

**AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS**

COLOUR FILM TECHNIQUES FOR HOT-CELL RADIOGRAPHY

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ABSTRACT

The report describes the processing and exposure conditions required to produce good colour radiographs of dummy fuel pins. Using a travelling microscope, cladding tube diameters, fuel pellet diameters and tube/pellet gaps were measured on colour radiographs to an accuracy of better than ± 0.002 inches. The minimum detectable tube/pellet gap was 0.003 inches. In all cases the colour radiographs proved to be as good as or better than black and white radiographs of the same object. To use a microdensitometer to measure colour radiographs, it was necessary to print the radiographs on black and white film. A suitable black and white emulsion for this process was established and the results obtained compare favourably with those taken from black and white radiographs. Colour film is more tolerant to gamma radiation than an equivalent black and white X-ray film.

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COLOR; FUEL PINS; GAMMA RADIATION; IMAGES; NONDESTRUCTIVE TESTING; OPENINGS; PELLETS; PHOTOGRAPHIC FILM; RADIATION DOSES; RADIOGRAPHY; THICKNESS; TUBES; URANIUM DIOXIDE; X RADIATION; ZIRCONIUM.

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1. INTRODUCTION

X-radiography is an established technique for the examination of highly radioactive components, such as fuel pins. The main difficulty encountered is fogging of the film by gamma radiation emitted from the sample itself. This can be overcome to some extent by using a rotating, slotted lead disc to cut down the amount of gamma radiation reaching the film (Swanson and Kerswell 1962) or by chemically reducing the fogged film to obtain an acceptable image (Parish and Pullen 1964a). A further alternative is to replace the conventional black and white X-ray film by colour film, which is relatively insensitive to high energy gamma radiation (Parish and Pullen 1964a). In addition to its greater tolerance for gamma radiation, colour radiographs are reported to have other advantages over black and white radiographs. These are:

- (a) Colour radiographs show detailed features in a more striking fashion, merely because the human eye is more sensitive to colour changes than it is to small differences in shades of grey (Beyer 1961).
- (b) The "edge-burn" characteristic of black and white radiographs does not occur (Parish and Pullen 1964b).
- (c) Colour radiographs often exhibit a very narrow yellow (or red) fringe along the boundary marking an abrupt change in sample thickness. This tends to "high-light" small gaps between relatively opaque regions of the sample - for example, the gap between a fuel pellet and the surrounding cladding material (Parish and Pullen 1964b).

The current project was designed to gain experience in colour radiography and to assess the reported superiority of the technique over black and white radiography, particularly in the examination of radioactive components such as fuel pins. Two types of specimen were selected:

- (a) "Dummy" fuel pins consisting of UO_2 pellets encased in a zirconium tube, and
- (b) a "stepped" zirconium tube, machined to give half inch long steps of differing wall thickness.

2. EXPOSURE AND PROCESSING OF COLOUR RADIOGRAPHS

Radiographs were taken at 180 kV and 5 mA using Kodak Ektacolour Print film at distances between 18 inches and three feet from the X-ray source with the specimen in contact with the film cassette. Most of the exposures were made without intensifying screens, although a few radiographs were taken with lead screens. The lead screens had no appreciable effect on the results obtained.

The film was developed with the Kodak C22 colour film process following the procedure described by Parish and Pullen (1964b). After development at 80°F for

four minutes, the film was removed from the developer and flashed for two to three seconds to yellow light. The flashing was done using a safelight with a 150 watt Photocrescenta bulb and a Wratten series 00 yellow safelight filter. The film was positioned emulsion towards the light at a distance of four feet six inches from the safelight filter. The film was then returned to the developer for a further four minutes and the remainder of the C22 process carried out.

