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FRANK J. SEILER RESEARCH LABORATORY

FJSRL TECHNICAL REPORT - 76-0012

AUGUST 1976

OPTIMUM DESIGN OF AN INTENSITY LIMITED PINHOLE-SCINTILLATOR, IMAGE CONVERTOR CAMERA MODEL FOR SIMULTANEOUS ENERGY, SPATIAL, AND TIME RESOLUTION OF SOFT X-RAYS

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This report describes the optimum design of a generalized pinhole-scintillator, image converter camera model offering simultaneous energy, spatial, and time resolution of soft x-rays. This type of diagnostic system is particularly suited to analysis of x-rays from intense plasma discharge sources such as plasma focus and electromagnetic implosion devices having emitting dimensions in the mm to cm range and pulse lengths of 10 - 1000 nsec. The usual diffraction limited, optimum pinhole design for spatial resolution

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is not used since sufficient x-ray intensities are often not available from laboratory plasmas to take advantage of optimum pinhole resolution. Instead, the condition for obtaining optimum spatial resolution for the intensity limited case for given time and energy resolution requirements are derived. The controlling requirement of film exposure is satisfied. Graphical solutions of optimum pinhole-to-scintillator distance, optimum pinhole diameter, and spatial resolution at optimum conditions are presented as a function of a dimensionless exposure parameter (β) for several values of plasma-to-pinhole distance. This form of solution presentation allows rapid analysis of the effects of equipment changes and different degrees of time and energy resolution upon optimum spatial resolution.

BETA

FJSRL-TR-76-0012

OPTIMUM DESIGN OF AN INTENSITY LIMITED PINHOLE-SCINTILLATOR, IMAGE CONVERTER CAMERA MODEL FOR SIMULTANEOUS ENERGY, SPATIAL, AND TIME RESOLUTION OF SOFT X-RAYS

Robert A. Nuttelman

TECHNICAL REPORT FJSRL-TR-76-0012

AUGUST 1976

DIRECTOR OF CHEMICAL SCIENCES
FRANK J. SEILER RESEARCH LABORATORY
AIR FORCE SYSTEMS COMMAND
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FOREWARD

The work described in this report was sponsored by the X-Ray Simulations Branch, Air Force Weapons Laboratory (AFWL/DYS), Kirtland Air Force Base, New Mexico, under Project Order No. AFWL 76-099. The work was performed at the Department of Physics, United States Air Force Academy, Colorado. Fiscal administration was provided by the Directorate of Chemical Science, Frank J. Seiler Research Laboratory, United States Air Force Academy, Colorado under work unit WU #7903-03-81, "X-Ray Diagnostics for the AFWL SHIVA Simulator".

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This technical report has been reviewed and approved.

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SECTION I

INTRODUCTION

X-ray pinhole cameras are commonly used to provide spatial resolution of soft x-ray sources such as plasma focus and electromagnetic implosion devices having emitting dimensions in the cm to mm range and pulse lengths of 10-1000 nsec. Time resolution may additionally be obtained by imaging the x-ray source with a pinhole optic onto a scintillator viewed by a high speed IC (image converter) streak or framing camera. Energy resolution can be added by filtering techniques discussed later. Thus, methods are available to simultaneously obtain spatial, time, and energy resolution of soft x-ray sources (ref. 1).

The design of pinhole optics to maximize spatial resolution is well known (ref. 1) and will be discussed later. This design assumes that sufficient x-ray intensity is available to expose the camera film. However, as additional simultaneous information is desired from the diagnostics, such as time and energy resolution, camera film exposure is greatly reduced and may be insufficient if the "optimum" pinhole diameter is used.

This report addresses the problem of system design of the pinhole-scintillator, IC camera to achieve maximum possible spatial resolution while satisfying film exposure and energy and time resolution requirements. The effects on spatial resolution of geometric and physical optics and IC camera resolution are treated.

SECTION II

BRIEF DESCRIPTION OF THE PINHOLE-SCINTILLATOR, IC CAMERA

An x-ray pinhole-scintillator, IC camera may be represented by the simplified model shown in Figure 1. The functions of the components will be described later in detail. An image of the x-ray source is formed in the scintillator by the pinhole. The material in which the pinhole is formed must be thick enough to block high energy x-rays from the source. A large pinhole thickness, however, may allow image degradation by grazing incidence reflection of x-rays. The filter covering the scintillator serves as a high pass filter to pass x-rays of energies above a few hundred electron volts and thus blocks visible and ultraviolet wavelengths. The scintillator produces a visible wavelength image which may then be analyzed with the IC camera.

The IC camera objective lens shown in Figure 1 transfers the visible image in the scintillator to the camera photocathode. An electron beam image is formed, intensified, and swept along the camera phosphor plate by deflection electrodes. The phosphor plate produces a visible light image from the electron beam incident upon it. Relay optics transfer the visible light image on the phosphor plate to the film. The film may then be processed to obtain a record of x-ray intensity variation in the image as a function of time.

