*A proposed supplement to meter measurements and a means of measuring effectiveness in situations where meters cannot be used*

# A Bacteriological Method of Estimating Effectiveness of UV Germicidal Lamps

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THE RADIATION from ultraviolet (UV) germicidal lamps is being depended on more than ever for disinfection and sanitation of air, surfaces, and liquid products. The lamps are used in bacteriological laboratories and in industrial and medical situations to reduce or eliminate chance contamination of air, surfaces, and liquids by micro-organisms (*1*). The American Medical Association, having recognized the value of UV lamps, has accepted them for disinfecting purposes (*2*). The Food and Drug Administration has accepted UV radiation in the processing and treatment of food under specified intensity limits (*3*). In many uses, UV radiation is a supplement and adjunct to other means of disinfection.

Unlike an illuminating lamp, the effective radiation from a UV lamp is not its visible light nor is its blue glow an index of its germicidal capability. An assumption of disinfection based on the blue glow may give a false sense of security.

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According to rating tables provided by manufacturers, the average lamp life ranges from 2,500 to 17,500 hours. Lamp life depends primarily on characteristics of an individual lamp and the number of times it is started during its useful life. Intermittent operation decreases a lamp's average burning life. The manufacturers' descriptions do not clearly define average life, burning life, or UV life of their lamps.

If the lamp rated 2,500 hours were used almost continuously, its average life would be about 100 days. Similarly used, the 17,500-hour lamp would have an average life of about 2 years. Information concerning the germicidal effectiveness over such periods is not readily available in sufficient detail to be of value.

Although it is possible to keep records of a lamp's use, few laboratory workers would perform this tedious detail conscientiously. In situations where effective lamp life may be as short as 3 months or as long as 2 years, regular testing of the UV output is needed.

Another detail which can cause confusion is the unit of intensity of UV from the germicidal lamps. Different manufacturers rate their lamps differently. Some give data in watts per square foot at 1 yard from the lamp, others give it in microwatts per square centimeter at 1 meter. One manufacturer gives the UV output for his lamps in both tabular and graphic forms. The tabular data and graphic values for particular lamps have a difference of approxi-

mately 20 percent (*4*). The AMA Council on Physical Therapy has adopted the microwatt unit (*5*).

Other important factors that influence the UV output from a lamp include the line voltage at the lamp, the transformer or ballast output, and the use of a reflector in the fixture. Although these factors may be measured, they are not usually under the lamp user's control.

Several types of portable meters can be used to measure UV intensity. The importance and the difficulty of measuring UV output accurately have been reported by several workers (*6–8*). At the Communicable Disease Center of the Public Health Service the GE intensity meter, T-L standard light meter with fluorescent adapter, WSM600, and GE wattmeter were available for our study. These meters are generally useful measuring devices; their accuracy and precision vary. Their costs range from $50 to $200. The WSM200 (the click meter), listed at $500, was not available.

At CDC most of the UV installations could be measured with a GE intensity meter. Some installations, however, could not be measured with this meter because of its size, a box approximately 6 inches cubed, and because of the position method of reading. The intensity meter's sensitive phototube, located at the front of the box, is exposed to the UV radiation and the reading is taken from the scale on the rear of the box. In close quarters, the reading shown will be that at 6 inches or more above the surface for which the intensity is desired.

With the T-L meter with the fluorescent adapter, it was possible to get readings much closer to the surface. However, according to a 1958 personal communication from H. Haynes of the General Electric Large Lamp Department, it is not as sensitive as the intensity meter and it had an incorrect conversion factor. Subsequently, a WSM600 meter and a GE wattmeter were used. In situations where all of the meters could be used, questions arose regarding comparisons of results, accuracy, and precision.

The UV lamps in the glove-port type bacteriological safety cabinets frequently presented problems. The intensity meter was too large to fit into the glove port. Also, the lamps were too far from the port openings for contact meters to be used at the lamps. In the hazardous organism laboratories, the situation was frequently handled by disinfecting the area and then removing the front of the cabinet with mechanical tools.

The UV lamps at CDC were installed in various ways: behind shields with reflectors around them, in small air ducts, in small holding boxes, in small transfer boxes, and in small self-contained units. A few were attached to the walls and near the ceiling, where use of meters was hazardous and practically impossible. Another difficulty was the translation of UV intensity into bactericidal terms that could be easily understood by the laboratory worker.

All of these difficulties indicated a need for a simple, inexpensive, visual, and reliable method of estimating UV intensity. Consequently, the initial development of a bacteriological method was undertaken at CDC. A change of assignment, however, necessitated putting the study aside for a few years. Development of the method, later resumed on an expanded and more intensive scale, was completed in 1965 at the D. W. Fuller Ultraviolet Equipment Co. in Chicago.

