25X1 [redacted]

Mailing Address

November 30, 1965

25X1 [redacted]

Monthly letter progress report, [redacted] 25X1

Comments on Status

Task I - Item 1 "Special Investigations"

Two visitations were made this month at the request of the Technical Representative of the Contracting Officer to [redacted] 25X1

25X1 [redacted]

Task II - Item 1 "Submicron Measurement Error Analysis"

In reviewing the test data on floor vibration measurements conducted by Bureau of Standards in 1960, it became evident that a better presentation of the data would be desirable. In the October progress report it was suggested that a vibration power spectrum presentation of G^2/ cps vs cps would be more useful. A brief literature review of the fundamental concept has reinforced our opinion that the vibration data should be presented as a power spectrum rather than isolated amplitude and frequency numbers. Further work on this item was deferred in favor of more urgent work on items 6 and 8.

Task II - Item 5 "Lamps for Rear Projection Viewers"

The technical data received on the new high pressure arc lamps under development show considerable promise for these lamps. If they prove to be truly applicable to rear projection viewers, it appears that a 400 watt lamp will do the same or better job than a 1000 watt tungsten lamp. Although analysis of the lamps was begun, completion was deferred in favor of more urgent work on items 6 and 8.

Task II - Item 6 "Evaluation Criteria"

A technical report on Item 6 was completed and final draft is being prepared for submission.

25X1 [redacted] November 30, 1965

Comments on Status (Continued)

Task II - Item 8 "Laser Metrology"

Fundamental work on item 8 was initiated and the data will be reviewed with the Technical Representative of the Contracting Officer. The technical report was blocked out but additional analytical work will be required before it can be completed.

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[redacted]

MEMORANDUM FOR THE RECORD

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SUBJECT: [redacted] Visit to NPIC on 14 January 1964.

1. Enclosed are Dr. [redacted] comments concerning the performance of the microscope and viewing conditions which he observed during his trip to NPIC. 25X1

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2. [redacted] submitted this memorandum during his visit to Headquarters on 25 February 1964.

[redacted] 25X1

Executive Secretariat
Scientific Advisory Board

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1631

2 March 1964

MEMORANDUM FOR THE RECORD

SUBJECT: Comments on Trip to NPIC, 14 January 1964.

1. These are a part of my observations made at NPIC during my visit of 14 January 1964. I asked to see materials of the best quality. I was shown KH 4 and KH 7 samples, including the resolution targets near Washington, D. C., and other samples from the flights that occurred over Washington on 26 December 1963, and a number of the other best photographs thus far achieved. My interest in the inspection of these materials was not so much in the materials themselves as it was in the performance of the microscope and the viewing conditions. It seems to me that the end product of the whole reconnaissance system is the light that enters the eye of the interpreter. It is his interpretation of what he is able to see that produces the final intelligence of value to our country, and I am not convinced that everything has been done to maximize his ability to extract the best possible retinal image from the pictures.

2. This is a natural interest of mine partly because I have, since World War II days, been a member of the Armed Forces-National Research Council Committee on Vision, and partly because all of my activities have been devoted exclusively to visibility matters for many years. I was interested, therefore, in looking at the microscope from the standpoint of the visual performance achieved with it and the viewing conditions under which the photo-interpreters presumably operate.

3. I endeavored to ask questions concerning the way in which the actual interpreters use the microscopes. I did not meet any of the interpreters or see them in the performance of their work. So far as I am aware, the interpreters use the same type of microscope and presumably work under the same sorts of conditions that I experienced during my visit on 14 January. From many things that have been said both in the various presentations I have heard and in the responses to the questions I have asked, I realize that the Agency is well aware of some of the shortcomings of the microscope and the viewing conditions under which it is used. For example: I recall from the briefings that studies have been made of means for increasing the apparent luminance of the diffusing surface against which transparencies are viewed. This is an important matter because, at high power, the exit pupil of the microscope is quite small and produces retinal illumination lower than is desirable in the darker portions of the scenes. I am convinced that any observer can obtain more information from the film at high power if more light could be made available. I am prepared to believe that the optical design of these constructions has been carefully considered and that a larger exit pupil is not practicable. If this is true, there seems to be little recourse except to increase the light available below the transparencies.

4. The performance of the observer can also be increased by improving the contrast rendition of the microscope. No one to whom I talked had any information concerning the contrast rendition of the system as now exists. My impression is that the system is far from being poor in this respect, but on the other hand, I would be surprised if worthwhile improvement could not be achieved rather easily. Quantitative measurements of contrast rendition which I have seen on other high quality microscopes indicates that improvement is almost always possible if a small opaque stop can be introduced at the transparency. In one installation with which I am familiar, a thin piece of metal containing a hole only large enough to allow the microscope to inspect the portion of the transparency corresponding to the field of view of the scope was provided in order to prevent light from other portions of the picture from reaching the microscopic

objective lens. It produced a very noticeable improvement in the apparent contrast of the photographs, particularly at high power. Such a result could be achieved automatically if illuminated diffusing glass beneath the transparency is replaced by a lamp housing from which light is emitted only by a small area directly beneath the microscopic objective.

5. In the present instrument the large illuminated diffusing glass produces a very distracting glare field into which the observer is forced to look. I understand that some operators make a practice of covering this illuminated area with opaque material, such as cardboard, in order to diminish this glare. I heartily endorse this practice and strongly urge its adoption and extension. I understand also that the interpreters tend to turn off the lights in the room while looking into the microscope. This also is a desirable practice. Unless both of these precautions are taken, the observer will be surrounded by enough room light to impair his visual performance unless well fitted eye cups are provided.

