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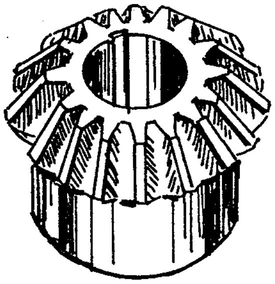
Application Bulletin

FLUORESCENT LIQUID PENETRANT AND MAGNETIC PARTICLE METHODS OF NONDESTRUCTIVE TESTING



Liquid penetrant and magnetic particle methods of fluorescent nondestructive testing are today highly efficient and widely used processes. They are used in nearly all kinds of industry providing economy, speed and sensitivity in testing. Some examples follow:

Tools and dies with cracks in critical locations may cause production shutdowns, as well as being hazardous to personnel. Even the reworking of the tool can be a source of cracks. Finding such cracks improves future rework practices permitting salvage so that sound tools can be put back into service.

Regular inspection of hand tools is a good safety practice that is coming into increasing use. A chisel or hammer that breaks can send a flying chip into a worker's eye or body.

Conveyor chains, crane hooks and chains, fork lifts, trucks and frames of punch presses and other heavy equipment must be defect-free.

Regular inspection of tanks, vessels, reactors, driers, piping and pumps is a critical operation in the chemical, petroleum, food, paper and process industries. It is found to pay off in terms of smoother operations without emergencies or unplanned shutdowns.

Diesel locomotive parts, trucks and buses are inspected and maintained regularly to provide long and reliable service. Some of the parts inspected are, axels, wheels, gears, crankshafts, cylinder blocks, connecting rods, cylinders, transmission components and heavily loaded parts such as the frames. Ship repairers and shipyards use similar techniques to examine critical parts in the drive train and steering of the ship and enable possible early repair at a fraction of the cost of replacement parts.

Oil and gas pipe line welds are inspected section by section as they are welded and before they are laid.

Oil fields where the drilling rigs, drill pipe casings and other oil drilling equipment should be regularly

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checked.

Aircraft engine parts, propellers, wing fittings, castings and many other critical parts are routinely examined with these inspection methods. Both the military and private sectors are covered. When it is known that parts will be free of critical defects at highly stressed locations, the designer can often use less expensive or lighter parts. If final quality is unknown, an unduly high safety margin must be allowed for in the form of additional weight, size and strength to make up for the strength lost when defects occur undetected. Modern aircraft could not be built as light as they are in the absence of such testing. Payloads would be reduced and operation made less economically feasible.

Gas turbines, containing thousands of critical parts, would have a very high probability of containing a potentially defective component and possibly disastrous consequences. Use of such techniques is essential in these examples of highly stressed, high speed machines.

Plastic molding should be examined for distortion cracks, molding defects, gas cracks and shrinkage cracks.

Porcelain insulator manufacturing is a similar field(3) for the application of black light inspection techniques. Receiving departments often inspect parts when delivered to insure that the product is sound before incorporation into another assembly.

INSPECTION METHODS:

The majority of inspections use a fluorescent method, where the parts to be inspected are illuminated with near ultraviolet radiation ("black light") that cannot be seen by the human eye but which causes the inspection material to fluoresce, producing visible light which can be seen by the eye. Because the inspection is normally done in the absence of visible light, other than that of the indication, even small indications are highly visible. Therefore, the fluorescence method produces a very sensitive inspection with relatively low inspector fatigue.

There are two accepted processes of nondestructive fluorescent particle inspection. One method is fluorescent magnetic particle inspection and the other is nonmagnetic fluorescent penetrant inspection.

(1) Fluorescent Magnetic Particle:

The fluorescent magnetic particle process is used on magnetic materials only and consists of establishing a magnetic field in the piece to be inspected. The degree of magnetization depends upon the size, shape and material composition of each piece. When the field cuts across a crack or discontinuity in the material, the two sides effectively form new magnetic poles.

A special fluorescent magnetic paste, mixed with a suitable oil solution to form a suspension of fluorescent particles, is then applied to the piece being inspected. The magnetic field around the defect attracts and holds the fluorescent magnetic particles, forming a brilliant fluorescent pattern of the defect when observed under a black light source. The fluorescent material will show the defect as a bright color contrasting to the dull purple of the reflected visible radiation from the rest of the sample.

