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TITLE: RADIOGRAPHIC DETECTION OF 100Å THICKNESS VARIATIONS IN 1-μm-THICK COATINGS APPLIED TO SUBMILLIMETER-DIAMETER LASER FUSION TARGETS

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RADIOGRAPHIC DETECTION OF 100 Å THICKNESS VARIATIONS IN 1-μm-THICK COATINGS APPLIED TO SUBMILLIMETER-DIAMETER LASER FUSION TARGETS

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INTRODUCTION

We have developed x-ray radiography to measure thickness variations of coatings on laser fusion targets. Our technique is based on measuring the variation in x-ray transmission through the targets. The simplest targets are hollow glass microshells* or microballoons** 100 to 500 μm in diameter (Fig. 1), that have several layers of metals or plastics, 1 to 100 μm thick (Fig. 2). Our goal is to examine these opaque coatings for thickness variations as small as 1% or 0.1%, depending on the type of defect. Using contact radiography we have obtained the desired sensitivity for concentric and elliptical defects of 1%. This percentage corresponds to thickness variations as small as 100 Å in a 1-μm-thick coating. For warts and dimples, the desired sensitivity is a function of the area of the defect, and we are developing a system to detect 0.1% thickness variations that cover an area 10 μm by 10 μm.

We must use computer analysis of contact radiographs to measure 1% thickness variations in either concentricity or ellipticity. Because this analysis takes so long on our minicomputer, we preselect the radiographs by looking for defects at the 10% level on a video image analysis system.

Detection of 0.1% warts or dimples requires a signal-to-noise ratio of 700 to 1. This range exceeds the signal-to-noise ratio of photographic products, and we are therefore developing a point-projection radiography system that uses an x-ray-sensitive television camera. The video images from this system are digitized and summed in a computer until the desired signal-to-noise ratio is obtained. Point-projection radiography magnifies the x-ray image to match the spatial resolution of the camera. All of these techniques can be used on other objects with different sizes and shapes.

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* Microshell is a registered trademark of KMS Fusion, Inc., Ann Arbor, MI 48106

** Microballoon is a registered trademark of Emerson and Cuming, Inc., Canon, MA 02021. In this paper, microballoon and microshell are used interchangeably.

Laser fusion target designers have concluded that the thicknesses of the metal or plastic coatings on the microshells must be uniform to 1% for concentric and elliptical defects and 0.1% for warts and dimples (smoothness). In Fig. 3, a concentric defect in a coating is shown on the left. Here, the inner and outer surfaces of the coating are spherical but nonconcentric. If either or both surfaces of the coating are elliptical, as shown in the middle example, the defect is elliptical. The third type of defect is a wart or dimple in either surface, or a void in the interior of the coating, as shown in the right-hand example of Fig. 3. For the concentric and elliptical defects, the thickness variation must be no more than 1% in $\Delta t/t$, where Δt is the variation in the thickness and t is the average thickness. We detect 1% defects [1] that are as small as 100-Å thickness variations in 1-μm thick coatings. For warts, dimples, and voids, the uniformity requirement depends on the area covered by the defect: this thickness variation must be no more than 0.1% in $\Delta t/t$ for an area t by t. We are developing a system to detect these 0.1% defects in areas as small as 10 μm by 10 μm.

X-RAY TRANSMISSION ANALYSIS

All of our techniques are based on measuring x-ray transmission variations caused by coating thickness variations. In Fig. 4, a uniform beam of x rays is incident on the tops of two coated microshells. For simplicity, only the coatings are shown in the diagram. Below the coated microshells, the x-ray transmission is plotted. If the coating is uniform, as shown in the example on the left, the x-ray transmission will have an inverted cup shape [2] that is symmetric about the axis A-A. If the coating is not uniform, as shown on the right, the x-ray transmission is not symmetric about the axis B-B. X-ray transmission variations due to the substrate(s) are negligible if the x-ray attenuation in the substrate is negligible or if there are no thickness variations in the substrate. This method will also work for coatings on solid spheres when the x-ray attenuation in the sphere is negligible.

In contact radiography, photographic emulsion is the x-ray detector, and the variations in x-ray transmission appear as optical-density variations in the emulsion. Because the object is in direct contact with the emulsion, the x-ray image of the microballoon is the same size as the balloon. The emulsion can be replaced with various types of x-ray detectors for real-time applications.

With contact radiography, we realize 1% sensitivity to concentric and elliptical defects [3,4,5]. First, we use an image-analysis system to inspect a contact radiograph of the sample. If the sample has no defects that are 10% or larger in $\Delta t/t$, we then computer analyze it for 1% defects (Fig. 5).

PRESELECTION FOR 10% DEFECTS

On our microcomputer, analysis takes 30 to 40 minutes per image. Because we make three orthogonal views of each microballoon to characterize it completely, we require 1.5 to 2 hours for one target analysis at the 1% level. Furthermore, those targets that have more than one coating require a separate analysis before each coating is applied. Therefore, we have chosen the video image-analysis system to preselect the coated targets for 10% defects. The video analysis system is available commercially, and an operator can be trained in 1 or 2 hours. Preselection of each image takes 10 to 15 seconds. Our system has a microscope. The contact radiograph is viewed through the microscope, and the video signal is processed in real time in the analysis system, which displays the x-ray image in two ways.

In the first way, isometric displays of uniform coatings appear as symmetric cups similar to the x-ray transmission curve for uniform coatings. These displays plot the optical densities of the radiographs vertically. The upper left-hand graphic of Fig. 6 shows the isometric display of a coating that is uniform to less than 2% in $\Delta t/t$. The coating is symmetric about the axis a-a. The lower left-hand graphic shows the same type of plot for a coating that is 30% in $\Delta t/t$ and is not symmetric about the axis b-b. The isometric image can also be rotated and tilted, as shown in the right-hand portion of Fig.6. This manipulation occurs in real time without any discernible time lag because the image-analysis system is an analog device and does not do any digital processing. Warts and dimples appear as bumps and pits in the cups of these displays, but none are visible here.

The other kind of display is the false-color image, shown in Fig. 7, in which the optical densities on the radiograph have been arbitrarily divided into color bands. False-color displays, or "color slicing," of uniform coatings have color bands that are concentric and uniform. A false-color display of a uniform coating is shown on the left for a coating that is uniform to ± 7%. On the right, a coating with a 30% nonuniformity is shown. The noise in this analog system limits the detection of defects to those larger than 5 to 10% in $\Delta t/t$ for concentric and spherical defects. This limit is also determined by the exposure and the grain size of the photographic emulsion.

DIGITAL COMPUTER ANALYSIS FOR SMALLER DEFECTS

Computer processing is required for sensitivity to 1% defects because the image analyzer is, at best, sensitive to 5% defects. In digital computer processing a black and white densitometric television camera views the contact radiographs through an optical microscope as shown in Fig. 8, but instead of sending the signal to the analog image processor, we use a computer to digitize and store the image. A code, written by Whitman [6], analyzes the image and calculates the per cent defect due to nonconcentricity and ellipticity. It also finds warts and dimples, calculates their thicknesses and areas and prints out a map of their locations. The code was written for a Control Data Corporation 7600 computer and was modified by Thomas [1] to run on our Data General S/230 minicomputer. The complete analysis takes 30 to 40 minutes per view. Before processing the image, the operator uses the computer-controlled stage on the microscope to locate each radiographic image on the photographic emulsion. The computer remembers the location of each image and processes each automatically without further operator assistance.

