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GAS-MANTLE LIGHTING CONDITIONS IN TEN
LARGE CITIES IN THE UNITED STATES

BY

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and

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Bureau of Standards

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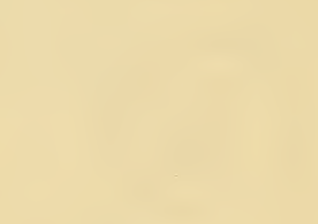
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THE HISTORY OF THE
CITY OF BOSTON

FROM THE FIRST SETTLEMENT
TO THE PRESENT TIME

BY
NATHANIEL BATES



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By R. S. McBride and C. E. Reinicker

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I. OBJECT AND SCOPE OF WORK

In connection with the determination of the proper standards for gas service, an important question is the improvement which results in the service obtained when lamps are systematically maintained by the gas company or some other agency. A care-

ful inspection of mantle lights in service was made in order to find out to what extent the customer benefited through such maintenance and also to study the maintenance systems in force in the various cities of the country.

With this work an effort was also made to investigate the comparative effects on the efficiency of lighting equipment of so-called leaner and richer gases. Gas engineers quite generally believe that a gas containing a smaller percentage of condensable hydrocarbons will give better service than a gas containing a higher percentage of these vapors, because of smaller deposits of carbon on mantles, glassware, and ceilings, less clogging of orifices, greater reliability of pilots, and longer life of mantles. The results obtained in this part of the investigation are not extensive enough to furnish conclusive evidence, but they do not indicate that the quality of the gas has an appreciable effect upon the efficiency of the lighting equipment.

The gas-mantle lighting in 10 of the larger cities of the country was inspected during the late summer, and in 5 of the same cities also during the succeeding winter, in order to study the effect of changing seasons. The study included gases of different methods of manufacture and distribution as well as different methods of maintenance of lamps, and thus is believed to be representative of lighting conditions in general, without being influenced by particular local conditions. Three observers were engaged in this inspection at different times; in some cities they all worked together, while in others one man conducted the investigation.

Certain limitations of the results presented should be recognized at the outset. The methods of observation and the time available for the work made it impracticable to determine all the causes of the defects noted, but in view of the objects of the work this was not necessary. The character of the observations, of course, precluded a comparison with any precise standards. However, very satisfactory agreement in the results of the three independent observers indicates that this difficulty does not prevent reaching definite conclusions.

It is believed that the information will be of interest and value to the gas industry. The investigation shows what will probably be to many a surprising condition, and indicates clearly how gas-mantle lighting conditions may be improved appreciably. It is in the hope that some such benefit will result to the gas industry and its customers that this paper is presented.

II. METHODS OF INVESTIGATION

The investigation of the conditions of the gas-lighting units was pursued in the eastern, central, and western sections of the country. The gas supplied in the cities in which inspections were carried out is reported to the Bureau as indicated by Table 1.

TABLE 1
Character of Gas in Cities Visited

City	Kind of gas	Approximate candle-power	Approximate B. t. u.
Philadelphia:			
Philadelphia Gas Works district.....	20 per cent coal and 80 per cent carbureted water gas.	22	650
Northern Liberties district.....	Coal gas.....	9	575
Baltimore.....	40 per cent coke-oven and 60 per cent carbureted water gas.	18	600
Washington.....	Carbureted water gas.....	16	615
Chicago.....	90 per cent carbureted water gas, 10 per cent coke-oven gas.	22	665
Milwaukee.....	Coal and coke-oven gas.....	12	600
Indianapolis.....	Coke-oven gas.....	10	600
Minneapolis.....	35 per cent coal and 65 per cent carbureted water gas.	17	600
St. Paul.....	Carbureted water gas.....	16	600
Portland, Oreg.....	Oil gas.....	13	570
Spokane, Wash.....	60 per cent coal and 40 per cent carbureted water gas.	18	600

1. CHARACTER OF OBSERVATIONS MADE

The investigation was carried out by inspecting the units in place. When a frosted globe obscured the mantles the globe was removed, and in nearly every case the lamp was turned on in order to determine the adjustment of the burners and the pilot and the condition of the gas supply. Each lamp was inspected with regard to the condition of the mantles, glassware, and pilot, and the cleanliness of the ceiling or ceiling shield around each unit was noted. Other information obtained was the make and type of the lamp, the owner of the equipment, and by whom it was maintained. The information available regarding the time of burning, position of the air shutter, and gas set screw and the condition of the gas supply was, in general, so unreliable as to be of no practical value. Notation of the ceiling distance was made for later use in connection with work of the Bureau on the National Gas Safety Code. For recording the observations a data sheet of the following form was used for each location.

Address..... Char. of location..... Series.....
 Sheet.....
 Lamp..... No. of units..... Date.....
 Maker..... Inside..... Outdoor..... Ceiling..... Bracket.....
 Mantle: Upr..... Inv..... No. per lamp..... Ceiling dist.....
 Owner: Co..... Cust..... Maintenance: By Co. free..... Contract.....
 None..... How long since last cleaned..... Hours burning per day.....

	1	2	3	4	5	6
Location exposed to—						
Draft.....						
Vibration.....						
Shock.....						
Dust.....						
Alignment.....						
Mantle (clean or dirty).....						
Mantle (whole or broken).....						
Mantle (quality).....						
Glassware (clean or dirty).....						
Glassware (whole or broken).....						
Pilot (lighted or out).....						
Pilot (properly placed).....						
Pilot (properly adjusted).....						
Ceiling (clean or dirty).....						
Air shutter (degree open).....						
Gas set screw (degree open).....						
Gas supply (condition).....						

C= clean. O. K.= whole, satisfactory, etc. Ex.= excellent.
 D= dirty. N= none. G= good.
 Carb.= carboned. Dis.= discolored. F= fair.
 B= broken. S= smoky. P= poor.
 Cr.= cracked.

2. CHARACTER OF LAMPS INSPECTED

Only those places of a public or semipublic nature were visited, such as stores, shops, markets, garages, restaurants, manufacturing establishments, etc. No residence lighting was included, and as very indefinite results were obtained from the small number of street-lighting units inspected, no figures on this class of lighting have been prepared.

Inspections were made of lamps maintained by companies and those which were maintained by customers, the endeavor being to examine an equal number of units under each condition. By lamps maintained by companies are meant those lamps which are visited at stated intervals for the purpose of cleaning the glassware, replacing broken or dirty mantles, cleaning the burner tubes

or other parts of the lamp, adjusting the gas supply to the burners and the pilot, or repairing or replacing any other parts of the lamp in order to leave it in good condition and adjustment. This maintenance work was conducted either by the local gas company or by some other firm on the payment of a certain fixed charge per month or through some other arrangement. In one city the maintenance labor is furnished without cost, the only charge to the customer being the replacement of parts becoming damaged or worn out through service. Lamps maintained by the customers usually have no regular care or attention from any experienced person. Such units are sometimes taken care of by the customers, but frequently are not taken care of at all.

Some of the lamps inspected were owned by the users and some were rented from the gas company or some lamp company. The rate charged the customer in the latter case includes maintenance.

The inspection embraced all the types and classes of gas-mantle lighting units which were found in service. Those lamps which were manufactured by well-known lamp makers were subjected to the same scrutiny as were those put out by small or unknown manufacturers. Indoor and outdoor units, those with single or with multiple mantles, and both the inverted and upright types were included in the work.

3. COOPERATION OF GAS COMPANY

In every case the cooperation of the local gas company was obtained. In several instances the gas company does not itself do the lamp maintenance work, but in such cases it secured the cooperation of the maintenance company.

Every facility for conducting the work in a satisfactory and expeditious manner was extended to the representatives of the Bureau, and great interest was manifested in the undertaking on the part of the company officials. Frequently one of the men of higher position in the operating force was in charge of the inspections and a number of regular maintenance men were detailed to aid. The benefit to the Bureau's representatives arising from such an arrangement was considerable, for the work connected with the actual mechanical inspection was greatly facilitated. The Bureau is glad to express here its appreciation of the assistance rendered. Some benefit also accrued to the company since minor adjustments could be immediately made and complaints remedied which otherwise might not have been brought to the notice of the company.

In order to obtain as full a knowledge of lighting conditions as the time and number of observers would permit, the inspections were made both in the central business district and in outlying regions of commercial activity. Typical locations were selected by the representatives of the Bureau after conference with the local company.