### Bacteriological Method

The bacteriological method of estimating the effectiveness of UV lamps uses a test organism that is exposed to the UV lamp under standardized or controlled conditions of time and distance. For our study, organisms of the coliform group were used as indicators. An organism species from a human source was readily available, and a fresh strain was used for each series of trials. Reduction information, obtained from the total counts of pour plates by "Standard Methods" (*9*) before and after exposure to UV radiation, was used with time, distance, conversion factors, manufacturers' rating specifications, and the UV assumed necessary for approximately 100 percent colony inhibition to determine the effectiveness of the UV source. For 100 percent colony inhibition, 5,000 microwatt-seconds of UV energy was taken as the rounded and practical estimating standard. The calculations in a formula are:

$$\text{Percent of rating} = \frac{(5{,}000)\ (\text{Percent reduction})}{\dfrac{(\text{Distance of rating})^2\ (\text{Time})\ (\text{Rating})}{(\text{Distance of exposure})^2}}$$

Duplicate dilution plates were made of the indicator organism. One open plate was exposed to the UV radiation for a definite time interval at a definite distance, and the closed plate was the control. The unexposed plate provided the "before" count and the exposed plate the "after" count. The open and closed plates were exposed for the same time periods before agar was added. A 24-hour nutrient broth culture prepared from a completed test for the coliform group (*9*) was the stock test organism. The culture was diluted in buffered dilution water to contain about 300 organisms on a 100-mm. petri dish per exposed portion. If the exposure was to be in a horizontal position, 1.0 ml. of diluted culture was used. If the exposure was to be at an angle or inverted, 0.1 ml. was used. The use of open, exposed plates for up to 5 minutes did not result in contamination in this study. The distance of exposure may be at 1 meter, 1 yard, or any convenient measurable distance.

*Transmission.* A "Standard Methods" buffered dilution water has 42.5 mg. per liter of total solids. This is considered a soft water, and it will transmit 99.23 percent of the incident UV radiation, as calculated from the absorption coefficient (alpha=0.0258) assumed to be similar to that from a community water of similar total solids content.

To determine the depth of the exposed bacterial suspension, 20 replicate measurements were made of the area covered by 1.0 ml. of buffered dilution water in plastic and glass petri dishes. The average area of 1.0 ml. as a single drop was 3.14 cm.$^2$ in the plastic dishes and 8.28 cm.$^2$ in the glass dishes. From this, the average depth was computed to be 0.32 cm. in plastic and 0.121 cm. in glass. The 0.32 cm. figure was used to compute the transmission through the bacterial suspension. The transmission figure, 99.23 percent for the buffered dilution water, is close enough to 100 percent for this estimating method.

*Results.* In the first trial series, made with six GE15T8 UV installations, only the GE intensity meter was used for meter measurements. A summary of the 12 individual trials in this series is shown in table 1. The arithmetic average of the series, 4,770 microwatt-seconds of UV energy, was required to inhibit 95.4 percent average colony growth.

**Table 1. UV energy required to inhibit coliform colonies by intensity meter, bacteriological method, and manufacturer's data, summary of series 1 (12 trials)[1]**

| Trial No. | UV lamp | Percent colony inhibition | Intensity meter (μw-sec.) | Bacteriological method (μw-sec.) | Manufacturer's data[2] | |
|---|---|---|---|---|---|---|
| | | | | | Table (μw-sec.) | Graph (μw-sec.) |
| 1 | Bare | 92. 5 | 6, 330 | 4, 625 | 5, 040 | 4, 400 |
| 2 | do | 98. 8 | 7, 230 | 4, 940 | 5, 760 | 5, 030 |
| 3 | Covered reflector | 85. 8 | 5, 230 | 4, 290 | 4, 320 | 3, 770 |
| 4 | do | 86. 3 | 5, 430 | 4, 915 | 4, 320 | 3, 770 |
| 5 | With reflector | 90. 0 | 2, 710 | 4, 500 | | |
| 6 | do | 97. 0 | 5, 430 | 4, 850 | | |
| 7 | do | 99. 0 | 2, 690 | 4, 950 | | |
| 8 | do | 99. 0 | 3, 230 | 4, 950 | | |
| 9 | do | 99. 9 | 4, 840 | 4, 995 | | |
| 10 | do | 99. 1 | 6, 460 | 4, 955 | | |
| 11 | Bare | 98. 0 | 2, 560 | 4, 900 | 2, 045 | 1, 610 |
| 12 | do | 100. 0 | 5, 120 | 5, 000 | 4, 090 | 3, 230 |
| Arithmetic average | | 95. 45 | 4, 770 | 4, 820 | 4, 260 | 3, 635 |
| Standard deviation | | 5. 35 | 1, 600 | 230 | 1, 250 | 1, 070 |
| Standard error of mean | | 1. 55 | 460 | 65. 5 | 510 | 435. 5 |
| Coefficient of variation | | 5. 62 | 33. 4 | 4. 7 | 29. 3 | 29. 4 |

[1] Series 1 was performed at the Communicable Disease Center, Public Health Service, Atlanta, Ga., with six GE15T8 lamps.

