EMISSION TEST REPORT
U.S. STEEL - CLAIRTON COKE WORKS
COKE OVEN BATTERY 17
CLAIRTON, PENNSYLVANIA

OCTOBER 1980

PEDCo ENVIRONMENTAL

EMISSION TEST REPORT
U.S. STEEL - CLAIRTON COKE WORKS
COKE OVEN BATTERY 17
CLAIRTON, PENNSYLVANIA

OCTOBER 1980

Prepared by

PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

Contract No. 68-02-3546
Task No. 5
PN 3530-5

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
EMISSION MEASUREMENT BRANCH
EMISSION STANDARDS AND ENGINEERING DIVISION
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

Roy Neulicht, Task Manager

CONTENTS

1.0 INTRODUCTION

On October 16 and 17, 1980, PEDCo Environmental, Inc., personnel participated in a series of emission tests at Clairton Coke Works, U.S. Steel Corporation, Clairton, Pennsylvania. The purpose of the test program was to determine if EPA test Method 109, Part C is applicable for determining door emissions at coke oven batteries with coke side sheds.

Battery 17 at Clairton coke works is equipped with a pushing shed that is closed on the coke wharf side except for a single large opening to permit access for a front-end loader.

This report presents the results of the test series and discusses the applicability of Method 109 Part C at a coke oven battery with a coke side shed.

2.0 SAMPLE LOCATION AND TEST METHOD

Procedures for determining emissions from coke oven doors are detailed in EPA Test Method 109, Part C. These procedures require the observer to traverse each side of the battery from ground level. For safety reasons, the method recommends that the traverse be conducted outside of the pusher machine and quench car tracks. Figure 1 presents a diagram of a coke oven battery showing observer positions for the traverses.

Battery 17 is equipped with a shed that is closed on the coke wharf side except for a single opening to permit front-end loader access to the quench car tracks. Figure 2 presents a diagram of the shed arrangement of battery 17. The physical layout of the shed does not allow an observer to traverse the coke side of the battery as detailed in the method (e.g., from the ground outside the quench car tracks). Furthermore, safety regulations prohibited traversing on the coke car tracks. Therefore, the procedures used in this test program resulted in a modification to the procedures specified in Method 109, Part C. This modification consisted of conducting the traverses on both sides of the oven from the bench. The emissions on the push side were also observed from the ground level (per Method 109 procedures) so that results from both locations (bench and ground) could be compared.

