.96	124.3	5.39	16.69	27.1	2712	.74
4.34	348	356		58.8	1495	464.5	159.4	2.22	119.4	5.14	15.86	27.8	2784	.74
4.35	356	365		59.6	1493	454.2	155.8	2.59	115.4	5.00	15.51	28.6	2863	.74
4.36	365	373		60.9	1492	460.3	159.0	2.66	117.3	5.10	15.72	29.3	2935	.74
4.37	373	381		63.6	1489	446.1	155.5	2.07	115.8	5.0	15.27	30.0	3005	.74
4.38	381	389.1		61.1	1488	404.2	142.0	2.34	103.3	4.53	13.80	30.7	3069	.73
4.39	389.1	397.1		60.0	1487	427.2	151.0	2.33	109.6	4.81	14.59	31.3	3137	.73
4.40	397.1	405.1		61.9	1488	438.5	149.9	2.37	113.1	4.85	14.97	32.0	3205	.75

The average pressure was 155 psig for all points 4.1 through 4.82

## EGCR MODERATOR GRAPHITE - SLEEVE IV (National Carbon Company) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		% Burn Off	(g) Total Carbon Burned	$\frac{\text{CO}}{\text{CO}_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr.cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr.cm <sup>2</sup>			
4.41	405.1	413		60.6	1486	396	135	2.23	100	4.36	13.55	32.7	3267	.74
4.42	413	421		60.0	1486	422	143	2.52	108	4.64	14.43	33.3	3332	.75
4.43	421	429		62.0	1485	378	125	2.08	97	4.11	12.91	33.9	3390	.77
4.44	429	437		60.3	1484	409	137	2.31	103	4.46	13.99	34.5	3453	.75
4.45	437	445.1		58.7	1485	436	147	2.51	111	4.77	14.91	35.2	3521	.75
4.46	445.1	453		59.6	1487	419	144	2.39	106	4.63	14.31	35.6	3560	.74
4.47	453	459		60.6	1487	425	145	2.06	108	4.68	14.53	36.1	3609	.75
4.48	462	470		59.6	1580	1246	513	7.95	252	14.15	42.56	36.6	3659	.49
4.49	470	478		59.1	1585	1157	469	6.80	238	13.06	39.51	38.6	3858	.50
4.50	478	486		57.3	1583	1301	506	8.31	286	14.64	44.43	40.4	4041	.56
4.51	486	494		53.4	1582	1215	504	8.28	265	14.21	41.49	42.5	4247	.52
4.52	494	503		57.4	1580	1155	473	8.10	262	13.60	39.45	44.5	4447	.55
4.53	555.7	563	(4110)	68.3	1307	10.0	3.44	.03	3.50	.12	.34	46.6	4662	1.01
4.54	563	571		71.5	1301	9.8	3.48	.04	3.16	--	.33	46.7	4665	.94