The code is sensitive to all concentric and almost all elliptical defects that are 1% or larger in $\Delta t/t$. However, a few elliptical defects must be 2% or larger before the code will detect them. For a defect with a 10-μm lateral dimension (10-μm-by-10-μm area), the code will detect a 4% variation in wall thickness when the optical density is digitized in 1-μm-by-1-μm steps [3].

A POINT-PROJECTION SYSTEM TO DETECT 0.1% DEFECTS

Figure 9 shows the target designers' estimate for the size of warts and dimples that will disrupt the performance of the laser fusion target (shaded area) [7]. Each 10-μm-by-10-μm area on a 10-μm-thick coating must have a defect height less than 0.1% for the target to implode. For comparison, the best obtainable sensitivity with contact radiography for this coating thickness on a 200-μm-diameter microshell is shown in the upper right-hand corner in Fig. 9 by the diagonal-line shading. For a defect with lateral dimensions of 10 μm by 10 μm, the best obtainable sensitivity with contact radiography is 4%; however, the required sensitivity is 0.1%. Therefore, we must use another method that is 40 times more sensitive than contact radiography.

We are developing a point-projection radiography system, shown in Fig. 10, that uses a point source of x rays to illuminate a coated glass microshell. Most real-time x-ray imaging devices do not have the required spatial resolution. Therefore, a magnified x-ray shadow of the microballoon is cast onto the x-ray-sensitive camera so that a 10-μm-by-10-μm area on the microshell is enlarged to the size of the resolution element on the camera. This magnification by projection geometry is due to the small size of the source and the relative distances between the source, microballoon and detector.

Successive video frames from the camera are digitized and summed in the computer. We will use the wart and dimple detection routines to analyze the sample for these defects. However, because the signal-to-noise ratio for these images will be so much better than for the images made with film, the 0.1% defects will be found. All of the equipment for this point-projection system is available commercially. The best candidate for an x-ray sensitive camera is an x-ray image intensifier coupled to a regular video camera. However, if this system is too noisy, we will use a solid state sensor [8,9] with a laser scanner readout.

The performance of the proposed point-projection radiography system will meet target designers' requirements for smoothness for all coatings 10 μm thick or thicker. Figure 11 shows that the predicted sensitivity of the point-projection system (diagonal-line shading) will meet the target designer's estimates from Fig. 9 (shaded region) for 10-μm-thick coatings.

Target designers estimate that warts or dimples equal to or greater than 0.1% in Δt/t will degrade the performance of the implosion. This variation corresponds to a 100-Å thickness variation in a 10-μm-thick coating. The point-projection system will detect these defects in about 30 minutes for areas larger than 10 μm by 10 μm.

CONCLUSIONS

The measurement of thickness variations on laser fusion target coatings is sensitive to 1% variations caused by both nonconcentricity and ellipticity. These variations correspond to a 100-Å change in the thickness of a 1-μm-thick coating. While it is necessary to analyze contact radiographs with a computer program to obtain this sensitivity, using a video image-analysis system to presort the radiographs for 10% defects saves time by lowering the number of radiographic images that the computer analyzes. This technique is also sensitive to warts and wart and dimple detection, and we are designing a point-projection radiographic system with an x-ray-sensitive camera to meet these requirements. This system will detect a 100-Å thickness variation due to a wart or dimple in a 10-μm-thick coating. All of these techniques can be adapted to measure coating thickness uniformity on objects with different sizes and shapes.

REFERENCES

1. D. M. Stupin, K. R. Moore, G. D. Thomas, and R. L. Whitman, J. Vac. Sci. Technol. 20, 1071-1074 (1982).
2. T. M. Henderson, D. E. Cielaszyk, and R. J. Simms, Rev. Sci. Instrum. 48, 835-840 (1977).
3. R. L. Whitman and R. H. Day, Appl. Opt. 19, 1718-1722 (1980).
4. R. L. Whitman, R. H. Day, R. P. Kruger, and D. M. Stupin, Appl. Opt. 18, 1266-1274.
5. R. H. Day, T. L. Elsberry, R. P. Kruger, D. M. Stupin, R. L. Whitman, "X-Ray Microradiography of Laser Fusion Targets," in: "Eighth International Conference on X-Ray Optics and Microanalysis," Science Press, Princeton, NJ (1979), pp. 275-282.
6. R. L. Whitman, J. Vac. Sci. Technol. 20, 1359-1361 (1982).
7. B. W. Weinstein, J. Vac. Sci. Technol. 20, 1349-1354 (1982).
8. G. H. Stokes, D. M. Stupin, N. E. Elliott, and M. Graser, Jr., Rev. Sci. Instrum. 56, 2173-2175 (1985).
9. G. J. Berzins and M. Graser, Jr., App. Phys. Lett. 34, 500-503, (1979).

FIGURE CAPTIONS

Fig. 1. A human hair (a) threaded through the eye of a sewing needle supports a glass microshell (b). These hollow glass microballoons are coated with several layers of plastics or metals and are used as targets in laser fusion experiments.

Fig. 2. A simple target for laser fusion studies is a glass microballoon filled with a mixture of deuterium and tritium gases. In this example, the glass balloon is coated with 50 μm of plastic; however, this coating could be metallic. Typical thicknesses of the coatings range between 1 and 100 μm. More complex targets have additional coatings.

Fig. 3. Our goal is to measure three types of defects found in coatings applied to hollow microshells. For simplicity, only the coatings are shown in these examples. The inner and outer surfaces of the coating must be spherical and concentric with a thickness variation no more than 1% in $\Delta t/t$, where t is the average coating thickness and Δt is the variation in t. This corresponds to a 100-Å change in the thickness of a 1-μm-thick coating. For warts, dimples, and voids, the thickness variation must be no more than 0.1% if a defect covers an area of the thickness squared, t by t.

Fig. 4. Thickness variations in coatings cause variations in x-ray transmission through the microshell. In these two examples, a spatially uniform flux of x rays illuminates concentric (left) and nonconcentric (right) coatings, giving transmission curves that are respectively symmetric and asymmetric about the axes A-A and B-B. A wart (c) on the inner surface of the nonconcentric coating shows up as a blip (d) in the x-ray transmission curve.

Fig. 5. Contact microradiographs are examined for 10% defects before being processed by the computer for 1% defects. This preselection process takes 10 to 15 seconds per image and saves time by eliminating from computer analysis the samples with gross defects.

Fig. 6. Isometric displays from the video image analyzer plot the optical densities of the radiographs vertically, giving the cup shapes that are explained in Fig. 4. The upper left-hand graphic shows the isometric display of a coating that is uniform to less than 2% in $\Delta t/t$ and is symmetric about the axis a-a. The lower left-hand graphic shows the same type of plot for a coating that is 30% in $\Delta t/t$ and is asymmetric about the b-b axis. On the right, the image of the uniform coating has been tilted to show the isometric features of this display more completely.

Fig. 7. False-color displays from the image analyzer have concentric color rings for uniform coatings (left) and nonconcentric color rings for nonuniform coatings (right) that are shown here in black and white. These two examples have respective thickness variations of 7% and 30% in $\Delta t/t$.

Fig. 8. Computer processing is required to find the 1% defects. In this processing, the contact radiograph is viewed through a microscope by a black and white densitometric television camera, and the video image is digitized, stored in a computer, and processed.