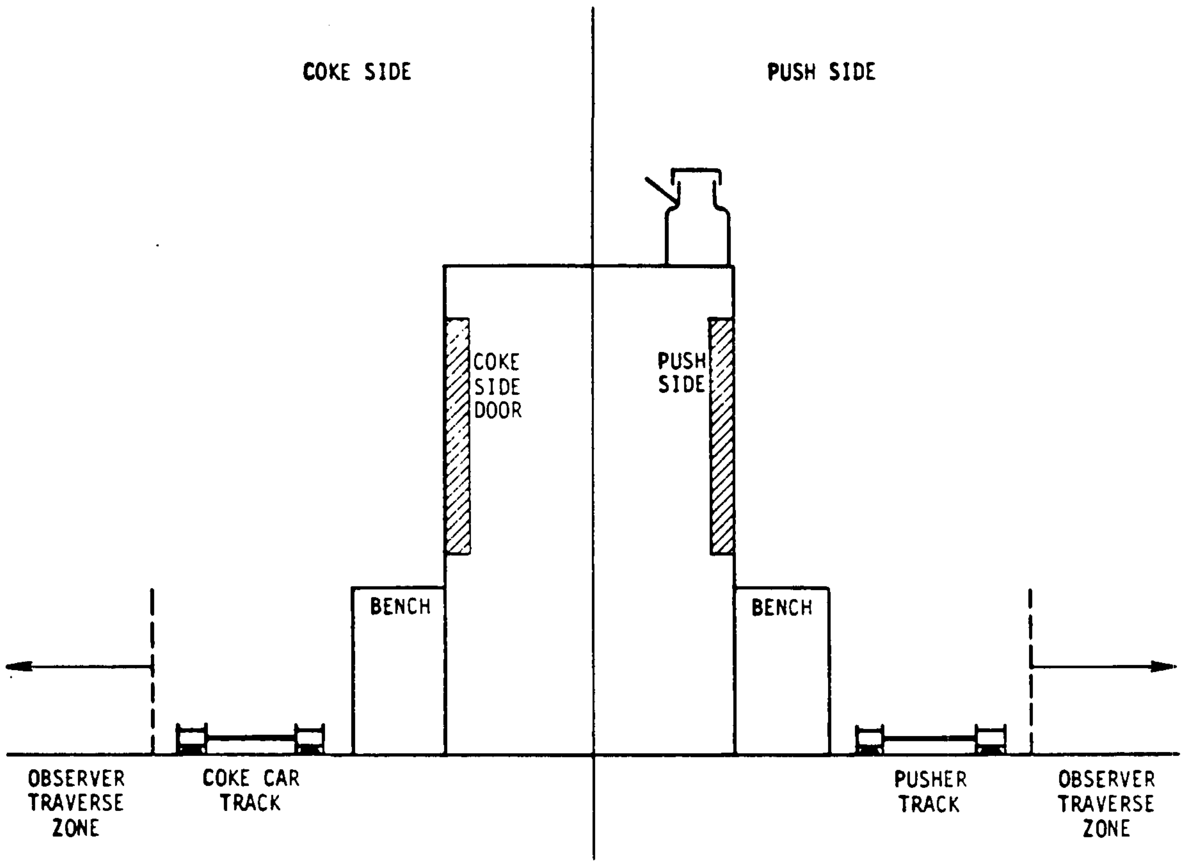

Figure 1. End view of coke oven battery showing recommended traverse zone.