4.55	571	579		57.6	1302	9.8	3.89	.03	2.96	--	.33	46.7	4667	.76
4.56	579	587	(3030)	50.2	1314	31.3	9.72	.10	8.12	.32	1.06	46.7	4672	.83
4.57	587	595		53.6	1313	27.9	9.14	.09	7.51	.30	.95	46.8	4676	.82
4.58	595	603		52.7	1309	25.8	11.0	.09	7.86	.34	.88	46.8	4681	.71
4.59	603	611		49.7	1310	26.3	10.9	.10	7.79	.34	.89	46.9	4686	.71
4.60	611	619		51.6	1310	26.8	10.4	.10	7.82	.33	.91	46.9	4690	.75
4.61	619	627		54.5	1311	43.7	16.5	.14	12.13	.52	1.49	47.0	4698	.73
4.62	627	635	(4010)	66.5	1303	30.6	12.8	.11	8.89	.40	1.04	47.1	4703	.69
4.63	635	643		73.5	1294	28.3	10.7	.10	9.13	.36	.96	47.2	4709	.85
4.64	643	647.9		73.5	1293	56.6	18.3	.18	18.4	.67	1.93	47.2	4715	1.00
4.65	650.7	659		99.5	1391	82.3	32.9	.35	23.6	--	2.81	47.4	4740	.72
4.66	659	667		104.5	1389	112.3	41.5	.47	32.1	1.35	3.83	47.6	4767	.77
4.67	667	675.2		109.3	1386	108.1	45.3	.44	31.7	1.41	3.69	47.8	4787	.70
4.68	675.2	684		122.6	1386	78.9	28.8	.34	23.3	--	2.69	48.0	4802	.81
4.69	684	692		115.6	1386	75.4	31.2	.35	21.5	--	2.58	48.1	4815	.69
4.70	692	700		109.6	1385	109.6	42.1	.48	31.6	--	3.74	48.3	4835	.75
4.71	700	709		33.8	1411	113.6	44.3	.52	29.0	1.35	3.88	48.5	4854	.65
4.72	709	717		28.8	1406	133.6	41.8	.47	27.5	--	4.56	48.7	4872	.66
4.73	717	725		27.8	1417	126.2	56.2	.57	33.8	1.65	4.31	48.9	4895	.60
4.74	725	733		23.8	1406	138.6	66.3	.62	37.7	--	4.73	49.2	4922	.57
4.75	733	742		23.8	1403	109.7	46.9	.49	30.5	1.42	3.75	49.4	4944	.65
4.76	742	750		23.8	1402	126.7	51.2	.53	33.6	1.60	4.33	49.6	4966	.66
4.77	750	758		27.8	1399	123.8	52.6	.53	33.8	1.58	4.23	49.9	4988	.64
4.78	758	766		39.7	1396	113.6	42.9	.44	34.3	1.41	3.88	50.1	5008	.80
4.79	766	774		32.9	1392	69.1	26.9	.25	18.9	--	--	50.2	5021	.70
4.80	774	782		32.8	1395	88.2	28.2	.31	20.4	--	--	50.3	5033	.72
4.81	782	790.1		30.8	1389	87.7	21.4	.24	14.6	--	--	50.5	5047	.68
4.82	790.1	798		29.8	1386	102.0	19.7	.31	15.9	--	--	50.6	5056	.81