TABLE 2
Types of Lamps Inspected^a

Type of lamp	Maintained by company		Maintained by customers	
	Units	Mantles	Units	Mantles
Inside.....	2380	4928	1652	2871
Outside.....	326	1384	64	275
Inverted.....	2296	4744	1375	2164
Upright.....	410	1568	341	982
Single mantle.....	1362	1362	1224	1224
Multiple mantle.....	1344	4950	492	1922

^a The 46 units listed in Table 2 as "miscellaneous" are not included in this summary. Lamps on free-lighting service are included with those maintained by company.

III. SUMMARY OF OBSERVATIONS

1. NUMBER AND KIND OF LAMPS OBSERVED

During the course of this investigation the Bureau's representatives inspected 3174 units during the summer; 1803 maintained by companies and 1371 not so maintained. These units were equipped with 6607 mantles; 4196 on units maintained by companies and 2411 on units not so maintained. During the winter 1294 units were inspected; 834 maintained by companies, 105 on free lighting service, and 355 maintained by the customers. These were equipped with 2993 mantles, 2097 on units maintained by companies, 147 on those units on free lighting service, and 749 on units maintained by the owners themselves.

Table 3 shows the various kinds of lamps observed, as well as the number of each kind, while in Table 2 different groupings of the total number of lamps are given.

2. MAINTENANCE SYSTEMS OBSERVED

In eight of the cities visited lamp maintenance work is done by the local gas company, while in the other three it is turned over to one or more of the well-known lamp-manufacturing com-

panies. The frequency of maintenance visits varied from once each week to once each month or longer, and the charge for this service likewise varied in each city according to the local policy.

TABLE 3
Number and Kind of Lamps Inspected

Lamp	Maintained by company ^a		Maintained by customers	
	Units	Mantles	Units	Mantles
Humphrey No. 30, inside.....	538	1614	70	210
Humphrey No. 50, inside.....	53	265	26	130
Humphrey No. 30, outside.....	80	240	3	9
Humphrey No. 50, outside.....	167	835	11	55
Humphrey 4-mantle standard, inside.....	284	1136	134	536
Humphrey 4-mantle standard, outside.....	8	32	7	28
Humphrey Radio X.....	12	12	7	7
Humphrey Radio No. 30.....	37	111	5	15
Humphrey No. 10.....	33	33		
1911 Multiflex 5 mantle.....	41	205	27	135
1911 Multiflex 3 mantle.....	18	54	4	12
905 Welsbach 4-mantle upright.....	48	192	52	208
Intenso.....	52	208	14	56
Reflex No. 20.....	801	801	200	200
Welsbach No. 10.....	1	1	16	16
Single-mantle Reflex.....	474	474	603	603
No. 71.....	31	31	125	125
901 Portico.....	10	10	5	5
C. E-Z.....	9	27	7	21
Junior.....			5	5
Intenso (3 mantle).....	6	18	3	9
Welsbach 5-mantle outside upright.....			3	15
Welsbach 4-mantle outside upright.....	2	8	4	16
Welsbach Cluster, 4 mantle.....			2	8
Miscellaneous.....	37	133	15	31
Foreign.....			265	272
Graetzen.....			7	7
Exello.....			34	136
Capitol.....			1	4
New Idea.....			10	40
Solar 4 mantle.....			59	236
Solar 5 mantle.....			2	10
Total.....	2742	6440	1726	3160

^a Includes lamps on free-lighting service.

Several features of interest in this connection are worth mentioning. For example, in one city a type of lamp equipped with a single large mantle is featured in conjunction with several multiple-mantle types; but different intervals between calls prevail for these single-mantle units and different men are employed for this

work. In another city the gas company has specialized to some extent in an outside multiple-mantle unit, the daily lighting and extinguishing of these lamps being a part of the maintenance work. Still another city has recently adopted a policy of free maintenance labor on lamps of good quality installed in public or semipublic places, whereby the customer pays only for any new material which may be used on the lamp. This is called "free lighting service."

In several of the cities visited small lamp companies conducted some pretence of maintenance on their own lamps, but as the lamps were of poor quality and the maintenance was poor these lamps were not considered as being on company maintenance.

3. BAD INFLUENCES TO WHICH LAMPS ARE SUBJECTED

During the course of the investigation a great many of the lamps inspected were found to be subjected to one or more detrimental influences, such as draft, dust, or vibration. This applied both to the lamps maintained by customers and to those maintained by companies. The percentages in the following instances are based wholly upon the results of the summer inspection.

(a) *Drafts*.—Drafts had a decided effect upon 14 per cent of the units on company maintenance and upon 15 per cent of those not so maintained. The effect of drafts was often manifested by extinguished pilots, cracked glassware, a decided flicker of the light, and a disturbance of the adjustment of the burner. These effects were brought about through several causes, one of the most prevalent being electric fans, and another open doors and windows. In several locations, particularly in those places which required spot lighting over individual machines, electric fans were so located that they seriously affected long rows of units.

(b) *Vibration*.—The effect of vibration was noticeable in 10 per cent of the units on company maintenance and 10 per cent of those not so maintained; in extreme cases this condition was seemingly responsible for broken or cracked mantles. It was found that overhead trucking or machinery running overhead was usually the direct cause of the trouble. In some locations an effort had been made to minimize the bad effect of vibration through the installation of antivibrators, but such accessories introduced the additional possibility of broken mantles through shock as described in the next paragraph. In some rare instances, an outside lamp was found equipped with broken mantles, the probable result of excessive swaying of an insecurely braced supply pipe.

(c) *Shock*.—Including the cases of actual collision in which parts of the lamp had been demolished, 5 per cent of the lamps on company maintenance and 5 per cent of those not so maintained were seemingly subject to shocks. These frequently had resulted in broken or cracked mantles or glassware, or had caused a leakage of gas at the stem or other portions of the piping to the lamp. It was evident in a great many cases that the cause of such a shock was the jerk with which the lamp was lighted or extinguished. This may have been the result of some defect in the lamp itself or in its installation, but more often was the result of carelessness on the part of those who light or extinguish the lamps. Under the former head may be mentioned valves which operate stiffly or pull chains which are too short; under the latter head are the cases in which the chain is jerked, instead of the lamp being lighted by a steady pull, this causing a sudden shock to the whole unit. When an antivibrator is installed on the lamp, this shock is frequently intensified, thus producing a condition which may greatly offset the good which the device is supposed to exert.

(d) *Dust*.—Dust, dirt, or grease in the atmosphere affected 16 per cent of the lamps on company maintenance and 16 per cent of those not so maintained. Dirty mantles or insufficient supply of gas often appeared to be the result of dust or dirt drawn into the lamp, because of open doors or windows, or when the work carried on near the lamp was such that a large quantity of dust was raised. In some locations it was evident that some effort had been made to overcome this latter trouble by means of gauze attachments, but with indifferent success. Flies added greatly to the maintenance difficulties during the period of year in which the inspections were made, and in a great many restaurants grease greatly interfered with the proper operation of the lamps.

4. ALIGNMENT

The alignment of the units as a whole and of the various parts of the units was, in general, good, both as regards those on company maintenance and those which were not so maintained. However, several per cent of the units were noted as more or less faulty in this particular.

5. MANTLES

The condition of the mantles inspected is presented in Tables 4 and 5. The percentages in these tables are based upon the num-

ber of mantles in the units involved and not upon the number of units themselves. In the preparation of these tables it was considered advisable to show for each city the results obtained by