[2] Ratings for lamps with reflectors were not readily available.

In 11 additional series of 126 trials, one lamp per series was measured 10–13 times by the bacteriological method and by several meters (table 2). Eleven 30-watt lamps had been taken out of routine use and used only for these trials. All the lamps were bare. They were installed in a test panel in which voltage measurements as well as pertinent meter and bacteriological measurements were taken.

The overall averages and ratios of the data in tables 1 and 2 show that with the 17 lamps (12 series of 138 trials) an average of 68.1 percent colony inhibition required 3,450 $\mu$w-sec. of UV energy by the intensity meter and 3,410 $\mu$w-sec. of UV energy by the bacteriological method. The ratio of the two methods was 98.8 percent from the totals and 104.5 percent from the average of the series averages. The series averages by intensity meter and by bacteriologically measured UV energies are shown in the graph. A straight line fitted by least squares has the form of $Y=0.649X+1{,}170$ and a correlation coefficient of 0.949. This indicates with a high degree of confidence that a close correlation exists between the meter and bacteriological methods of measuring UV energy.

Table 1 also shows data based on the manufacturer's average life rating table and graph (*4*). The manufacturer's detail specification data for the GE15T8 lamp at 100 hours showed 42.0 milliwatts in a table and 37.0 milliwatts in a graph. The difference is more than 10 percent. For the GE30T8 lamp, the difference is more than 20 percent.

The manufacturer gives specification data at 10 feet, 3 feet, 1 foot, 8 inches, 4 inches, and 2 inches in a table. His graph, however, shows specifications from 10 feet down to 1 inch for five specific lamps, and these data are simpler to use for distances that are not specifically written out. However, both the table and graph are for bare lamp installations. No similar data were readily available for lamps with reflector installations. In 6 of the 12 trials in series 1 (table 1), the lamps were in reflector installations.

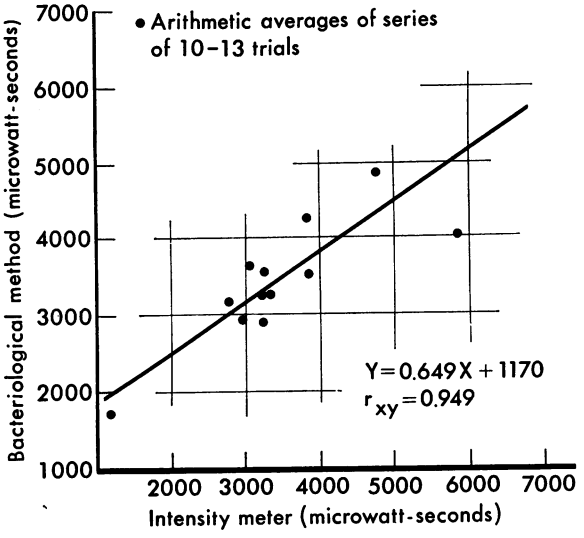
In the 11 series of 126 trials (table 3), 11 lamps were measured for UV output by the bac-

**Table 2. UV energy required to inhibit coliform colonies by intensity meter and bacteriological method, series 1–12 (138 trials)**

| Series No.[1] | UV lamps | Number of trials | Arithmetic averages | | | |
|---|---|---|---|---|---|---|
| | | | Intensity meter ($\mu$w-sec.) | Percent colony inhibition | Bacteriological method (5,000 $\mu$w-sec.) | Ratio bacteriological method to meter method (percent) |
| 1 | GE15T8 | 12 | 4, 770 | 95. 45 | 4, 820 | 101. 05 |
| 2 | GE30WT8–1 | 11 | 3, 250 | 57. 8 | 2, 890 | 88. 92 |
| 3 | GE30T8–2 | 10 | 3, 350 | 64. 9 | 3, 250 | 96. 72 |
| 4 | GE30W–3 | 10 | 2, 980 | 58. 8 | 2, 940 | 98. 66 |
| 5 | GE30T8–4 | 10 | 5, 890 | 80. 8 | 4, 040 | 68. 59 |
| 6 | GE30T8–5A | 11 | 3, 850 | 70. 0 | 3, 500 | 90. 91 |
| 7 | W782H–30–3 | 13 | 2, 780 | 63. 2 | 3, 160 | 113. 67 |
| 8 | W782H–30–4 | 12 | 3, 070 | 72. 3 | 3, 620 | 117. 91 |
| 9 | W782H–30–5A | 13 | 3, 800 | 85. 0 | 4, 250 | 118. 84 |
| 10 | W782H–30–9 | 13 | 3, 270 | 70. 3 | 3, 520 | 107. 64 |
| 11 | W782L–30–13 | 12 | 3, 280 | 64. 9 | 3, 250 | 99. 09 |
| 12 | W782H–30–18 | 11 | 1, 110 | 33. 8 | 1, 690 | 152. 25 |
| Total | | 138 | 41, 400 | 817. 25 | 40, 930 | 1, 254. 25 |
| Arithmetic average | | | 3, 450 | 68. 10 | 3, 410 | 98. 84 |
| Standard deviation | | | 1, 140 | 15. 48 | 780 | 36. 81 |
| Standard error of mean | | | 330 | 4. 47 | 220 | 10. 62 |
| Percent coefficient of variation | | | 33. 04 | 22. 73 | 22. 76 | 26. 19 |

[1] Series 2–12 were performed at the D. William Fuller Ultraviolet Equipment Co., Chicago, Ill.