Exposure times were established by trial and error. For the two dummy fuel pins - one with a cladding diameter of 0.631 inches and a wall thickness of 0.028 inches (mock SGHWR fuel pin) and the other with a cladding diameter of 0.600 inches and a wall thickness of 0.017 inches (mock CANDU fuel pin) - the optimum exposure time was 20 to 30 minutes with a source/film distance of three feet and about five minutes at a distance of 18 inches. The stepped zirconium tube (i.d. 0.630 inches, o.d. varying from 0.655 inches to 0.725 inches in 0.010 inch steps) was used to establish the range of wall thicknesses which would give an acceptable radiograph at any particular exposure. The criterion of acceptability was that the i.d. of the tube was sufficiently well defined to allow wall thickness measurements to be made to within 0.002 inches. With a source/film distance of three feet, wall thicknesses in the range 0.010 inches to 0.030 inches could be measured on radiographs exposed for 20 minutes, while for an exposure time of 40 minutes the corresponding range was 0.015 inches to 0.035 inches. The results from the dummy fuel pins and the stepped tube agreed and indicated that, at the source/film distance of six feet used in the hot cells, the optimum exposure for both CANDU and SGHWR fuel pins would be between 1-1/2 and 2 hours.

3. RESULTS

3.1 Dummy Fuel Pins

The effective thickness traversed by an X-ray beam varies with distance from the outside edge of a dummy fuel pin as shown in Figure 1. The UO_2 pellets are sufficiently dense to absorb the incident X-rays entirely and therefore the pellets appear on the radiographs as blue - the complementary colour to the yellow light used in the flashing process. The thickness profile for the zirconium tube itself is such that the greatest thickness traversed by the X-rays is along the i.d. of the tube. In radiographs given the optimum exposure the i.d. of the tube shows up as a band of dark green, which fades to pale green and then to yellow away from the i.d. position (Figure 2). This means that the tube/pellet gap shows up as a pale green or yellow-green line. If this gap is too narrow the dark green line representing the i.d. merges into the blue of the pellet and the gap becomes undetectable. Overexposure of the film shifts all the colours to the red end of the spectrum, the green line marking the i.d.

tends to yellow and the clarity of the tube/pellet gap diminishes. Underexposure produces the opposite colour shift, darkens the green line to blue-green and widens it sufficiently to obliterate the smaller tube/pellet gaps.

The thin walled dummy fuel pin contained three UO_2 pellets. Two of these were a tight fit in the tube and tube/pellet gaps were less than 0.002 inches. These gaps were not detected in the colour radiographs. The third pellet was 0.030 inches smaller than the i.d. of the tube giving tube/pellet gaps of about 0.015 inches on each side. These gaps were very easy to detect and measure with a travelling microscope (Figures 2 and 3).

To establish a value of the minimum detectable tube/pellet gap a pair of "waisted" UO_2 pellets were loaded into a zirconium tube to provide the second dummy fuel pin. The dimensions of the pellets were such that the tube pellet gap varied from about 0.003 inches at the ends of the pellet to about 0.006 inches at the centre. Colour radiographs of the waisted pellet fuel pins (Figure 4) were measured at different distances along the pellet to give values of tube o.d., tube i.d., pellet diameter and tube/pellet gaps. These values are compared in Figure 5 with corresponding measurements made with a vernier micrometer. The results indicate that tube/pellet gaps down to 0.003 inches can be detected and that the accuracy of diameter and gap measurements is ± 0.002 inches or better.

3.2 Stepped Zirconium Tube

Radiographs of the stepped tube were used to establish the exposures needed to obtain acceptable results from tubes of various wall thicknesses. The results are shown in Figure 6 and 7, which indicate the range of wall thicknesses that can be measured for different exposure conditions and an estimate of the accuracy of measurement obtainable.

3.3 Black and White Radiographs

Conventional black and white radiographs of both the dummy fuel pins and the stepped tube were taken to compare with the colour radiographs. Because of the relatively coarse grained emulsion the black and white radiographs were not as sharp as the colour radiographs and they showed the characteristic "edge-burn" in a number of cases (for example see Figure 3(b)). In addition the contrast associated with the i.d. of the tube was generally poor by comparison with the colour radiographs. In every case where measurements from the two types of film were made the colour radiographs proved to be as good as or superior to the black and white radiographs.