6. The small plastic shields with which the present instrument is provided are virtually useless and doubtless are seldom used. A dramatic improvement in visual performance can be effected simply by using ones hands to form eye cups before the microscope. The full improvement is not experienced until all of the stray light is excluded. I strongly recommend that the existing microscope be fitted with very good soft rubber eye cups. It would be desirable to have these specially made for each photo-interpreter so that he can achieve a comfortable, tight fit. If such cups are provided, the glare produced by the large illuminated diffusing glass will be negated, except for the deleterious effect arrising from abrupt changes in his adaptation which will occur when he lifts his eyes from the eye cups and looks at the brightly lightly lighted field beneath the microscope. Presumably it is necessary for him to do this at frequent intervals. Despite the fact that adaptation is a comparatively rapid process at high light levels, visual performance will be degraded for periods of several seconds after the eyes are returned to the eye cups if there is any form of glare source in the working enviornment. Glare-free viewing conditions in the work space outside the microscope eye-piece is highly desirable.

7. My visual inspection of the microscope made me believe that achromatigation conditions could be improved, particularly at high power. It is possible that some of the chromatic effects which I seemed to observe stem from the spectral distribution of the light from the illuminating system. It is possible that the spectral distribution of the light from the diffusing glass has a very different composition than that which was assumed by the lens designer who achromatized the microscope. This might be worth reviewing. In any event, reduction of chromatic effects in these microscopes could improve visual performance on the part of the photo-interpreters.

8. The microscopes eye pieces have focussing adjustments but these are not provided with diopter markings. The adjustments for interpupillary distance, moreover, do not appear to have a calibration scale. The photo-interpreter should not be expected to operate eye piece adjustments and make settings of interpupillary distance by trial and error. Just as in the case of military lookouts, his refractive correction and interpupillary distance should be determined carefully by clinical procedures, and he should set the diopter rings and the interpupillary adjustment in accordance with clinical findings before he attempts to look through the microscope. If the clinical work is done properly and if the microscope is properly adjusted and calibrated, the observer will have his eyes properly aligned with the optic axis of the instrument and provided with the optimum (spherical) correction. In no other way will he obtain the best visual performance of which the microscope is capable.

9. The photo-interpreters should not wear spectacles while looking through the microscope. These will not be necessary unless he is inflicted by astigmatism or some other visual defect for which ordinary eye piece focussing adjustments do not provide a correction. Each photo-interpreter should be given a very careful periodic opthalmic examination. Provisions should be made in the microscope for introducing cylinders (and prisms and if needed), tailored to the prescription of each man. Spectacles will then not be necessary.

10. I wish particularly to emphasize the loss in visual accuity in the use of microscopes such as those now employed by the Agency if the observer has uncorrected astigmatism, even astigmatic defects so slight as ordinarily to be considered as sub-clinical. These can quite demonstratively impair his visual performance.

11. The effect of small amounts of the astigmatism can be quite insidious, because the interpreter is ordinarily looking at non-sharp images and must endeavor to discriminate fine details buried in soft or grainy photographic images. He has no way to know whether the unresolved image he sees is truly representative of the film or whether part of the apparent loss of resolution is created by astigmatic or other defects in his own eyes. He should not be asked to make this judgement; rather, he should be subjected to frequent, careful othalmic examinations and he should be provided with full corrections on each eye piece. In fact, I would strongly urge that the photo-interpreter on whose visual performance so much depends should have very careful special eye examinations not less frequently than once a month, primarily in order to detect small changes in astigmatism which may develop. Experience may indicate whether such tests should be done less frequently or more frequently than monthly, but clearly a testing program should be instituted by the Agency and should be mandatory and not left to the discretion of the individual photo-interpreter or his private opthalmologist or optometrist. No detectable sub-clinical astigmatism should go uncorrected.

12. It would be desirable to give careful consideration to improving the comfort of the photo-interpreter while working through the microscope. Professional attention to such items as seats, arm rests, head rests, etc. should be given and these should be tailored to the stature and requirements of each photo-interpreter. The accoustical enviornment should also be considered and everything done to eliminate distraction, discomfort, and fatigue for these men.

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13. Visual performance varies with age. I understand that the group of photo-interpreters used by the Agency contains a wide spectrum of age. The visual capabilities of the men should be considered and possibly measured. Critical materials might profitably be looked at by more than one individual, inasmuch as there maybe a trade-off between the effects of age on visual performance and interpretation capabilities.

14. Finally, a review might profitably be made of design compromises of the microscope, primarily if it affects their performance at high power. A different instrument with higher power capability might reveal more information in some instances than can be obtained with the present microscope. It was my impression that more power would have been helpful in a few instances.

15. A study might also be made of the color and the spectral distribution of the lighting. Small second order improvements might result from a change of lighting.

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Optics Panel
Scientific Advisory Board

Approved For Release 2005/06/06 : CIA-RDP78B04770A001200040001-5
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High-Pressure Sodium Discharge Arc Lamps

By W. C. Louden and K. Schmidt

THE potential of sodium and other metallic atoms for use in light production was examined by Dushman[1] and others.[2] These results stimulated work by Fonda and Young[3] and in 1932 they demonstrated low-pressure sodium lamps in several installations. The lamps were characterized by their monochromatic yellow color and had an efficacy of 30 to 70 lumens per watt. Highway lighting installations were the principal use for these early lamps as application to other use was limited for esthetic considerations.

Commercial history of high-pressure discharge arc lamps began in the early 1920's with the development of mercury lamps. Developments in the mercury lamp since Elenbaas,[4], by Noel[5] and others,[6] have resulted in a generally accepted light source that has replaced the low-pressure sodium lamp in almost all the old installations. However, the low-pressure sodium lamp still finds wide application in European countries where development work has continued. Efficacies of over 120 lumens per watt are now common through improvements in techniques and innovations in arc tube designs. The lamps are popular in those countries that pay a premium for electrical power.