TABLE 4
Condition of Mantles in Units on Company Maintenance ^a

City	Observer	Season	Units in- spected	Man- tles in- spected	Dirty	Car- boned	With holes	Cracked	Broken ^b	Sum of per- cent- age defects
					Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	B	Summer.....	67	187	0.0	1.1	0.0	3.2	0.5	4.8
2	B	.....do.....	60	154	.0	.0	.0	1.9	1.9	3.8
3	A	.....do.....	132	153	.7	.7	.0	3.9	2.0	7.3
	B	.....do.....	112	168	.....	.6	1.2	1.8	.6	4.2
	A+B	.....do.....	244	321	.3	.6	.6	2.8	1.2	5.5
4	A	.....do.....	67	79	.0	1.3	.0	7.6	2.5	11.4
	B	.....do.....	33	41	2.4	4.9	2.4	.0	4.9	14.6
	A+B	.....do.....	100	120	.8	2.5	.8	5.0	3.3	12.4
5	A	.....do.....	126	458	15.9	3.5	.9	4.6	2.6	27.5
	B	.....do.....	93	302	.0	.3	8.9	2.0	1.3	12.5
	C	.....do.....	106	318	.9	2.2	.....	.....	6.6	9.7
	A+B+C	.....do.....	325	1078	7.0	2.3	2.9	2.5	3.4	18.1
	C	Winter.....	209	801	.5	2.6	1.7	.5	7.4	12.7
6	A	Summer.....	92	293	1.0	1.7	1.7	8.2	5.5	18.1
	B	.....do.....	155	449	.0	1.1	2.7	.4	1.5	5.7
	C	.....do.....	128	394	.3	5.0	.....	.....	3.3	8.6
	A+B+C	.....do.....	375	1136	.4	2.6	1.5	2.3	3.2	10.0
	C	Winter.....	224	688	.4	4.5	.9	1.6	2.9	10.3
7	C	Summer.....	125	191	3.1	.0	.....	.....	23.0	26.1
	C	Winter.....	68	97	1.0	11.2	3.1	2.1	5.1	22.5
7 ^c	C	.....do.....	105	147	.0	16.3	4.1	.7	9.5	30.6
8	C	Summer.....	152	296	4.0	2.4	.....	.....	13.2	19.6
	C	Winter.....	112	140	.0	3.6	2.9	1.4	10.0	17.9
9	C	Summer.....	207	362	.8	.9	.....	.....	3.0	4.7
	C	Winter.....	221	371	.3	9.4	2.2	.5	3.0	15.4
10	C	Summer.....	80	116	1.7	2.6	.....	.....	4.3	8.6
11	B	.....do.....	68	235	1.2	1.3	25.2	2.1	2.1	31.9

^a The percentages in these tables are, for uniformity, all given to 0.1 per cent, but in the case of the larger percentages the tenths are, of course, of no significance.

^b Results of observer C include in the general heading "Broken mantles" all of the mantles with holes and mantles cracked.

^c Entries for city 7 are separated to show the results on free lighting service independent of the results for regular maintenance work.

the individual observers during the first or summer series. In the two cases where rather large percentage differences exist in results as reported by different observers the cause was evident; in city 5 observer A found 70 dirty mantles in one location and

in city 6 the same observer found unusually poor work on one maintenance route inspected, which accounts for the relatively high percentage of defects noted.

TABLE 5
Condition of Mantles Maintained by Customers^a

City	Observer	Season	Units in-spected	Mantles in-spected	Dirty	Car-bened	With holes	Cracked	Broken ^b	Sum of per-cent-age defects
					Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
3	A	Summer	120	159	2.5	8.8	0.6	15.7	21.4	49.0
	B	.....do.....	108	134	3.0	.0	.0	10.4	10.4	23.8
	A+B	.....do.....	228	293	2.7	4.8	.3	13.3	16.4	37.5
4	A	.....do.....	42	56	.0	5.4	1.8	1.8	17.9	26.9
	B	.....do.....	56	108	2.3	1.8	3.7	.0	23.2	31.0
	A+B	.....do.....	98	164	1.8	3.1	3.1	.6	21.3	29.9
5	A	.....do.....	64	187	2.7	4.3	.5	13.4	.0	20.9
	B	.....do.....	119	276	.0	1.1	5.1	1.1	10.9	18.2
	C	.....do.....	34	63	3.2	4.7	.....	.....	27.0	34.9
	A+B+C	.....do.....	217	526	1.3	2.7	2.9	.6	13.7	21.2
	C	Winter	49	133	.0	6.8	.0	.8	23.2	30.9
6	A	Summer	174	185	1.6	5.9	2.2	16.8	7.0	33.5
	B	.....do.....	37	75	.0	8.0	4.0	.0	18.7	30.7
	C	.....do.....	32	94	2.1	6.4	.....	.....	50.0	58.4
	A+B+C	.....do.....	243	354	1.4	6.5	2.0	3.6	26.0	39.6
	C	Winter	76	173	2.3	12.2	1.2	3.5	11.5	30.7
7	C	Summer	173	340	12.6	1.5	.....	.....	40.9	55.0
	C	Winter	73	158	8.9	8.9	5.0	.6	36.8	60.2
8	C	Summer	127	201	17.9	9.9	.....	.....	47.2	75.0
	C	Winter	59	132	2.3	11.3	3.3	.0	27.3	44.2
9	C	Summer	285	341	23.1	1.9	.....	.....	46.0	71.0
	C	Winter	98	153	.0	20.2	9.1	9.6	9.6	48.5
10	C	Summer	54	109	9.2	1.8	.....	.....	28.4	39.4
11	B	.....do.....	46	83	1.2	10.8	7.2	3.6	21.7	43.7

^a In cities 1 and 2 the observer reports practically no lamps except on company maintenance.

^b Results of observer C include in the general heading "Broken mantles" all of the mantles with holes and mantles cracked.

It will be noticed that in those cities where more than one observer worked the percentage in the line which shows the combined results under the various column headings is not the simple average of the percentages, but is the weighted average of the figures of each observer during this series.

In the consideration of mantle defects only those which existed in the body of the mantle were generally noted. However, in some instances in the case of upright mantles where the skirt of the

mantle was damaged to such an extent as to allow the mantle to be displaced the mantle was entered as defective under the proper heading.

The column headed "per cent dirty" means those mantles which were rusty, discolored by dust, or otherwise discolored except through carboning; this latter condition was entered in the column headed "per cent carboned." The column headed "per cent holes" refers to those mantles with one or more small holes in them. Although it is conceded that the presence of such small holes in a mantle may not appreciably affect its light-giving qualities until the texture is seriously damaged, it is evident that when these holes become of any appreciable size such mantles could not be classed as good. The column headed "per cent cracked" refers to those mantles which were frayed or in which a small crack had developed in the body, while the column headed "per cent broken" refers to those which were more seriously damaged or which were entirely demolished. The figures in the last column in each table are the sums of the entries in the five previous columns; they are significant only as a measure of the likelihood of some defect being found in the mantle.

6. QUALITY OF THE MANTLES

As nearly as could be determined, the mantles of the units on company maintenance were of good quality, while about 50 per cent of the units not on company maintenance were of poor quality. The quality of the mantles was largely judged from the appearance of the mantle fabric, but as the correctness of many observations as to this matter was uncertain no further conclusions have been drawn from the data. In a number of gas companies dissatisfaction with the quality of mantles now being furnished is due to circumstances beyond the control of the mantle manufacturers.

7. GLASSWARE

The condition of the globes, chimneys, reflectors, both glass and metal, and any other such equipment of the units inspected is shown in Table 6. In this tabulation only the combined results of the various observers are shown.

The percentages used in these tables are based upon the number of units involved. The column headed "per cent dirty" refers to those units which were equipped with dirty, greasy, carboned, or badly flyspecked glassware or metal reflectors. Because of the great number of flies at the time the summer inspections were made, the percentage of dirty glassware for maintenance lamps is somewhat higher than was the case when the winter inspections were made. The column headed "Per cent cracked" refers to the glassware which was not seriously cracked; while that headed "Per

TABLE 6

Condition of Glassware, Classified According to Character of Maintenance Service

City	Season	Units inspected		Dirty glass		Cracked glass		Broken glass		Sum of percentage defects	
		Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers
				Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	Summer.....	67	(a)	0.0	.....	1.5	.....	1.5	.....	3.0	.....
2	.....do.....	60	.....	15.0	.....	.0	.....	5.0	.....	20.0	.....
3	.....do.....	244	228	4.1	58.8	.4	7.5	.4	9.6	4.9	75.9
4	.....do.....	100	98	21.0	46.9	9.0	2.0	1.0	14.3	31.0	63.2
5	.....do.....	325	217	1.8	41.5	.6	1.8	.3	10.1	2.7	53.4
	Winter.....	209	49	1.0	24.5	.0	4.1	1.0	10.3	2.0	38.9
6	Summer.....	375	143	6.7	35.0	1.9	3.5	1.6	11.2	10.2	49.7
	Winter.....	224	76	5.8	27.6	1.3	4.0	.4	6.6	7.5	38.2
7	Summer.....	125	173	11.2	36.9	(b)	.....	3.2	19.6	14.4	56.5
	Winter.....	68	73	4.1	57.8	1.5	6.8	1.5	22.0	7.1	86.8
7 ^c	.....do.....	105	.....	2.9	.....	4.8	.....	9.5	.....	17.2	.....
8	Summer.....	152	127	3.3	39.0	.....	.....	3.3	18.1	6.6	57.1
	Winter.....	112	59	3.6	62.7	2.7	10.3	5.4	39.0	11.7	112.0
9	Summer.....	207	285	2.4	25.2	.....	.....	.5	7.0	2.9	32.2
	Winter.....	221	98	2.3	41.8	.0	3.1	1.4	6.1	3.7	51.0
10	Summer.....	80	54	2.5	14.8	.....	.....	3.7	11.1	6.2	25.9
11	.....do.....	68	48	.0	76.2	14.7	2.2	4.4	24.0	19.1	102.4

^a In cities 1 and 2 the observer reports practically no lamps not on company maintenance.