3.4 Microdensitometer Measurements

As an alternative to a travelling microscope, a recording microdensitometer can be used to measure radiographs. Black and white radiographs are often ideal

for microdensitometer measurement and a number of the black and white films, which could not be measured accurately with the travelling microscope, gave good results in the microdensitometer (Figures 8(b), 9(b) and 10(b)). Colour radiographs on the other hand were difficult to measure directly with a microdensitometer even using colour filters. This disadvantage can be overcome by printing the colour radiograph on to black and white film and then measuring the resulting print in the microdensitometer. To obtain optimum results with this technique it is essential to translate the colour changes into black and white images with the maximum possible contrast. This can be done by selecting a black and white emulsion which is sensitive to only part of the visible spectrum. This type of emulsion will usually respond to blue and green, but is not particularly sensitive to yellow and red. As a result the yellow-green line corresponding to a tube/pellet gap will show up dramatically against the green line of the tube i.d. or the blue of the pellet, (see Figures 3 and 4). A number of emulsions were tried and the most satisfactory results obtained with Ilford N5-31 film, although some of the stepped tube radiographs gave acceptable prints on Kodak Royal Ortho film.

Microdensitometer traces from black and white radiographs and prints of colour radiographs are shown in Figures 8 to 10. Wall thickness and gap measurements in parentheses correspond to values obtained with a vernier micrometer on the actual specimen. In all cases only the interesting features on either side of the tube were examined and after a trace was taken from one side of the radiograph image, the film was manually traversed to the other side of the image for the corresponding microdensitometer trace. Note that for both the stepped tube and the dummy fuel pins the traces correspond remarkably well with the expected thickness profiles shown in Figure 1. When the measurements made from the microdensitometer traces are compared with the micrometer measurements it is obvious that the prints from colour radiographs give results which are generally better than those obtained directly from black and white radiographs.

3.5 The Effect of Gamma Radiation on Colour Film

The main advantage in the use of colour film for radiography of active components is the reported tolerance of the film to gamma radiation. This was investigated by exposing a number of films to the radiation from a cobalt-60 source with principal photon energies 1.17 and 1.33 MeV. After exposure to a range of gamma ray doses the films were developed in the normal way, except that half of the film was blanked off during the flashing process. This was done for two reasons:

- (a) Parish and Pullen (1964a) omitted the colour flashing step in their radiographs of active samples, and

- (b) unexposed, unflashed colour film develops to give a clear background, so the effect of gamma ray fogging shows up more dramatically than it does on the blue background of an unexposed film flashed to yellow light.

The results obtained after various gamma ray doses are listed in Table I. The final column in this Table denotes whether the gamma ray dose would have been sufficient to render the film useless for radiography. Note that at high doses the film appears the same whether it is flashed or not. These trials indicated that colour film could tolerate a dose of at least 55 roentgens and still give acceptable radiographs. By comparison a black and white film of similar speed (Gevaert D2) would not give reasonable radiographs with a dose of more than 14 roentgens, (i.e. the background fog density exceeded 1.5).

Having established that the colour film could tolerate over 50 roentgens of gamma radiation, two radiographs of the "stepped" tube and a dummy fuel pin were subjected to 41 roentgens from the cobalt-60 source before development. One film was then developed in the normal way, while the flashing step was omitted in the processing of the other film. In both cases satisfactory radiograph images were obtained. The main effect of the gamma radiation fogging was to limit the range of colours to shades of amber verging towards a pale yellow-green. The effect of the yellow flash was also reduced, except for the absence of yellow-green tones in the unflashed version. Despite the lack of a full colour range the gamma fogged radiographs still showed the required detail (compare Figures 6(a) and 6(b)). A comparison black and white radiograph taken on D2 film was subjected to 14 roentgens of gamma radiation. In this case the fogged image was still reasonable, but suffered to some extent from lack of contrast.