The low-pressure lamp operates with a sodium pressure of several microns. Special arc-tube glasses and glazes have been developed to resist the corrosive chemical characteristics of the sodium. Higher sodium pressures achieved by increasing arc-tube temperatures cannot be attained in conventional glass or quartz arc tubes as rapid chemical action darkens the arc tube. This reduces the efficacy and eventually causes failure of the lamp. Therefore, all commercially available sodium lamps, even with recent innovations and increased efficacy, have a characteristic yellow color with the associated poor color rendition.

Schmidt[7, 8] has studied high-pressure discharges through the vapors of alkali metals, sodium, potassium, rubidium and cesium, and discovered that sodium provides the highest efficacy in a light source with a good color rendition. The high-pressure sodium discharge is enclosed in an arc-tube envelope of high-temperature, alkali-vapor-resisting, high-density, polycrystalline aluminia. Nelson[9] and Rigden[10] have since made similar studies and have substantiated these findings. Operation of the high-pressure sodium discharge differs from that of the high-pressure mercury-metallic-iodide discharge[11] in that the discharge is wall stabilized with high-volume loading, the sodium pressure is higher by a factor of several hundred, and it is primarily the sodium atoms that are excited. The iodide lamp operates constricted and convection determined, the sodium pressure is ordinarily a few torr; it uses mercury as well as metal iodides, and atoms of all the metals and mercury are excited. The high-pressure sodium lamp differs from the former low-pressure sodium lamp in that the discharge is wall stabilized with high-volume loading and the sodium pressure in the arc is 200 torr compared to several microns, about 100,000 times higher than in the older light source.

Physical Construction

A 400-watt high-pressure sodium discharge arc tube is shown in Fig. 1. The arc tube (B) is sintered, high-density polycrystalline alumina manufactured by a process[12] that promotes controlled grain growth. The alumina tubes produced by this process are translucent and have a total transmission of light in the visible region greater than 90 per cent. The translucent alumina is highly resistant to alkali vapor at high temperatures. As a comparison, a high-pressure sodium arc operating in a conventional quartz arc tube would cause chemical darkening of the quartz by forming sodium silicate in less than an hour of operation. The translucent alumina shows no attack even after 10,000 hours of operation. Subassemblies *A* and *C*, consisting of metal end-caps and standard

A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 29 to September 2, 1965, New York, N. Y. AUTHORS: General Electric Co., Large Lamp Dept., Nela Park, Cleveland, Ohio.

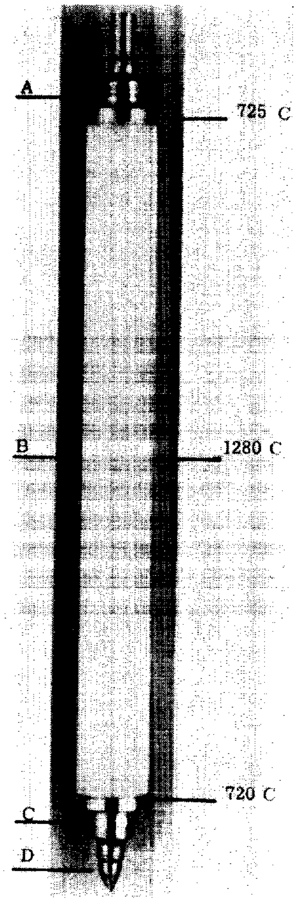

Figure 1. The 400-watt high-pressure sodium discharge arc tube and operating outside-wall and seal temperatures. B—Translucent alumina arc tube; A and C—metal end cap subassemblies; D—closed exhaust tube.

electrode structures, are sealed to the alumina tube. A metal tube, *D*, on one end of the structure serves as a means for exhausting and for dosing the arc tube with an amalgam of sodium and mercury. This tube is sealed off after processing is completed. The final lamp structure, similar in outward appearance to other high-pressure discharge lamps, is shown in Fig. 2. The translucent alumina arc tube is supported by a metal framework in an evacuated outer glass jacket. As in the mercury-metallic-iodide lamp, evacuation of the outer jacket serves to increase lamp efficacy by reducing conduction heat losses from the arc tube.

Discharge Mechanism

In the low-pressure sodium lamp almost all the energy is radiated in the sodium *D*-lines. Since they are located in the yellow portion of the eye-sensitivity curve, very high efficacies can be obtained but the color rendition of the source is poor. As the sodium vapor pressure is increased, a great percentage of the total radiation is emitted on either side of the *D*-lines and the line radiation becomes imprisoned or self-reversed. As a result, the source loses its characteristic monochromatic yellow color to become golden white with a significant amount of energy in the red. Mercury is added to the sodium in the discharge tube and acts only as a buffer gas. Little radiation of mercury lines is apparent in the visible region. Mercury raises the voltage gradient of the arc, permitting higher efficacies in the current range of 2.5 to 5.0 amperes.

Stable operation of the discharge is maintained with a reservoir of liquid sodium amalgam located in the exhaust appendage. By a careful balance of heat flow the appendage temperature is held constant; thus the sodium and mercury pressure in the discharge is constant.

The discharge is operated wall stabilized with an arc length of 70 mm between electrode tips. The tube diameter, 7 mm, is small enough for the positive column to be stabilized only by heat conduction to the wall. Convection disturbances in the arc chamber are negligible.

Design Characteristics

The scope of this paper has been limited to a discussion of the measurements made on a representative sample of the high-pressure sodium discharge lamp. The reader is referred to Reference 8 for further details concerning the discharge and its characteristics. The variation of design parameters has not been included as investigation of all variables has not been completed.

The spectral-energy distribution[13] of a 400-watt lamp operated at three different wattage inputs is shown in Figs. 3a, b and c. Since the discharge characteristics depend on the temperature of the liquid

Figure 2. Complete 400-watt high-pressure sodium discharge lamp assembly.