**Ultraviolet energy required to inhibit coliform colonies by intensity meter and bacteriological method, averages of 12 series of 138 trials (least squares fitted line and correlation coefficient)**




teriological method and by four meters: GE intensity, Westinghouse WSM600, and two GE wattmeters. The percentages of ratings for the five measurement methods are shown in table 3.

The ages of the 11 lamps ranged from a new lamp at 100-hour life (GE30T8–4) to one reported to be 7 years old (W782H–18). The first lamp listed in table 3, GE30T8–1, was measured 11 times by each of the measuring methods. From the measurements, it was computed that this lamp had a rating of 50.3 percent by the GE intensity meter, 57.5 percent by the WSM600 meter, 58.5 percent by GE wattmeter-1, 55.1 percent by GE wattmeter-2, and 51.1 percent by the bacteriological method. These were the measured ratings compared to the manufacturer's 100-hour rating.

The averages of the coefficients of variation for lamp GE30T8–1 (table 3) were: GE intensity meter, 12.73 percent; WSM600, 10.82 percent; wattmeter-1, 4.58 percent; wattmeter-2, 5.83 percent; and bacteriological method, 15.68 percent.

The overall averages for the 11 lamps were: GE intensity meter, 10.80 percent; WSM600, 6.58 percent; wattmeter-1, 4.35 percent; wattmeter-2, 5.26 percent; and bacteriological method, 14.54 percent. The wattmeters could not be used for the Westinghouse lamps because an adapter was not available. Although the GE intensity meter is considered the most sensitive and precise, it showed greater variations among the individual readings in 3 of the 11 series than did the bacteriological method. Generally, the contact meters showed less variation than the GE intensity meter.

### Precision of UV Meters

After the 12 bacteriological series were completed, four additional meters became available for the study, presenting an opportunity to check the precision of UV meters. One lamp, GE30W–1, was measured by each of the meters 20 times at 5-minute consecutive intervals to determine the precision and accuracy of the meters (table 4). The summary data show that for the 20 readings the average rating for the GE intensity meter was 54.5 percent; the three WSM600 meters, 43.8 to 58.1 percent; and the four wattmeters, 54.4 to 66.5 percent. To compare the measurements, all data were calculated to percentage of lamp rating. One WSM600 meter was consistently lower than all other meters, and it had the greatest coefficient of variation.

The coefficient of variation indicates the precision of the measurements. The range for the 8 meters was from 0.25 to 14.58 percent. The GE intensity meter had a coefficient of variation of 4.98 percent. These data indicate that meter precision may be a factor in accuracy of measurements.

The same eight meters were also used to measure one lamp with and without a reflector attached (table 5). For the bare lamp, the meter readings ranged from 41.49 to 70.48 percent; with a reflector attached, the readings ranged from 46.89 to 158.38 percent. With the reflector, the intensity change varied from "no change" to plus 5 percent and minus 3 percent for the measurements made with the contact meters, whereas the change was approximately plus 300 percent for measurements with the GE intensity meter. Bacterial studies made with reflector installations seem to require the accuracy of a space meter rather than a contact meter unless reflector factor calculations are included. In such studies, a standardized bac-

teriological measuring method should be considered because it would measure the overall effectiveness of the UV lamp installation.

### Lamp Replacement

The germicidal UV output of a lamp decreases gradually during its useful life. With neglected maintenance, however, the depreciation is more rapid. Experience at the D. W. Fuller Ultraviolet Equipment Co. indicated that lamps will be down to about 50 percent of their rated UV output in their rated hours of life. Replacement is usually recommended for lamps that have depreciated to below 70 percent of the 100-hour rating. At CDC replacement was recommended when the lamp was below the range of 50–67 percent of its rating. For lamps within the 50–67 percent range, replacement usually required an administrative decision.