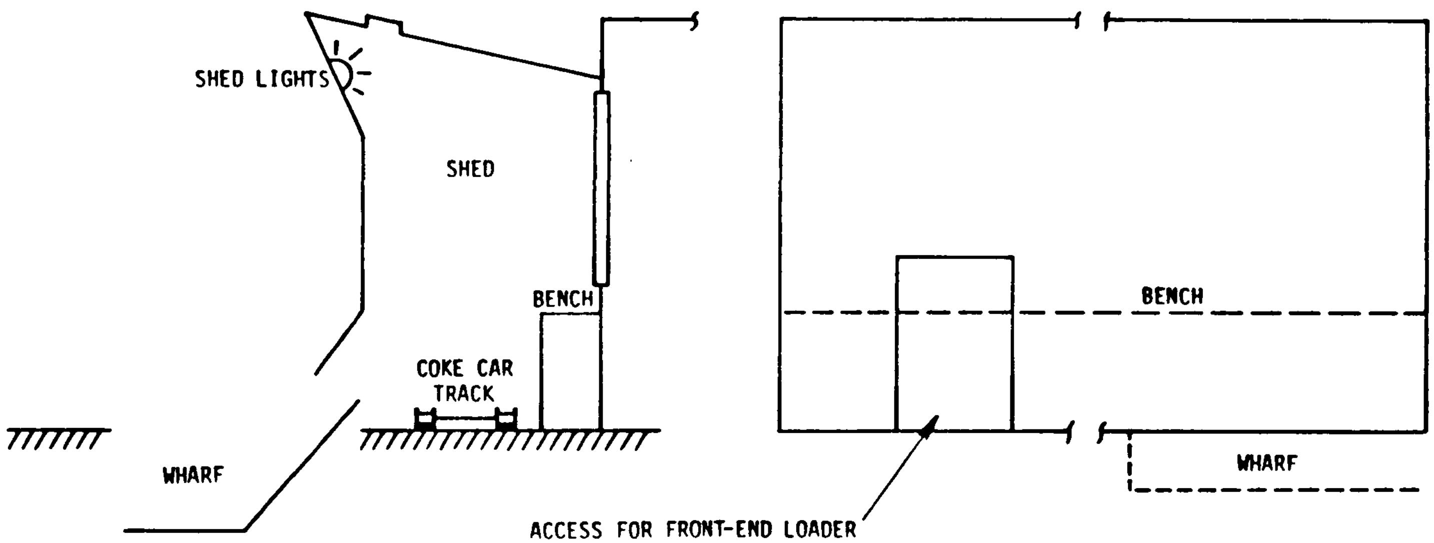

Figure 2. Coke oven battery 17, Clairton Coke Works.

To determine door leaks at this facility, the following specific procedures were used:

The test crew was comprised of four members who were divided into two teams. Each team traversed the same side of the battery simultaneously. This was accomplished by starting the teams at opposite ends of the battery, which required the teams to cross during each traverse. Each observer started his traverse approximately one minute after his teammate.

Each test consisted of each team completing a push side traverse from the bench, a coke side traverse from the bench, and a push side traverse from the yard.

Additionally, several runs included each team observing door leaks from ground level on the coke side while standing stationary at the access opening in the shed side.

3.0 SUMMARY OF RESULTS AND STATISTICAL ANALYSIS

Four individuals each reported the number of leaking doors observed on coke oven battery 17. A series of eight runs were made over a two-day period. The four individuals were separated into two teams; however, the makeup of the two teams was not the same on the two days. A run consisted of counting the number of leaking doors from the Push Side Yard, the Push Side Bench, and the Coke Side Bench. For an individual run there was an average time lapse of about one minute between the observations made by the two teams. The results of the emission tests are presented in Table 1.

3.1 CONCLUSIONS

The average number of leaking doors reported by all observers was 9.7 for measurements made from the Coke Side Bench, 8.8 for measurements made from the Push Side Bench, and 6.3 for measurements made from the Push Side Yard. For the Push Side the average number of leaking doors observed from the Bench was 40 percent higher than that observed from the yard.

Based upon the results of an Analysis of Variance (ANOVA) of observations reported by the four observers, the following conclusions were obtained.

TABLE 1. NUMBER OF LEAKING DOORS

Run	Push Side Yard Observer				Push Side Bench Observer				Coke Side Bench Observer			
	1	2	3	4	1	2	3	4	1	2	3	4
1	6	4	1	8	6	6	2	7	11	8	5	16
2	4	3	1	5	8	8	8	8	9	7	10	16
3	2	1	2	3	6	6	5	7	5	6	5	11
4	9	9	8	10	10	11	11	11	9	8	7	12
5	6	6	3	8	12	13	7	15	14	10	8	16
6	10	8	6	10	12	13	9	12	10	11	7	16
7*	4 (10)	8	7	12	(8)	(9)	7	10	(8)	(7)	7	11
8	7	10	4	10	7	9	8	12	8	10	8	13
Observer Avg.	6.8 [6.3][a]	6.1	4.0	8.2	8.6	9.4	7.1	10.2	9.2	8.4	7.1	13.9
Position Avg.	6.3				8.8				9.7			

[a][6.3] Average based upon the questionable results originally reported by Observer 1.
(*) Estimate of missing or questionable value.

1. There was a statistically significant difference between the average number of leaking doors reported by the four observers.

2. The results reported by two of the four observers displayed a statistically significant bias. For the average number of leaking doors reported over all runs and for the average reported for each position, Observer No. 3 was always lowest and Observer No. 4 was always highest.

3. The difference between the average number of leaking doors observed from the three positions was not statistically significant when compared with the variation between the averages reported by the four observers.

4. The difference in observer variance for the three positions was not statistically significant.

5. The observer variance, which includes the process variance, was 7.24 with a corresponding standard deviation of 2.69.

While Observers Nos. 3 and 4 each introduced a bias into the results of the emission tests, the results reported by Observer No. 4 appeared to be more erratic than that for Observer No. 3. The ANOVA was repeated using the data for Observers Nos. 1, 2, and 3 only. Based upon this second analysis, the following conclusions can be made.