Many variables affect the formation and appearance of the pattern displayed by the finely divided fluorescent ferromagnetic particles. Among these are the method of magnetization used; size, shape, direction of the discontinuity; direction and strength of the magnetic field, character of the surface of the part under test and the method of applying the ferromagnetic material.

This "wet" method is effective both for inspection in manufacture of parts at any stage and for most maintenance inspections and is the most commonly used. A "dry" method where finely divided iron is blown onto the part is sometimes used, especially for inspection of welds, large forgings and castings and other parts having extremely rough surfaces and where location of subsurface defects is needed.

<u>Limitations of the Method</u>:

1. It does not always locate discontinuities that lie entirely below the surface.
2. The magnetic field must be in a direction that will intercept the principal plane of the discontinuity.
3. Demagnetization, following inspection, often is necessary because all ferromagnetic materials, after having been magnetized, will retain a residual magnetic field to some extent. Effective industrial demagnetizing is not an easy job - especially if it is necessary to reduce the field to a very low level. There are often very valid reasons to do so. It may interfere with subsequent machining operations, electric arc welding and with the operation of instruments that are sensitive to magnetic fields,

functioning of the part itself or proper cleaning.

4. Post-cleaning, to remove remnants of magnetic particles clinging to the surface, sometimes is required after testing and demagnetizing.
5. Exceedingly heavy currents are required at times to test very large castings.
6. Individual handling of parts for magnetization usually is necessary and is a disadvantage with large numbers of small parts.

Advantages of the Method:

1. It is rapid and simple to operate.
2. There is no electric circuitry or electronic readout to be calibrated or kept in proper operating condition.
3. Indications are produced directly on the surface of the part and are a magnetic picture of the actual discontinuity.
4. There is no limitation due to size or shape of the part being tested.
5. The process will work through coatings of paint and plating.
6. Usually, no elaborate precleaning is necessary.
7. Because of the method's ability to locate fine, shallow surface fatigue cracks, the magnetic particle method is used preferentially for maintenance inspection of machinery of all kinds.

For dry powders, sensitivity to very fine discontinuities increases as particle size decreases. Most commercially available dry ferromagnetic powders are mixtures of particles of different sizes.

Cast iron does not usually permit an accurate identification of detrimental subsurface conditions because of the presence of graphite flakes which distort the magnetic particle inspection of white iron castings prior to malleablization assures that only sound castings go into further processing and is a wise economic move.

(2) Fluorescent Penetrant Inspection:

The nonmagnetic fluorescent penetrant inspection is usually applied to nonmagnetic materials such as aluminum, magnesium, plastics, glass or ceramics. It can be used with equally good results on many magnetic parts, however. The fluorescent material is dissolved in a special oil base which has high penetrating ability and is washable in water. As the fluorescent penetrant solution is applied, it is drawn into any surface defect by capillary action. The excess penetrant is washed away with a water spray or wiped off and the inspection piece is allowed to dry before a thin film of developer is applied. The developer draws the oil penetrant to the surface. The part is then inspected in a darkened area under black light.

For a given size defect and a given inspector, the "seeability" of the defect depends upon the penetrant and the inspection lamp. We shall deal with these in turn.

WHAT MAKES A GOOD PENETRANT?

Of course, the most important property of a penetrant is its ability to find defects. In the past, the best tests of this property have taken the form of cracked samples, which could be either actual cracked parts, or manufactured samples, such as quench-cracked aluminum blocks, aluminum fatigue strips, or any of a number of other devices.

Although the cracked sample still appears to be the best overall indicator of the crack-finding ability of a penetrant system, it soon becomes necessary to break the whole picture down into a series of parts or properties that can be measured, or at least compared with standards. Thus, it would be possible to pick the performance of a given material apart to determine just where it is deficient. Once this has been determined, the area of search for future improvement is considerably narrowed.

Experience indicates that the following four factors are the most important ones influencing penetrant-system performance:

(1) Penetrability, or the ability to enter a defect.

(2) Removability, or the ability of unwanted penetrant to be removed thoroughly from the surface of the part without affecting the penetrant in the defect.

(3) Developing technique.

(4) Fluorescent brightness of the penetrant. As will be demonstrated later, this factor is the most important of the four.

An indication must be seen by an inspector in order for it to be cause for rejection of a part. It will be seen because it contrasts with the part. The most sensitive penetrant, other factors being equal, will be the one that contrasts most with its background. In fluorescent penetrants, this contrast is achieved by making the background dark, by removing all light that the eye can see, and then making the indication as bright as possible by using a fluorescent material emitting as much light as possible in the region where the eye is most sensitive.