^b In results for cities 7, 8, 9, and 10 cracked parts are included under "per cent broken."

^c Entries for city 7 are separated to show the results on free lighting service independent of the results for regular maintenance work.

cent broken" refers to the glassware which was actually broken or missing. The percentage of the broken glassware is undoubtedly higher at this time due to the lack of imported material. Much of the glassware of domestic make which has thus far been available has caused considerable trouble to the gas companies, due to frequent breakage, both before and after it is installed. After installation, not only does the glassware break, but in the case of those lamps equipped with cylinders the probability of the glassware breaking the mantles is also very high.

8. PILOT LIGHTS

The information regarding the condition of the pilot lights of the units under discussion is given in Table 7. In this table only the combined results of the various observers is shown.

The percentages used in this table, like those in Table 6, are based upon the number of units involved.

The column headed "Per cent out" refers to those units in which the pilots were extinguished through the presence of dirt

TABLE 7

Condition of Pilot Lights, Classified According to Character of Maintenance Service

City	Season	Units inspected		Pilots out		Improperly placed pilot		Improperly adjusted pilot		Sum of percentage defects	
		Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers	Com-pany	Cus-tomers
				Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	Summer.....	67	(a)	0.0	(b)	0.0	(b)	3.0	(b)	3.0	(b)
2	.....do.....	60	-----	3.3	-----	.0	-----	5.0	-----	8.3	-----
3	.....do.....	244	228	6.2	9.2	5.3	17.1	3.3	25.0	14.8	51.3
4	.....do.....	100	98	2.0	6.1	1.0	13.3	19.0	13.3	22.0	32.7
5	.....do.....	325	217	3.4	15.2	2.5	4.6	6.5	10.6	12.4	30.4
	Winter.....	209	49	.0	2.0	3.3	14.3	1.4	14.3	4.7	30.6
6	Summer.....	375	143	1.3	4.2	.0	12.7	4.0	17.5	5.3	34.4
	Winter.....	224	76	.9	10.5	.4	6.6	4.5	18.4	5.8	35.5
7	Summer.....	125	173	4.8	20.8	1.6	14.5	4.0	18.5	10.4	53.8
7 ^c	Winter.....	68	73	1.5	23.3	7.2	26.0	6.2	26.0	14.9	75.3
	.....do.....	105	-----	3.8	-----	5.7	-----	13.3	-----	22.8	-----
8	Summer.....	152	127	6.5	18.9	2.0	4.7	4.0	9.4	12.5	33.0
	Winter.....	112	59	.9	17.0	21.4	28.8	20.6	40.7	42.9	86.5
9	Summer.....	207	285	7.2	21.0	.9	6.3	1.4	10.9	9.5	38.2
	Winter.....	221	98	.9	8.2	2.3	24.5	5.9	17.4	9.1	50.1
10	Summer.....	80	54	10.0	16.7	1.2	5.5	3.7	3.7	14.9	25.9
11	.....do.....	68	48	1.5	15.2	1.5	6.5	10.3	13.1	13.3	34.8

^a In cities 1 and 2 the observer reports practically no lamps not on company maintenance.

^b Under the nonmaintenance subheadings the percentages are based on the assumption that all lamps were equipped with pilots. In actual-inspection it was found that about 5 per cent were not so equipped.

^c Entries for city 7 are separated to show the results on free lighting service independent of the results for regular maintenance work.

or carbon in the tip or through some other cause. In some instances it was found that the adjustment of the flame was such that a slight draft would readily cause it to go out. In this case the condition would also be noted under the heading "Per cent improperly adjusted." When the fixture cock was closed or when the pilots were not lighted through the desire of the customer, these were not recorded "out."

Attention is called to the large number of pilots which were out during the summer inspection in city 7. While the exact

cause is unknown, this company explains the cause in the following manner:

While we can not tell definitely what is the cause of this trouble, we believe that in some way it is due to the presence of some hydrocarbon carried by the gas to the pilot adjusting screw. If we had been distributing last summer and for several years previously a gas relatively low in all kinds of hydrocarbons, we think it is reasonable to conclude that this epidemic of pilot outages would not have occurred.

It seems that similar epidemics of pilot outages have been known previously in other cities following a dry, hot summer. As you know, this weather condition prevailed in the summer of 1916. It is conceivable that any unusual combination of underground temperature, cellar temperature, and burner temperature might cause the gas to deposit in the pilot a liquid resulting from something that might have been picked up from the surface of the underground pipe system, material which, under normal conditions, would not be taken up by the gas. Again, it is conceivable that unusual weather conditions might have some effect, either on the manufacture of the gas or on its composition, as it passes through various scrubbing and purifying apparatus and into and out of the gas holders.

The column headed "Per cent improperly placed" refers to those units in which the pilot was found in such position that it projected the flame directly against the glassware or against the mantle to such an extent that the latter was damaged at this point, or where the pilot stem or tip was touching the mantle, or where the location of the pilot was such as to delay ignition of the gas. A number of units were found in which the pilot stem was broken or the tip was missing, in which event they were placed under this heading. The column headed "Per cent improperly adjusted" refers to those units in which the pilot flame was either too long or too short, or when the flash of a flash pilot was either too high or improperly directed.

9. CELLINGS

It was at first thought that the condition of the ceilings surrounding the units might be one of the best indications regarding the likelihood of carboning or related troubles with rich gas that could be obtained. Although some interesting results were obtained, they are inconclusive in this matter, since a number of factors which enter into the matter obscure any results as to the effect of gas quality.

The observers were unable to procure any definite information regarding the last cleaning of the ceilings, and were therefore skeptical of accepting discoloration around any unit as prima facie evidence of the effect of the lamp. However, if a ceiling was distinctly darker above or near a unit it was entered as dirty or carboned; and if a baffle plate or ceiling shield showed distinct

effects of soot escaping from the lamp this also was listed as with a "dirty ceiling." Even when a ceiling was distinctly darkened by the lamp it was not known whether this was the result of soot from the flame or whether the blackening had been mainly caused by dust, lint, or soot in the air carried up against the ceiling. Since it was found in those sections of a city where the atmosphere contained an unusual quantity of dust or soot that the ceilings were distinctly darker, due to the action of the heated column of air carrying these particles of dust or soot against the ceiling it is believed that this is the important factor. This is borne out by the fact that the percentage of dirty ceilings in cities where rich gas is supplied was 17; in other cities 17½ per cent were found dirty. If due regard is given to these limitations, the results shown in Table 8 can be safely used; the percentages are based upon the number of units observed.

TABLE 8
Conditions of Ceilings around Units (Summer Inspection)

City	On company maintenance		Maintained by customer	
	Units observed	Ceilings discolored	Units observed	Ceilings discolored
		Per cent		Per cent
1.....	67	15.0	(a)	.....
2.....	60	5.0		
3.....	244	20.0	288	24.6
4.....	100	12.0	98	29.6
5.....	325	12.3	217	18.9
6.....	375	23.5	143	39.1
7.....	125	12.0	173	25.0
8.....	152	15.8	127	32.3
9.....	207	4.3	285	11.9
10.....	80	1.2	54	7.4
11.....	68	19.2	46	18.9

^a In cities 1 and 2 the observer reports practically no lamps not on company maintenance.

10. GAS SUPPLY

As far as the observers were able to judge in all of the cities the gas supply to the lamps on company maintenance was good except in individual cases where a governor was installed on the outlet of the gas meter, the house piping was too small or stopped up, the gas meter was overloaded or out of order, or other similar cause existed. In one city in which the gas supplied was high in hydrocarbons it was noticed that in a great many instances,

particularly in the case of upright mantles, the mantle was not properly "filled out"—that is, had an insufficient supply of gas to give full luminous brilliancy over the entire mantle surface. On investigating the reason for this fact it was stated that owing to trouble with carboning of the mantles the maintenance men had been instructed to adjust the gas supply to produce the apparent maximum candlepower and then to close the gas adjusting screw until a slight diminution of the light was noticed. It was evident that in those instances referred to the maintenance man had closed the gas set screw too far and had thus unnecessarily reduced the gas supply to the mantles.