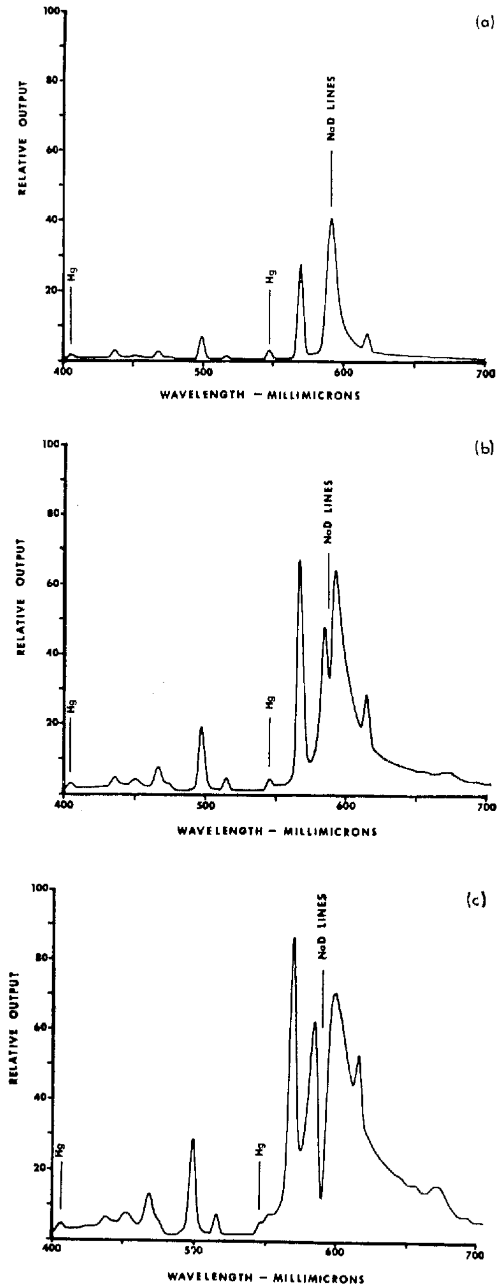

Figure 3. High-pressure sodium discharge lamp spectral distribution: (a) 3.0 amps, 68.5 volts and 185 watts; (b) 4.4 amps, 105 volts and 400 watts; (c) 5.0 amps, 143 volts and 620 watts.

amalgam, a change in energy input results in a change of the amalgam temperature. The effect of temperature and vapor pressure can be seen on the energy distribution. As the wattage increases (pressure increases) the line wing broadening becomes more apparent. The lamp color changes from a light yellow at 185 watts to a golden white at 400 to 620 watts. The golden-white color may be obtained in any wattage, however, by varying the length and holding other parameters constant.

The operating temperatures of the 400-watt arc tube are indicated in Fig. 1. High-pressure mercury arc tubes generally operate with a center bulb-wall temperature of 700 to 800 C and a seal temperature of 400 to 500 C. By virtue of the high-density translucent alumina the center arc tube wall can be operated at 1280 C, and proprietary seal design allows operation of the seals at 720 to 725 C.

Electrical Characteristics

The electrical-characteristic curves for the 400-watt sodium lamp are illustrated in Figs. 4 and 5. The operating points for the three energy distribtuions in Fig. 3 are indicated by the circles on the volt-ampere characteristics. These curves represent the measurable characteristics of a typical lamp operated on an adjustable choke ballast. As mentioned under "Discharge Mechanism," the reservoir of liquid sodium amalgam in the appendage is maintained at a constant temperature. However, in making characteristic

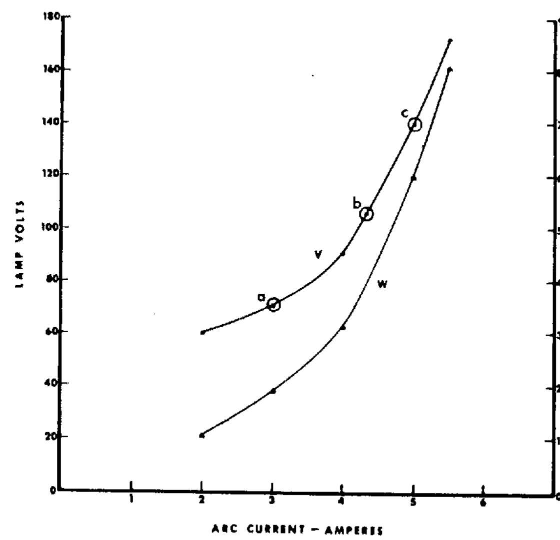

Figure 4. Lamp volts and lamp watts as a function of arc current for a 400-watt high-pressure sodium lamp.

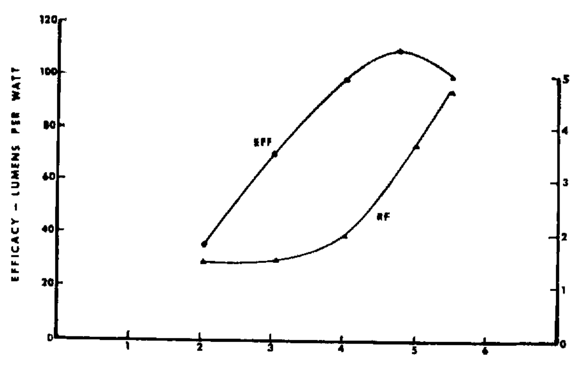

Figure 5. Lamp efficacy and red factor as a function of arc current for a 400-watt high-pressure sodium lamp.

measurements on a finished lamp the appendage temperature will vary and adjust itself to a different value dependent upon the ballast conditions. Therefore, it would appear that the volt-ampere characteristic has a positive slope when actually the characteristic is negative at any single dynamic operating point that the sodium and mercury pressure is constant.