4. CONCLUSIONS

(a) The conditions required to produce good colour radiographs have been established. The procedure is relatively simple and extremely reproducible.

(b) Colour radiographs are easier to measure by eye and give results that are in general superior to those obtained with black and white radiographs. In dummy fuel pins tube/pellet gaps as small as 0.003 inches can be measured with an accuracy of better than ± 0.002 inches. Diameter measurements on fuel pellets and zirconium tubing can be made to an accuracy approaching ± 0.001 inches.

(c) For use with a microdensitometer, colour radiographs must first be printed on to black and white film. Suitable emulsions for this process have been established and the results from the prints compared favourably with microdensitometer traces taken directly from black and white radiographs.

(d) Colour radiographs can tolerate at least a 55 roentgen dose of high energy gamma radiation without too great a loss in image quality. The corresponding

value for a black and white film of comparable speed is 14 roentgens.

(e) Long exposure times are required by colour film in comparison with fast black and white X-ray film such as Gevaert D10. This is not a serious disadvantage and is completely outweighed by the greater tolerance of colour film for gamma radiation. Colour radiographs can stand at least four times the high energy gamma radiation dose of a black and white film of the same speed. Using faster black and white films will cut down the gamma radiation dose received by the film during radiography of an active component. However the increased speed of the film will presumably result in an equal amount of fogging by this reduced dose. Hence the only improvement gained by moving to faster films is that of time and not of image quality. In fact the faster films will give inferior radiographs because of their coarse grain size.

Finally the exposure times for colour radiographs can be reduced by using intensifying screens. Experiments with screens are in progress and preliminary results are very encouraging.

5. ACKNOWLEDGEMENTS

The authors would like to thank P. A. Gillespie for his assistance in taking a number of radiographs used in this project. Valuable discussions with P. A. Gillespie and N. W. D. Chrimes are also gratefully acknowledged.

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TABLE I

THE EFFECT OF γ -RADIATION FOGGING ON COLOUR FILM

Gamma Radiation Dose (Roentgens)	Colour of Unflashed Portion of Film	Colour of Portion of Film Flashed to Yellow Light	Assessment of Degree of Fogging
ZERO	Clear	Blue	None
1.25	Very Pale Green	Blue	Acceptable
2.5	Very Pale Green	Blue	Acceptable
6.85	Pale Yellow-Green	Dark Blue	Acceptable
13.7	Pale Yellow-Green	Blue-Green	Acceptable
55	Pale Amber	Blue-Green	Acceptable
110	Dark Brown	Dark Brown	<u>Not</u> Acceptable
220	Dark Brown	Dark Brown	<u>Not</u> Acceptable