## EGCR MODERATOR GRAPHITE - SLEEVE VIII (National Carbon Company)

Original Weight of Sleeve - 10,100 grams  
 Final Weight of Sleeve - 5,450 grams

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g) Total Carbon Burned	$\frac{\text{CO}}{\text{CO}_2}$
	Start hr	End hr	System Pres. Psig ( $N_{Re}$ )	Steam Flow lb/hr	Average Graphite Temp. °F	$H_2$ scc/min	$CO_2$ scc/min	$CH_4$ scc/min	CO scc/min	$R_{CA}$ mg/hr.cm²	$R_{H_2A}$ scc/hr.cm²		
8.1	0	8				302.2	134.1	1.46	48.7	3.37	10.32	.47	47.3 .36
8.2	8	17.4				324.8	144.1	1.57	52.4	3.62	11.09	1.06	107.2 .36
8.3	17.4	33.0				297.3	131.8	1.42	48.0	3.31	10.15	1.95	197.9 .36
8.4	33.0	41.0				302.9	133.3	1.45	48.5	3.35	10.34	2.42	245.2 .36
8.5	41.0	50.0				244.1	108.2	1.18	41.3	2.75	8.33	2.86	288.7 .38
8.6	50.0	58.0				354.1	157.8	1.72	60.2	4.02	12.09	3.41	345.2 .38
8.7	58.0	66.0				378.7	168.7	1.84	65.6	4.32	12.93	4.01	405.9 .39
8.8	66	74.1				373.9	168.0	1.83	67.2	4.33	12.77	4.63	467.7 .40
8.9	74.1	83.0				382.4	172.0	1.87	68.8	4.44	13.06	5.31	537.1 .40
8.10	83.0	92.0				388.5	174.8	1.90	69.9	4.51	13.26	6.03	608.8 .40
8.11	92.0	100.1				414.5	187.8	2.39	78.5	4.91	14.15	6.72	678.8 .42
8.12	100.1	108				403.2	181.1	2.34	77.1	4.76	13.77	7.37	744.9 .42
8.13	108	116				444.7	196.2	2.54	83.7	5.16	15.18	8.09	817.5 .43
8.14	116	139.1				489.1	215.7	2.79	91.9	5.68	16.70	10.37	1048 .43
8.15	139.1	149				473.4	207.0	2.89	97.6	5.62	16.17	11.34	1146 .47
8.16	149	157				446.5	188.5	2.68	86.9	5.09	15.25	12.04	1217 .46
8.17	157	165				455.1	197.4	2.83	89.4	5.29	15.54	12.79	1292 .45
8.18	165	173				475.2	206.1	2.87	93.3	5.53	16.23	13.55	1369 .45
8.19	173	181				468.1	197.2	2.81	91.0	5.32	15.98	14.29	1444 .46
8.20	181	189.1				457.8	199.0	3.22	89.9	5.34	15.63	15.04	1520 .45
8.21	189.1	197				477.5	207.1	3.12	93.4	5.56	16.31	15.81	1597 .45
8.22	197	205				480.6	208.5	3.14	97.8	5.66	16.40	16.60	1677 .47
8.23	205	213.1				490.6	214.5	3.54	98.6	5.79	16.75	17.41	1759 .46
8.24	213.1	221				506.1	221.7	3.68	104.5	6.03	17.28	18.24	1843 .47
8.25	221	229.1				504.6	220.6	3.74	104.1	6.01	17.23	19.09	1929 .47
8.26	229.1	237.1				526.2	230.0	2.06	108.6	6.23	17.97	19.96	2016 .47
8.27	237.1	245				544.7	237.0	4.11	109.1	6.41	18.60	20.84	2105 .46
8.28	245	253.1				530.6	232.4	4.21	109.6	6.33	18.12	21.73	2195 .47
8.29	253.1	261.1				542.9	237.8	4.30	112.1	6.48	18.54	22.64	2287 .47
8.30	261.1	269.1				541.9	237.3	4.12	111.9	6.46	18.51	23.53	2377 .47
8.31	269.1	277.1				532.5	233.2	4.04	110.0	6.35	18.18	24.42	2467 .47
8.32	277.1	288.9				541.7	237.3	4.21	111.9	6.46	18.50	25.70	2600 .47
8.33	288.9	297.1				559.7	245.1	4.25	115.6	6.67	19.11	26.60	2696 .47
8.34	297.1	305				583.3	257.0	4.52	117.4	6.93	19.92	27.60	2793 .46
8.35	308	314				582.1	261.5	4.36	121.1	7.07	19.88	28.70	2905 .46
8.36	314	322.1				498.9	224.2	3.74	103.7	6.06	17.03	29.60	2991 .46
8.37	322.1	330.1				504.0	220.5	3.74	109.3	6.10	17.21	30.40	3076 .49
8.38	330.1	338.1				534.8	240.1	4.00	111.1	6.50	18.26	31.30	3168 .46

The average graphite temperature is 1500°F for all data points.  
 (8.1 through 8.64)  
 The system pressure was steady at 155 psig for all data points.