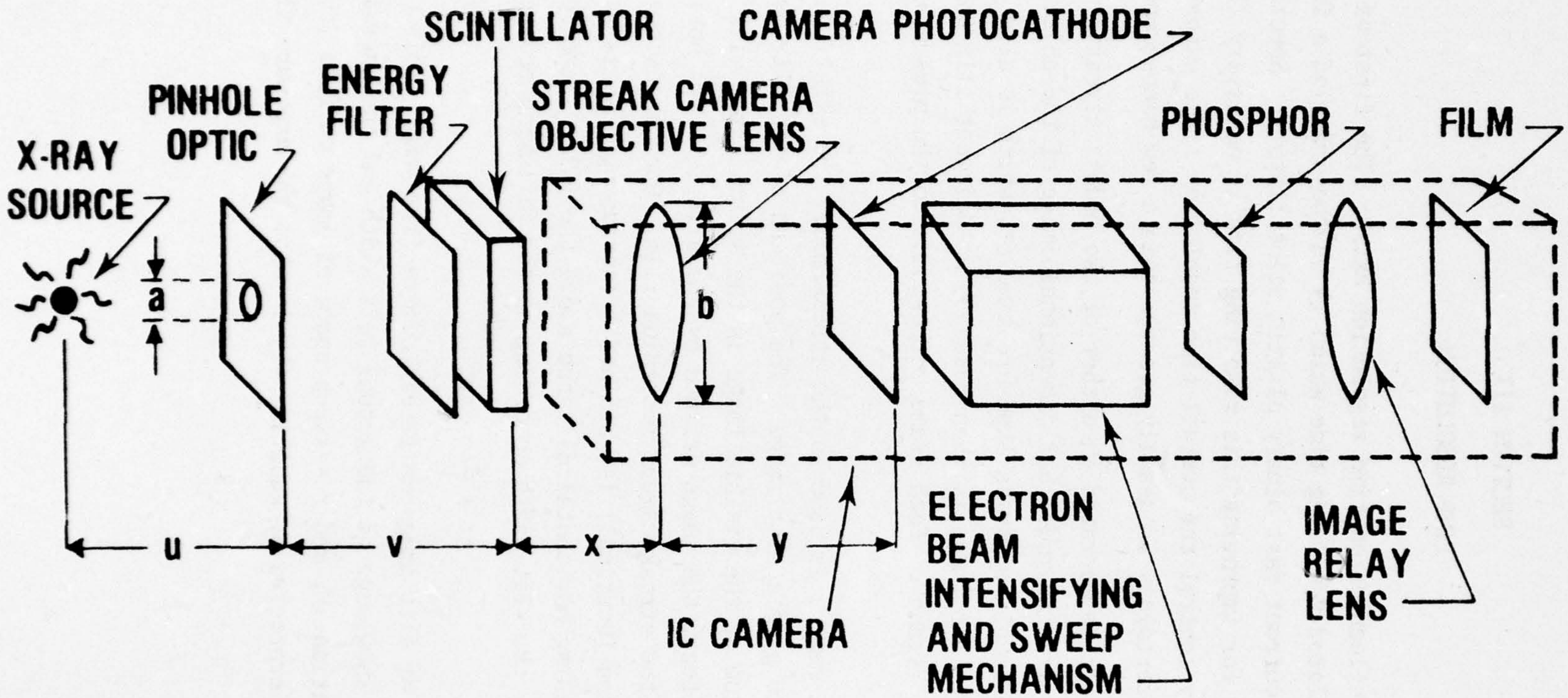

FIGURE 1. SCHEMATIC DIAGRAM OF AN X-RAY PINHOLE-SCINTILLATOR, IC CAMERA.

SECTION III

TIME RESOLUTION

Two major influences on time resolution exist. The first of these is scintillator resolving time which is on the order of a few nanoseconds for current fast binary plastic scintillators. Special techniques exist for improving this resolving time if necessary (ref. 2). The IC camera may control the overall time resolution since exposure time and thus time uncertainty is usually greater than a few nanoseconds.

The camera can be operated in either of two modes, streak or framing. In the framing mode, a 2-dimensional image of the object appears on the film plane for an exposure time Δt, which is also the time uncertainty. The image is then moved to an adjacent film position for another "frame". Each frame corresponds to the plasma at a particular time.

When the IC camera is used in the streak mode, the scintillator must be masked to give a slit image. The position of the slit determines what portion of the visible image in the scintillator will be analyzed. In effect, the image defined by the slit is swept horizontally across the streak camera recording film. One dimensional spatial resolution (vertical) is obtained. Increasing time is represented by increasing horizontal distance along the film. Time resolution is determined by the slit width according to the following equation:

$$\Delta t = \frac{s}{r} \quad \text{(sec)} \qquad (1)$$

where s = width of slit image on streak camera film (cm). This may be obtained from a knowledge of the actual slit width and the overall camera magnification, M, and r = sweep speed of image on film (cm/sec). The value of Δt expressed by equation (1) is also the exposure time of the film.

SECTION IV

ENERGY RESOLUTION

Several techniques have been developed to give energy resolution of soft x-rays. Spectrographic techniques give excellent resolution but are not compatible with simultaneous spatial and time resolution methods. Several filter techniques are compatible with our diagnostic requirements. In the present application, these filter techniques are used with a scintillator detector. The filter techniques are thick K-edge, differential absorber or Ross filter (ref. 1), and Bernstein bandpass filter (ref. 3). The thick K-edge absorber technique is most useful when the power spectrum being measured is known to drop rapidly with increasing energy. This method is of limited usefulness where line radiation is known to be present.

The Ross filter technique uses two identical detectors covered by two x-ray absorbing foils matched in transmission except in the energy region between their K-edges. The difference in response between the two detectors is proportional to the source energy in the region between the K-edges. Ross filters have been constructed for the energy range between 4.5 and 116 keV. The filters become difficult to fabricate in the region below 4.5 keV. In addition, photon efficiency is low with this technique.