This factor is relative luminosity or brightness. The eye does not respond equally to all colors, but sees some as much brighter than others. The relative luminosity response of the average human eye is shown in Fig. 1. This curve is the curve of the response of the eye in normal light (photopic vision). In subdued light, the curve gradually shifts to the left and increases in height, because the eye shifts from cone to rod vision to see low light levels. This is scoptic vision. In designing a penetrant, it is wise to make the color one that the eye can see easily. Usually the amount of light emitted will be such that the eye will be using the photopic vision curve, or very near to it.

In actual inspection work, the coating of developer deposited on the part will be the same thickness on any given area, regardless of the size of cracks present.

However, not all cracks are the same size, so not all hold the same amount of penetrant. A large crack holds enough penetrant to nearly saturate the developer around it and allow much spreading of the indication to adjacent developer. A very small crack may hold just enough penetrant to reach the opposite side of the developer layer. There will be much more penetrant per unit volume of developer over a large crack than over a small one. It is useful to be able to duplicate this effect for testing, because it has been observed in practice that the brightness difference between two penetrants will have a much greater effect with small indications than with large ones.

THE INSPECTION LAMP:

The black light source used for inspection should be of relatively high intensity, (Fig. 2), efficient, reliable, long-lived and easy to replace in the event of a burnout. The most commonly used sources for black light today are the mercury-vapor lamps. Like all vapor-type lamps, the mercury lamp must have ballasting or transformer equipment to initiate the arc and to limit the current flowing across the arc after the lamp is started.

The 100-watt spot and flood lamps, such as the B-100A Lamps, are the most popular for industrial inspections with the "spot" types used almost exclusively to attain the high intensities required for local use. In inspection use, these generally are of the high-pressure type consisting of a quartz or vycor cartridge, containing the electrodes and mercury surrounded by a heat-resisting glass bulb which usually contains a focusing reflector.

The self-contained reflector will not tarnish despite the corrosive atmospheres commonly found in industrial locations. Because the lens is made from clear glass these lamps must be fitted with a suitable filter to absorb the visible radiations. As for all mercury lamps, the filter should be made from a heat resisting glass. The filter should be round, and inserted within a housing designed to prevent leakage of visible radiation. Such a lamp is the B-100A.

Most of the other mercury vapor lamps also require filters and generally need reflecting equipment to direct the rays onto the work area. One standard lamp requires no filter since the outer bulb is made of filter glass. Reflecting equipment is, however, needed with this lamp.

A time interval of several minutes is required for all mercury lamps to warm up and reach full output. An interruption of the power supply or a sudden drop in voltage of more than 15% will extinguish the arc of these lamps. Before the lamp will relight, it must cool sufficiently to reduce the mercury vapor pressure to a point where the arc will restrike at the available voltage. If the lamp is to be used for frequent, but intermittent inspections, it should be burned continually.

Black light is also available from tubular fluorescent type lamps. These lamps are identical to general lighting fluorescent lamps, with the exception that they contain a special phosphor, which radiates large quantities of black light ultraviolet energy. These lamps are available in several sizes, but the 15, 30 and 40-watt are the most applicable where large pieces are being inspected, and a general flood of black light is needed throughout the inspection area. BLAK-RAY® X-15, XX-15, X-30 and XX-40 Lamps are good examples.

Portable units are desirable where the volume of inspection is low or the equipment to be inspected is large, bulky, or heavy. These permit maximum flexibility at minimum cost. Small, portable fluorescent lamp units are available in 4 and 6-watt sizes, such as the BLAK-RAY M-16 and ML-49 Lamps, but they may lack the ultraviolet output required for critical inspection work. For critical inspections, units containing either 100-watt mercury flood or spot lamps are used. These are generally recommended where high intensities of directed ultraviolet light are required. For high volume inspection, there are several types of unitized equipment designed to provide rapid inspection operations.

The X-Series of black light fixtures and the ML-49 are normally recommended to be provided with BLB type tubes, whereas, the M-16 is provided with a BL type tube and a plain ultraviolet transmitting filter glass. Both the tubular filter glass in the BLB tubes and the M-16 filter glass are designed to limit the amount of visible light and make the lamps ideal for inspection purposes.