Fig. 9. Target designers require 40 times more sensitivity to warts and

with defect heights and lateral dimensions shown in the region with the diagonal lines. This region is compared to the shaded region, which includes all the defects which, according to the target designers, will prevent the target from performing properly.

Fig. 10. The proposed point projection radiography system includes a small point x-ray source that casts an x-ray shadow onto an x-ray-sensitive television camera. This x-ray shadow is magnified by the geometry of the small source size and by the relative distances between the source, coated microballoon, and camera. In this way, the 10-μm-by-10-μm areas of the defects are enlarged to 100-μm-by-100-μm, the size of the resolution element of the camera. The resultant video images are digitized and summed in a computer. Then the summed image is processed to find the warts, dimples, and voids in the coating.

Fig. 11. The performance of the proposed point-projection radiography system will meet target designers' requirements for smoothness for all coatings that are 10 μm thick or thicker. It will be sensitive to defect heights of 0.1% in $\Delta t/t$ for all defects that are 10 μm by 10 μm or larger in area. This corresponds to a 100-Å defect height in a 10-μm-thick coating.

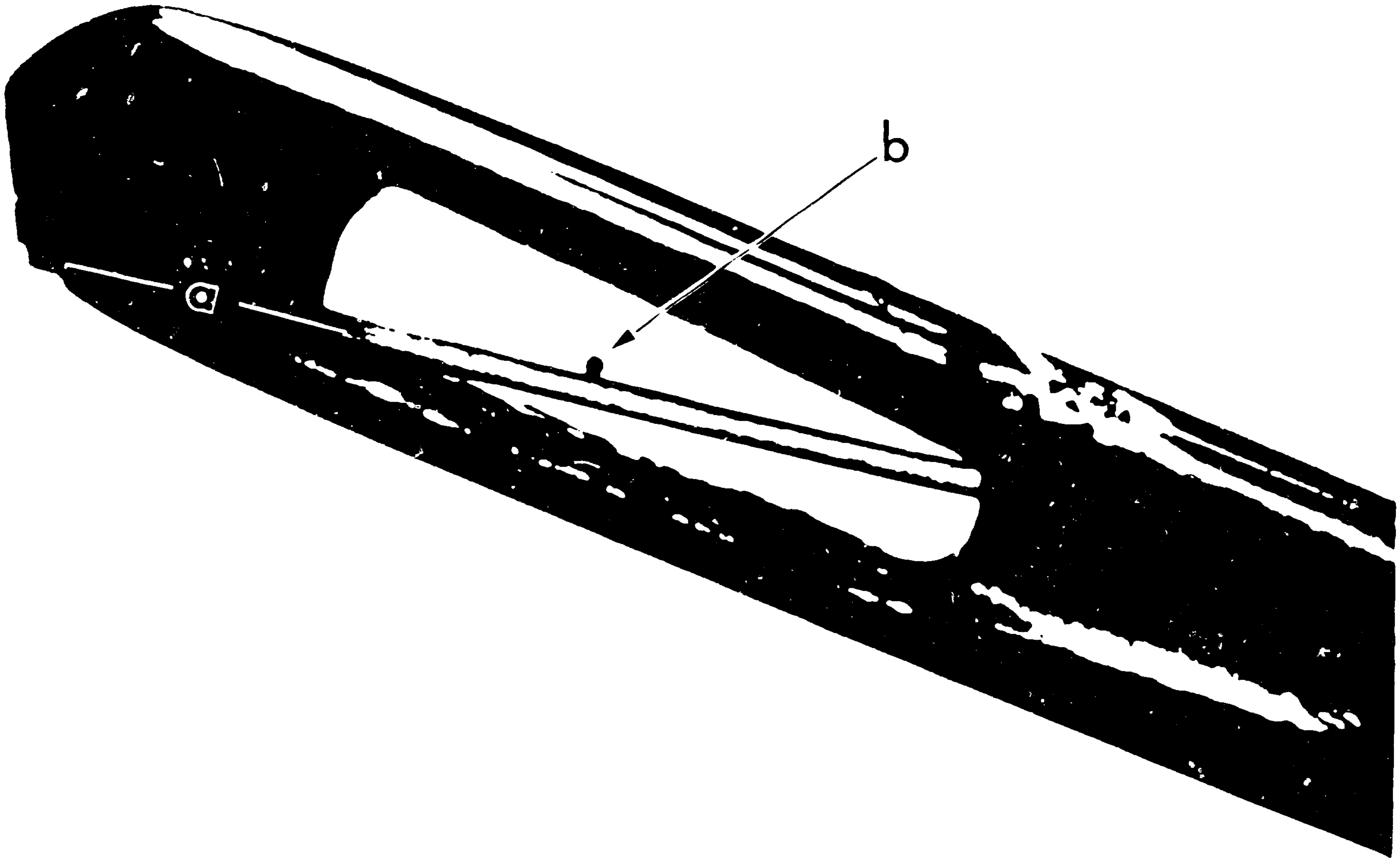
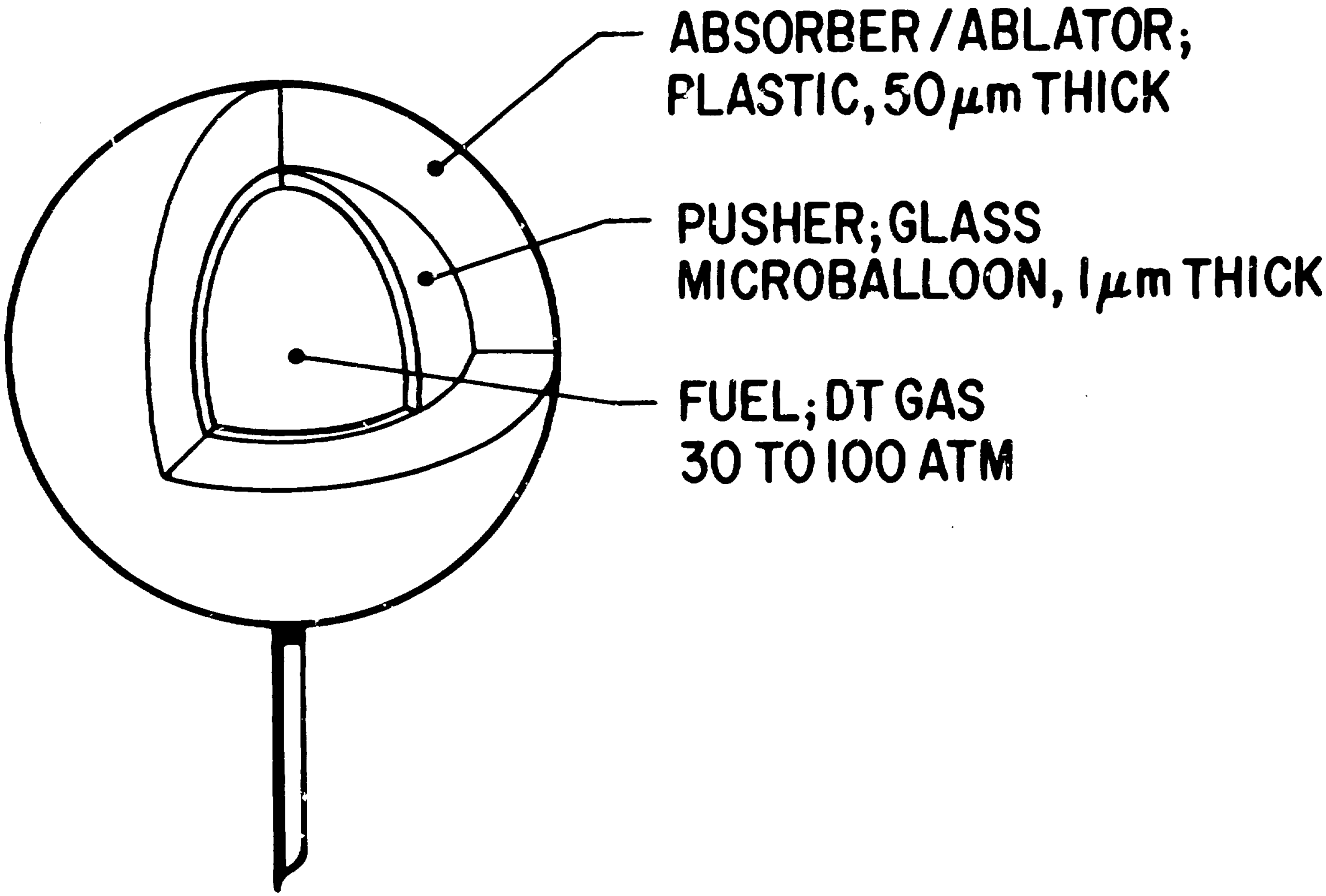