The Bernstein bandpass filter technique has advantages for intensity limited diagnostics where a knowledge of the spectrum is not assumed. This technique will be used in this report. Matched K-edge filters and thin layers of plastic scintillators have been constructed for the energy range of interest, 1-5 keV (ref. 3). The filter limits the low x-ray energy transmission, and the thin scintillator response drops off rapidly for high energies. The band-pass detectors provide more spectral information than is possible with simple absorber techniques, yet have high sensitivity.

The unfolding techniques used to obtain spectral composition information are contained in the source documents cited previously. These techniques have been fully developed and will not be addressed further in this paper.

SECTION V

SPATIAL RESOLUTION

Presently, two x-ray imaging techniques exist which are capable of spatial resolution of soft x-ray sources. The simplest is the pinhole optic, a small aperture in a material opaque to the incident x-ray spectrum. The pinhole is energy independent up to the energy at which significant transmission occurs through the pinhole material. It is limited in resolution by two effects: geometric optics, which increases image uncertainty proportional to a, the pinhole diameter, and the diffraction effect, which increases image uncertainty inversely proportional to a. There is thus an optimum pinhole diameter a_{opt} which minimizes image uncertainty (ref 1):

$$a_{opt} = 2\sqrt{\frac{0.9\ \lambda\ v}{1 + M_p}} \quad \text{(cm)} \tag{2}$$

where λ = wavelength of x-rays (cm),
v = pinhole-to-image distance (cm),
M_p = v/u = pinhole magnification,
and u = *object-to-pinhole distance (cm).*

The optimum pinhole diameter obtained by equation (2) is often not realized in practice. As the pinhole diameter decreases to a_{opt}, the x-ray source intensity decreases, and the x-ray detector may receive insufficient energy for measurement. The pinhole diameter may be increased to allow greater camera sensitivity with the consequent loss of resolution.

The x-ray microscope offers better resolution than the pinhole with the disadvantage of much more complexity (ref. 4). Multiple grazing incidence optics are used to form images of the source. In some cases, the x-ray microscope may have insufficient sensitivity to realize its potentially superior resolution.

The diagnostic system modeled in this report uses a pinhole optic since it offers simplicity and sensitivity. For many applications, its resolution is more than adequate.

SECTION VI

SPATIAL RESOLUTION OF AN INTENSITY LIMITED, PINHOLE-SCINTILLATOR, IC CAMERA

The spatial resolution of a pinhole scintillator, IC camera may be expressed as σ, the position uncertainty in centimeters of the camera film image of a point (or zero width) element in the object (plasma). The parameter σ is given by

$$\sigma = \left\{ \rho^2 + \underline{a}^2 \left(1 + \frac{v}{u}\right)^2 M_\ell^2 M_c^2 + \frac{(2.44)^2\ \lambda^2 v^2 M_\ell^2 M_c^2}{\underline{a}^2} \right\}^{1/2} \quad \text{(cm)} \qquad (3)$$

where ρ = IC camera image uncertainty (cm),

$\underline{a}$ = pinhole diameter (cm),

$M_\ell = \frac{y}{x} = \frac{D_{pc}}{D_s}$ = IC camera objective lens magnification,

y = objective lens-to-photocathode distance (cm),

x = scintillator-to-objective lens distance (cm),

D_{pc} = dimension of plasma image on IC camera photocathode (cm),

D_s = dimension of plasma image on scintillator (cm),

$M_c = \frac{D_f}{D_{pc}}$ = IC camera photocathode-to-film magnification,

and D_f = dimension of plasma image on IC camera film (cm).

The image dimensions given in equation (3) and following equations are the lengths of the smallest image dimensions if the IC camera is used in the framing mode. If the camera is used in the streak mode, image dimensions should be those orthogonal to the streak direction. The IC camera image undertainty ρ is simply the inverse of the camera resolution in lines per centimeter. The second and third terms on the right hand side of equation (3) are the squares of the geometric image uncertainty and diffraction image uncertainty, respectively.

Equation (3) may be simplified by neglecting the diffraction term. This simplification is valid for intensity limited pinhole cameras where the pinhole diameter is considerably larger than that predicted by equation (2).

A more useful form of equation (3) results from considering the fractional uncertainty R in the image size on the film:

$$R = \frac{\sigma}{D_f} = \frac{\sigma}{D_o M_p M_\ell M_c} \tag{4}$$

where D_o = characteristic dimension of object (plasma) in centimeters. From equations (3) and (4) and ignoring diffraction effects, one obtains

$$R = \frac{u}{D_o} \left\{ \frac{\rho^2 x^2}{v^2 y^2 M_c^2} + \frac{a^2 \left(1 + \frac{v}{u}\right)^2}{v^2} \right\}^{1/2} . \tag{5}$$

The relationship between x and y is given by

$$\frac{1}{x} + \frac{1}{y} = \frac{1}{f} \tag{6}$$

where f = focal length of IC camera objective lens (cm). Equation (6) may be substituted into equation (5) to yield

$$R = \frac{u}{D_o} \left\{ \left[\frac{\rho f}{v M_c (y - f)} \right]^2 + \left[\frac{a}{v} \left(1 + \frac{v}{u}\right) \right]^2 \right\}^{1/2} . \tag{7}$$