## EGCR MODERATOR GRAPHITE - SLEEVE VIII (National Carbon Company) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g)	Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr cm <sup>-2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr cm <sup>-2</sup>			
8.39	338.1	346.1				532.1	239.1	3.98	110.6	6.47	18.18	32.3	3259	.46
8.40	346.1	356.1				529.4	237.8	3.96	110.1	6.44	18.08	33.4	3372	.46
8.41	356.1	364				538.2	239.8	3.99	106.5	6.41	18.38	34.3	3461	.44
8.42	364	372				509.6	227.8	3.79	102.9	6.11	17.40	35.1	3547	.45
8.43	372	380				584.5	260.4	4.34	115.7	6.96	19.96	36.0	3645	.44
8.44	380	390				502.9	231.6	2.94	105.3	6.21	17.17	37.1	3754	.45
8.45	390	398.1				567.0	247.5	3.08	116.7	6.71	19.36	38.0	3849	.47
8.46	398.1	406.1				481.9	204.7	2.59	98.4	5.59	16.45	38.9	3928	.48
8.47	406.1	414				391.8	175.7	2.14	81.3	4.74	13.38	39.5	3994	.46
8.48	414	422.1				417.4	187.2	2.28	86.6	5.04	14.25	40.2	4066	.46
8.49	422.1	430.1				416.8	187.5	2.29	88.2	5.08	14.23	40.9	4137	.47
8.50	430.1	438				428.6	192.2	2.27	89.0	5.18	14.63	41.6	4209	.46
8.51	438	446				426.2	191.8	2.27	90.2	5.20	14.55	42.4	4282	.47
8.52	446	454.1				445.0	194.6	2.42	91.8	5.28	15.19	43.1	4357	.47
8.53	454.1	463.1				463.1	202.1	2.59	95.3	5.48	15.81	44.0	4444	.47
8.54	463.1	471.1				448.9	195.9	2.36	92.4	5.32	15.33	44.7	4519	.47
8.55	471.1	480.2				437.7	200.4	2.46	90.6	5.37	14.94	45.6	4604	.45
8.56	480.2	488.1				440.7	197.6	2.48	91.5	5.33	15.05	46.3	4678	.46
8.57	488.1	496				523.9	241.3	2.98	109.7	6.47	17.89	47.2	4768	.45
8.58	496	503.9				523.6	241.2	2.98	109.6	6.47	17.89	48.1	4860	.45
8.59	503.9	512.2				528.6	243.4	3.09	110.6	6.53	18.05	49.0	4951	.45
8.60	512.2	520.2				499.3	236.1	2.86	105.4	6.30	17.05	49.9	5042	.45
8.61	520.2	528.1				511.3	241.8	2.93	107.9	6.44	17.46	50.8	5131	.45
8.62	528.1	536.1				506.4	239.5	2.99	106.9	6.39	17.29	51.6	5220	.45
8.63	536.1	544.1				522.3	247.0	2.99	110.2	6.59	17.83	52.6	5314	.45
8.64	544.1	548.8				--	--	--	--	--	--	--	5367	-

