BNL 7805

BROOKHAVEN NATIONAL LABORATORY

BY F. Anderson DATE 9/29/60 SUBJECT Illumination of 80" Chamber SHEET No. 1 OF

CHKD. BY DATE JOB No. BC-04-2-D

File No. E-67

DEPT. OR PROJECT

1. INTRODUCTION

An estimate is made of the illumination required for the 80" chamber based on the absolute sensitivity of the film. Estimates have been made previously[1] from comparisons with the 72" and 20" chambers. These comparisons are brought up to date and compared with the new results.

2. BASIC FORMULA

We assume no light losses, and use as far as possible the same notation as Ref. 1. Let I be the light intensity in the chamber. Then the intensity registered at the film will be given by

$$\mathcal{J} = G(\theta)\,\frac{\gamma^2}{R^2}\,\frac{d^2}{S^2}\,I \qquad (1)$$

where γ = bubble radius

R = camera to bubble distance

$G(\theta)$ = scattering function[2]

d = diameter of camera pupil

s = diameter of image disc on film

For a scattering angle of 10°, $G(\theta)$ has the value 7.[3]

We can calculate with this expression as it stands putting in estimates for the bubble size in the chamber and the image size on film but it is

(1) BCCG Internal Report, H. L. Kraybill, BC-04-2-C

(2) G. E. Davis, J. O. S.A. 45, 572, 1955

(3) Curve for hydrogen given by N. C. Barford, Low Temperature Bubble Chambers, Fig. 19

DISCLAIMER

E 67

convenient to re-express the quantities involved. The diameter of the "object" in the chamber to which S corresponds is $S^1 = MS$ where M = magnification (film to chamber). We might loosely call this the diffraction diameter in the chamber although S and therefore S^1 takes account of other effects leading to the actual image size. Let

$$2r = \epsilon S^1 = \epsilon MS$$

Then

$$\epsilon = \frac{\text{bubble diameter}}{\text{"diffraction" diameter in chamber}} \simeq 1$$

Also let $$N = f/d$$

where f is the focal length of lens

N is the f number of lens.

Then $$d^2/R^2 = \frac{1}{N^2 (M+1)^2}$$

This gives

$$\mathcal{J} = \frac{1}{4} \frac{M^2}{(M+1)^2} \frac{1}{N^2} G(\theta) \epsilon^2 I \qquad (2)$$

The only uncertain quantity in this expression is ϵ. Since a bubble does not behave like a uniformly luminous sphere but may have local "hot-spots" due to the scattering process, it is hard to set an upper limit to ϵ; however, for this very reason, values of $\epsilon \ll 1$ seem unlikely and one might chose $\epsilon = .5$ as a safe lower limit. Also to compare one bubble chamber with another it seems reasonable as in Ref. 1 to assume the same value of ϵ, i.e, that one lets the bubbles grow until the bubble size begins to contribute undesirably to the bubble image. This should occur at the same value of ϵ for each chamber.

3. ILLUMINATION ESTIMATE FOR 80" CHAMBER

(a) Intensity required at film:

From the spectral sensitivity curve for linograph ortho published by Eastman Kodak Co., we find the value of 0.2 ergs per cm^2 as the average exposure required to produce a density of 1.0 above gross fog. Films exposed with the 20" chamber show a background density of about .08 and while it has not been possible to measure the density of the negative in the bubble images, several observers agree in a visual comparison with graded density scales that a density of 1.0 is a reasonable estimate for good images on the 20" chamber film.

(b) Intensity required in chamber:

Setting M = 14, N = 28, G(θ) = 7, we get

$$I = \frac{515}{\ell^2} \mathcal{J}$$

with $\ell = 1$, I = 0.2 ergs / cm^2 we get

$$I = 103 \text{ ergs} / cm^2 \qquad (3)$$

(c) Correspondence between Luminous flux and Energy flux

It is usual to discuss chamber illumination in terms of luminous flux in lumens. The correspondence between luminous flux and energy flux is given by

$$L = K_m \int E_\lambda V_\lambda d_\lambda$$

where $1/K_m$ is the so called mechanical equivalent of light $1/K_m$ = .00161 watt/lumen, i.e. K_m = 621 lumens per watt. V_λ is the "visibility factor" for the standard eye.[4] and E_λ is the energy flux.