Fluorescent black light tubes put out reasonable amounts of black light but because of their configuration, they cannot be easily focused. Therefore, their intensity per unit area illuminated is much lower than that provided by the high-pressure mercury arc lamps, and fluorescent black lights should not be considered for critical inspections.

Fluorescent black lights, especially in the smaller sizes are, however, the most practical source for battery-powered, portable black lights. They are more efficient in the use of current than high-pressure arc types and even more important, start and reach full output in a few seconds rather than the 15 minutes required by the high pressure arc.

There are also many smaller mercury arc lamps ranging down to the PEN-RAY® Lamp series. These may find certain very specialized uses in inspection but are not often suitable because they do not have built-in reflectors and their usually lower power is widely and unusably dispersed.

For information on BLAK-RAY® ultraviolet lamps used for fluorescent inspection, refer to UVP Brochure #410.

HOW MUCH BLACK LIGHT IS NEEDED AND HOW MUCH WHITE LIGHT CAN BE TOLERATED?

In the past, there have been two axioms in this area. They are first, the more black light applied, the smaller the indication detectable, and second, the lower the visible white light level, the better the contrast, hence the smaller the detectable indications. These concepts are still true, but it is possible to operate under less than optimum conditions with usable results.

Schmidt (1) has assembled a table illustrating the effect of various levels of ambient light on detectability which he considers a rough guide only because the black light was set at given levels and not varied to determine accurate minima. The only criterion was whether the indications could be seen or not and only one observer was used.

	Measured Ambient Level	Black Light Needed ($\mu W/cm^2$)	
Description	(FC)	Small Indication	Large Indication
Black Light Booth (102 footcandles)	1	50	30-50
Average Plant (10-30 footcandles)	10	500	50
Office or Laboratory (30-50 footcandles)			
Very Bright Interior (100 footcandles)	100	5000	500
Bright Day, Deep Shade (100-300 footcandles)			

Bright Day, Open Shade (300-600 footcandles)			
Cloudy Day, No Shade (1000 footcandles)	1000	over 20,000	over 20,000
Bright Day, Direct Sun (3000-7000 footcandles)			

Schmidt's work indicates that extremely dark inspection areas and high light levels are not always necessary. They are, however, always helpful and do ease the inspection chore considerably. Further, in inspections for the very smallest indications such as micro cracks in jet turbine blades, they are necessary.

In many instances of minute indications it could only be detected by a dark-adapted inspector working in a booth with no more than 1 footcandle of visible light and then only by holding the part two or three inches from a 100-watt mercury arc source producing 15000 to 18000 μW/cm^2 on the part.

Thus, the axiom that high black light levels and low ambient light levels produce the best sensitivity is still true but maximum sensitivity is not always necessary and inspections can often be carried out under far from ideal conditions. Nevertheless, those ideal inspection conditions will considerably ease the inspection and should be used if at all possible.

MILITARY SPECIFICATIONS:

MIL-I-6868D (12-30-1971) is a mandatory specification for use by all departments and agencies of the Department of Defense and concerns general requirements for performing fluorescent magnetic particle inspection.

> "4.4.2 Fluorescent particle techniques. Fluorescent magnetic particle inspection shall be performed in a darkened booth with a maximum ambient light level of 1 footcandle. The inspection area shall be equipped with black light (s) in accordance with MIL-L-9909. The intensity of the properly filtered black light shall be minimum of 800 μW/cm^2 when measured in accordance with 7.3.2.
>
> 7.3.2 The intensity of black light shall be measured at the surface of the parts with Ultra-Violet Products, Inc. J-221 Meter or equivalent. Black light intensities shall be a working minimum of 800 microwatts per square centimeter."

MIL-I-6866C calls out the same requirements for the liquid penetrant method.

For information on the J-221 BLAK-RAY® Meters refer to UVP Brochure #200.

HOW LONG WILL THE INSPECTION LAMPS LAST?

Generally, the 100-watt source recommended for the application has less variation in output from the time that it is new until it has exceeded the rated life (2000 hours) than most other sources.

The most common cause of low intensity is merely dirty filters. Reductions of up to 50% of normal output have been noted when a film is allowed to build up on the filters. Lamps will generally cease to function before there is a reduction in output to an unuseable level.

Another cause of low light intensity may be low line voltage. Light output of the same bulb has shown nearly a 100% increase when line voltage was setpped up from 90 V to 130 V.