## EGCR MODERATOR GRAPHITE - SLEEVE IX (National Carbon Company)

Original Weight of Sleeve - 10,000 grams  
 Final Weight of Sleeve - 7,800 grams

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g) Total Carbon Burned	$\frac{\text{CO}}{\text{CO}_2}$
	Start hr	End hr	System Pres. Psig (NRe)	Steam Flow lb/hr	Average Graphite Temp. °F	$H_2$ scc/min	$CO_2$ scc/min	$CH_4$ scc/min	CO scc/min	$R_{CA}$ mg/hr.cm <sup>-2</sup>	$R_{H_2A}$ scc/hr.cm <sup>-2</sup>		
9.1	.2	8.9				95.19	38.35	--	2.74	.75	3.25	.11	11.48 .07
9.2	8.9	18.1				118.90	50.95	--	4.47	1.01	--	.27	27.85 .08
9.3	18.1	30.9				--	32.28	--	6.18	.70	--	.43	43.72 .19
9.4	30.9	38.8				76.34	31.88	.47	7.84	.73	2.61	.53	53.91 .24
9.5	38.8	54.9				74.84	31.38	.08	9.42	.74	2.55	.75	75.00 .30
9.6	54.9	62.9				76.80	31.20	.19	10.54	.77	2.62	.85	85.80 .34
9.7	62.9	70.9				77.90	31.90	.08	11.19	.79	2.66	.96	96.92 .35
9.8	70.9	80.9				80.70	32.44	.09	12.36	.82	2.75	1.11	111.3 .38
9.9	80.9	88.9				83.08	32.70	.09	13.08	.84	2.84	1.23	123.0 .40
9.10	88.9	96.9				83.86	33.28	.11	13.71	.86	2.86	1.35	135.1 .41
9.11	96.9	104.9				89.58	35.83	.14	15.76	.94	3.06	1.48	148.4 .44
9.12	104.9	114.4				89.69	35.87	.14	15.78	.94	3.06	1.64	164.2 .44
9.13	114.4	122.1				93.34	37.34	.15	16.43	.98	3.18	1.77	177.5 .44
9.14	122.1	129.9				98.42	39.36	.16	17.32	1.04	3.36	1.92	191.8 .44
9.15	129.9	138.0				95.93	38.37	.15	16.88	1.01	3.27	2.06	206.2 .44
9.16	138.0	146.0				102.3	40.12	.18	18.01	1.06	3.49	2.21	221.1 .45
9.17	146.0	153.9				102.5	41.03	.16	18.05	1.08	3.50	2.36	236.2 .45
9.18	153.9	162.2				105.8	42.32	.17	19.46	1.13	3.61	2.52	252.7 .46
9.19	162.2	169.0				122.8	49.10	.19	22.60	1.31	4.19	2.68	268.4 .46
9.20	169	177.9				92.3	36.40	.18	16.37	.97	3.15	2.83	283.5 .45
9.21	177.9	186.0				104.5	41.80	.22	18.40	1.10	3.57	2.99	299.2 .44
9.22	186	193.9				107.7	43.10	.21	19.80	1.15	3.68	3.15	315.2 .46
9.23	193.9	200.9				105.8	42.30	.24	19.40	1.13	3.61	3.29	329.2 .46
9.24	200.9	210.0				108.0	43.20	.22	19.80	1.15	3.69	3.48	347.7 .46
9.25	210	217.9				109.7	43.90	.24	20.20	1.17	3.75	3.64	363.9 .46
9.26	217.9	225.9				113.9	45.60	.25	20.90	1.22	4.89	3.81	381.1 .46
9.27	225.9	233.9				108.4	43.40	.22	19.90	1.16	3.70	3.97	397.4 .46
9.28	233.9	241.9				106.9	42.70	.22	19.70	1.14	3.65	4.13	413.5 .46
9.29	241.9	249.9				110.6	44.30	.23	20.40	1.18	3.78	4.30	430.2 .46
9.30	249.9	257.9				114.7	45.90	.27	21.10	1.22	3.92	4.47	447.5 .46
9.31	257.9	265.8				112.5	45.30	.32	20.80	1.22	3.84	4.64	464.4 .46
9.32	265.8	273.9				114.3	46.10	.33	21.20	1.23	3.90	4.81	481.9 .46
9.33	273.9	282				111.7	44.70	.28	20.50	1.20	3.81	4.98	498.9 .46
9.34	282	289.9				120.7	48.30	.32	22.20	1.29	4.12	5.17	516.9 .46
9.35	289.9	297.9				125.0	49.90	.34	22.90	1.34	4.27	5.36	535.7 .46
9.36	297.9	306.3				118.5	47.80	.32	22.00	1.28	4.05	5.54	554.7 .46
9.37	306.3	314.2				131.4	53.00	.36	24.30	1.42	4.49	5.74	574.4 .46
9.38	314.2	321.9				130.2	52.50	.36	24.10	1.40	4.45	5.93	593.5 .46

The average graphite temperature is 1400°F for all data points.  
 (9.1 through 9.123)