(4) Tabulated for example in the Handbook of Chemistry and Physics, Page 2779.

Taking account of the spectral distribution of a typical long gap high voltage Xenon flash-tube[5] and the response of Linograph Ortho, we find for the ratio

$$\frac{L}{I} = \frac{\text{Luminous Flux}}{\text{Energy flux in range useful to Linograph Ortho (3800A-5800A)*}}$$

$$= 305 \text{ lumens per watt.}$$

This given for the luminous flux required in the 80" chamber with no losses from (3) above

$$L = 2.92 \text{ lumen sec per sq. foot.} \qquad (4)$$

d. Non-Uniformity correction:

There is one other consideration we should take into account in arriving at a theoretical figure for the illumination. We have calculated for a density of 1.0 on the film which appears to give good bubble images. However, we may anticipate intensity variations of the order of a factor of 3 due to being out of focus, different scattering angle and inverse square law effects. Since the γ of the film is about 2 where

$$\gamma = \frac{\Delta(\text{Density})}{\Delta(\text{Log Exposure})}$$

we have for a factor of 3 in exposure

$$\Delta \text{ density} = 2 \log 3$$

$$= .96$$

This would bring us down to the level of the background so we should set the peak density a little higher than 1.0, say to be conservative about 1.5.

(5) G. E. Flash Tube Data Manual, Page 7

* The lower limit of 3800A° is estimated for the glass cut off.

This implies a minimum density of 0.5 and a factor of 2 in exposure. This gives for the illuminating intensity with no losses

$$L = 5.8 \text{ lumen sec per sq. foot at } \epsilon = 1 \qquad (5)$$

We may also write down here our upper limit at $\epsilon = .5$.

$$L = 23.4 \text{ lumen sec per sq. foot} \qquad (5)a$$

These figures are for comparison with other chambers.

4. DESIGN FIGURES FOR THE 80" CHAMBER

(a) Reflecting and Absorption Losses

Contributing to light losses from the flash-tube to the film we have:

Condenser optics and flare lens	6 surfaces	~ 6" glass or equiv.
Light path into chamber	8 "	12" "
Light path to camera	8 "	12" "
"Coat hanger"	2 "	5" "

If the glass or plastic surfaces are uncoated as they are in the 12" chamber, the transmission allowing for 4% loss for each surface, is given by

$$(0.96)^{24} = 0.38$$

With coated optics we might expect a loss of 1 % to 0.5% at each reflection giving at 1% loss

$$(0.99)^{24} = 0.78$$

Thus we can obtain a gain of a factor of two through the use of anti-reflection coatings.

Spectrophotometric measurements of transmission through two 1" pieces of 20" chamber coated glass indicated a loss of 7%. Since the chamber results indicate that the anti-reflection coatings work this presumably means a large absorption of light either in the glass or in the coatings. The glass in question is soda-lime glass. An absorption of 5% to 6% per inch does not seem unreasonable, and while further work remains to be done to check this point we assume that we can neglect absorption in the coatings.* Then with the use of a low absorption glass throughout (eg Borosilicate crown ~ 1.3% per inch) the transmission factor allowing for absorption should be

$$e^{-.013 \times 35} = 0.63$$

Finally, allowing for a 10% loss at the coat hanger reflector strip the overall transmission factor is

$$(.78)(.63)(.90) = 0.44$$

b. Filters:

The 20" chamber uses a filter peaked at about 4500A and transmitting at half-height about 1000A°. Spectrophotometric transmission curves give an energy transmission of about 25% in the range useful to Linograph Ortho. The use of a filter is indicated by (a) to increase the effectiveness of the coatings, and (b) to achieve some simplification of the optics of the condenser and flare lens. With the above filter the effect on (b) is probably not very great. Another filter under consideration, Kodak Wratten 47B is peaked at 4300A with a width at half-height of 500A°. This filter gives a reduction of a factor of 8 in transmitted intensity. Because of (b) above it would be attractive to incorporate this degree of filtering; however, we will allow only for a filter factor of 4 as in the 20".