Simplification of equation (7) may be obtained by considering the film exposure E for the generalized pinhole-scintillator, IC camera model shown in Figure 1:

$$E = \frac{\underline{a}^2 b^2 \eta G}{256\, A_o v^2 y^2 M_c^2} \left(\frac{\Delta t}{\tau}\right) \int_0^\infty S_o(h\nu) T(h\nu) A(h\nu) d(h\nu) \quad (\text{ergs/cm}^2) \tag{8}$$

where $\underline{a}$ = pinhole diameter (cm),

b = IC camera objective lens diameter (cm),

η = energy conversion efficiency of scintillator $\left(\frac{\text{ergs light}}{\text{ergs x-rays}}\right)$,

G = optical energy gain of IC camera $\left(\frac{\text{ergs on film}}{\text{ergs on objective lens}}\right)$,

Δt = film exposure time (sec),

A_o = source area as viewed from scintillator (cm^2),

v = pinhole-to-scintillator distance (cm),

y = camera objective lens-to-photocathode distance (cm),

M_c = IC camera magnification,

τ = effective source radiation time (sec),

$S_o(h\nu)$ = energy dependent x-ray source function (ergs/eV),

$T(h\nu) = \exp\left[-\mu_f(h\nu)x_f\right]$

= fractional transmission of energy resolution filter at energy $h\nu$,

μ_f = energy dependent x-ray photoelectric absorption coefficient for filter material (cm^{-1}),

x_f = filter thickness (cm),

$A(h\nu) = 1 - \exp\left[-\mu_s(h\nu)\,x_s\right]$

= fraction of incident x-rays of energy $h\nu$ absorbed in scintillator,

$\mu_s(h\nu)$ = energy dependent x-ray photoelectric absorption coefficient for scintillator material (cm^{-1}),

and x_s = scintillator thickness (cm).

Several assumptions are implicit in the derivation of equation (8):

(1) Both the x-ray source and the scintillator radiate isotropically.

(2) $a \ll u$.

(3) $b \ll x$.

(4) G factor accounts for wavelength overlap of scintillator output spectrum and IC camera photocathode sensitivity.

(5) G factor accounts for wavelength overlap of streak camera phosphor spectrum and film sensitivity.

(6) η is not dependent on x-ray energy.

(7) Source x-ray power remains constant over pulse length of τ seconds.

Equations (7) and (8) may now be examined together to determine parameter values to obtain desired fractional image uncertainty R and film exposure E. The parameters u, ρ, and f should be kept as small as possible to minimize R. These three parameters have no effect upon E. The parameter a should be as small as possible to minimize R, but it should be as large as possible to maximize E. The parameters v, M_c, and y should be as large as possible to minimize R, but they should be as small as possible to maximize E.

Obviously, methods are required to determine the proper trade-off between E and R for the parameters a, v, M_c, and y. Generally, M_c is fixed for any particular IC camera. R has a 1/(y-f) dependence, thus y should be made as much larger than f as possible (close focusing) for small R. This choice of y_{max} will have a minimum detrimental effect on E since y is usually variable over a very small range in any given IC camera.

The best choice of parameters a and v can be obtained by the following procedure. If E in equation (8) is set equal to the minimum exposure E_m which will adequately expose the film, one may obtain a in terms of v:

$$\underline{a} = \frac{v}{\beta} \tag{9}$$

where

$$\beta = \frac{b}{16 y_{max} M_c} \left\{ \frac{\eta G \left(\frac{\Delta t}{\tau}\right) \int_0^\infty S_o(h\nu) T(h\nu) A(h\nu) d(h\nu)}{E_m A_o} \right\}^{1/2} . \tag{10}$$

The parameter β may be considered a dimensionless film exposure parameter. Substitution of equation (9) into equation (7) results in

$$R = \frac{u}{D_o} \left\{ \left[\frac{\rho f}{v M_c (y_{max} - f)} \right]^2 + \left[\frac{1 + \frac{v}{u}}{\beta} \right]^2 \right\}^{1/2} . \tag{11}$$

The optimum choice of v, v_{opt}, to minimize R is obtained by setting $\frac{\partial R^2}{\partial v} = 0$ and solving for v. This requires solving the equation

$$v_{opt}^4 + uv_{opt}^3 - u^2\phi = 0 \tag{12}$$

where

$$\phi = \left[\frac{\beta\rho f}{M_c(y_{max} - f)}\right]^2 . \tag{13}$$

The expression for R simplifies to final form using equation (13):

$$R = \frac{u}{\beta D_o}\left\{\frac{\phi}{v^2} + (1 + \frac{v}{u})^2\right\}^{1/2} . \tag{14}$$

Equation (12) for v_{opt} may be solved readily with fourth degree solving routines commonly available on desktop calculators (ref. 5). Solution curves of v_{opt} as a function of ϕ for three different choices of u are given in Figure 2. A typical range of ϕ is used.

Figure 2 may be used to obtain v_{opt} for any pinhole-scintillator, IC camera diagnostic system and x-ray source whose physical parameters are described by u and ϕ. The value v_{opt} may then be used with the system β in both equation (14) to obtain the fractional spatial uncertainty R and in equation (9) to obtain a, the pinhole diameter.

Using the method just outlined, it is possible to operate the camera system to obtain maximum resolution compatible with film exposure requirements. The procedure may be used to determine the effect on film exposure [equation (8)] and image uncertainty by changes in the diagnostic system.