FIG 1



OVERALL DIAMETER ≃ 400 μm

FIG. 2

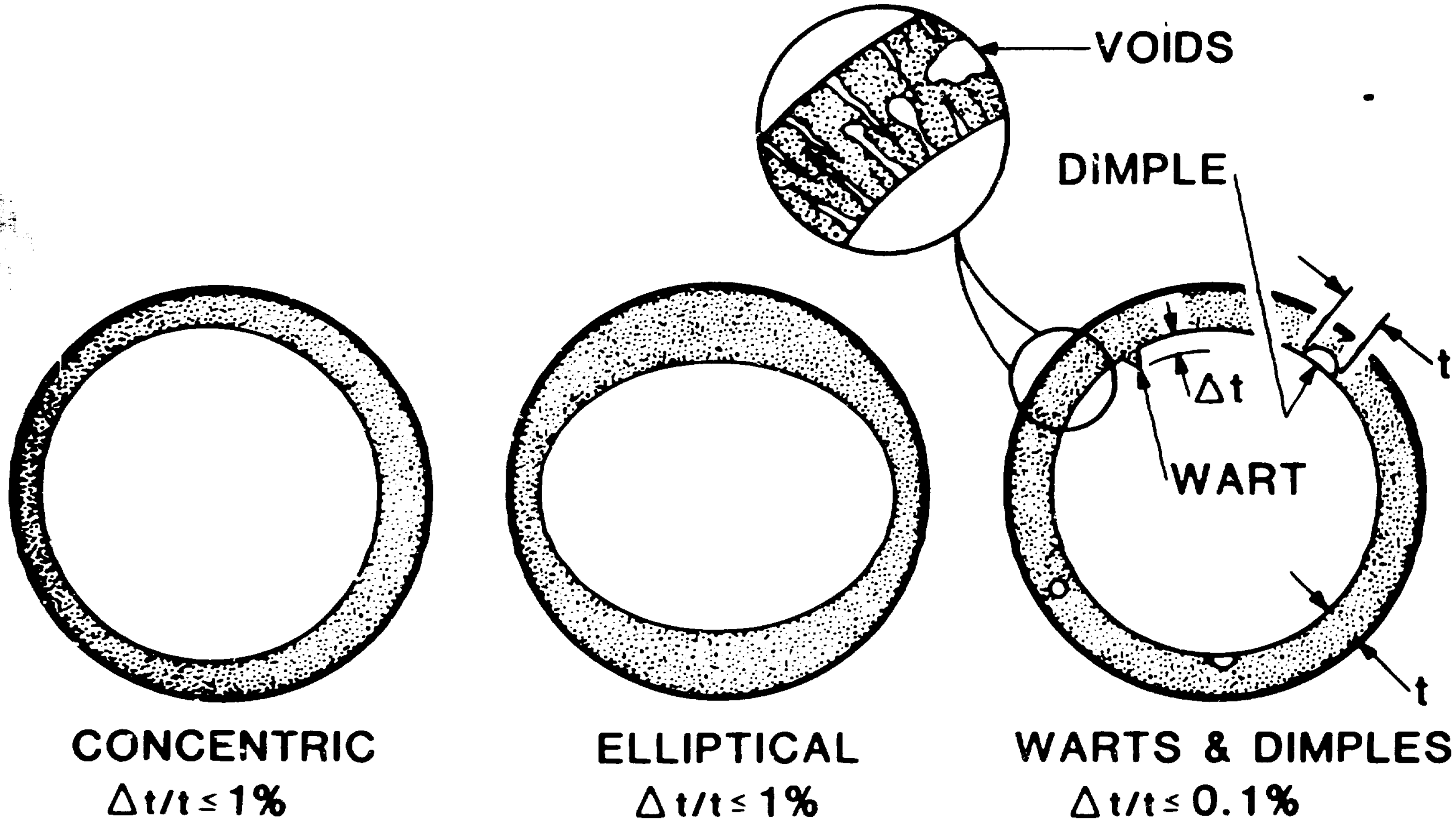

VOIDS
DIMPLE
Δt
t
WART
t
CONCENTRIC
Δt/t ≤ 1%
ELLIPTICAL
Δt/t ≤ 1%
WARTS & DIMPLES
Δt/t ≤ 0.1%

FIG 3

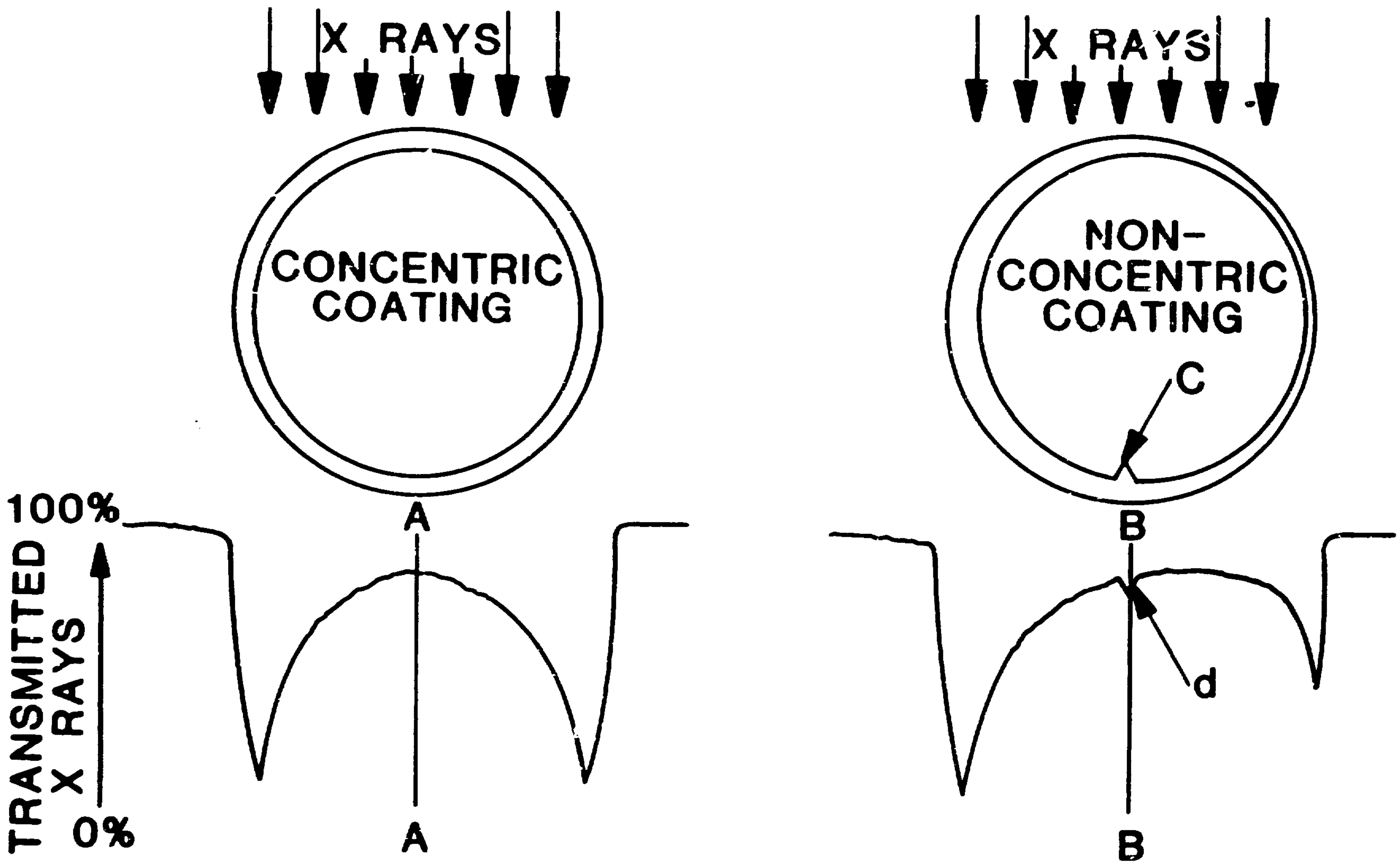

X RAYS
CONCENTRIC COATING