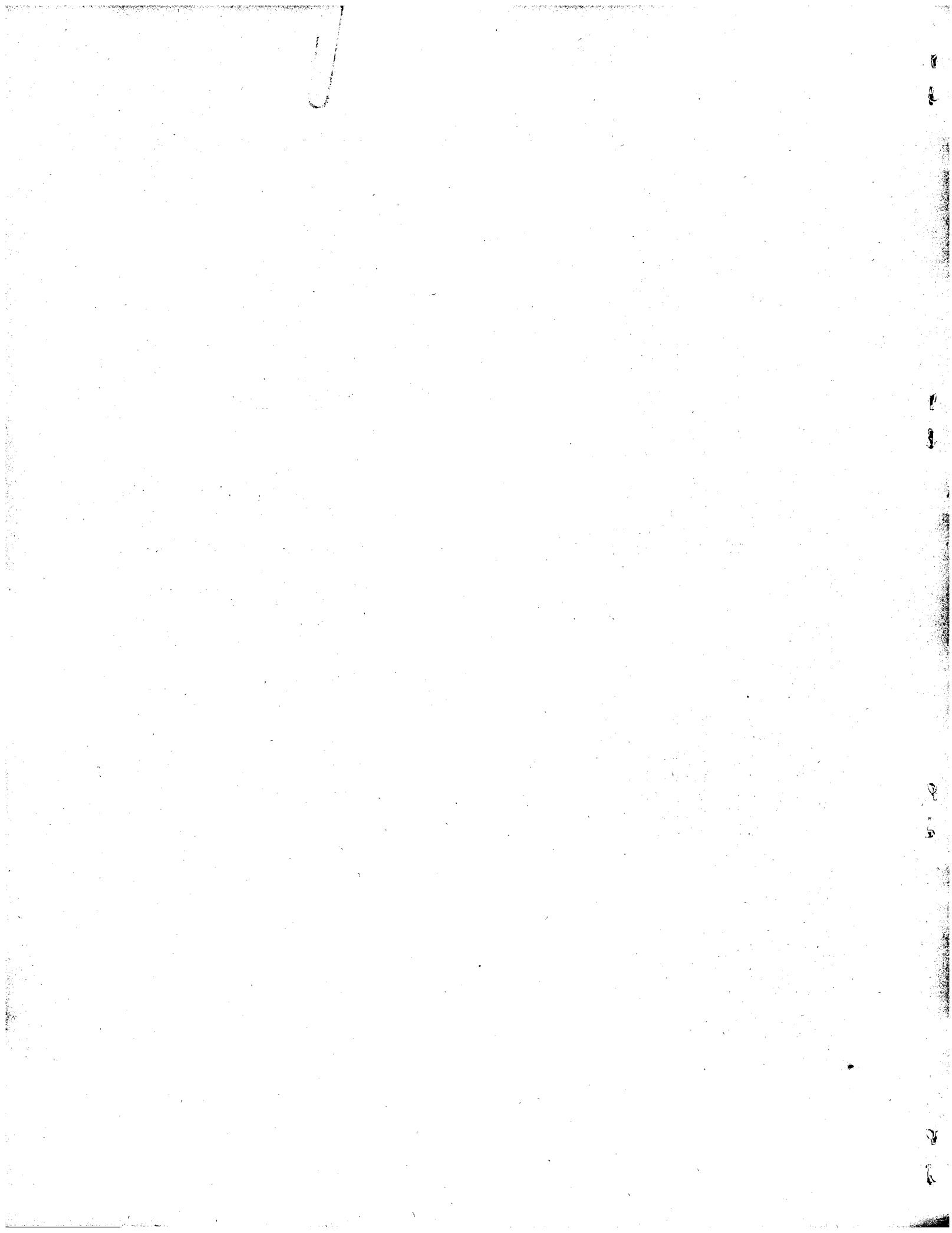
The system pressure was held steady at 155 psig for all data points.