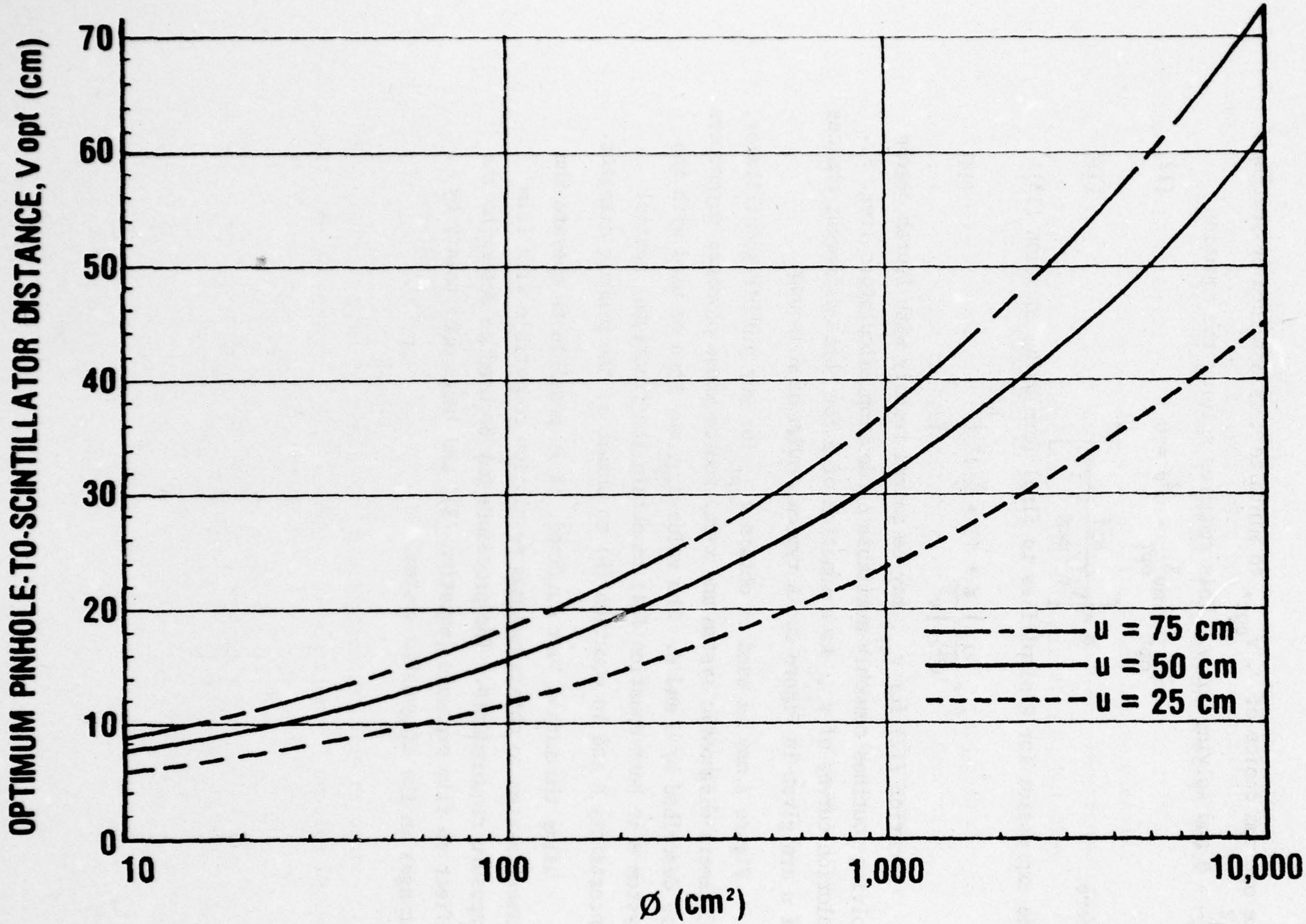

FIGURE 2. OPTIMUM PINHOLE-TO-SCINTILLATOR DISTANCE AS A FUNCTION OF Ø.

SECTION VII

APPLICATION OF THE GENERAL SOLUTION METHOD TO A PARTICULAR DIAGNOSTIC PROBLEM

The general solution method described in the previous section for obtaining v_{opt}, R, and a can be applied to an example diagnostic problem. A soft x-ray source will be assumed where $A_o = 8\ cm^2$ and $D_o = 4$ cm. The desired resolution characteristics assumed are given in Table 1:

Table 1.

DESIRED RESOLUTION CHARACTERISTICS OF THE X-RAY SOURCE

Characteristic	Desired Resolution
Time (Δt)	$\frac{\Delta t}{\tau} = 0.1$
Spatial (R)	<0.1
Energy	maximum possible

Table 2 contains diagnostic system parameters assumed for the analysis.

Table 2.

ASSUMED DIAGNOSTIC SYSTEM PARAMETERS

Parameter	Value
ρ	0.01 cm
f	12.7 cm
M_c	0.70
y_{max}	21.8 cm
b	6.35 cm
E_m	0.01 ergs/cm^2
η	0.02
G	50.

These parameters are representative of the TRW image convertor camera, Model 1D, which has both streak and framing modes of operation. The value of E_m is appropriate for a high speed panchromatic film (ref. 6). The scintillator conversion efficiency η is applicable to NE 111 which has excellent time resolution characteristics - less than 2 nsec (ref. 7).

Using the data from Table 2 and equation (13),

$$\beta = 50.\ \sqrt{\phi}\ . \tag{15}$$

The v_{opt} as a function of β may be obtained from Figure 2 and equation (15) as shown in Figure 3. Three curves are given for three possible values of u. As described in the preceding section, optimum pinhole diameter <u>a</u> (Fig. 4) and fractional image uncertainty R (Fig. 5) are obtained as a function of β for three values of u.