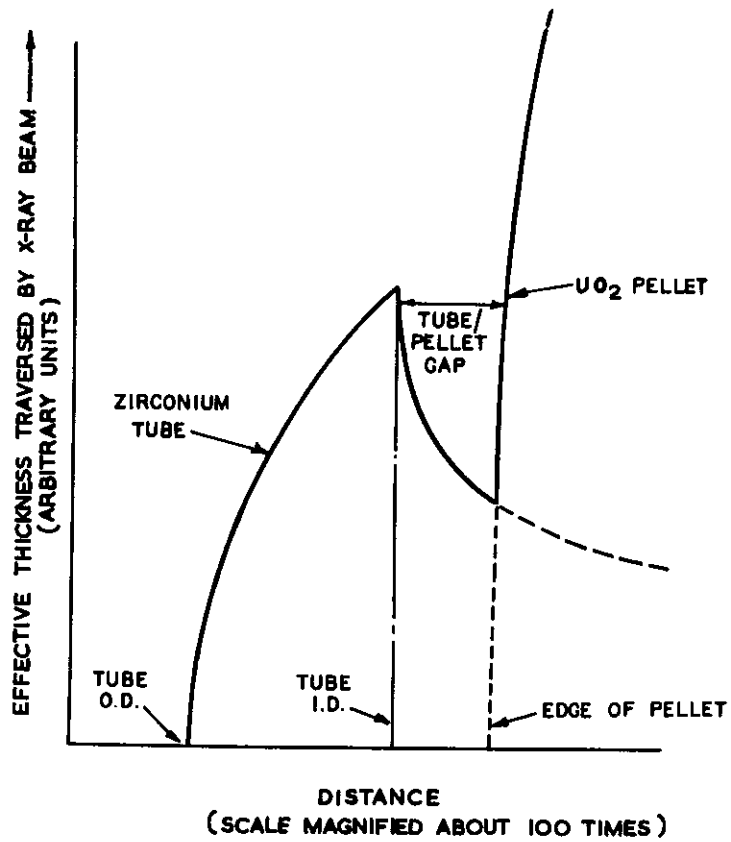


FIGURE 1 VARIATION OF EFFECTIVE DISTANCE TRAVERSED BY X-RAY BEAM WITH DISTANCE FROM OUTSIDE EDGE OF DUMMY FUEL PIN

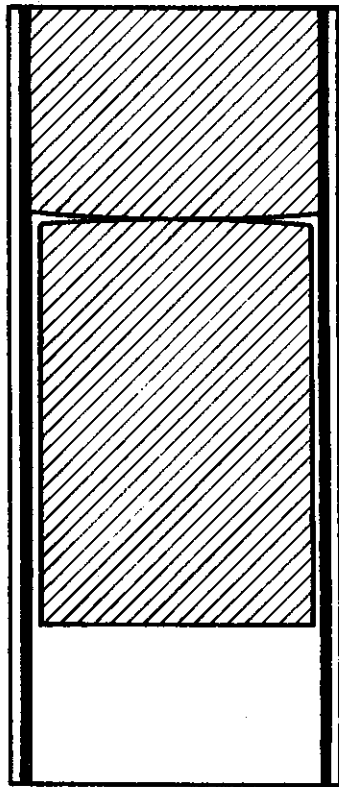


FIGURE 2 DIAGRAMMATIC REPRESENTATION OF A COLOUR RADIOGRAPH OF A DUMMY FUEL PIN, ENLARGED 2.7 TIMES. THE FUEL PELLETS APPEAR BLUE (SHOWN HATCHED), THE i.d. OF THE ZIRCONIUM ALLOY FUEL CLADDING TUBE APPEARS AS A GREEN LINE (SHOWN SOLID) AND THE EMPTY TUBE AT THE BOTTOM OF THE PICTURE APPEARS ORANGE (SHOWN BLANK). THE LOWER FUEL PELLET IS .030 inch SMALLER THAN THE TUBE i.d. AND THE TUBE/PELLET GAPS SHOW AS YELLOW LINES (SHOWN BLANK). THE GAP ON THE LEFT OF THE PICTURE IS 0.016 inch AND THE GAP ON RIGHT IS 0.014 inch.



FIGURE 3 (a) BLACK AND WHITE PRINT (X 2.7) OF COLOUR RADIOGRAPH, SHOWN IN FIGURE 2.

(b) PRINT (X 2.7) OF BLACK AND WHITE RADIOGRAPH OF DUMMY FUEL PIN SHOWN IN (a). NOTE LACK OF DEFINITION ALONG o.d. OF FUEL CLADDING TUBE. THIS IS DUE TO THE 'EDGE-BURN' CHARACTERISTIC OF BLACK AND WHITE RADIOGRAPHS.