11. GENERAL SUMMARY OF OBSERVATIONS

The results of the observations are given in concise form in Table 9. It is believed that the figures are in each case of the right

TABLE 9
General Summary of Observations

	Not on company maintenance		Maintained by company		Ratio, A B
	A		B		
	Summer	Winter	Summer	Winter	
Lamps inspected.....	1371	355	1803	834	
Mantles inspected.....	2411	749	4196	2097	
	Per cent	Per cent	Per cent	Per cent	
Mantles broken, cracked, or with holes.....	32	28	9	8	3½
Mantles carboned or dirty.....	12	15	4	5	3
Glassware cracked or broken.....	14	21	3	2	7
Glassware dirty.....	40	43	5	3	10
Pilots out.....	15	12	4	1	5½
Pilots improperly placed.....	10	20	2	5	4½
Pilots improperly adjusted.....	15	23	5	6	3½
Ceilings discolored.....	22	.....	15	.....	1½
Total.....	160	162	47	30	.....
Average.....	.....	.....	.....	.....	5½

order of magnitude and the ratios in the last column are also substantially correct, although in the nature of the case they can not be very accurate.

The above table shows that a lamp not on regular maintenance is likely to be defective five and one-half times as frequently as a lamp which is regularly maintained. Also it shows that on the average 1 in 3 of the lamps on regular maintenance were not in good condition, whereas the defects noted in the lamps not so maintained average more than one for every lamp.

Although the table illustrates these conditions, it is necessary to call attention to one very important point in which the table may be misleading. For example, it will be seen that the ratio of *A* to *B* for mantle conditions is $3\frac{1}{2}$. In this case the ratio does not fully express the true contrast which exists between the two conditions, since what appears to be the same defect in mantles under the two conditions is, in practice, not the same in so far as the magnitude of the defect is concerned. This is evident when one considers that a broken mantle on units properly maintained is usually not so badly broken as is the case when the units are not so maintained. This is true not only of the mantle conditions, but also of the glassware and pilots as well.

As already indicated, it was difficult to compare one city with another. However, using six different bases for comparison, substantially the same results have been obtained. We therefore feel justified in classifying the cities visited into three groups as indicated from the comparisons referred to. In the first group are three cities in which strikingly good maintenance results were being obtained. In the second group are placed three cities in which poor maintenance work appeared to be rendered. These three cities were the three in which gas companies did not conduct the maintenance work. The third group includes the five cities where fair to good maintenance work prevailed. In the case of each city in the third group there were certain particulars in which unusually successful results appeared to be obtained, but in other particulars the results did not appear to be satisfactory. In no case did any of the six methods of appraising give departures of rank from the groups thus indicated, but there were several fluctuations within these groups, so that relatively a city that might rank fourth by one method might be as low as sixth or seventh when appraised in another manner.

IV. DISCUSSION OF MAINTENANCE SERVICE

It is our hope to show from this investigation some of the practices which we believe seriously interfere with the satisfactory use of gas lighting, and which may lead to a decrease of the lighting business unless improvements be made. The greatest loss probably results from entire neglect or from poor maintenance, and clearly the correction of such faults lies within the control of the gas company itself. The following items bearing on this question appear to be worthy of serious consideration.

1. CRITICISMS OF MAINTENANCE WORK INSPECTED

The principal defects noted in the maintenance systems investigated can be traced to one or more of the following causes: (a) Too little attention to the work; (b) undue effort to have the maintenance self-supporting; or (c) lack of appreciation of the customer's needs.

A striking indication of too little attention on the part of gas companies to the subject is found in the three cities where all of the maintenance work is left to the various lamp-manufacturing concerns. In none of these cities does the maintenance work appear to be as well done as it is in those cities where the gas company conducts this work. Such a result is to be expected since the two interests are working from entirely different points of view. The gas company is in business to render gas service and expects its profit chiefly from the sale of the gas.

The lamp-manufacturing companies which conduct this maintenance work do not do it primarily from any profit that there may be in it. Their business is the manufacture and sale of lamps and equipment and they would doubtless be glad to be relieved of maintenance work. Such companies would not be required to enter the maintenance field if gas companies gave proper attention to this phase of their work; but in some localities they have been forced to do so in order to hold gas lighting, and thereby increase the outlet for their products.

Furthermore, if the work is to be done at no profit, or even at a loss, this is less serious with the gas company, for with it the maintenance work is a relatively small part of its activity, and extra good maintenance without profit helps its business more perhaps than a profit on the maintenance work with poorer service to its customers; but with an appliance company it is a large part. Of course, each company must determine for itself whether the saving resulting from doing no maintenance work is offset by the resulting loss of gas-lighting customers, as is believed by some. However, management officials should recognize in any case the disadvantages of neglect of this field or of placing the responsibility wholly on lamp companies.

Another evidence of too little attention to these problems is found in the gas company manager, division superintendent, or other official who is not sufficiently in touch with the maintenance work. He turns this work over to a subordinate, who frequently sees only the necessity of getting so much work accomplished

regardless of other results. An occasional evening trip by a higher official is useful in order to gain a more intimate knowledge of maintenance conditions. Besides, the moral effect of such an occasional trip is marked.

If the subordinates are also to retain the necessary closeness of acquaintance with their districts, and particularly with their customers, the foremen must not be required to cover too large districts and the individual lamp men must have routes of reasonable length.

It appears to be possible in most cities to build up a system of maintenance with the primary object of giving service and yet have it eventually cease to be a serious liability; but this will be accomplished principally by increasing the number of lamps on maintenance rather than through high price to each individual.

The maintenance department can not, of course, be from the first self-supporting, for to make it so necessitates speeding up unduly with a consequent lack of thoroughness in the work. The wage scale should be adequate to secure the proper kind of maintenance men; that is, men who are more than mere lamp cleaners, able to make only the most simple adjustments. What is required is a type of man who can intelligently remedy a poor condition of service as well as clean the glassware and replace mantles. Of course, this requires a higher schedule of wages than is usually prevalent, but it likewise means a reduced complaint force. Most important of all, it means more satisfied customers.

Efforts for great economy should not force the foremen to be drivers, which in turn means discontent among the men that is reflected even in the customers' attitude. Poor workmanship also is soon evident. Frequent maintenance visits are very desirable, but this is not possible when the districts and routes are too large. In that case the foremen lose that personal touch with the customers which promotes good feeling on the part of the customers. He has not the time which is required to gain a proper relation to the work if his whole day is spent covering his district to speed up his men.

Another of the factors noted as interfering with success in the gas-lighting field is the use of units put out by irresponsible dealers. Such a person buys discarded parts of high-grade lamps, and assembles a unit which, sold for a low price, appeals to the poorer class of gas users. In order to compete with such lamps, the gas company should sell a reliable unit for about the same price, and in addition should make available maintenance service. This can

only be accomplished through a standardization of equipment and the development of extended maintenance systems by which expense will be made the minimum that is compatible with good service.

Although no field study was given to the question of effect of the fluctuation of pressure or of different mixtures of gas when supplied to mantle lamps, there are undoubtedly serious effects on the efficiency of operation caused by variations in these factors. For specific information on the subject see the technologic paper which discusses the influence of various conditions upon the candlepower and efficiency of mantle lamps as shown by extended experimental work.

Still another problem worthy of mention is that of standardization of lamps and lamp parts. From Table 1 it will be observed that there are 24 types of lamps found in use in the different cities visited, and in hardly any cases can the parts of these lamps be regarded as interchangeable. Fifteen different types of lamps have been found in one city and handled by the same gas company. A type suited to one use is, of course, not always applicable to another use, but such multiplicity of *types* (not makes) is unnecessary. This is very undesirable, when one considers the great advantages of standardization. All basic parts should be interchangeable so far as possible so that the gas companies would not be required to carry a multitude of different repair parts instead of a comparatively few standard parts. The gas industry can well profit by the experience of the electrical industry in this particular.

2. ADVANTAGES OF LAMP MAINTENANCES

The most striking advantage of lamp maintenance work is that shown by the summary of Table 9, which shows the much greater likelihood of a defect in lamps without maintenance than with regular care. Even though the advantage in any one case be not as great as $5\frac{1}{2}$ to 1, as indicated in Table 9, there would unquestionably be some decided benefit to the customers.

Another less evident advantage results from the greater promptness of correction of various gas service troubles that can conveniently be brought to the attention of a maintenance man for correction or reference to the suitable department of the company. This, of course, promotes pleasant relations between the company and its customers, and facilitates rendering adequate and satisfactory service in all lines. The reduction in the burden of complaint work, as already mentioned, is another closely related benefit.