Other factors have a relatively insignificant effect. If the proper black light source is selected and used with a recommended filter glass, that is kept clean, there should be practically no chance of a substandard light source.

Because of the fact that each time a lamp is started there is an abnormal wear on the electrodes and severe thermal stresses set up, the practice of leaving the lamps on throughout the day is recommended. An appreciable decrease in bulb life will also occur with an input voltage higher than is necessary to maintain the desired pressure.

HOW LONG SHOULD BE ALLOWED FOR DARK ADAPTION?

MIL-I-6866 "Penetrant Inspection", was recently reviewed by the McDonnell Douglas Corporation.(2) It was discovered during this review that the 5-minute wait period required for an inspector's eyes to become acclimated to the dark each time he is exposed to white light, could result in 2 hours or more of lost time during an 8-hour day.

It is understood that this requirement was originally established by the Air Force to provide adequate time for a pilot's eyes to become acclimated to the dark and allow him to see the luminous instrument panel of an aircraft during night flying. Although this instruction was probably reasonable for its original application, its use in the penetrant inspection specification may not be reasonable.

The general approach used in this study was to expose a group of 34 certified penetrant inspectors (ASNT Level II) first to ambient light and then to the darkened conditions of a typical penetrant inspection booth. The time required for inspectors to see a fluorescent inspectability scale was measured and statistically summarized. The inspectors used in this study had an average of more than 10 years experience and worked in four widely separated divisions of the McDonnell Douglas Corporation in the U.S. and Canada.

The average eye adaption time for each inspector was determined and combined with the data from other inspectors for each of the two levels of relative brightness.

The study results clearly indicated that the 5-minute wait period required by MIL-I-6866 was not realistic for use with penetrant inspection and resulted in a significant amount of wasted time.

It appears that a more practical and yet conservative eye adaption time could be stated as "not less than 30 seconds." Based on the results of this study, this would represent an upper limit which is 5.2 standard deviations above the mean.

PHYSIOLOGICAL EFFECTS RESULTING FROM THE USE OF BLACK LIGHT:

Long wave ultraviolet radiation (black light) is a natural component of our environment because the atmosphere does not completely filter out this radiation reaching us from the sun. Whether the radiation comes from natural or artificial sources, it is capable of causing the eye media to fluoresce, causing unusual and/or uncomfortable sensations. This fluorescence effect is temporary and black light is normally considered harmless to the average person. However, in a few instances permanent histological changes have been reported and abnormally high sensitivities can be produced by certain drugs and chemicals. Persons exposed to these agents or those that are particularly photosensitive can possibly expect adverse reactions.

WHAT CAN BE DONE?

Should only eye discomfort or fatigue be experienced, BLAK-RAY® UVC-303 Contrast Control Spectacles or UVC-503 Safety Goggles, which are impregnated with ultraviolet absorbers should virtually eliminate the problem. Good work practice would indicate that the UVC-503 Safety Goggles should be worn all the time anyway to reduce fatigue and also protect the eyes against chemical splashes.

CONCLUSION:

The best source of black light is still the medium pressure, mercury arc lamp, fitted with an ultraviolet-transmitting visible absorbing filter (i.e. BLAK-RAY B-100A Lamp). For best inspection, the area should be as dark as possible although inspection may be accomplished at high ambient levels if absolutely necessary. The smallest indications will only be detected by high black light intensities associated with low visible light levels.