From our experiences and those of the D. W. Fuller Co. with UV devices, a lamp's output decreases very rapidly after its rated hours of

**Table 3. Percentage of lamp rating, measured by meters and bacteriological method**

| Series No. | UV lamp | Number of trials | GE intensity meter | Westinghouse WSM600 meter | GE wattmeter-1 | GE wattmeter-2 | Bacteriological method | Arithmetic average |
|---|---|---|---|---|---|---|---|---|
| 2 | GE30T8–1 | 11 | 50. 3 | 57. 5 | 58. 5 | 55. 1 | 51. 1 | 54. 50 |
| 3 | GE30T8–2 | 10 | 56. 0 | 61. 1 | 65. 3 | 63. 4 | 55. 2 | 60. 20 |
| 4 | GE30W–3 | 10 | 52. 1 | 59. 7 | 62. 0 | 58. 5 | 52. 9 | 57. 04 |
| 5 | GE30T8–4 | 10 | 110. 6 | 111. 5 | 117. 5 | 119. 6 | 103. 4 | 112. 52 |
| 6 | GE30T8–5 | 11 | 61. 7 | 68. 7 | 69. 4 | 66. 4 | 56. 7 | 64. 58 |
| 7 | W782H–3 | 13 | 69. 5 | 82. 6 | ---------- | ---------- | 77. 8 | 76. 63 |
| 8 | W782H–4 | 12 | 67. 8 | 77. 5 | ---------- | ---------- | 79. 3 | 74. 87 |
| 9 | W782H–5 | 13 | 76. 1 | 84. 9 | ---------- | ---------- | 83. 6 | 74. 87 |
| 10 | W782H–9 | 13 | 75. 9 | 84. 8 | ---------- | ---------- | 84. 5 | 81. 73 |
| 11 | W782L–13 | 12 | 89. 3 | 96. 2 | ---------- | ---------- | 94. 8 | 93. 43 |
| 12 | W782H–18 | 11 | 34. 7 | 32. 2 | ---------- | ---------- | 48. 6 | 38. 50 |
| Total | | 126 | 744. 0 | 816. 7 | 372. 7 | 363. 0 | 787. 9 | 788. 87 |
| $\overline{X}$ | | | 67. 63 | 74. 24 | 74. 54 | 72. 67 | 71. 62 | 71. 72 |
| S(X) | | | 20. 63 | 21. 54 | 24. 35 | 26. 63 | 19. 36 | 20. 20 |
| Percent coefficient of variation | | | 30. 50 | 29. 01 | 32. 67 | 36. 65 | 27. 03 | 28. 16 |

NOTE: Lamps in series 7–12 could not be measured by GE wattmeter-1 and GE wattmeter-2 because an adapter was not available.

**Table 4. Precision of ultraviolet intensity meters [1]**

| Meter and units | Sum of 20 readings | Arithmetic average | Standard deviation | Percent coefficient of variation | UV at 1 meter or at lamp | Percent of rating |
|---|---|---|---|---|---|---|
| GE intensity meter, mw./ft.$^2$ | 842. 5 | 42. 13 | 2. 10 | 4. 98 | 45. 4 μw | 54. 5 |
| WSM600–1, f=2.59, μw/cm.$^2$ | 377. 3 | 18. 67 | . 35 | 1. 86 | 48. 4 μw | 58. 1 |
| WSM600–2, f=2.10, μw/cm.$^2$ | 435. 1 | 21. 76 | . 44 | 2. 02 | 45. 7 μw | 54. 4 |
| WSM600–3, HI-LO, f=1.20, μw./cm.$^2$ | 608. 8 | 30. 44 | 4. 45 | 14. 58 | 36. 5 μw | 43. 8 |
| GE wattmeter-1, watts at lamp | 96. 0 | 4. 80 | . 24 | 4. 96 | 4. 80 w | 57. 8 |
| GE wattmeter-2, watts at lamp | 91. 3 | 4. 57 | . 15 | 3. 27 | 4. 57 w | 55. 0 |
| GE wattmeter-3, watts at lamp | 90. 2 | 4. 51 | . 12 | 2. 64 | 4. 51 w | 54. 4 |
| GE wattmeter-4, watts at lamp | 123. 6 | 5. 62 | . 01 | . 25 | 5. 62 w | 66. 5 |
| Voltmeter, volts on line | 2, 398. 5 | 119. 93 | . 66 | . 55 | ---------- | ---------- |

[1] One GE30W lamp was measured 20 times by each meter at 5-minute consecutive intervals. The measurements were at 1 meter or at surface contact as the meters indicated. The 100-hour rating for this lamp was 94.5 mw./ft.$^2$ at 1 yard or calculated to be 83.4 μw/cm.$^2$ at 1 meter. The contact rating was 8.3 watts at 100 hours.