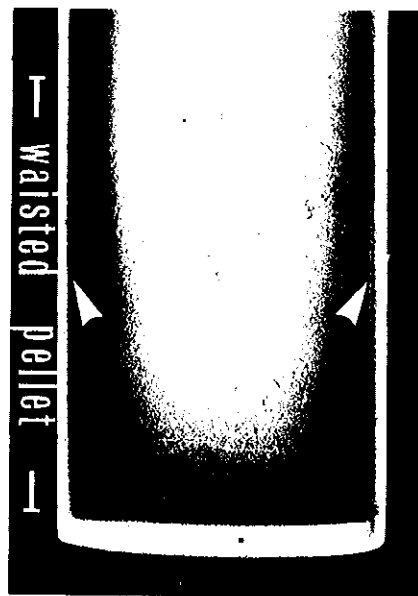


FIGURE 4 BLACK AND WHITE PRINT (X 2.7) OF COLOUR RADIOGRAPH OF DUMMY FUEL PIN CONTAINING 'WAISTED' FUEL PELLETS. THE MAXIMUM TUBE PELLET GAP AT THE CENTRE OF THE 'WAIST' IS INDICATED BY ARROWS AND CORRESPONDS TO 0.006 INCH. AT THE ENDS OF THE PELLETTHE GAP NARROWS TO 0.003 INCH.

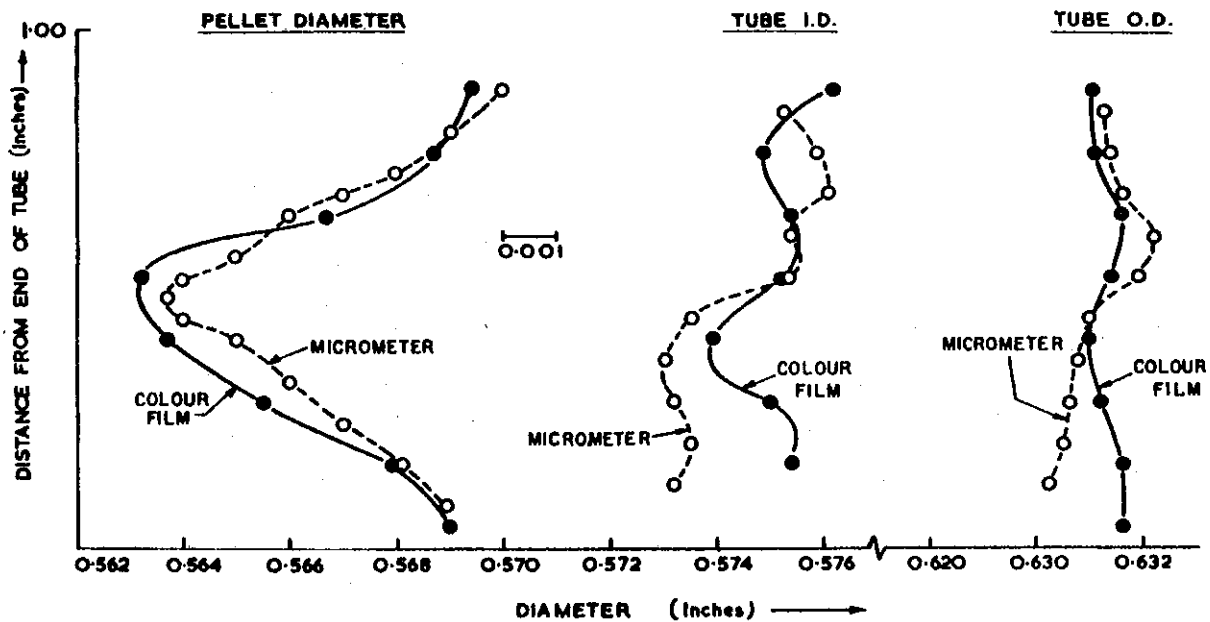


FIGURE 5 (a) COMPARISON OF TUBE o.d., TUBE i.d. AND PELLETT DIAMETER MEASUREMENTS MADE ON COLOUR RADIOGRAPH OF WAISTED PELLETT FUEL PIN (FULL LINES) WITH CORRESPONDING MICROMETER MEASUREMENTS.