The electrical parameters of the 400-watt design point have been chosen to obtain maximum efficacy with the objective color. The wall loading on this lamp is 22 watts per square centimeter if electrode losses are deducted. The maximum of the efficacy curve appears not to occur at the design point as this characteristic also is the combined effect of both the increase in loading and the increase in sodium and mercury pressure.

The red factor, an arbitrary measure of the red segment of the visible spectra, is measured with a filter that has a transmission characteristic as illustrated in Fig. 6. As demonstrated by the spectral distribution curves, the higher-wattage operation increases the line wing broadening and therefore the red factor increases.

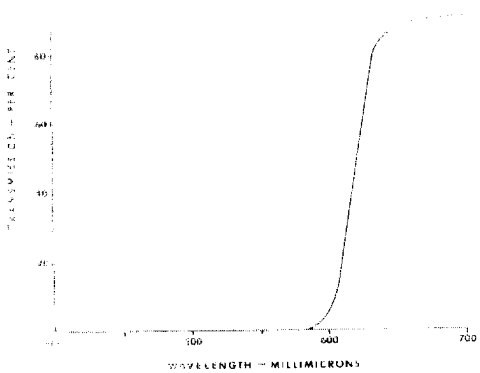

Figure 6. Transmission characteristic of CS2-61 filter used to measure lamp red factor.

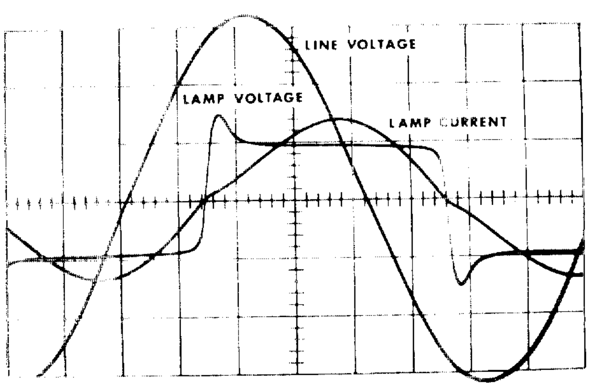

Figure 7. Oscillogram of line voltage, lamp voltage and lamp current at 60 cps for a 400-watt high-pressure sodium lamp. Line voltage is 240 volts, 100 volts/cm; lamp current, 4.5 amps, 5.0 amps/cm.

Operating curves of lamp voltage and current at the rated 400-watt input are shown in the oscillogram, Fig. 7. Line voltage, indicated by the sine wave, is 240 volts. The lamp voltage curve indicates that the re-ignition voltage required to sustain the arc is somewhat more pronounced than that which normally occurs in a standard mercury discharge arc.

Starting Voltage

Xenon at 20-torr pressure is used as the starting gas to raise the temperature of the sodium and mercury to a vapor pressure that will cause excitation of the sodium atoms. The combination of this gas pressure and the small-diameter arc tube results in a starting voltage of 1800 volts peak. A compact auxiliary starting circuit that provides 2500 volts peak has been designed for use with a series inductive ballast. A peak starting current of 3 amperes with a pulse width of 1 microsecond is delivered by the starting circuit to insure that a hot spot develops on the electrodes.

Restarting of the lamp requires two to three minutes cool-down time for re-ignition and two minutes to re-establish operating temperatures. The short re-ignition time, compared to that of standard mercury lamps, is a result of the lower vapor pressure of sodium at any given temperature and the high starting voltage generated by the auxiliary starting circuit.

Lamp Life and Maintenance

With initial efficacy in excess of 100 lumens per watt, 10,000-hour lumen maintenance has been measured on laboratory test lamps at over 90 per cent. Median life at the present time is in the 3000- to 6000-hour range. From an engineering viewpoint it is reasonable to expect that this can be increased as techniques for constructing the lamps are improved. Both life and maintenance can be expected to equal and possibly exceed those of the present mercury types, which use quartz arc tubes. This results from the use of sintered translucent alumina for the arc tube. Unlike quartz, it is not only free from chemical reactions with sodium but also shows no depreciation in transmission with lamp life due to devitrification or other similar effects.

Applications

High luminous efficacy with acceptable color combined with a small, high-brightness source and low ultraviolet radiation make the high-pressure sodium discharge lamp attractive as a lighting source. Since

Figure 8. Parking-lot installation of 25 400-watt high pressure sodium discharge lamps.

the cost of light generally is inversely proportional to lamp efficacy, other factors remaining constant, the new lamp shows promise of wide acceptance in new outdoor installations such as street lighting, floodlighting and area lighting. Indoors it will be used in high-bay industrial installations and eventually on other commercial applications. More complete coverage of lighting applications will ensue as a line of 100- to 1000-watt lamp sizes is introduced. The small high-brightness translucent alumina arc tube allows an increase in precision of refractor and reflector design and therefore greater control of light. Low ultraviolet radiation may permit the use of lower-cost plastics in refractor design.

A trial installation of 25 400-watt lamps used to illuminate an 87,000-square-foot parking lot and its entranceways is pictured in Fig. 8. The lamps are mounted in modified 1000-watt mercury luminaires on 30-foot poles spaced 85 feet apart on a diagonal grid layout. The lighting level is 4.5 footcandles—more than twice the level of the average well-lighted parking lot. The new light source combines, for the first time, efficacy of over 100 lumens per watt with good color rendition. Laboratory tests enable us to predict, with confidence, further improvements in efficacy and life. The impact of the high-pressure sodium discharge arc lamp on lighting technology and lighting applications is foreseen to equal that of the fluorescent lamp.