A
100%
TRANSMITTED X RAYS
0%
A
X RAYS
NON-CONCENTRIC COATING
C
B
d
B

FIG 4

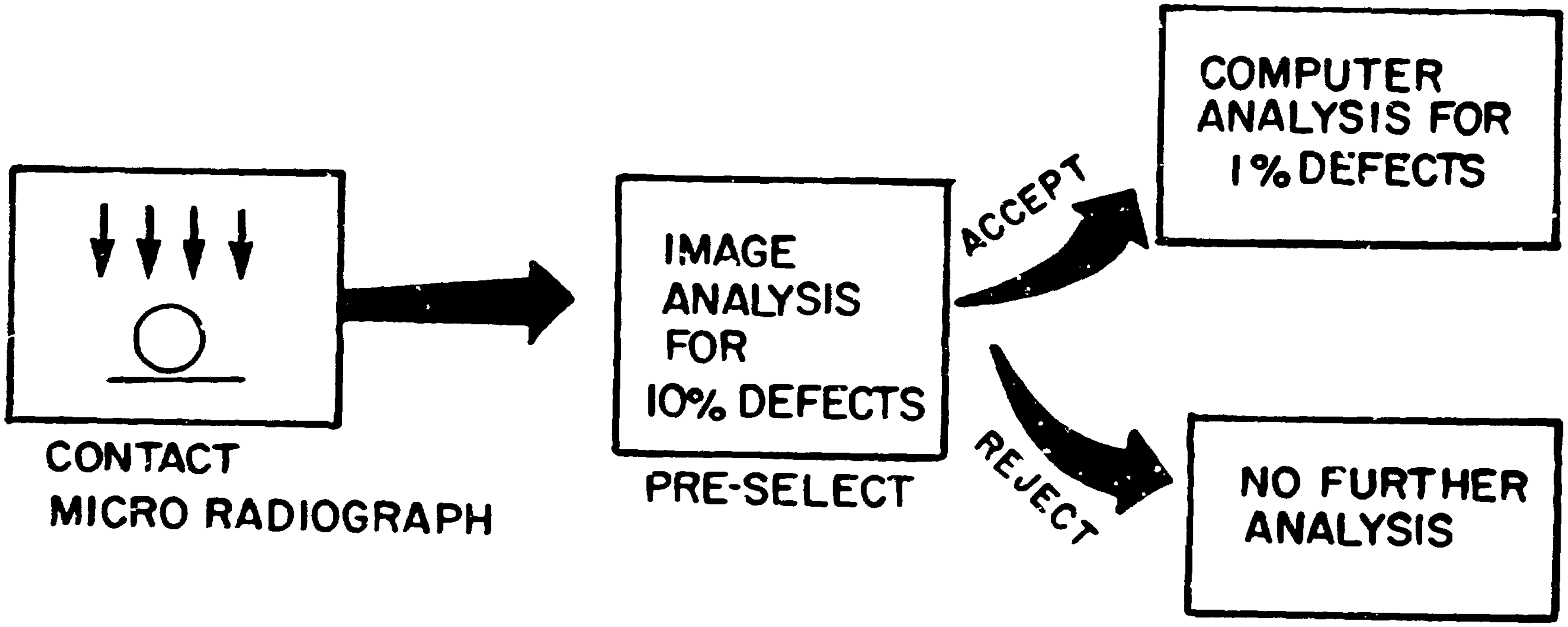

CONTACT
MICRO RADIOGRAPH
IMAGE
ANALYSIS
FOR
10% DEFECTS
PRE-SELECT
ACCEPT
REJECT
COMPUTER
ANALYSIS FOR
1% DEFECTS
NO FURTHER
ANALYSIS