## EGCR MODERATOR GRAPHITE - SLEEVE IX (National Carbon Company) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g) Total Carbon Burned	$\frac{CO}{CO_2}$
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr.cm <sup>2</sup>	R <sub>H<sub>2</sub>A</sub> scc/hr.cm <sup>2</sup>		
9.39	321.9	329.9				128.5	51.8	.35	23.8	1.39	4.39	6.13	.46
9.40	329.9	339.9				136.3	54.9	.44	25.2	1.47	4.65	6.39	.46
9.41	339.9	347.9				129.4	52.2	.42	24.0	1.40	4.42	6.58	.46
9.42	347.9	357.1				130.4	52.5	.42	24.2	1.41	4.45	6.81	.46
9.43	357.1	364.9				130.2	52.5	.42	24.1	1.41	4.45	7.00	.46
9.44	364.9	372.9				125.4	50.6	.40	23.3	1.36	4.28	7.19	.46
9.45	372.9	380.9				118.7	47.9	.38	22.0	1.29	4.05	7.41	.46
9.46	380.9	388.9				120.1	48.4	.39	22.3	1.30	4.10	7.62	.46
9.47	388.9	396.9				131.7	53.9	.42	24.4	1.44	4.49	7.82	.45
9.48	396.9	404.9				125.3	50.5	.40	23.2	1.35	4.28	8.01	.46
9.49	404.9	412.9				127.8	51.5	.41	23.7	1.38	4.36	8.20	.46
9.50	412.9	420.9				124.2	50.1	.40	23.0	1.34	4.24	8.39	.46
9.51	420.9	428.9				120.8	50.8	.41	23.4	1.37	4.12	8.59	.46
9.52	428.9	436.9				132.5	53.4	.43	24.6	1.43	4.52	8.78	.46
9.53	436.9	444.9				132.4	53.4	.43	24.5	1.43	4.52	8.98	.46
9.54	444.9	452.9				133.8	53.9	.43	24.8	1.44	4.57	9.19	.46
9.55	452.9	461.9				133.8	53.9	.43	24.8	1.44	4.57	9.42	.46
9.56	461.9	469.9				129.8	52.3	.42	24.1	1.40	4.43	9.62	.46
9.57	469.9	477.9				130.2	52.5	.42	24.1	1.41	4.45	9.82	.46
9.58	477.9	485.9				128.2	51.7	.41	23.7	1.39	4.38	10.0	.46
9.59	485.9	493.9				128.1	51.7	.41	23.7	1.39	4.37	10.2	.46
9.60	493.9	501.9				127.8	51.5	.41	23.7	1.38	4.36	10.4	.46
9.61	501.9	509.9				129.4	52.2	.42	24.0	1.40	4.42	10.6	.46
9.62	509.9	517.9				126.4	50.9	.41	23.4	1.37	4.32	10.8	.46
9.63	517.9	525.9				125.1	50.4	.40	23.2	1.35	4.27	10.9	.46
9.64	525.9	534.9				134.2	54.1	.43	24.8	1.45	4.58	11.2	.46
9.65	534.9	542.9				135.7	54.7	.44	25.2	1.47	4.63	11.4	.46
9.66	542.9	550.9				130.7	52.7	.42	24.2	1.41	4.46	11.6	.46
9.67	550.9	558.9				135.8	54.8	.44	25.2	1.47	4.64	11.8	.46
9.68	558.9	566.9				132.0	53.1	.42	24.4	1.42	4.51	12.0	.46
9.69	566.9	574.9				132.1	53.3	.43	24.5	1.43	4.51	12.2	.46
9.70	574.9	582.9				133.9	54.0	.43	24.8	1.45	4.57	12.4	.46
9.71	582.9	590.9				134.3	54.2	.43	24.9	1.45	4.59	12.6	.46
9.72	590.9	598.9				136.9	55.2	.44	25.4	1.48	4.67	12.8	.44
9.73	598.9	606.9				137.0	55.3	.44	25.4	1.48	4.68	13.0	.46
9.74	606.9	614.9				133.4	53.8	.43	24.7	1.45	4.56	13.2	.46
9.75	614.9	623.9				136.3	54.9	.44	25.3	1.47	4.65	13.5	.46
9.76	623.9	630.9				139.5	56.2	.45	25.9	1.51	4.76	13.7	.46
9.77	630.9	639.9				128.9	51.9	.41	23.9	1.39	4.40	13.9	.46
9.78	639.9	647.9				135.9	54.8	.44	25.2	1.47	4.64	14.1	.46
9.79	647.9	655.9				139.1	56.1	.45	25.8	1.51	4.75	14.3	.46
9.80	655.9	663.9				133.6	53.9	.43	24.8	1.45	4.56	14.5	.46