Figures 3 - 5 allow several qualitative interpretations:

(1) Optimum pinhole-to-scintillator distance increases as β and u increase.

(2) Optimum pinhole diameter decreases as β increases and u decreases.

(3) Fractional image uncertainty decreases as β increases and u decreases.

The exact solution to this example diagnostic problem may be found when the value of the following integral is known for use in equation (10):

$$\int_0^{\infty} S_0(h\nu)T(h\nu)A(h\nu)d(h\nu)\ .$$

The values of the parameters T and A depend on the energy filtering used. As an upper limit, T and A may be set equal to 1.0. A representative value for $\int_0^{\infty} S_0(h\nu)d(h\nu)$ is 10^8 ergs. Then, using

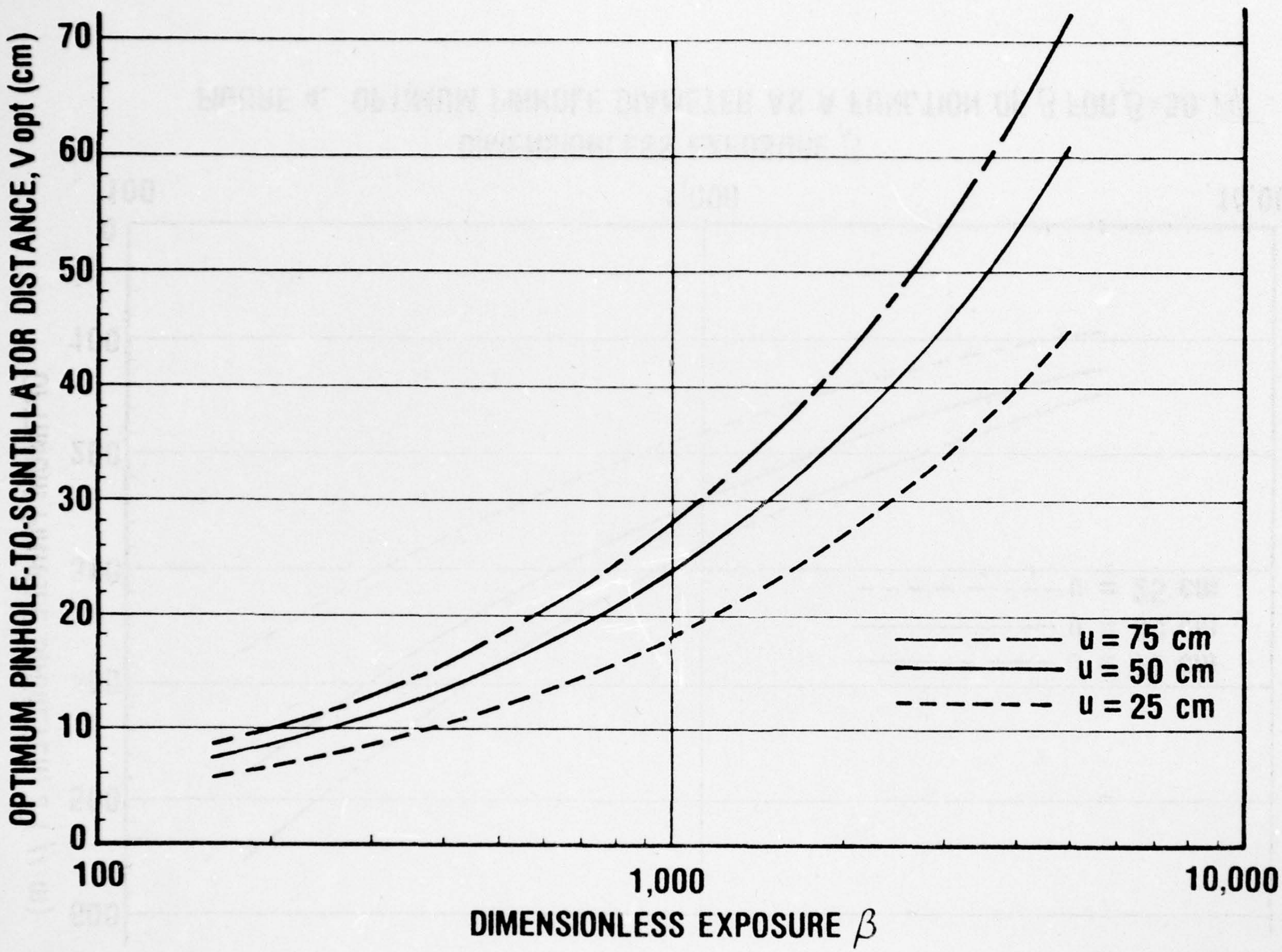

FIGURE 3. OPTIMUM PINHOLE-TO-SCINTILLATOR DISTANCE AS A FUNCTION OF β FOR β=50.$\sqrt{\varphi}$.