FIG 5

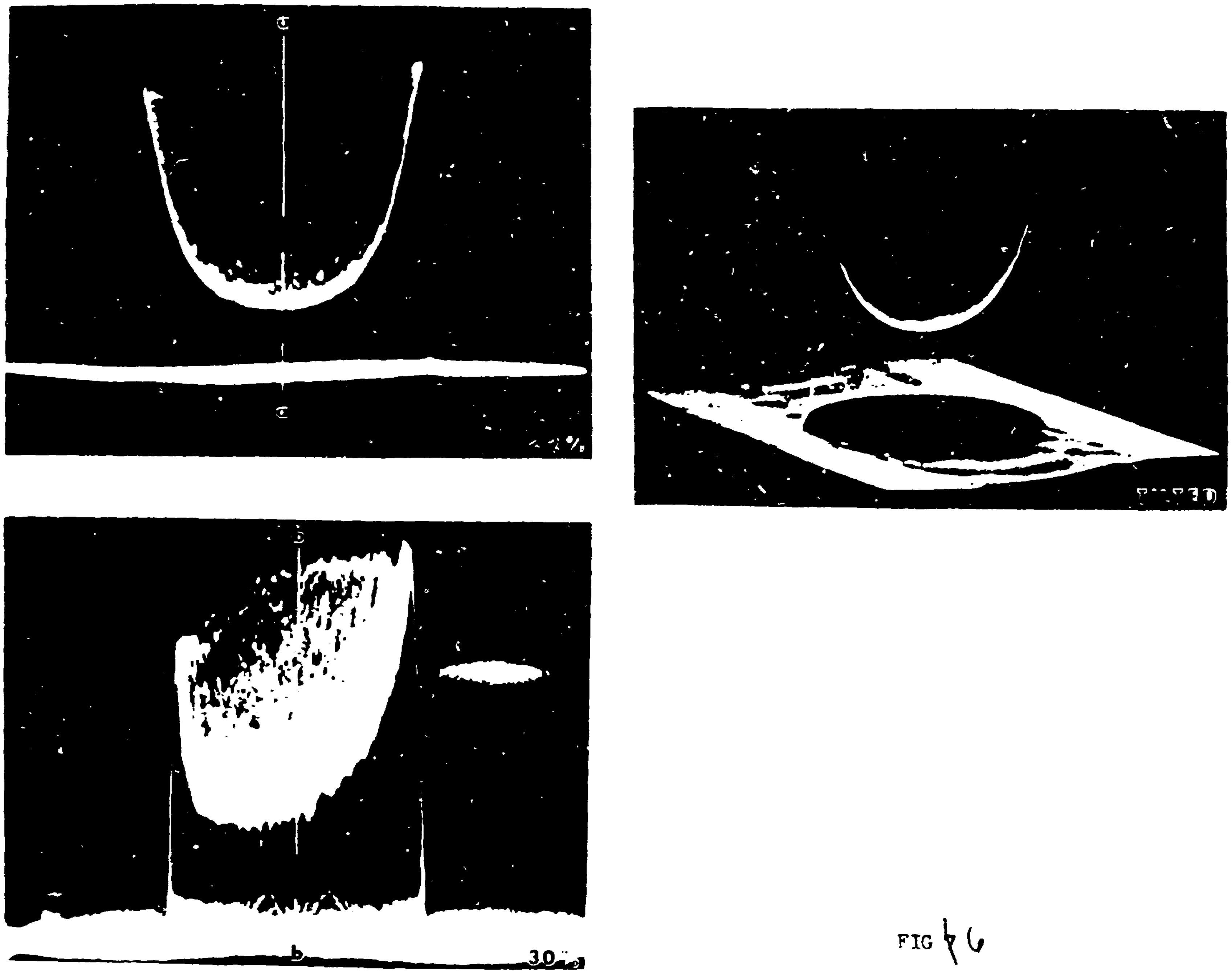


FIG 6

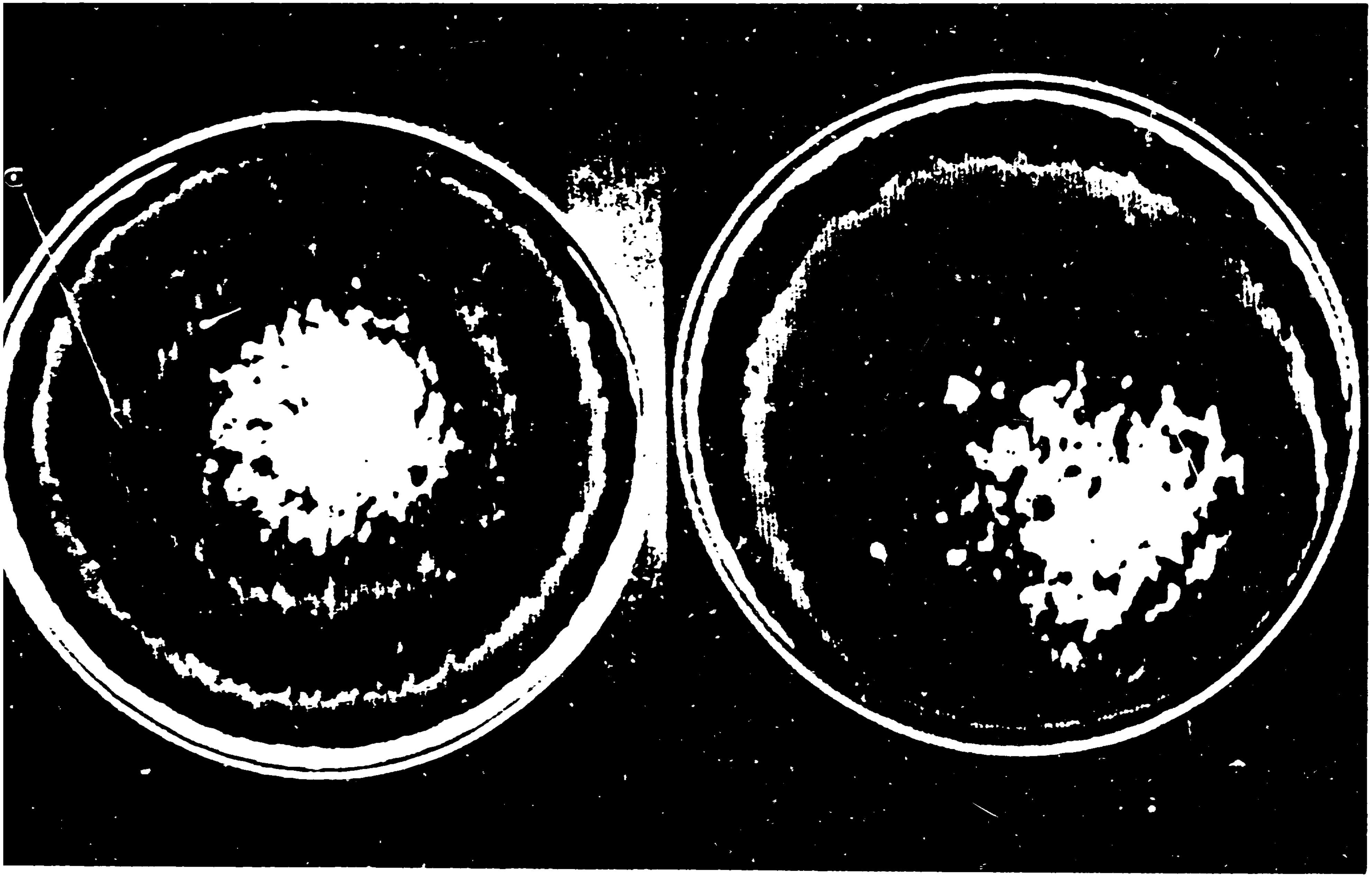
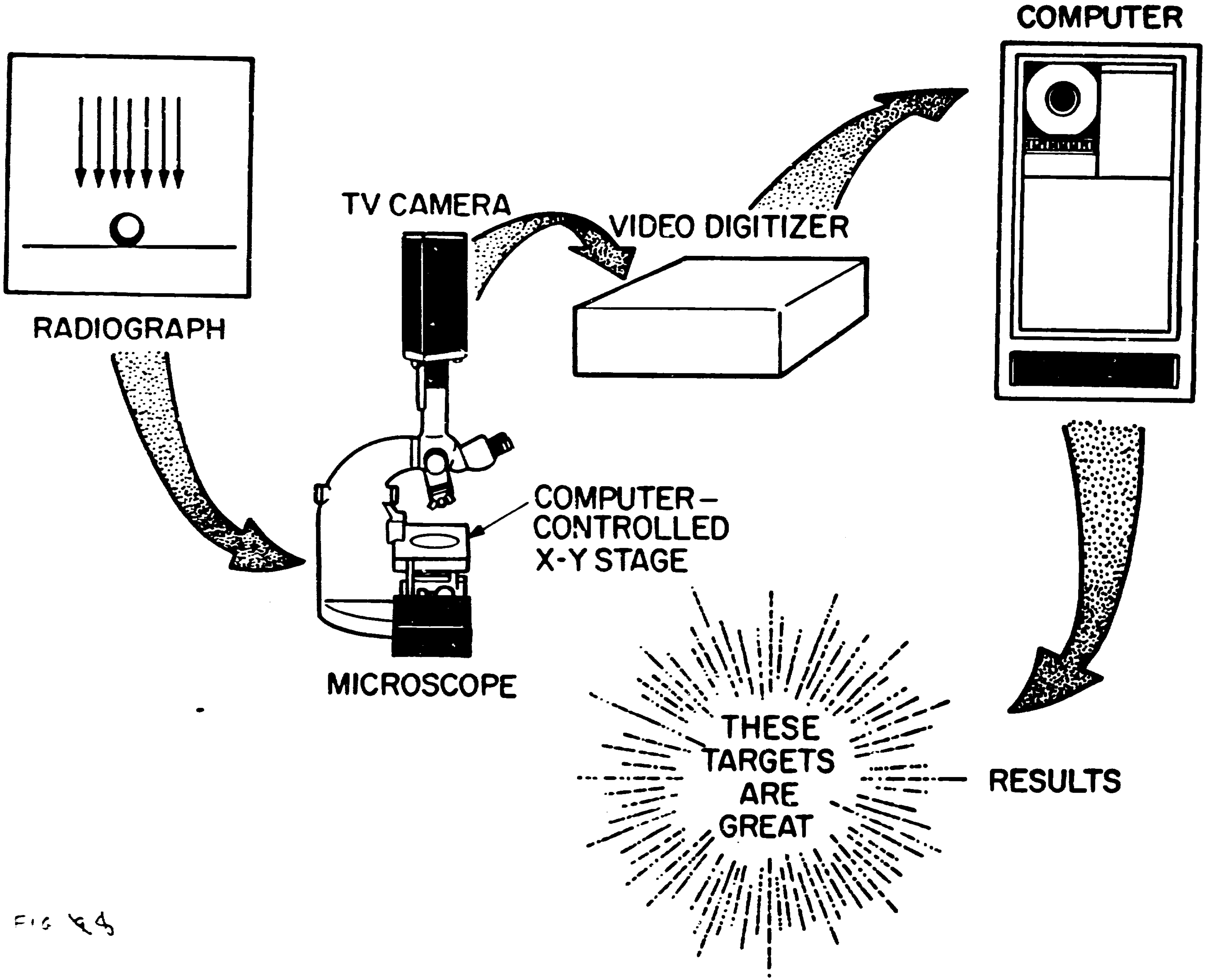