## EGCR MODERATOR GRAPHITE - SLEEVE IX (National Carbon Company) (Cont.)

Data Point	Timer		Test Section			Average Gas Production Rate at STP				Reaction Rate		(g)		
	Start hr	End hr	System Pres. Psig (N <sub>Re</sub> )	Steam Flow lb/hr	Average Graphite Temp. °F	H <sub>2</sub> scc/min	CO <sub>2</sub> scc/min	CH <sub>4</sub> scc/min	CO scc/min	R <sub>CA</sub> mg/hr.cm <sup>2</sup>	R <sub>H2A</sub> scc/hr.cm <sup>2</sup>	% Burn Off	Total Carbon Burned	CO/CO <sub>2</sub>
9.81	663.9	671.8				141.6	57.1	.46	26.3	1.53	4.84	14.7	1473	.46
9.82	671.8	679.9				143.1	57.7	.46	26.5	1.55	4.89	14.9	1495	.46
9.83	679.9	687.9				138.8	55.9	.45	25.7	1.50	4.74	15.1	1516	.46
9.84	687.9	695.9				142.5	57.4	.46	26.4	1.54	4.87	15.4	1537	.46
9.85	695.9	704.0				140.4	57.1	.52	26.3	1.53	4.79	15.6	1562	.46
9.86	704.0	711.9				141.1	57.8	.53	26.6	1.55	4.82	15.8	1583	.46
9.87	711.9	721.9				150.4	59.7	.48	27.5	1.60	5.14	16.1	1612	.46
9.88	721.9	729.9				150.2	59.6	.48	27.4	1.60	5.13	16.3	1634	.46
9.89	729.9	737.9				143.0	56.7	.45	26.1	1.52	4.88	16.5	1656	.46
9.90	737.9	745.9				140.6	55.8	.45	25.6	1.50	4.80	16.7	1677	.46
9.91	745.9	753.9				141.5	56.1	.45	25.8	1.51	4.83	16.9	1698	.46
9.92	753.9	761.9				145.4	55.7	.46	26.5	1.55	4.96	17.2	1720	.47
9.93	761.9	769.8				152.1	60.4	.48	27.7	1.62	5.19	17.4	1742	.46
9.94	769.8	777.9				148.6	59.0	.47	27.1	1.58	5.07	17.6	1765	.46
9.95	777.9	785.9				149.6	59.4	.47	27.3	1.59	5.11	17.9	1787	.46
9.96	785.9	793.9				154.2	61.2	.49	28.1	1.64	5.27	18.1	1810	.46
9.97	793.9	801.9				157.5	62.5	.50	28.7	1.68	5.38	18.3	1834	.46
9.98	801.9	809.9				149.9	59.5	.47	27.3	1.60	5.12	18.6	1857	.46
9.99	809.9	818.9				158.0	62.7	.63	28.8	1.68	5.39	18.8	1884	.46
9.100	818.9	826.9				143.4	56.9	.57	26.2	1.53	4.89	19.1	1907	.46
9.101	826.9	834.9				147.0	58.3	.58	26.8	1.57	5.02	19.3	1929	.46
9.102	834.9	842.9				141.8	56.3	.56	25.9	1.51	4.84	19.5	1951	.46
9.103	842.9	850.9				140.9	55.9	.56	25.7	1.50	4.81	19.7	1972	.46
9.104	850.9	858.9				142.0	56.0	.57	26.0	1.54	4.85	19.9	1994	.46
9.105	858.9	866.9				154.4	61.3	.61	28.2	1.64	5.27	20.2	2017	.46
9.106	866.9	874.9				170.2	67.5	.65	31.1	1.70	5.81	20.4	2041	.46
9.107	874.9	882.9				163.9	65.1	.65	29.9	1.75	5.59	20.6	2065	.46
9.108	882.9	889.9				165.2	65.6	.65	30.1	1.76	5.64	20.8	2087	.46
9.109	889.9	898.9				166.4	66.0	.66	30.4	1.77	5.68	21.1	2114	.46
9.110	898.9	906.9				157.5	62.5	.62	28.7	1.68	5.38	21.4	2138	.46
9.111	906.9	914.9				162.8	64.6	.65	29.7	1.74	5.56	21.6	2163	.46
9.112	914.9	922.9				167.8	66.6	.66	30.6	1.79	5.73	21.9	2188	.46
9.113	922.9	930.9				159.8	63.4	.63	29.2	1.69	5.46	22.1	2211	.46
9.114	930.9	938.9				166.9	66.2	.66	30.5	1.78	5.70	22.4	2237	.46
9.115	938.9	946.9				166.8	66.2	.66	30.4	1.78	5.70	22.6	2262	.46
9.116	946.9	954.9				170.9	67.8	.68	31.1	1.82	5.84	22.8	2287	.46
9.117	954.9	962.9				174.3	69.1	.69	31.8	1.86	5.95	23.1	2314	.46
9.118	962.9	970.9				176.7	70.1	.70	32.2	1.88	6.03	23.4	2340	.46
9.119	970.9	978.9				175.5	69.6	.69	32.0	1.87	5.99	23.7	2366	.46
9.120	978.9	986.9				172.7	68.5	.68	31.5	1.84	5.90	23.9	2392	.46
9.121	986.9	994.9				173.5	68.8	.69	31.7	1.85	5.92	24.2	2418	.46
9.122	994.9	1003.4				172.5	68.5	.68	31.5	1.84	5.90	24.4	2444	.46
9.123	1003.4	1010.9				172.9	68.6	.69	31.5	1.84	5.90	24.7	2469	.46



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