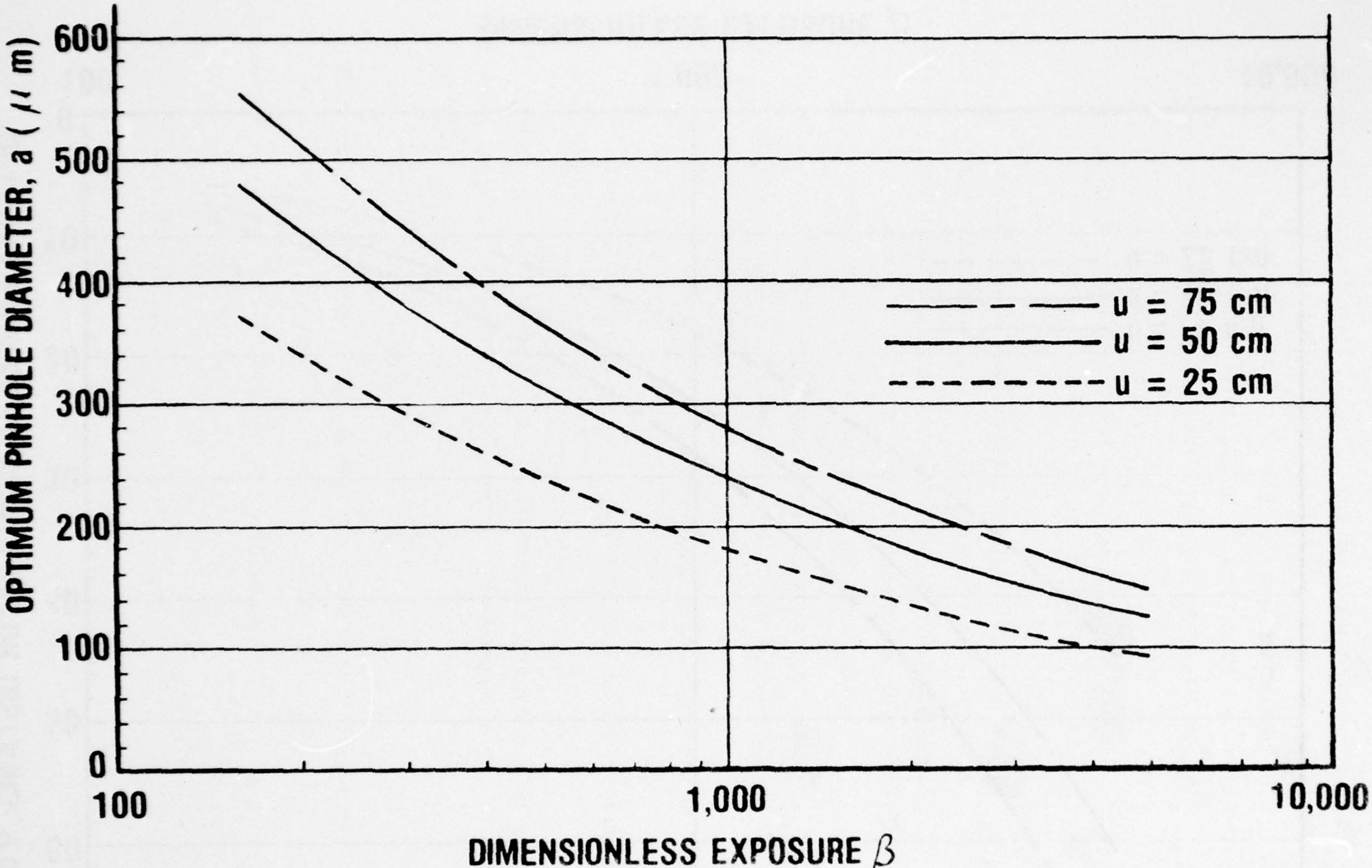

FIGURE 4. OPTIMUM PINHOLE DIAMETER AS A FUNCTION OF β FOR $\beta = 50.\sqrt{\varphi}$.