Acknowledgments

The authors wish to thank E. Homonnay and H. Wattenbach for the lamp characteristic and arc-tube temperature measurements and R. L. Brown for the spectral measurements.

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Printed in U.S.A.
Reprinted from ILLUMINATING ENGINEERING
Vol. LX, No. 2, February 1965

A New Metal Halide Arc Lamp

By J. F. WAYMOUTH
W. C. GUNGLE
J. M. HARRIS
F. KOURY

THE PRODUCTION of light using medium-pressure electric discharge devices (one to two atmospheres) is one of the older lighting techniques. Work was done in this field as early as 1906 by Kuch and Retchinsky[1] and even before. The commercial development of the medium-pressure device in which mercury was the active ingredient commenced in the period between 1920 and 1940. This source has been widely accepted. Unfortunately, however, the color rendition was poor, due mainly to the lack of red light being emitted by the elemental mercury. This serious drawback has been partially corrected through the use of fluorescent phosphors coated upon the inner wall of the lamp's outer jacket.

Spectroscopists[2] have used electrodeless electric discharge devices containing metals to study their emission lines. Most of the metals that have been studied have low vapor pressures at temperatures which are compatible with envelope materials having high transmission to visible radiation. To circumvent this difficulty, metal iodides were used. The vapor pressures of these iodides are significantly higher than for the corresponding metals. Quite unexpectedly it was discovered that certain of the basic concepts of the electrodeless devices could be utilized for practical lighting devices. Some work in this direction has been reported to this Society by Larson *et al.*[3] and Martt *et al.*[3a] who discussed the use of additives in conventional mercury lamps. This presentation will describe a completely novel source in which mercury has taken on a different role.

The use of metals other than mercury for medium-pressure arc discharges must take into consideration their relatively low vapor pressures when used in the elemental form. In general, their vapor pressures are of the order of tenths of torrs or less, at temperatures compatible with presently used envelope materials. These pressures are just too low to produce visible radiation efficiently. These low metal vapor pressures can be increased by orders of magnitude with the use of a metal iodide in lieu of the metal.

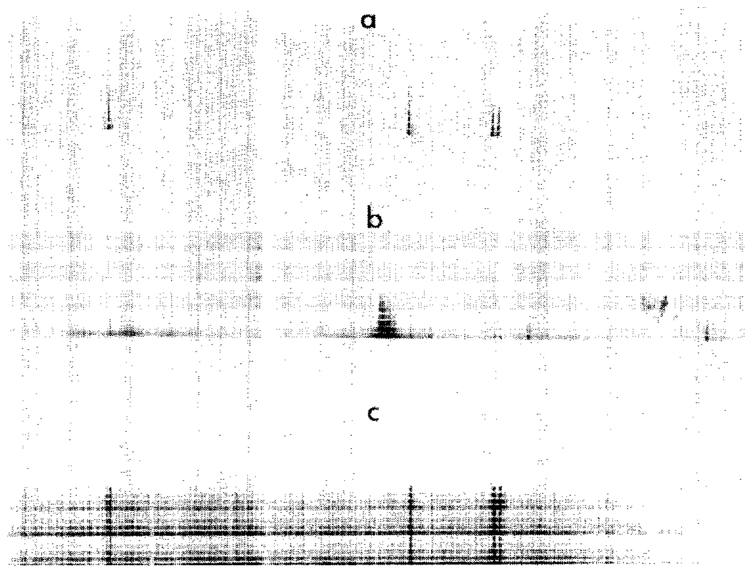
A paper presented at the National Technical Conference of the Illuminating Engineering Society, August 30 to September 3, 1964, Miami Beach, Fla. AUTHORS: Sylvania Electric Products Inc., Salem, Mass.

Most iodides have vapor pressures of the order of torrs and higher at bulb wall temperatures of the order of 700 to 800 C. As the metal iodide diffuses from the wall into the gas of the discharge, it becomes dissociated, yielding free metal atoms and free iodine atoms. Thus, the discharge has produced for itself a high metal vapor pressure. These metal atoms will participate in the operation of the discharge. This participation will consist of: (1) excitation of atoms to energy levels from which they may radiate energy as they return to lower levels of excitation; (2) ionization and participation in the passage of current through the tube. For the efficient production of light by this device, a significant number of the radiative transitions need to be in the visible energy range. Of course, the metal atoms and iodine atoms do not stay in the higher temperature zones of the device exclusively. They will diffuse outward toward the bulb walls. As they diffuse outward, the temperature decreases so that at the bulb wall the temperature is down to a value of 700 to 800 C. During the passage of the various species through this temperature transitional region, a temperature will be reached at which volume recombination with iodine can occur. Thus metal iodides will again be formed and the metals cannot condense out on the low-temperature bulb wall. The iodides used can be chosen from the various metals of the periodic table. The basic requirements have been discovered to be as follows:

1. The metal atom must form an iodide which is stable at the operating temperature of the bulb wall.
2. The vapor pressure of the metal iodide molecule needs to be high.
3. The metal atom must have excitation levels lower than for mercury.
4. The metal atom's energy levels need to be such that a significant percentage of its emitted radiation is in the visible spectral region.

Three classes of metals have been studied. Representatives of each are presented in Fig. 1. They are metals having a simple spectrum of a few narrow lines, such as mercury. Mercury has lines in the region of 5780 Å, 5461 Å, 4359 Å, 4060 Å.

Secondly, there are metals having broadened emis-



3900 Å 6700 Å

Figure 1. Spectrum for (a) mercury discharge; (b) thallium-mercury discharge; and (c) thorium-mercury discharge.

sion lines; a member of this class is thallium (second spectrum in Fig. 1). This metal has its primary emission in the region of 5350 Å. Two weaker lines are to be found at longer wavelengths—in the red region.