An advantage that compensates the gas company for expense or difficulties incident to maintenance work comes from the fact that the appearance of lamps is one of the strongest advertising agencies for gas lighting. A dilapidated lamp prominently displayed in a store window is a poor exponent of gas lighting; on the other hand, bright, clean units are an argument for this type of lighting. If the management should decide that maintenance, conducted in the proper manner, guaranteeing service to the customer was the end to be sought for rather than an increase in profits from the maintenance, some of the advertising appropriation could be diverted to this department.

When one recognizes the great advantage of good maintenance to both company and customers, it seems desirable to have this service rendered to all users of gas for lighting. Such universal maintenance would not only give its benefits to all customers, but also permit reduction in the cost per customer for rendering the service because of the economies possible in a larger undertaking. However, in many localities it is probably impossible for maintenance service to be universal at present. A large proportion of the users of mantle lighting units either can not or will not pay for such service; nor is it practicable for many gas companies to undertake the entire financial burden of this universal maintenance. It is rather to be hoped that the companies will recognize the benefits stated above, and will be prepared to stand some of the expenses for maintenance so that the rates can be made correspondingly low, and therefore more attractive to a great number of customers, thus approaching universal maintenance.

Universal maintenance may likewise be approached by the company by providing at regular intervals all the labor necessary to the maintenance of the units in certain classes of locations. This has been done recently by one of the gas companies visited. This company announces free lighting service, agreeing that it—

will, upon request, regulate and clean, every 10 days, all standard gas lamps in any store, office, or shop within the city limits. * * * There is no charge for this service. * * * Mantles or glassware will be furnished and put on at the usual prices if desired.

This latter method has, however, one very marked disadvantage. Although the customer has his units maintained in as good operating condition as is possible under the circumstances, the replacing of broken parts, which the customer pays for, is usually not readily accomplished until the part is entirely destroyed. Therefore the lamps can not be kept in as good condition as would

be possible if all replacements were made as promptly as is necessary in the judgment of the maintenance men.

V. COSTS OF MAINTENANCE WORK

To supplement this discussion of the advantages of maintenance service we have made an analysis of the work done in the various cities where the inspections were made and have prepared a summary of the various costs for this work. In this section we do not wish to discuss the relative advantages of free maintenance and of service rendered for a fixed charge. It is desired rather to present a summary of one satisfactory system of estimating the expenses for maintenance work, together with a set of unit costs that will be useful for such computation. These unit costs are the result of careful analysis of the expenses of 10 gas companies which have done this work, which data has been courteously placed at our disposal by these companies.

The expenses and general costs for a maintenance department have been classified as follows:

1. Labor: Maintenance men, complaint men, and foremen or inspectors.
2. Materials: Mantles, glassware, and miscellaneous.
3. Equipment: Tools, kits, etc.
4. Transportation: Motor equipment and car fares.
5. Headquarters expense: Stock clerks, route clerks, stenographic service, and miscellaneous help.
6. General expense: Overhead and management, rentals, and interest on stock.

We have also classified the kinds of lamps to be considered into four groups, as follows: (1) Small single-mantle lamps; (2) large single-mantle lamps; (3) indoor multiple-mantle lamps; and (4) outdoor multiple-mantle lamps.

For each class of lamps we have separately estimated the unit cost per lamp or per burner as the case may require, except the overhead and management items, which, of course, must be estimated for a city as a whole.

1. LABOR

The cost for maintenance labor is, of course, determined by the frequency of maintenance, work required, the time used per unit, the length of the working day, and the wages paid.

Frequency of Maintenance.—Under ordinary conditions of use arc lamps may be satisfactorily maintained through visits every two weeks. However, this is dependent upon a number of con-

ditions. When a lamp trimmer first starts to put a number of lamps in shape, more frequent visits should be made until the lamps become regular in adjustment. When the lamps are installed in locations where dust, grease, or other flying material is present in the air, or when they are subjected to excessive vibration or shock, they should be visited more frequently, perhaps once each week. If customers are instructed to immediately report lamp trouble to the company at the time it is noted and not to wait for the regular visit of the maintenance man, this is always adequate. In the case of excessive damage to outside lamps during storms these lamps should be placed in good condition immediately, and should not be allowed to remain in the damaged condition until the regular visit of the maintenance man.

Small, single-mantle lamps should be visited for maintenance at least once each month, but in stores two visits per month, are often necessary to properly care for them. The customers should, of course, understand that they can obtain service at any time by calling the gas company.

In reaching this conclusion we have not given much weight to the limited experience of a few companies that recently have undertaken partial maintenance for all their customers, including regular visits only once in two to four months. In such work these companies are, no doubt, making great improvement in the lighting conditions, but they are hardly giving full maintenance service for the visits are not sufficiently frequent, and replacement of mantles, glassware, and lamp parts is dependent upon the customers' willingness to pay for the same.

Work of Maintenance Men.—In practically all of the companies from which data were received the maintenance men are required in addition to cleaning the lamps to replace and repair all parts of lamps which do not require the lamps to be removed to the shop. When a route which is largely composed of old equipment is first taken over, or when old equipment is taken on an existing route, it may be necessary for a complaint or repair man to place the lamps in good condition so that they may be properly maintained by the regular route man; but after a route has been placed in such good condition the maintenance man is compelled to make very few repairs, for minor adjustments and cleaning are all that are required.

Each maintenance man should carry cylinders or chimneys with him; but he may be given globes or shades the following

morning so that he can replace them at the beginning of the day's work.

It has also been suggested that three or four times a year a special man accompany the lamp men to aid in thoroughly washing and cleaning the equipment.

Lamps Cared for Per Day.—In order to accomplish the work described in the preceding paragraph it has been found that a man requires seven to eight minutes to clean and adjust a multiple-mantle lamp and three to six minutes for the single-mantle lamps. The working hours for this service have been reported to us as from 48 to 60 hours per week. We have assumed that not over 8 hours per days would be used in actual work on the routes, and of this time a varying amount is consumed in traveling between customers. From the results of the 10 companies which have given us their data, it is estimated that the following number of lamps can be cared for per working day:

	Lamps per day
Small single mantle.....	100-120
Large single mantle.....	80-90
Indoor multiple mantle.....	50-60
Outdoor multiple mantle.....	40-50

Wages for Maintenance Men.—The question of wages for maintenance men is largely a local one, but for successful work it is necessary that a sufficient wage be paid to secure competent men. A graduated scale, with promotions, would probably best serve the interests of the company, for long-continued service of the men is highly desirable in order both to reduce the cost of training new men and to insure a higher quality of work. Less than \$2.50 per day will not generally attract the right grade of men, and on the average the wages may be \$2.75 per day or more. We have used this latter figure for the following estimates, although, of course, higher wages may often be necessary, especially under the present abnormal labor conditions.

For foremen or inspectors a higher wage than has been reported would appear desirable; it is suggested that \$125 per month be paid for this class of service, which requires a man skillful in handling other employees as well as expert in meeting the public.

A bonus system for payment of maintenance men has been worked out by some companies, but our observation of the results of such system does not lead us to favor it.

The following statement has been received from one of the companies advocating the bonus system:

Do not be prejudiced against the bonus system of compensation because of results in the three cities in question. The system is sound but no doubt susceptible of

improvement. The mistake probably has been in overconfidence in the system, feeling that it did check itself and was practically automatic.

It has greatly reduced complaints, which is strong evidence of its effectiveness. Men are actually stimulated to do more work and *better* work. Therefore, in effect, more money is left to apply to supervision. Your reports seem to indicate that it has not so applied, which is a defect of management not inherent in the system.

A description of the system may be found by those interested in the National Commercial Gas Association Proceedings for 1915 on page 180 of the report of the committee on illumination.

Unit Costs.—Basing our conclusions upon the above assumptions, we have reached the following unit costs for maintenance labor:

	Cents per month
Small single-mantle lamps (monthly inspection).....	2. 5
Large single-mantle lamps (semimonthly inspection).....	6. 5
Indoor multiple-mantle lamps (semimonthly inspection).....	10
Outdoor multiple-mantle lamps (semimonthly inspection).....	12

To these figures must be added the cost for extra men during sickness and vacations, complaint men, and inspectors or foremen in order to arrive at the total labor charge. The number of men required for such additional service depends largely upon local conditions, especially in the matter of inspectors or foremen. The grouping of the lamps, the size of the territory, the transportation facilities, and the character of the foremen employed are all factors. In every case the more serious defects of the systems which we have studied have appeared to be the result of inadequate supervision, and we therefore recommend a larger force for such work than is usual. We believe that one extra man for complaints and to replace absentees should be provided for every 8 to 10 regular men, and that not more than 15 maintenance men should ever be under 1 inspector. On this basis the unit costs above become, for total maintenance labor, as follows:

	Cents per month
Small single-mantle lamps (monthly inspection).....	3
Large single-mantle lamps (semimonthly inspection).....	8
Indoor multiple-mantle lamps (semimonthly inspection).....	12. 5
Outdoor multiple-mantle lamps (semimonthly inspection).....	15

2. MATERIALS.

The expense for materials includes three items: Mantles, glassware, and replacement of lamp parts. We have separately obtained data for the mantle costs, but the other two items are estimated together in the following section.