1. The difference between the average number of leaking doors reported by the three observers was not statistically significant.

2. The difference between the average number of leaking doors observed from the three positions was statistically significant.

3. For the push side the average number of leaking doors observed from the Bench (8.4) was 50 percent higher than that observed from the Yard (5.6).

4. The difference in the average number of leaking doors observed from the Bench for the Push Side (8.4), and the Coke Side (8.2) was not statistically significant.

To further assess the difference in the number of leaking doors reported from the Bench and Yard on the Push Side, the results reported by each observer were analyzed separately. The following conclusions can be made.

1. On the average Observer No. 1 reported 26 percent more leaking doors from the Bench than the Yard; however, the difference was not statistically significant.

2. Observers Nos. 2 and 3 reported 54 and 78 percent more leaking doors, respectively, from the Bench compared with the Yard. For both observers the difference was significant.

3. On the average, Observer No. 4 reported 24 percent more leaking doors from the Bench than from the Yard; however, the difference was not statistically significant.

3.2 METHOD OF STATISTICAL ANALYSIS

Based upon the hierarchial design of the emission tests the components of variance include: (1) the difference in the number of observed leaking doors as a result of the position of the observer with respect to the coke ovens, (2) the difference between observers for the same position of the observer, and (3) the difference between runs for the same observer for the same position. The difference between runs for the same observer for the same position is assumed to be an estimate of the variance of an individual observation. As such it includes the variance due to the observer and the variance due to the process. These data were analyzed by the method of Analysis of Variance based upon the model:

$$x_{ijk} = \mu + \xi_i + \beta_{j(i)} + \varepsilon_{ijk}$$

where:

μ = overall mean
ξ_i = effect due to position (i.e., Push Side Yard, etc.)
$\beta_{j(i)}$ = effect due to difference between observer within position
ε_{ijk} = random error (i.e., between runs within observer within position)

For Run No. 7, Observers Nos. 1 and 2 did not report any results for the Push Side Bench and the Coke Side Bench. Also the number of leaking doors reported by Observer No. 1 for the Push Side Yard was questionable. The number of leaking doors (4) was substantially fewer than that reported by any of the other observers. In order to maximize the amount of data available for the statistical analysis, a procedure was used to derive estimated values for the four missing and one questionable values in Run No. 7.* The procedure estimates the missing value so as to minimize the residual variance. As such the estimated values have no effect upon the statistical analysis other than to balance the experimental design necessary to apply the Analysis of Variance. The application of this procedure to estimate the two missing values for the Push Side Bench is illustrated in Appendix A. The estimated values used in the analysis are shown in Table 1 in parentheses.

The data presented in Table 1 were statistically analyzed to determine the following:

1. Observer variance (includes process variance).
2. Variance between observers.

---

*Bennett, C.A., and N.L. Franklin. Statistical Analysis in Chemistry and the Chemical Industry. John Wiley and Sons, Inc., 1954, pp. 379-385.

3. Whether or not observer precision for Yard and Bench readings are significantly different.

4. Whether or not the number of leaking doors measured at the Push Side Bench and Push Side Yard are significantly different.

3.3 RESULTS

The Analysis of Variance of the number of leaking doors reported by the four observers is presented in Table 2. The mean square error between runs within observer within position of 7.24 is assumed to be an estimate of the variance (δ^2) of an individual observation. For the three positions from which observations were made, the variances of an individual observation (i.e., the observer variance) were:

Push Side Yard $S_1^2 = 8.96$

Push Side Bench $S_2^2 = 7.77$

Coke Side Bench $S_3^2 = 4.89$

Based on Bartlett's Test* the differences in observer variance between the three positions is not statistically significant (see Appendix B).