Fig 87



COMPUTER
RADIOGRAPH
TV CAMERA
VIDEO DIGITIZER
COMPUTER-
CONTROLLED
X-Y STAGE
MICROSCOPE
THESE
TARGETS
ARE
GREAT
RESULTS

FIG 43

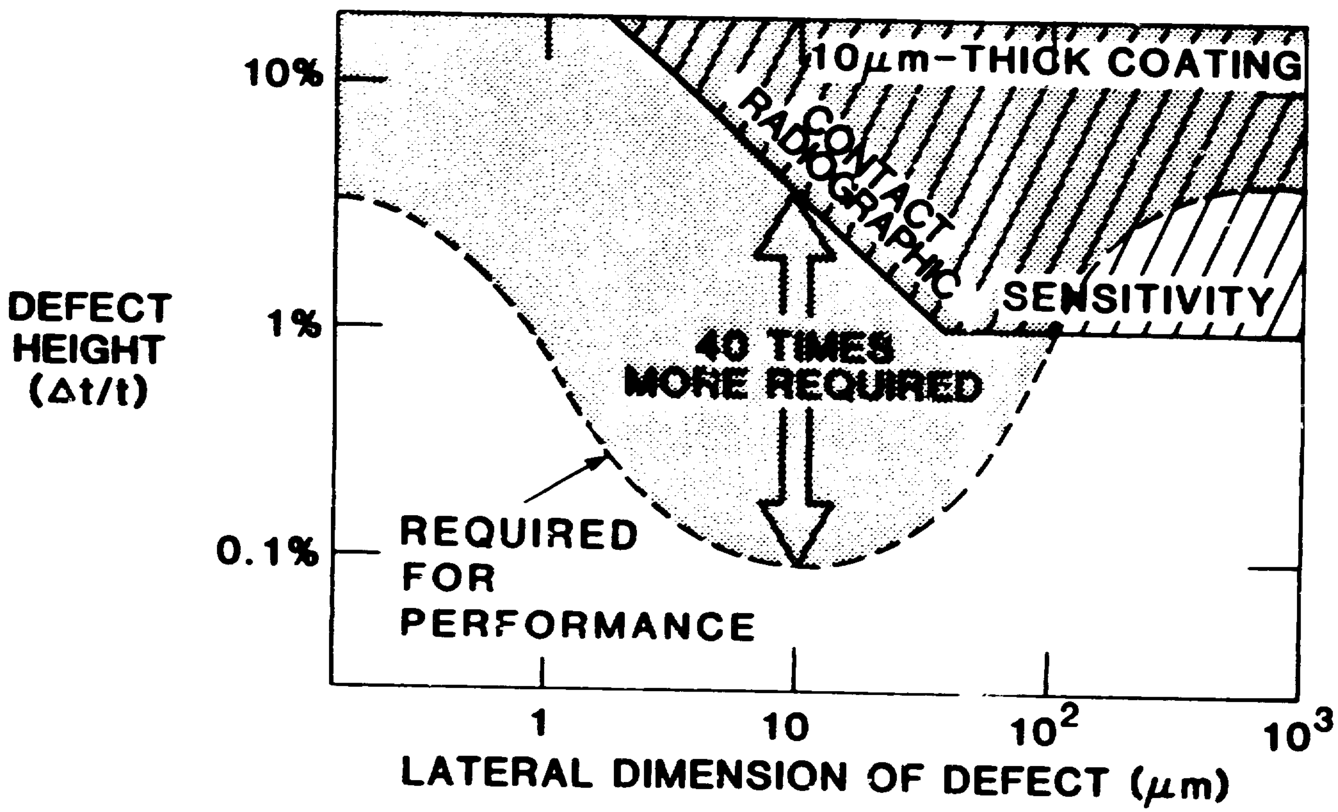

10μm-THICK COATING
CONTACT
RADIOGRAPHIC
SENSITIVITY
40 TIMES
MORE REQUIRED
REQUIRED
FOR
PERFORMANCE
DEFECT
HEIGHT
(Δt/t)
10%
1%
0.1%
1
10
10^2
10^3
LATERAL DIMENSION OF DEFECT (μm)