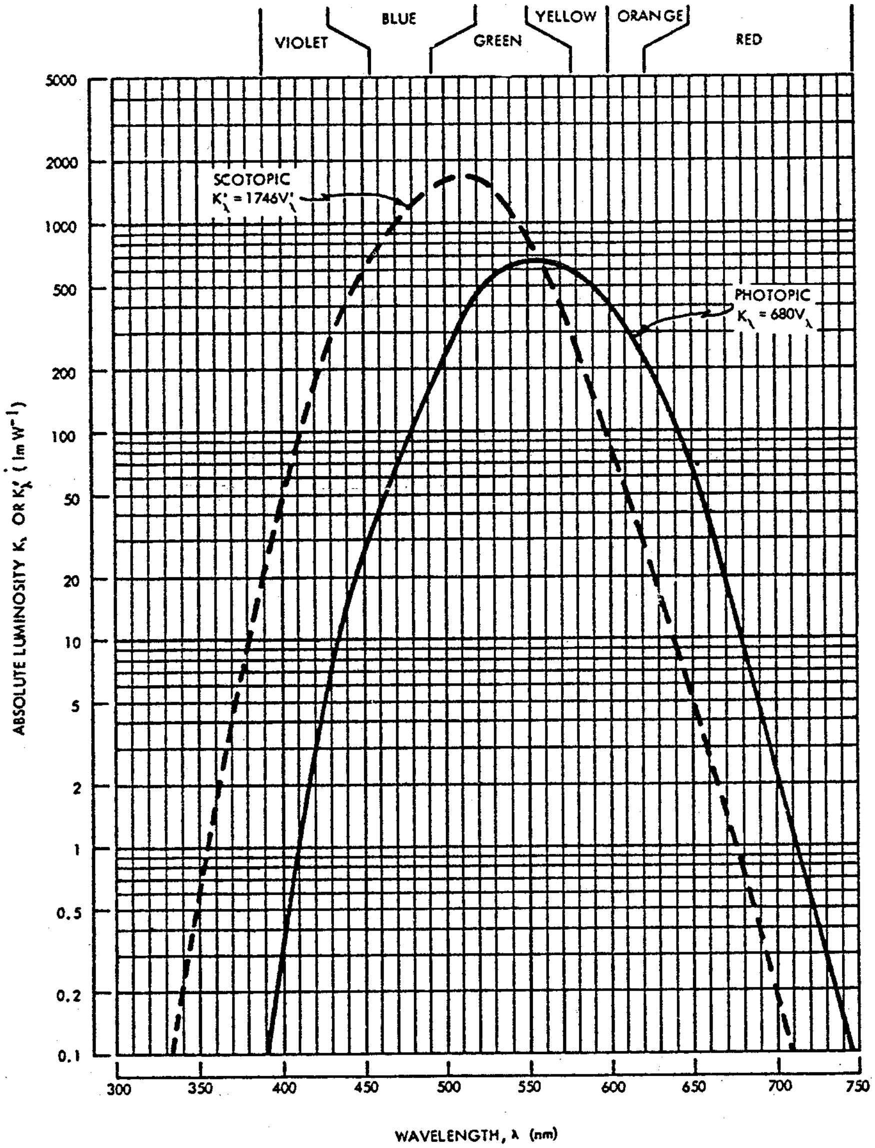

FIG. 1 Response of the Average Human Eye as a Function of Wavelength

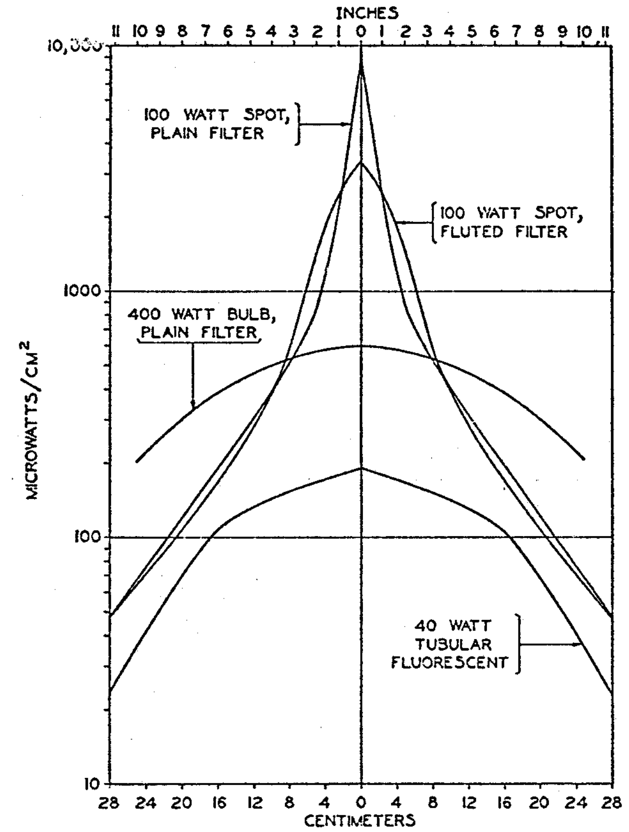

FIG.2 *Intensity of several types of black light versus distance from the center of the beam, 12 in. lamp-to-subject distance.* (from. ref. (

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(3) D.E. Alexander, Insulation p. 24, Aug. 1957

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