Analysis of Variance is a procedure for testing one or more null hypotheses. With respect to the study of leaking doors, Analysis of Variance is used to test two null hypotheses. The first is that the mean numbers of leaking doors over a series of eight runs are the same for all four observers. The second is that the mean number of leaking doors is the same for all observation positions. If the null hypothesis is rejected, it is

*Bennett, C.A., and N.L. Franklin. Statistical Analysis in Chemistry and the Chemical Industry. John Wiley and Sons, Inc., 1954, pp. 379-385.

TABLE 2. ANALYSIS OF VARIANCE OF NUMBER OF LEAKING DOORS ON COKE OVENS

Source of variation	Degrees of freedom	Sum of square	Mean square	F ratio	Average value of mean square
Between position	2	198.58	99.29	2.76 N.S.	$\sigma^2 + 8\sigma_\beta^2 + 32\sigma_\xi^2$
Between observer within position	9	323.91	35.99	4.97**	$\sigma^2 + 8\sigma_\beta^2$
Between runs within observer within position	79	572	7.24		σ^2
Total	90	1094.49			

Variance of an individual observation $s^2 = 7.24$

Variance between observers $s_\beta^2 = 3.59$

Variance between position $s_\xi^2 = 1.98$

N.S. = Not statistically significant - $p > 0.10$

** = Statistically significant - $p < 0.01$

then concluded that there is a statistically significant difference between the several means in question.

Testing the null hypothesis that there is no difference in the mean number of leaking doors reported by the four observers involves a comparison of the between observer mean square (35.99) and the within observer mean square (7.24). If there is no difference between the means of the four observers, the ratio of the two mean squares (referred to as the F ratio) would be about one. Because of sampling errors, the F ratio can deviate from one. An F ratio much greater than one may be sufficient evidence to reject the null hypothesis and conclude that there is a statistically significant difference between the means of the four observers.

The distribution of F is dependent upon the number of degrees of freedom associated with the two mean squares. Table 2 shows that the number of degrees of freedom for the between observer mean square is 9 and that for the within observer mean square is 79. Tables of the distribution of F for varying numbers of degrees of freedom for the numerator and denominator mean squares for risk levels (α) are included in nearly all statistics test books. If the value of F calculated from the mean squares in the analysis of variance table exceeds the critical value of F taken from the table of the F distribution, the null hypothesis is rejected. The critical value of F with degrees of freedom of 9 and 79 for $\alpha = 0.01$ is about 2.67. Since the calculated value of F (4.97) exceeds 2.67, it is concluded that the difference between the mean number of leaking doors reported by the four observers is highly significant.

The F ratio for testing the hypotheses that the average number of leaking doors is the same for all observation positions is F = 99.29/35.99 = 2.76. Referring again to the table of the F distribution for 2 and 9 degrees of freedom, the critical value for a risk level $\alpha = 0.10$ is 3.01. Thus, when the between position mean square is compared with the between observer mean square, the ratio is not sufficiently greater than one to reject the null hypothesis. It is therefore concluded that there is no difference in the average number of leaking doors as observed from the three positions.

The conclusions from the analysis of variance should be interpreted along with the results presented in Tables 1 and 3. While the overall average number of leaking doors as observed from the Coke Side Bench (9.7) is higher than that from either the Push Side Bench (8.8) or the Push Side Yard (6.3), in relation to the significant variation between observers this difference between averages for the different positions is not statistically significant.