**Table 5. Precision of ultraviolet intensity meters in measuring 1 lamp with and without a reflector [1]**

| Meter | Without reflector | | With reflector | | Percent intensity change with reflector |
|---|---|---|---|---|---|
| | UV at 1 meter or at lamp | Percent of lamp rating | UV at 1 meter or at lamp | Percent of lamp rating | |
| GE intensity meter | 44. 76 μw | 53. 67 | 132. 09 μw | 158. 38 | [2] +300 |
| WSM600–1 | 50. 20 μw | 60. 19 | 53. 22 μw | 63. 81 | +3 |
| WSM600–2 | 46. 22 μw | 55. 42 | 49. 66 μw | 59. 90 | +4 |
| WSM600–3–HI-LO | 34. 60 μw | 41. 49 | 39. 11 μw | 46. 89 | +5 |
| GE wattmeter –1 | 4. 82 w | 58. 07 | 4. 83 w | 58. 19 | none |
| GE wattmeter –2 | 4. 54 w | 54. 70 | 4. 58 w | 54. 92 | none |
| GE wattmeter –3 | 4. 66 w | 56. 14 | 4. 40 w | 53. 01 | −3 |
| GE wattmeter –4 | 5. 85 w | 70. 48 | 5. 92 w | 71. 33 | +1 |

[1] Lamp GE30W was measured by each meter at 5-minute consecutive intervals for 12 readings without reflector and 12 readings with an aluminum reflector attached to the lamp fixture. Without the reflector, readings were made at 1 meter or, as the type of meter indicated, at contact. With the reflector, distance readings were made at 50 inches, because the readings at 1 meter were off the scale of the intensity meter. Readings were calculated back to 1 meter by using the distance factor of 0.64 (*22*).

[2] Approximate values for changes.

life. The output curve can be described as an elongated horizontal S curve. The output falls rapidly down to its 100-hour rating value and then it follows a long normal downward sloping curve to its rated life at 50–70 percent. After passing the 50–70 percent range, the output falls sharply downward. The UV output intensity and the rated average life information given in the manufacturers' specifications represent average values. For individual lamps, the intensity and life vary considerably (D. W. Fuller Co. and *10*).

## Discussion

The bacteriological method was developed to meet the need for a reliable measuring method in problem situations, and it was extended to serve as a training and teaching aid for laboratory workers. Later, experiences and a search of the literature revealed peculiarities of meters and differences in manufacturers' data; therefore, we used the method in the comparison studies reported here.

A study of the literature presented difficulties in comparing the work of different investigators using different methods. The possibility of variable results is greater in the study of biological mechanisms than in the study of chemical reactions. With differing techniques and methods, reproducible results become more difficult. The results obtained by different investigators can be compared and evaluated only by careful attention to the details of bacteriological techniques. The UV effect on bacteria depends primarily on the conditions of the UV exposure (*1*, *6*, *11–20*).

The precision and accuracy of the proposed bacteriological method compare favorably with meter methods. The method solved the measuring need in problem situations, served as a training aid, and complemented and supplemented meter measurements. It uses recognized laboratory techniques and equipment that is readily available in a bacteriological laboratory.

The need for a standardized bacteriological method and the compilation of comparable data has been indicated. by the American Medical Association (*2*, *5*), the Food and Drug Administration (*3*), the D. W. Fuller Ultraviolet Equipment Co., and many investigators (*6*, *12–15*, *18*, *19*, *21*).

Much of the literature on the germicidal effect of UV radiation reports on killing in the high ranges, 85–100 percent. Although there may be some reasons for planning a study to center around 50 percent reduction, most uses of UV are directed toward practically complete inhibition of colony growth. The proposed bacteriological method is based on inhibition of 100 percent or very nearly 100 percent by approximately 5,000 μw-sec. of UV energy.

The data reported by many other workers as well as those reported here seem to support this figure for estimating purposes.

Although the manufacturer and fixture designer may be completely familiar with the electrical power UV units, the user may be more familiar with the results of bacteriological measurements. Both kinds of measurement have a place in the broad field of UV applications.

The measurement chain consists of many links; some are controllable by the lamp user, many are not. Each link has its peculiarities with respect to accuracy, precision, error, and uncertainty. Primary links in the UV situation are: UV intensity reaching the surface or point of use and time of exposure. The user can exert some control over the intensity by controlling the distance and time. He may or may not be able to control the intensity of voltage control, use of reflectors, lamp and fixture maintenance, airflow, and temperature.

The following examples of calculations with the proposed bacteriological method illustrate its usefulness in estimating the effectiveness of UV lamps.

Example 1: A lamp has an intensity rating of 46 microwatts per square centimeter at 1 meter. Assume that a 120-second exposure at 1 meter resulted in 100 percent bacterial kill. The exposure (intensity multiplied by time) was at least 5,000 $\mu$w-sec. The lamp output: $\frac{5,000}{120}=41.7$ microwatts per square centimeter at 1 meter. As this lamp at 100 hours of life was rated to be 46 microwatts, it is satisfactory at 90 percent effectiveness.

Example 2: The steps in calculations may be combined into a formula as follows:

$$\text{Percent of rating}=\frac{(5,000)(\text{Percent reduction})}{\frac{(D_1)2}{(D_2)2}(T)(W)}$$

Where: 100 percent kill intensity is 5,000 microwatt seconds per square centimeter (or milliwatt seconds per square foot).

$D_1$ = distance at which lamp is rated

$D_2$ = distance at which open plate is exposed

T = time interval of exposure in seconds

W = lamp's rating in microwatts or milliwatts (units must be compatible in the formula).