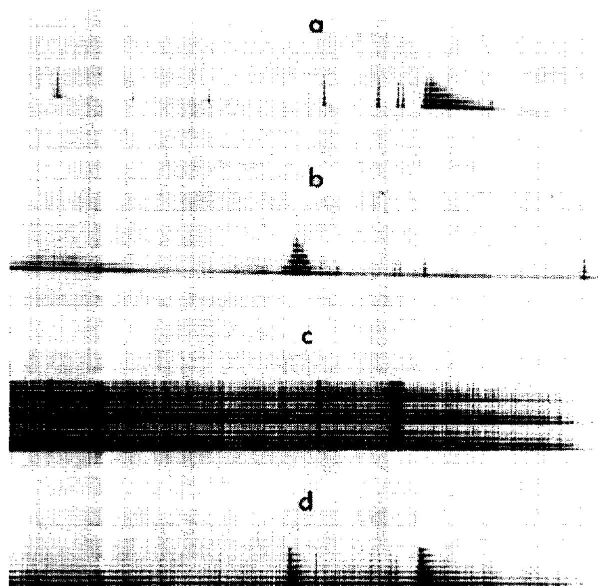
Thirdly, there are others having a high density of lines throughout the visible region. Thorium, the third spectrum in Fig. 1, is representative of this class of metal. Thorium has such a high density of lines that its spectrum has been called a "forest of lines."

On the basis of the extremely high density and balance of lines in the visible spectrum of thorium, together with other considerations, it has been used as the major light producing metal for this lamp. It has an average excitation potential of approximately 3.0 electron volts. In addition, thallium and sodium are added to improve the color balance further. Sodium yields most of its radiation in the doublet 5890 Å and 5896 Å. It has another set of somewhat weaker lines at 5681 Å and 5688 Å. The average excitation potential of thallium is approximately 3.0 electron volts; that for sodium is approximately 2.0 electron volts.

To improve the efficiency of the discharge, a buffer gas is introduced. The main purpose of the buffer is to reduce the rate of diffusion of metal ions and atoms to the walls. With a decrease in the rate of diffusion, the probability of recombination of metal and iodide atoms in the gas increases. Any energy left over after recombination will be used to maintain the temperature of the gas. Mercury has proved to be an excellent buffer gas. Even though the average excitation potential for mercury is double that of any of the other species, a significant amount of energy is radiated by mercury in the visible region.

The spectrum for each of these is shown in Fig. 2, along with the total sum. The final spectrum shows the good balance which has been obtained between the various regions of the visible spectrum using these atomic species.

The pressure of this lamp during operation is of the order of several atmospheres. It has been shown[4] that in this pressure range thermodynamic equilibrium exists in the plasma. Thus, the ionization and excitation rates for the various atomic species will be a function of the plasma temperature. To obtain a significant amount of thorium radiation, not only is



4200 Å 6600 Å

Figure 2. Spectrum for (a) sodium-mercury discharge; (b) thallium-mercury discharge; (c) thorium-mercury discharge; and (d) sodium-thallium-thorium-mercury discharge.

an optimum temperature needed, but also a high density of thorium atoms is required. Further, to obtain a good balance between the red and blue parts of the spectrum, it is necessary that the plasma temperature be relatively low. Studies have been made of the plasma temperature and how it is affected by the various components. Fig. 3 depicts the effect of iodine on temperature and Fig. 4 depicts the effect of sodium on temperature. As shown by these figures, the plasma temperature can be increased by an increase in the ratio of iodine to mercury and it can be decreased by an increase in sodium. Thus with these two handles, the average plasma temperature can be set, within reason, at almost any predetermined value.

Sodium performs another very important function. As a consequence of its low ionization potential, it can become ionized at greater radial distances than other species in the plasma. Sodium will be a donor of electrons in this region. With an increased supply of electrons, the energy dissipated as heat in this outer region will increase. With the total energy of the arc remaining constant, the energy dissipated in the central core must go down. This will change the temperature profile across the discharge. Externally, this change in temperature profile will manifest itself as a stabler arc.

The temperature data presented here were obtained spectroscopically by comparison of the intensity of the lines.[5]

As mentioned above, to have an efficient lamp it is necessary to have a high density of thorium atoms. It has been shown[6] that the thorium pressure in the plasma is a direct function of the electrode temperature. Briefly, the thorium deposits out as the metal on the electrode. The electrode tip is bombarded by iodine atoms. These then combine with thorium to form thorium iodide. This compound, being volatile at these temperatures, readily vaporizes from the surface of the electrode and dissociates in the plasma.

Thus, by regulating the electrode temperature a high thorium atom concentration can be realized. Effective excitation of these atoms can be obtained by optimization of the plasma temperature by variations of iodine-to-mercury ratio in conjunction with a variation of the sodium atom concentration.

Lamp Construction

A sketch of the new metal arc lamp is shown in Fig. 5. The arc tube envelope is made of fused silica having a diameter of 20 millimeters. Molybdenum foil/tungsten electrode assemblies are pressed sealed into both ends of the tube. The electrode is a tungsten coil wrapped on a tungsten rod with a rod extension past the coil of approximately ⅛ inch. This rod extension length is extremely important as it controls the electrode temperature.

The quartz tube and electrode assemblies are evacuated and degassed using standard vacuum techniques. Metal iodides are introduced into the tube in addition to mercury (the buffer gas) and a moderate pressure of a rare gas, such as argon. The rare gas is introduced to facilitate ignition of the device.

The outer jacket is similar to the present mercury lamp and it is filled to a pressure of approximately ½ atmosphere with dry nitrogen gas.

Operating Parameters and Ballasting Requirements

The sketch shown in Fig. 5 is of the 400-watt lamp variety. The electrical and optical data for this lamp are presented in Table I. As can be seen, the lamp has been designed so that the electrical parameters are compatible with the mercury lamp.