For each position the average number of leaking doors reported by Observer No. 4 was higher than that for any of the other observers (see Table 1). The impact of the bias associated with Observer No. 4 is even more apparent from the results presented in Table 3. On the first day Observer No. 4 was a member

TABLE 3. AVERAGE NUMBER OF LEAKING DOORS

First day run	Push Side Yard			Push Side Bench			Coke Side Bench		
	Team		Run average	Team		Run average	Team		Run average
	A	B		A	B		A	B	
1	2.5	7.0	4.8	4.0	6.5	5.2	6.5	13.5	10.0
2	2.0	4.5	3.2	8.0	8.0	8.0	8.5	12.5	10.5
3	1.5	2.5	2.0	5.5	6.5	6.0	5.5	8.0	6.8
Average	2.0	4.7	3.3	5.8	7.0	6.4	6.8	11.3	9.1
Second day run	Team		Run average	Team		Run average	Team		Run average
	C	D		C	D		C	D	
4	9.5	8.5	9.0	11.0	10.5	10.8	10.0	8.0	9.0
5	7.0	4.5	5.8	14.0	9.5	11.8	13.0	11.0	12.0
6	9.0	8.0	8.5	12.5	10.5	11.5	13.5	8.5	11.0
7	10.0	8.5	9.2	9.5	7.5	8.5	9.0	7.5	8.2
8	10.0	5.5	7.8	10.5	7.5	9.0	11.5	8.0	9.8
Average	9.1	7.0	8.1	11.5	9.1	10.3	11.4	8.6	10.0

Team A - Observer Nos. 2, 3

Team B - Observer Nos. 1, 4

Team C - Observer Nos. 2, 4

Team D - Observer Nos. 1, 3

of Team B, and on the second day he was on Team C. In each case the team that included Observer No. 4 reported the highest number of leaking doors. The apparent bias of Observer No. 4 has no doubt had a significant impact upon the results of the emission tests and the analysis of variance.

Duncan's Multiple Range Test* was used to determine whether or not the average for an individual observer (or group of observers) differs significantly from the average of another individual observer (or group of observers). Because of the suspected difference in the average number of leaking doors observed from the Bench and the Yard, Duncan's Test was applied separately to the results reported for the three positions (see Table 4). Duncan's Test compares the range of pairs of averages, and sets of three averages with a least significant range (LSR). When the calculated range exceeds the LSR it is concluded that the means differ significantly.

The LSR was calculated for sets of two and three means using the variance of an individual observation (7.24) as determined from the analysis of variance (see Table 2). Referring to Table 4, the ranges of averages of pairs and triplicate observers that are underlined do not exceed the LSR. Based upon Duncan's Test, the differences in averages are not statistically significant. From this analysis it is again apparent that Observer No. 3 consistently reports the lowest and Observer No. 4 the highest number of leaking doors. In all cases, except for Observer No. 4

*Miller, I. Probability and Statistics for Engineers, 279.

TABLE 4. DUNCAN MULTIPLE RANGE TEST COMPARING AVERAGE NUMBER OF LEAKING DOORS REPORTED BY FOUR OBSERVERS

	Observer No.			
	3	2	1	4
Push Side Yard Average	4.0	6.1	6.8	8.2
Push Side Bench Average	7.1	8.6	9.4	10.2
Coke Side Bench Average	7.1	8.4	9.2	13.9

Least Significant Range = $(S_{\bar{x}})(P_i)$

where

$$S_{\bar{x}} = \left(\frac{S^2}{N}\right)^{1/2}$$

and $S^2 = 7.24$ (Table 1)

$N = 8$ runs per position

$P_2 = 2.82$

$P_3 = 2.97$

$LSR_2 = 2.68$ (pairs of observers)

$LSR_3 = 2.83$ (3 observers)

for the Coke Side Bench, the difference between averages of adjoining pairs was not significant. The average of 13.9 reported by Observer No. 4 was more than 50 percent higher than that reported by Observer No. 1.

The entire analysis of variance was repeated using only the data for Observers Nos. 1, 2, and 3 (see Table 5). For this reduced data set, the average number of leaking doors for observations made from the Push Bench (8.4) is nearly the same as that for the Coke Side Bench (8.2). Again the number of leaking doors observed from the Push Side Yard (5.6) was the lowest of the three positions. The results of the Analysis of Variance presented in Table 6 show that the difference between the average number of leaking doors for the three positions is highly significant ($p<0.01$). On the other hand the difference between the average number of leaking doors reported by the three observers is not statistically significant. The variance of an individual observation of 7.39 as determined from the data for the three observers agrees quite well with the variance originally reported for all four observers.