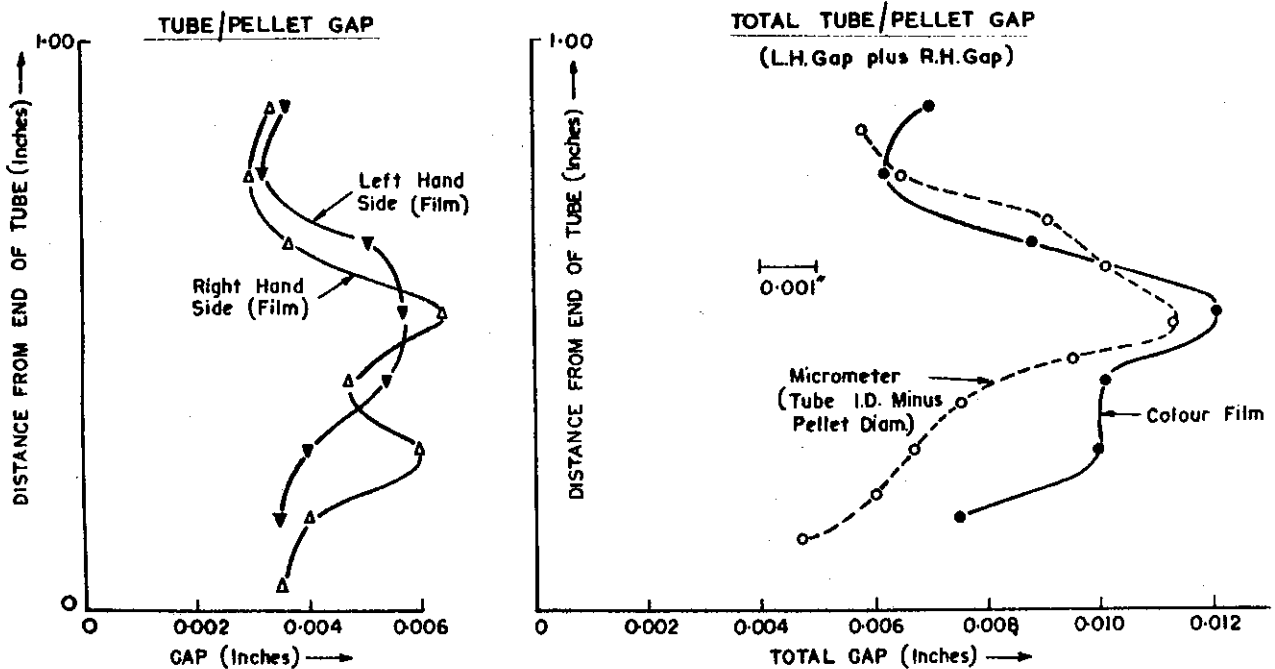


FIGURE 5 (b) TUBE PELLETT GAP MEASUREMENTS MADE ON WAISTED PELLETT FUEL PIN. MICROMETER MEASUREMENTS (TUBE I.D. MINUS PELLETT DIAM.) ARE INCLUDED FOR COMPARISON.



(a)

(b)

FIGURE 6. (a) PRINT (X 2.7) OF COLOUR RADIOGRAPH OF 'STEPPED' ZIRCONIUM TUBE. THE WALL THICKNESS FOR THE BOTTOM STEP IS 0.012 INCH AND INCREASES BY 0.005 INCH FOR EACH STEP UP TO 0.0275 INCH FOR THE STEP AT THE TOP OF THE PICTURE.

(b) PRINT (X 2.7) OF COLOUR RADIOGRAPH OF STEPPED TUBE SHOWN IN (a) AFTER EXPOSURE TO γ RADIATION DOSE OF 41 ROENTGENS.