* The large absorption in the glass appears to be confirmed by some curves supplied by Pittsburg Plate Glass Co. (note added in proofs)

(c) Flash Tube Brightness:

The design figures for the Berkeley chamber corresponded to flash tube brightness of about 200 lumen sec | cm^2 steradian, although at an unacceptable flash durations. There is some uncertainty as to the brightness under operating conditions, because of uncertainty as to how much energy is dissipated outside the flash-tube under test and operating conditions. From information supplied by Norgren and their published test results, we conclude that the figure lies somewhere between 75 and 100 Ls/cm^2 at 250μ sec duration. We have measured under <u>our</u> test conditions a brightness of 85 lumen sec | cm^2 steradian for this tube at the Berkeley capacitor and voltage values. The Siemen's tubes under test here are quoted by the manufacturer at 250 to 300 lumen sec per cm^2 steradians and indeed in preliminary testing have given 250 with about 200μ sec flash deviation. Without life-testing, however, it may be dangerous to use this figure so we will assume 100 lumens | cm^2 steradian.

<u>Calculation of Hole Size Required in 80" Chamber</u>

We want the equivalent of 23 lumen sec | sq. foot or 830 ergs | cm^2 (our chosen upper limit at $\epsilon = 0.5$). Allowing 44% transmission and a filter factor of 4 gives 209 lumen sec | ft^2.

Assuming a source brightness of 100 lumen sec | cm^2 steradians and a source to chamber distance of 100" give a source area of

$$A = \frac{209}{100} \times \left(\frac{100}{12}\right)^2 \; cm^2$$

$$= 145 \; cm^2$$

This would be supplied very closely, for example, by a hole 7" x 3 1/2" with semi-circular ends.

Safety Factors

If one believes the absolute calculation there would appear to be a safety factor of about 4 in the choice of $\epsilon = 0.5$. One might hope also for an additional factor of 1.5 to 2 in the flash tube brightness. If all else fails there is the filter! Simply removing the filter will give a factor of 4 while removing the filter and substituting Shell-Burst for Linograph Ortho would appear to give a factor of 6. The question of filters and coatings will have to be discussed elsewhere but from a preliminary examination it would appear that the most objectionable reflection effect would occur from a double reflection between the coat hanger surface and the main window. It will require better than 1% reflectivity per surface to kill this reflection ($\sim 10^{-5}$ down) so that the filter will probably be desirable for this reason. We simply point out that a factor of 4 is available with reflections!

5. COMPARISON WITH THE 20" and 72" CHAMBERS

This comparison differs from that in Ref. 1 in the inclusion of new data, glass losses, and film sensitivity, and in the use of equation (2) which gives results significantly different from the expression used in (1). Equation (2) contains only the magnification and f-number actually used and does not contain an implicit dependence of lens opening on chamber depth. To put it another way, it seems that the 72" and particularly the 20" are operated at smaller lens apertures than one would predict as optimum.

Data:

Chamber	Mag.	F. Number	Rel. Film Speed S.	Total Est. Transmission in absence of filters
20"	9	26	1	42%
72"	15	22	1.5*	29%
80"	14	28	1	44%

* The film speed factor is estimated from (1)No filter in 72", (2) Use of Pan film which is sensitive from 3800A - 7000A vs 3800A - 5800A for Linograph Ortho. Other differences are negligible.

The transmission data for the 80" have already been discussed.