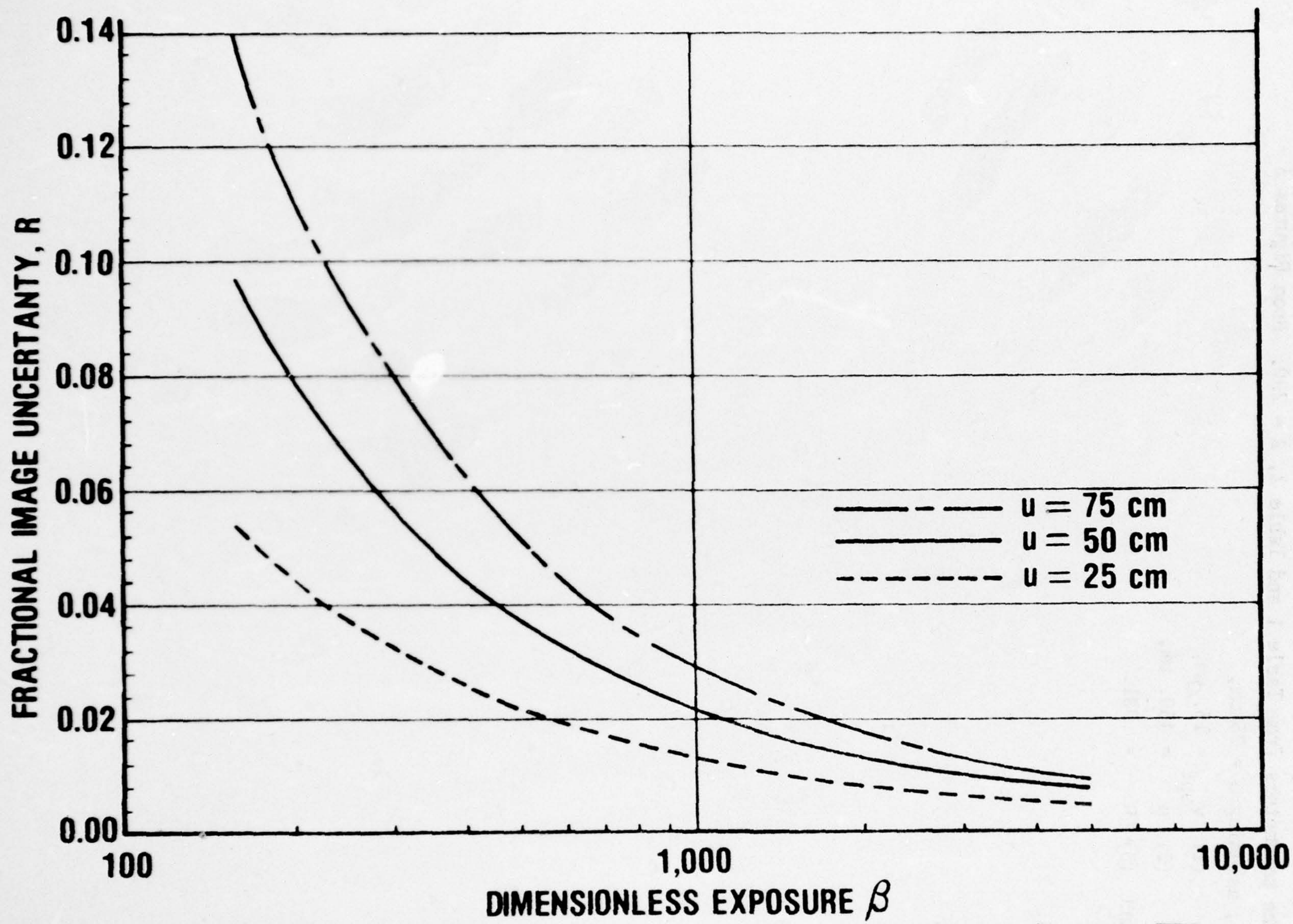

FIGURE 5. FRACTIONAL IMAGE UNCERTAINTY AS A FUNCTION OF β FOR $\beta = 50.\sqrt{\varphi}$.

the parameters from Table 1 and Table 2, $\beta = 290$. From Figures 3 - 5, assuming $u = 75$ cm,

(1) v_{opt} = 13. cm,

(2) $\underline{a}$ = 450. μm,

and (3) R = .081.

SECTION VIII
DISCUSSION

The time and spatial resolution requirements of the preceding example are satisfied for the case of no intentional energy filtering (A, T = 1). Spatial resolution for this case is slightly better than that required. One may trade excess spatial resolution (low R values) for increased energy resolution. For example, a bandpass energy filter may be constructed using the method referred to earlier in this report. A and T values are calculated and used with an estimate of $S_o(h\nu)$ in the filter energy window to calculate a new dimensionless exposure β. The required estimate of $S_o(h\nu)$ may be obtained from a time and spatially integrating x-ray detector analyzing x-rays from an experiment identical to the one of interest. Energy filtering of this detector may be used to obtain the desired $S_o(h\nu)$.

The sensitivities of v_{opt}, $\underline{a}$, and R to changes in β are not large. This finding minimizes the practical effect of uncertainties in the values of $S_o(h\nu)$ assumed and in other parameters included in β.

Figure 5 is used to find the new fractional spatial uncertainty. If this value of R meets the spatial resolution requirements, new values of v_{opt} and $\underline{a}$ are obtained from Figures 3 and 4 using the new β. Thus we have designed a pinhole camera for the energy filter assumed.

Other bandpass energy filters and scintillators may be designed and corresponding pinhole camera parameters obtained by the process just outlined. Several scintillators with different thicknesses and bandpass energy filters may be viewed simultaneously by the IC camera to obtain spatial and time resolution data simultaneously in several energy bands.

Although the Bernstein filter energy resolution technique was assumed to be most appropriate for this report, the optimization for spatial resolution is valid for other energy filter techniques. It is only necessary to use the values of A and T appropriate for the technique being used.

The techniques described in this report are applicable to other types of high speed camera than the IC camera, such as those employing Kerr cell shutters.

REFERENCES

1. Violet, C.E., "Instrumentation for X-Ray Diagnostics of Plasmas", Advances in X-Ray Analysis, Vol. 18, p. 26, Plenum Press, 1975.

2. Nuttelman, R.A., et al., "Subnanosecond X-Ray Measurements Using a Unitary Organic Crystal and Image Converter Streak Camera", Advances in X-Ray Analysis, Vol. 18, p. 197, Plenum Press, 1975.

3. Bernstein, M.J., "Simple X-Ray Bandpass Filters for Nanosecond Resolution of Plasma Spectra", Rev. Sci. Instr., Vol. 43, No. 9, p. 1323, 1972.

4. Seward, F.D. and Palmieri, T.M., "A Simple X-Ray Microscope for Photographing Laser Produced Plasmas", Report UCRL-75799, Lawrence Livermore Laboratory, 1974.

5. "Fourth or Fifth Degree Polynomial Roots", Program Library for Model 9100A Calculator, Hewlett-Packard, 1968.

6. Altman, J.H., Grum, F., and Nelson, C.N., "Photographic Speeds Based on Radiant Energy Units", Photographic Science and Engineering, Vol. 17, No. 6, p. 513, 1973.

7. Birks, J.B. and Pringle, R.W., "Organic Scintillators with Improved Timing Characteristics", Proc. R.S.E. (A), Vol. 70, No. 22, 1971/72.