FIG N9

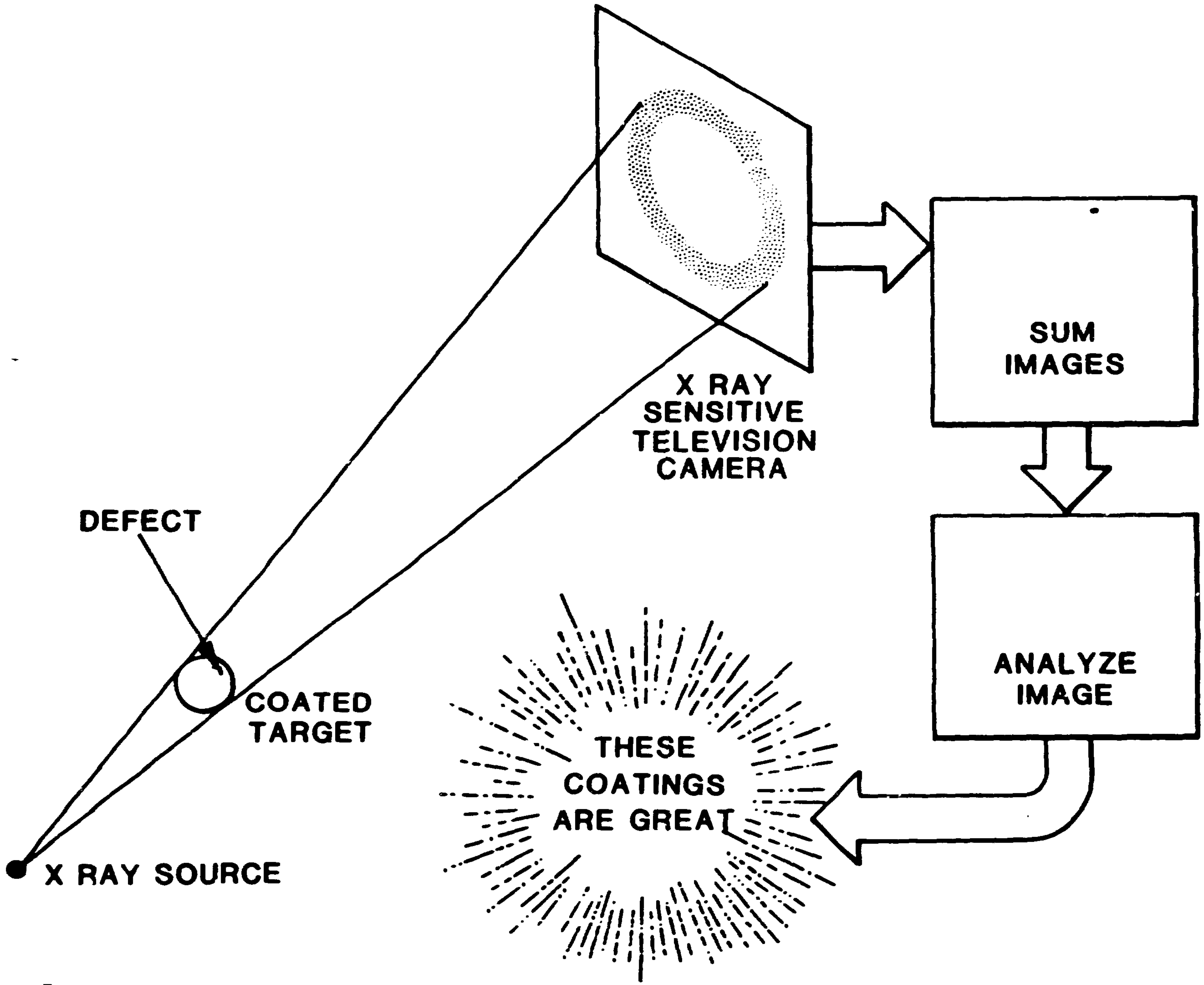

X RAY
SENSITIVE
TELEVISION
CAMERA
SUM
IMAGES
DEFECT
ANALYZE
IMAGE
COATED
TARGET
THESE
COATINGS
ARE GREAT
X RAY SOURCE

FIG #2/10

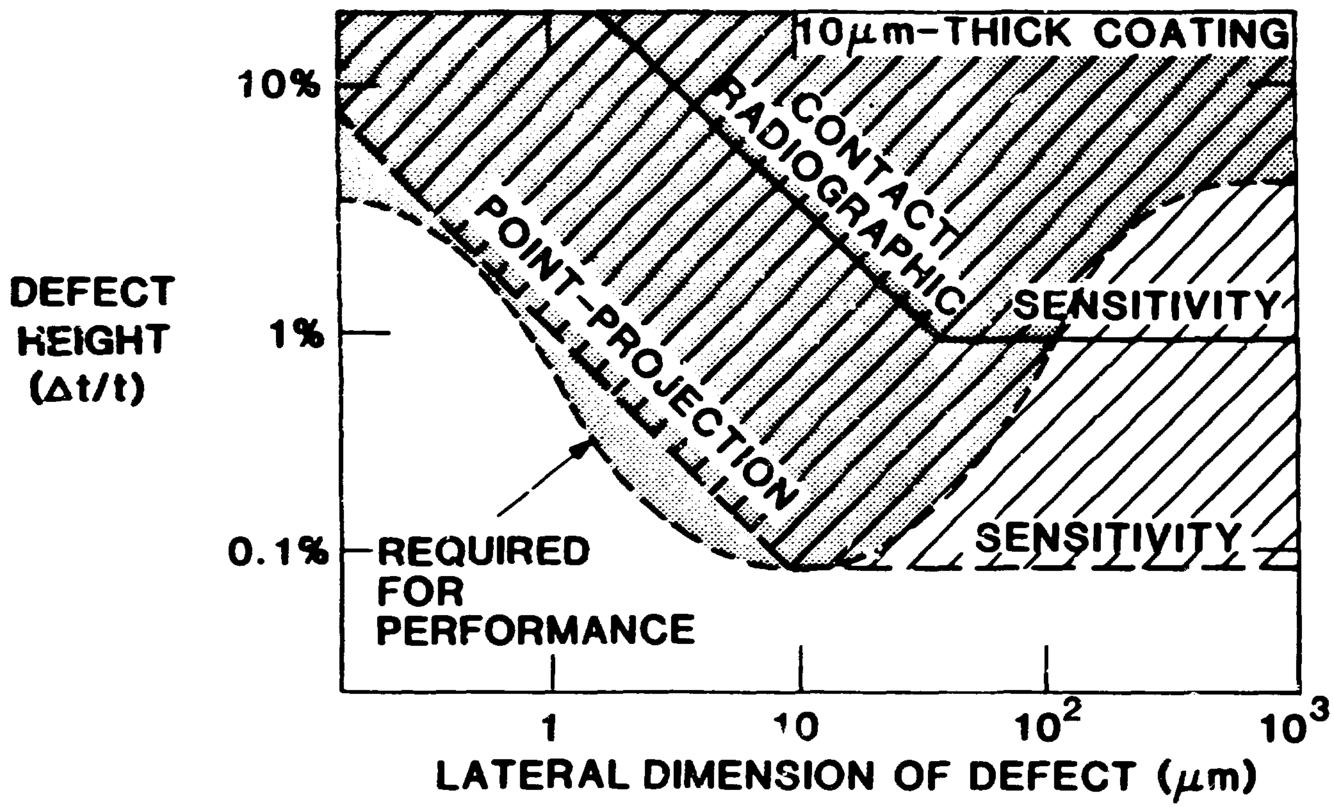

10μm-THICK COATING
10%
1%
0.1%
DEFECT
HEIGHT
(Δt/t)
CONTACT
RADIOGRAPHIC
SENSITIVITY
POINT-PROJECTION
SENSITIVITY
REQUIRED
FOR
PERFORMANCE
1
10
10²
10³
LATERAL DIMENSION OF DEFECT (μm)

FIG 11