20" Losses

Reflection at 1% at 20 surfaces = $(.99)^{20}$ = .82

Absorption at 1.3% per inch in 6" BSC glass (condensers) = .925

Absorption at 5% per inch in 10.5" soda lime glass = .56

Total 42%

72" Data from Norgren

Reflection 14 glass or plastic to air = $(.96)^{14}$ = .56

" 4 " " " " hydrogen = $(.975)^4$ = .90

" 2 aluminized reflectors = $(.90)^2$ = .81

Absorption 17 3/4" BSC or plastic at 1.3% = .79

" 2 1/4" Soda Lime at 5% = .89

Comparison Formula

As in Ref. 1 we regard ϵ and G(θ) as constant for the three chambers. Then we have:

$$I \propto \left(\frac{M+1}{M}\right)^2 N^2 \frac{1}{S}$$

where S is a measure of relative film speed.

This gives for $\frac{I_{80}}{I_{20}} = 1.08$

and for $\frac{I_{80}}{I_{72}} = 1.64S = 1.64 \times 1.5 = 2.46$

Comparison with 20" Chamber

The fundamental piece of information is a measurement of intensity in a mock-up of the flash-tube, condensing lenses, and diffusing screen. The measurement gave 36 lumen sec | ft^2. Making the appropriate corrections for losses and the effect of the filter not present in the measurements gives for the intensity in the lossless 20" chamber

$$L_{20} = 4 \text{ lumen sec} \mid \text{foot}^2$$

This predicts for the 80" chamber (x 1.08)

$$L_{80} = 4.3 \text{ lumen sec} \mid \text{foot}^2$$

Comparison with 72" Chamber

The information is less direct. The flash tube brightness has been discussed above. We estimated 100 lumen sec | cm^2 steradian. The aperture size based on flash tube area 4mm x 0.6" and a magnification of $(5.5)^2$ is 18.5 cm^2. On the other hand, the physical size of the aperture is 1 1/6" x 3 1/2" = 27 cm^2. According to Norgren, allowance was made in the aperture for aberrations in the condensers. We will use the figure of 18.5 cm^2. The source to chamber distance is about 81". Therefore, the illumination in the 72" chamber we estimate

$$18.5 \times 100 \times \frac{144}{81^2} = 41 \text{ lumen sec} \mid \text{foot}^2$$

Correcting for the estimated 29% transmission, the illumination for a lossless 72" chamber is 11.9 lumen sec | $foot^2$. This predicts for the 80" chamber

$$11.9 \times 1.64 \times 1.5$$

1.64 is the optical factor and 1.5 takes care of the smaller film speed of linagraph ortho. We get

$$L_{80} = 29 \text{ lumen sec} \mid \text{foot}^2$$

SUMMARY AND DISCUSSION

We have calculated an aperture size of 145 cm^2 based on a conservative flash-tube brightness, a realistic estimate of the losses in the 80" chamber and the requirement that we have an intensity in the 80" chamber of 23.4 lumen sec per ft^2.

The estimates of this intensity are as follows:

(1) Absolute Estimates

$$L_{80} = 5.8 \text{ Lumen sec} \,|\, \text{foot}^2 \qquad \epsilon = 1$$

$$= 23.4 \text{ " " "} \qquad \epsilon = .5$$

(2) 20" Comparison

$$L_{80} = 4.3 \text{ Lumen sec} \,|\, \text{foot}^2$$

(3)72" Comparison

$$L_{80} = 29 \text{ lumen sec} \,|\, \text{foot}^2$$

If all the factors have been properly taken into account, one would tend to weigh the 20" data more than the 72" since the measurements are relatively straight-forward and it is hard to see how the estimate can be wrong by more than about 25%. On the other hand, however, the optical systems of the 72" and 80" are more nearly the same. Almost certainly part of the discrepancy between the 72" and 20" estimates can be traced to a preference for denser bubble images in the Berkeley chamber. In addition the Berkeley flash-tube output has, if anything, been overestimated. Taking everything into account, we feel that the design figure based on the value 23.4 lumen sec $|$ foot^2 which involves something less than direct scaling from the 72" chamber, is adequate.