A lamp rated at 64 microwatts per square centimeter at 1 meter, and bacteriological method exposure at one-half meter for 60 seconds resulted in 80 percent reduction in the standard plate count.

$$\text{Percent of rating}=\frac{(5,000)(80)}{\frac{(1)^2}{(0.5)^2}(60)(64)}=28 \text{ percent}$$

This lamp should be replaced.

Using a manufacturer's data (*22*) for distance, the calculations become:

Distance conversion factor = 3.1

$$\text{Percent of rating}=\frac{(5,000)(80)}{(3.1)(60)(64)}=\frac{400,000}{11,900}=33.7 \text{ percent}$$

This lamp should be replaced.

Following are advantages of the proposed standardized bacteriological method of estimating UV effectiveness:

1. The standardized procedure makes it easier to compare data.
2. Buffered dilution water for dilutions and use of 1.0 ml. or 0.1 ml. of the suspension of coliform organisms will have very nearly 100 percent transmission for UV radiation.
3. Dilutions are made so that the exposed suspension contains approximately 300 organisms to avoid overcrowding.
4. The test for secondary effects is simplified, and the determinations of high and low survival ratios are possible.
5. Time and distance factors can be easily varied.
6. The method is relatively simple and inexpensive for bacteriological laboratories.
7. The results are directly in terms of the overall lamp fixture inhibiting power.
8. The results can be easily converted to lamp and fixture ratings by means of a simple formula.
9. The method can be modified to use any organism that is convenient or of interest to the laboratory.
10. The method is a useful teaching and training aid and can be a supplement to meter measurements.

Disadvantages of the proposed method are that it requires bacteriological techniques, about 1 week to prepare a culture of coliform and then 24 to 48 hours to obtain the count reduction information. Some calculations are required to make comparisons to meter methods. Its precision will be that of a standard plate count, about ±10–15 percent.

## Summary

A need for a dependable method of measuring the effectiveness of ultraviolet germicidal lamps led to the development of a standardized bacteriological method. The method uses recognized laboratory techniques and equipment that is readily available in a bacteriological laboratory.

In trials with the bacteriological method, coliform colonies were inhibited almost 100 percent by 5,000 microwatt-seconds of UV radiation. A standard plate count on an unexposed plate and the count on an exposed plate showed reduction due to the UV radiation. The reduction result, distance, time of exposure, lamp's initial rating, and 5,000 microwatt-seconds of UV radiation were used in a simple formula to obtain the lamp's rating. Consideration of replacement can be based on this rating. In evaluating reflector UV installations with the bacteriological method, measurement complications were eliminated because the method measures overall effectiveness.

Results of trials showed that the bacteriological method compared within 95 percent of meter measuring methods. The proposed method can be used in situations where meters cannot be used, when meters are not available, as a training aid, and as a supplement to meter measurements. Data obtained in the study indicated that the method is within the range of accuracy, precision, and coefficients of variation of eight meters that were used in the trials.

## REFERENCES

(*1*) Koller, L. R.: Ultraviolet radiation. John Wiley & Sons, Inc., New York, 1952.

(*2*) AMA Council on Physical Therapy: Acceptance of ultraviolet lamps for disinfecting purposes. JAMA 118: 298, Jan. 24, 1942.

(*3*) Food and Drug Administration: Ultraviolet radiation for the processing and treatment of food. Fed Register 121: 3006, July 7, 1965, 30 F.R. 8572.

(*4*) Buttolph, L. J., et al.: Ultraviolet product sanitation. General Electric Application Engineering Department, Lamp Division. Cleveland, Ohio. LD–14, revised September 1953.

(*5*) AMA Council on Physical Therapy: Acceptance of ultraviolet lamps for disinfecting purposes. JAMA 122: 503, June 19, 1943.

(*6*) Coblentz, W. W.: Standardization of ultraviolet lamps used as sources of germicidal radiation. *In* Aerobiology. American Association for the Advancement of Science Publication No. 17, July 24, 1942, p. 138.

(*7*) Rentschler, H. C.: Production and control of bactericidal ultraviolet radiation. *In* Aerobiology. American Association for the Advancement of Science Publication No. 17, July 24, 1942, p. 166.

(*8*) Buttolph, L. J.: Characteristics of some low voltage type germicidal lamps. *In* Aerobiology. American Association for the Advancement of Science Publication No. 17, July 24, 1942, p. 171.

(*9*) American Public Health Association: Standard methods for the examination of water and wastewater. Ed. 11. New York, 1960, pp. 492–508.

(*10*) Fort Detrick: Replacement and maintenance of ultraviolet lamps. Frederick, Md., April 1962.

(*11*) Seliger, H. H., and McElroy, W. D.: Light: physical and biological action. Academic Press, New York, 1965.

(*12*) Luckiesh, M., and Holladay, L. L.: Disinfecting water by means of germicidal lamps. General Electric Review, April 1944, p. 18.