The radiation parameters are also given in the table. This lamp combines high lumens and efficacy with a good color temperature and a high color rendering index. This is an indication of the balance

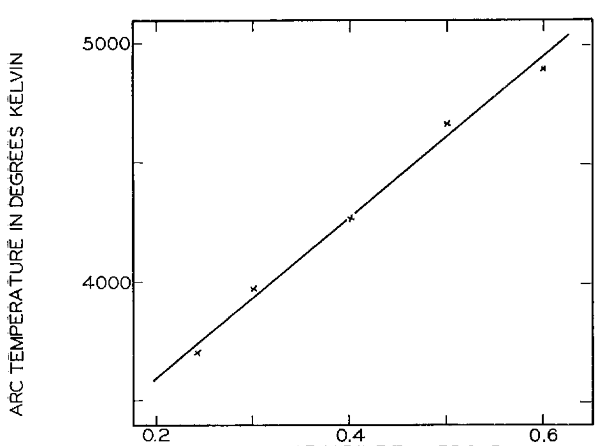


Figure 3. Effect of iodine-to-mercury ratio on arc temperature of metal halide arc lamp.

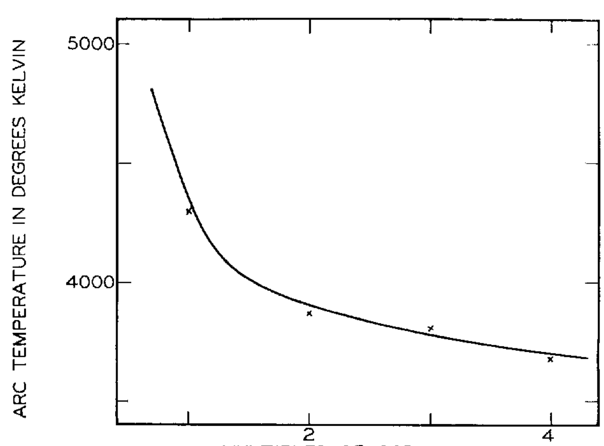


Figure 4. Effect of sodium on arc temperature of metal halide arc lamp.

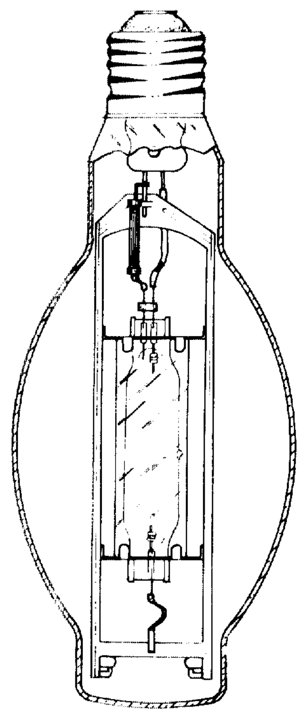


Figure 5. Metal halide arc lamp construction.

which has been accomplished between the various regions of the visible spectrum.

By a variation in the quantity and the types of atomic species, the color of light produced by a given lamp can be changed. In the laboratory color temperatures from as low as 2400 K to as high as 10000 K have been obtained with variations in lamp formulations. In all cases, the color rendering index ranged upward from a minimum of 60 with good efficiency.

Because of the role the electrodes play in maintaining the thorium pressure, and the presence of iodine in the tube, starting requirements are somewhat higher than for conventional mercury lamps with thoriated tungsten electrodes. The starting of this lamp is not based on a Penning gas mixture, thus the effect of temperature on starting is not as great as in other lamps. This effect is shown in Fig. 6. Due to the somewhat higher starting voltage requirements, it is recommended that a ballast having a high peak starting voltage be used as auxiliary equipment.

Applications of Lamp

This lamp has many applications as a light source. It can be used in all applications of the present JH-1 mercury lamp, such as street lighting and high-bay lighting and it markedly improves the level of illumination. Further, where an improved-color JH-1 lamp has been required, this new lamp will increase the level of illumination by nearly a third and increase the color rendering index of the installation. Some of the more important applications will be

Table I

ELECTRICAL PARAMETERS	
Power	400 watts
Current	3.4 amperes
Voltage	135 volts
RADIATION PARAMETERS	
Light Output	32,000 lumens
Efficacy	80 lumens per watt
Color Temperature	5800 K
Color Rendering Index	85
STARTING VOLTAGE	
Room Temperature	275-volt RMS
−20 F	300-volt RMS

indoor lighting, supermarkets, department stores, gymnasiums and similar applications where the combined requirements of light level and color rendition have previously required the use of fluorescent lamps.

Conclusion

Through the use of discharge lamps containing metal iodides, many different emission characteristics can be attained. This has opened a field of lighting just waiting for the ingenuity and subsequent exploitation by the lamp engineer.

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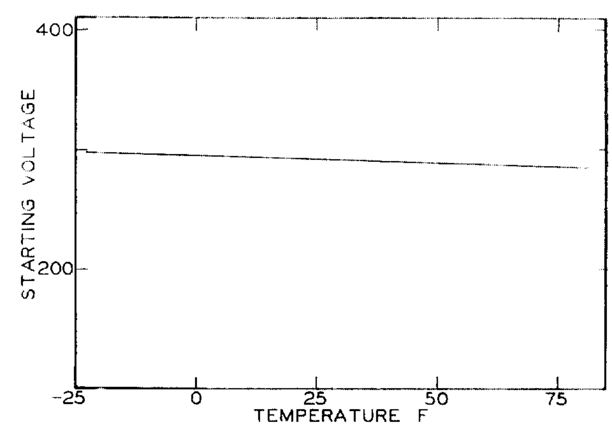

Figure 6. Metal halide arc lamp starting characteristics.