Single-mantle units require, according to three companies, from two to four mantles per lamp per year. It would seem, however, that three mantles should be allowed for domestic instal-

lations of this character and four for store and shop installations. For the large single-mantle lamps the experience of four companies is quite varied since they find from one and one-half to five mantles per year are needed. About four mantles per year for such lamps seems an average figure, since this corresponds to the experience of the two companies with the largest number of such lamps in service.

The results for mantle replacement in multiple-mantle units also vary widely as reported by eight companies. The range is from one and one-half to four and one-half mantles per burner per year, but in most cases the average lies between two and one-half to three and one-half mantles per burner. We have therefore chosen three as the proper average figure for purposes of estimating. But we recognize a greater mantle consumption on upright mantle or outdoor lamps than upon indoor inverted units. For the upright and the outdoor lamps we therefore suggest three and one-fifth mantles per burner per year as a proper average.

For purposes of estimating, the cost of mantles has been taken to be as follows:

	Cents per mantle
For small single-mantle lamps.....	15
For large single-mantle lamps.....	22
For multiple-mantle lamps.....	11

A higher figure for small single units than for multiple-mantle units, which might use substantially the same grade of mantle, is used because of the more serious nature of the defects when the mantle is damaged on a single-mantle unit than upon those where several mantles are used. Moreover, some of the lamps in the group called small single-mantle units require special types of mantles—for example, the Junior burners and the C. E-Z units, and these are, in general, slightly more costly than the standard multiple-mantle type.

From these two tabulations the monthly cost per burner for mantles is seen to be as follows:

	Cents per month per burner
Small single-mantle lamps, domestic.....	4
Small single-mantle lamps, industrial.....	5
Large single-mantle lamps.....	7.5
Indoor upright multiple-mantle lamps.....	3
Indoor inverted multiple-mantle lamps.....	2.8
Outdoor multiple-mantle lamps.....	3

Replacement of glassware and lamp parts is estimated by different companies quite differently, as shown by the following

summary which indicates the range of cost per burner per year as reported to us and the average which we have used for the following estimate:

Lamps	Range reported— Cost per year	Average used— Cost per year
	Cents	Cents
Small single mantle.....	30-60	50
Large single mantle.....	33-50	45
Indoor multiple mantle.....	5-12	12
Outdoor multiple mantle.....	10-25	20

The total materials cost per burner per month is therefore estimated to be as follows:

	Cents per burner per month
Small single-mantle lamps, domestic.....	8
Small single-mantle lamps, industrial.....	9
Large single-mantle lamps.....	11
Indoor upright multiple-mantle lamps.....	4
Indoor inverted multiple-mantle lamps.....	3.8
Outdoor multiple-mantle lamps.....	4.5

3. EQUIPMENT

The equipment required for a maintenance department is principally the kit or bag, tools, and in some cases ladders, provided for the maintenance and complaint men. Nine companies have given us their estimate for the cost of such equipment and we find the price per maintenance man supplied ranged from \$4 to \$21. In general, we believe that \$10 per man would be adequate to provide this equipment and that the interest, depreciation, and replacement for the equipment will not exceed \$10 per year per maintenance man. This may appear an unusual ratio of annual charge to initial cost, but the wear and tear of equipment is, of course, very high. The actual cost reported to us for maintenance of equipment ranged from \$1.50 to \$14 per man per year.

The allowance of \$10 per year per maintenance man for equipment, calculated on the same basis as the preceding items, amounts to the following figures per 1000 lamps maintained:

	Per month
Small single-mantle lamps.....	\$0.35
Large single-mantle lamps.....	.90
Indoor multiple-mantle lamps.....	1.35
Outdoor multiple-mantle lamps.....	1.70

In some cases two kits per maintenance man are provided, so that one may be in the stock room for cleaning and replenishing supplies while the other is in use. In this case, however, we would

include the second kits in the investment necessary for stock room, since this practice is justified only on the score of greater efficiency in handling stock-room service.

4. TRANSPORTATION

If motor equipment is provided for the foreman or inspectors of this department, allowance should of course be made for the interest, depreciation, and operating expense incurred. In addition, allowance for car fares must be made in accordance with local conditions. No effort has been made in our summaries to make a precise estimate for these items since they are so largely determined by local conditions.

5. HEADQUARTERS EXPENSE

The expense at headquarters consists of wages for stock clerks, route clerks, stenographers, and miscellaneous help. This work requires a number of persons, depending upon how closely this department can be coordinated with other branches of the company's work. We have not undertaken to give a precise estimate of this, but have included it with an allowance for transportation and overhead expenses in the final item discussed in the next section.

6. GENERAL EXPENSE

The general expenses for the maintenance department are made up of three distinct parts: (1) Rental of space; (2) interest upon stock; and (3) overhead or management.

Even though rent is not actually paid out for the space used by the maintenance department it would probably be desired by the management to make some charge to this department for its space allotment. Three companies have advised us of their practice in this matter, stating from \$3 to \$6 per 1000 lamps per month as the necessary allowance for rent. On the average \$3.50 per month per 1000 lamps appears adequate; but if the maintenance were extended to cover all lamps of an entire city the figure would be considerably less than this.

The value of the stock carried depends, of course, upon the number of units maintained, and as reported to us by eight companies ranges from \$180 to \$700 investment per 1000 lamps maintained. Of course, geographical location relative to sources of material in a measure determines the number of mantles and amount of glassware which must be carried in stock. In general, we believe that an investment of \$300 per 1000 lamps will serve for any system maintaining 10 000 lamps or more, but that an allow-

ance of \$4.00 per 1000 lamps maintained should be made for smaller systems. Considering the interest and breakage on this material, we believe that the annual expense allowance should be at least 10 per cent of the above figures. This amounts to \$3.50 to \$4.50 per month per 1000 lamps.

If a company owns and rents the lamps on maintenance, this necessitates additional allowance for the interest and depreciation upon the rented lamps. We have, however, not included any such allowance in our computations for maintenance service, since we desire to confine the estimate solely to the maintenance expense. In any case where lamps are rented the proper amount can readily be added to our estimate to determine the total cost of the department.

As suggested above, we have not undertaken to estimate precisely what allowance should be made for management and overhead, or expenses not otherwise listed. However, in order to make complete the examples in the following section, we have added to the total of expense definitely estimated an allowance of 10 per cent to cover these items and the cost of transportation and the headquarters expense for the maintenance department. Such an allowance does very well for a rough preliminary estimate, but, of course, more precise computations could be made by any management official with knowledge of the local conditions for which he was preparing a cost study.

7. SUMMARY OF COSTS

As a summary of the costs for several types of lamps which are thus estimated Table 10 is presented.

TABLE 10

Cost Summary for Maintenance Work (Cents per Month per Lamp)

	Small single		Large single	Indoor multiples				Outdoor multiples		
	Domestic	Industrial		3-mantle inverted	4-mantle inverted	5-mantle inverted	4-mantle upright	3-mantle inverted	5-mantle inverted	4-mantle upright
Labor.....	3	3	8	12.5	12.5	12.5	12.5	15	15	15
Materials.....	8	9	11	11.4	15.2	19	16	13.5	22.5	18
Equipment expense..	.04	.04	.09	.14	.14	.14	.14	.17	.17	.17
Rental.....	.35	.35	.35	.35	.35	.35	.35	.35	.35	.35
Interest on stock....	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
Subtotal.....	11.8	12.8	19.8	24.8	28.6	32.4	29.4	29.4	38.4	33.9
Ten per cent for overhead, headquarters, and transportation.....	1.2	1.3	2	2.5	2.9	3.2	2.9	2.9	3.8	3.4
Grand total.....	13	14.1	21.8	27.3	31.5	35.6	32.3	32.3	42.2	37.3

The unit costs stated above would undoubtedly be increased in practice so that a graduated scale, dependent upon the number of lamps maintained, could be adopted. For that reason the following basic schedule is suggested:

	Cents per month per lamp
Small single domestic units.....	15
Small single industrial units.....	15
Large single industrial units.....	25
Indoor 3-mantle inverted units.....	30
Indoor 4-mantle inverted units.....	35
Indoor 5-mantle inverted units.....	40
Indoor 4-mantle upright units.....	35
Outdoor 3-mantle inverted units.....	35
Outdoor 5-mantle inverted units.....	45
Outdoor 4-mantle upright units.....	40

VI. SUMMARY AND CONCLUSIONS

From an inspection of about 4500 gas mantle lamps in service in 10 cities a summary of the condition of mantles, glassware, pilot light, and other particulars was made in order to determine to what extent the customer benefited through periodic maintenance service.