TABLE 5. NUMBER OF LEAKING DOORS ON COKE OVENS
AS REPORTED BY THREE OBSERVERS

Run	Push Side Yard Observer 1	Push Side Yard Observer 2	Push Side Yard Observer 3	Push Side Bench Observer 1	Push Side Bench Observer 2	Push Side Bench Observer 3	Coke Side Bench Observer 1	Coke Side Bench Observer 2	Coke Side Bench Observer 3
1	6	4	1	6	6	2	11	8	5
2	4	3	1	8	8	8	9	7	10
3	2	1	2	6	6	5	5	6	5
4	9	9	8	10	11	11	9	8	7
5	6	6	3	12	13	7	14	10	8
6	10	8	6	12	13	9	10	11	7
7	10	8	7	8	9	7	9	7	7
8	7	10	4	7	9	8	8	10	8
Observer Avg.	6.8	6.1	4.0	8.6	9.4	7.1	9.2	8.4	7.1
Position Avg.	5.6			8.4			8.2		

TABLE 6. ANALYSIS OF VARIANCE OF LEAKING DOORS ON COKE OVENS - THREE OBSERVERS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F ratio
Between position	2	115.75	57.875	7.83**
Between observers within position	6	7.25	12.0833	1.75 N.S
Between runs within observer within position	60	415.25	6.9208[a]	
Total	68	603.5		

**Statistically significant $p < 0.01$.

N.S. - Not statistically significant $p > 0.10$.

[a]Because the difference between observers is not significant, the Sums of Squares for between observers is combined with that for between runs to provide an estimate of the variance of an individual observation of $s^2 = 7.39$.

4.0 LIGHTING SURVEY

Battery 17 is equipped with a pushing control shed that is closed on the coke wharf side except for an access opening. This design allows very little ambient light to enter the shed. Supplimental lighting is provided under the shed through the use of 12 strategically located 1000-watt mercury vapor lamps.

During several emission tests traverses, illumination levels were recorded at various locations under the shed at bench level. A General Electric Model 214 triple-range color- and cosine-corrected light meter was used to measure illumination levels. This instrument has a reading range of 10- to 1000-foot candles (fc) actual scale, and a 10x cell shield that extends the range to 10,000 fc. The model 214 has an accuracy of ± 15 percent in the 10- to 100- and 200- to 1000-fc ranges, and ± 10 percent in the 100- to 200-fc range. Table 7 presents the results of the lighting survey. Under the shed along the coke side bench, illumination levels ranged from 2 to 28 fc with an average of 14 fc. Along the bench on the push side, illumination levels ranged from 380 to 420 fc with an average of 403 fc. The illumination level measured inside the shed at ground level adjacent to the access opening was 16 fc. The illumination level under the shed did not affect the ability of the observers to detect door leaks.

TABLE 7. BATTERY 17 LIGHTING SURVEY

Date	Time	Position	Coke side bench illumination, fc	Date	Time	Position	Push side bench illumination, fc	Date	Time	Position	Coke side yard illumination, fc
10-16-80	13:22	A7	28	10-16-80	4:42	A8	420	10-16-80	2:16	Ground level inside access opening in shed	16
10-16-80	13:23	A28	14								
10-16-80	13:24	B8	5	10-16-80	4:43	B1	380				
10-16-80	3:25	A9	16	10-16-80	4:44	B26	410				
10-16-80	3:26	B1	5								
10-16-80	3:27	B27	12								
10-16-80	4:50	A3	24								
10-16-80	4:51	B1	2								
10-16-80	4:52	B26	12								
10-17-80	1:52	A31	5								
10-17-80	1:49	B15	5								
10-17-80	10:28	A9	28								
10-17-80	10:29	B3	5								
10-17-80	10:30	B29	30								
Average			14	Average			403				