(*13*) Hollaender, A.: Abiotic and sublethal effects of ultraviolet radiation on micro-organisms. *In* Aerobiology. American Association for the Advancement of Science Publication No. 17, July 24, 1942, p. 156.

(*14*) Rentschler, H. C., et al.: Bactericidal effect of ultraviolet radiation. J Bact 41: 745–774 (1941).

(*15*) Cortelyou, J. R., et al.: Effects of ultraviolet irradiations on large populations of certain water-borne bacteria in motion. Appl Microbiol 2: 227, July 1954; 269, September 1954.

(*16*) Wedum, A. G., et al.: Ultraviolet sterilization in microbiological laboratories. Public Health Rep 71: 331–336, April 1956.

(*17*) Deering, R. A.: Ultraviolet radiation and nucleic acid. Sci Amer 207: 135, December 1962.

(*18*) Yaglou, C., and Wilson, U.: Disinfection of air conditioning processes. *In* Aerobiology. American Association for the Advancement of Science Publication No. 17, July 24, 1942, p. 129.

(*19*) Luckiesh, M., and Holladay, L. L.: Tests and data on disinfection of air with germicidal lamps. General Electric Review, April 1942, p. 3.

(*20*) Sylvania Electric Products, Inc.: Germicidal ultraviolet radiation. Commercial Engineer-

ing Department, Salem, Mass. EN–151, Sept. 17, 1946.
(21) Oppenheimer, F., et al.: The ultraviolet irradiation of biological fluids in thin-flowing films. Amer J Public Health 149: 903, July 1959.
(22) Westinghouse Sterilamp Tenderay Department: Table for determining ultraviolet intensities from germicidal sterilamps at various distances. Westinghouse Electric Corp., Bloomfield, N.J. Data sheet ASC–152, Nov. 8, 1948.

# *Legal Note* . . . Air Pollution Control

Tall smokestack which eliminated heavy concentration of industrial pollution at ground level near plant by dispersion rather than removal of pollutants held not to qualify for tax exemption as an "air pollution control facility." *Ohio Ferro-Alloys Corp.* v. *Donohue,* 7 Ohio St. 2d 29, 218 N.E. 2d 452 (1966).

The Supreme Court of Ohio reversed a holding of an intermediate Court of Appeals, *Ohio Ferro-Alloys Corp.* v. *Donohue,* 3 Ohio App. 2d 256, 210 N.E. 2d 273 (1965), and held that a stack dispersing pollutants, but not removing them from emissions, is ineligible for tax exemption as an "air pollution control facility." (See *Public Health Reports,* May 1966, pp. 435–436.) The issuance of a certificate of tax exemption for such a facility is authorized pursuant to section 5709.25, Ohio Revised Code.

The court noted that the appellee's plant at Brilliant, Ohio, began its operation in 1951. Shortly thereafter residents began to complain about the volume of smoke the plant produced. The emission of smoke was at a volume of 7,000,000 cubic feet per minute, and contained volatized silica, alumina, magnesia, carbon, iron or iron oxides, and chrome or chrome oxides. The testimony indicated that 5 or 6 tons of pollutants were released every 24 hours.

To help abate this problem, a tall smokestack was erected to release the smoke at a level of 400 feet. This stack did not remove solid or gaseous pollutants from the air. The company sought to exempt the costs of erecting the stack from the application of the general tax laws by obtaining a pollution control certificate. The certificate was originally denied by the Ohio Board of Tax Appeals, but this decision was reversed by the intermediate appellate court.

In reversing the lower court's decision, the Supreme Court of Ohio noted that the applicable statute, in section 5709.20, requires as a prerequisite to exemption that the facility for which exemption is sought be designed, constructed, or installed for the primary purpose of eliminating or reducing air pollution which renders the air harmful or inimical to public health or property within the State. No evidence was ever adduced to the effect that dispersion of pollutants made the smoke any less harmful to public health or property within the State. A local nuisance was somewhat abated, but air pollution within the State was neither reduced nor eliminated.

In the court's view, the legislature designed the tax exemption to provide incentive for management to make capital investments designed to combat pollution generally. The court stated:

> It may be assumed that the General Assembly in enacting this statute intended to encourage company management to make capital investments which would benefit the public generally by reducing or eliminating a contribution to the overall pollution problem which is now present within this State, and which will, in the absence of some legislation, become a severe problem in the future. The cumulative effect of many minor contributions to general air pollution will not be lessened if everyone merely builds a smokestack.

It was further held that the tax commissioner could have found the stack not to be suitable nor reasonably adequate for the purpose of air pollution reduction or limitation even if intended for this purpose. Tax exemptions are contrary to the general policy of uniformity in taxation and should be carefully scrutinized. The court stated:

> This court has invariably recognized the proposition that . . . statutory language granting tax exemption when construction is required must be construed most strongly against exemption.

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