By these observations it is found that a lamp not on regular maintenance is likely to be defective five and one-half times as frequently as a lamp which is regularly maintained. Also it is shown that on the average 1 in 3 of the lamps on regular maintenance was not in good condition, whereas the defects noted in the lamps not so maintained average more than one for every lamp.

The principal defects in the maintenance systems investigated are traced to one or more of three causes: (a) Too little attention to the work; (b) undue effort to have the maintenance self-supporting; (c) lack of appreciation of the customers' needs. Each of these is discussed in turn and recommendations presented for bettering conditions.

One satisfactory system of estimating the expenses for maintenance work together with a set of unit costs is presented, based upon the analysis of the operation of 10 gas companies. A suggested table of costs for each type of unit is given.

The authors desire to express their appreciation of the help rendered by the gas industry and by those on the special staff of the Bureau who assisted in this work. Especial thanks are due to W. M. Berry, associate gas engineer, for his aid in conducting observations and summarizing data.

WASHINGTON, June 2, 1917.

APPENDIX

MAINTENANCE PRICES OF VARIOUS COMPANIES

The following statements are appended to give the schedules of the various companies which have given us their cost figures. In considering these, allowance must be made for local conditions which seem to confuse the unit costs.

City A

The following are rates for incandescent burner maintenance standard lamps:

3-mantle inverted, indoor.....	\$0. 40
4-mantle inverted or upright, indoor.....	. 40
5-mantle inverted, indoor.....	. 50
4-mantle upright, outdoor.....	. 50
5-mantle inverted, outdoor.....	. 60
1 to 3 arc lamps at above prices; over 3, a reduction of 5 cents per lamp per month.	
Portico lamps.....	. 25
Reflex lamps, single units.....	. 15
Welsbach lamps, upright, single units.....	. 15
Reflexoliers:	
2-lamp.....	. 30
3-lamp.....	. 40
4-lamp.....	. 50
5-lamp.....	. 60

Prices do not include renewal of Holophane or fancy glassware, which may be supplied at regular prices.

City B

Multiple lamps.....	\$0. 35
Single-mantle lamps.....	. 15

City C

Rental and maintenance charges for arc-lamp units are as follows:

Upright four-light inside gas arcs: ^a	Each per year
1 to 50.....	\$3. 15
51 to 100.....	2. 70
101 and upward.....	2. 25
Inverted three-light inside gas arcs: ^a	
1 to 50.....	4. 05
51 to 100.....	3. 60
101 to 300.....	3. 15
301 and upward.....	2. 70
No. 20 single-mantle inverted inside arcs: ^a 1 to 50.....	4. 50
Outside, four-light, upright: ^b Any number.....	7. 20

^a Payable in 9 monthly installments.

Outside, three-light, inverted: ^a

1 to 3.....	\$12.00
4 and upward.....	9.00
5 lights, inverted inside arcs: ^a Any number.....	7.20
Radio No. 30, special three-mantle inverted daylight gas arcs: ^b	
1 to 11.....	5.40
12 to 50.....	4.95
51 to 100.....	4.50
101 to 300.....	4.05
301 and upward.....	3.60

On small mantle lights equipped with standard glassware the renewal of glassware is included, but if they are equipped with special glassware, maintenance only covers the cleaning and renewal of mantles and lamp parts. For lamps on monthly maintenance the charge is \$0.10 per lamp; semimonthly, \$0.15 per lamp; and weekly, \$0.20 per lamp.

City D

The business maintenance system charges are as follows:

Indoor arc lamps, \$4 per year, payable in 8 installments of \$0.50 per month, with gas bill from September to May.

Outdoor arc lamps, \$6 per year, payable in 12 monthly installments of \$0.50 per month.

Single burner units, other than the single large mantle, \$2 per year, payable in 8 monthly installments from September to May.

Factory lamps, \$3 per year, payable in 6 installments of \$0.50 per month, with gas bill from September to March.

City E

The company charges \$0.50 a month per arc for the rental and upkeep, including globes, mantles, all repairs, trimmings, and cleaning. Customers who own their arcs are charged \$0.25 a month for trimming, globes, and mantles used. All replacements of parts are chargeable to the customer, also initial expenditures of putting arcs in condition.

City F

Regular maintenance on arc lamps is at the rate of \$0.25 per lamp per month, or \$2.50 per year if paid in advance. There is also a rate of \$2 per lamp per year when there are more than 100 lamps at one place, at least 90 per cent of which are of the inverted type.

City G

The maintenance charge is \$0.50 per month on outside lamps and \$0.35 on inside lamps.

City H

Small single units, \$1.80 to \$2 per year; large single units, \$4.20 to \$4.80 per year; and multiple units, \$4.80 to \$6.10 per year.

^a Payable in 9 monthly installments.

^b Payable in 12 monthly installments.

City I

Quantity	Standard lamps	Rate per lamp per month (cents)				
		1	2	3	4	5
1 to 9	Upright or inverted single lights and C. E-Z.	15				
10 and over		12				
1 to 3, inclusive	Upright inside arc			30	35	
4 and over	do			25	30	
1 to 3, inclusive	Inverted inside arc	15	30	35	40	45
4 and over	do	15	25	30	35	40
1	Upright outside arc			45	50	
2	do			40	45	
3 and over	do			35	40	
1	Inverted outside arc	20		50		55
2	do	20		45		50
3 and over	do	20		40		45
Any quantity	No. 2076; No. 10; No. 4276; No. 48; No. 1800.	25		25		
Do	Kinetic semi-indirect fixture	12	14	16	18	20
Do	No. 1680, semi-indirect fixture			25	30	

City J

The charges for maintenance have been abolished both for labor and material, including mantles, glassware, repair parts, etc. Also, the lamps are installed free of charge up to 15 feet of piping; for piping in excess of this length the customer pays.

In order to cover the interest, depreciation, and obsolescence on the lamps and installation cost the consumer agrees to use at least 12 000 cubic feet of gas per annum, to cover which a minimum bill is rendered for the eight lighting months in the year of \$1.50 per month.

The above includes only commercial gas arcs installed in business houses, restaurants, etc., in the following units: No. 30 Humphrey, No. 20 Welsbach, and No. 81 Welsbach, or White Radio X.

Similar lamps for domestic purposes must be purchased, installed, and maintained by the consumer. The company will, however, deliver and install mantles and glassware at salesroom prices with no extra charge for the labor service.

City K

Arc-lamp maintenance is charged to the customer at the rate of \$0.25 for each arc, paid for monthly, or \$2 per lamp per year if paid in advance. This price also entitles the customer to two cleanings per month. However, if the lamp on maintenance becomes defective between regular cleanings, special attention is given in addition.

Reflex maintenance charges are \$0.12 per lamp, if paid monthly; \$0.10 per lamp per month for two or more on one contract; \$1.25 for one lamp per year, if paid for in advance; \$1 per lamp per year for two lamps or more on one contract, if paid for in advance.

City L

Reflex gas lamps:	Charge per month
1 burner	\$0.15
2 burners	.30
3 burners	.40
4 burners	.50
5 burners	.65
6 burners	.75
7 burners	.90
8 burners	1.00

	Charge per month
Reflex gas lamps—Continued.	
9 burners.	\$1. 15
10 burners.	1. 25
11 burners.	1. 40
12 burners.	1. 50
13 burners.	1. 65
14 burners.	1. 75
15 burners.	1. 85
16-20 burners.	2. 00
Over 20 burners. each..	. 10
Single-mantle gas arcs:	
1 to 20 burners. ....	. 25
Over 20 burners. ....	. 15
4-mantle upright arc lamps:	
1 to 3 burners. ....	. 35
4 to 8 burners. ....	. 30
9 or more burners. ....	. 25
All outside lamps. ....	. 50
4-mantle inverted arc lamps: Each lamp. ....	. 25