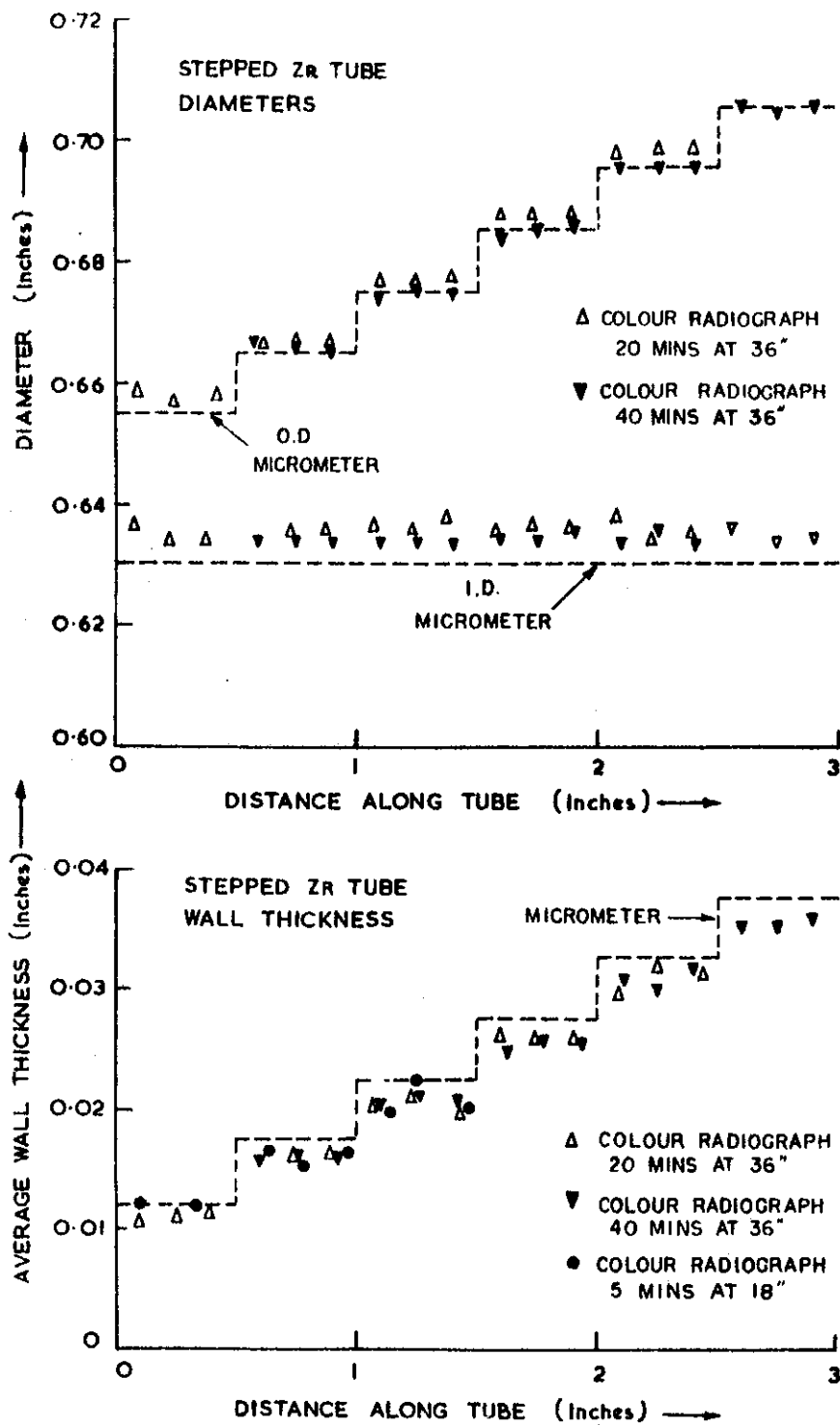
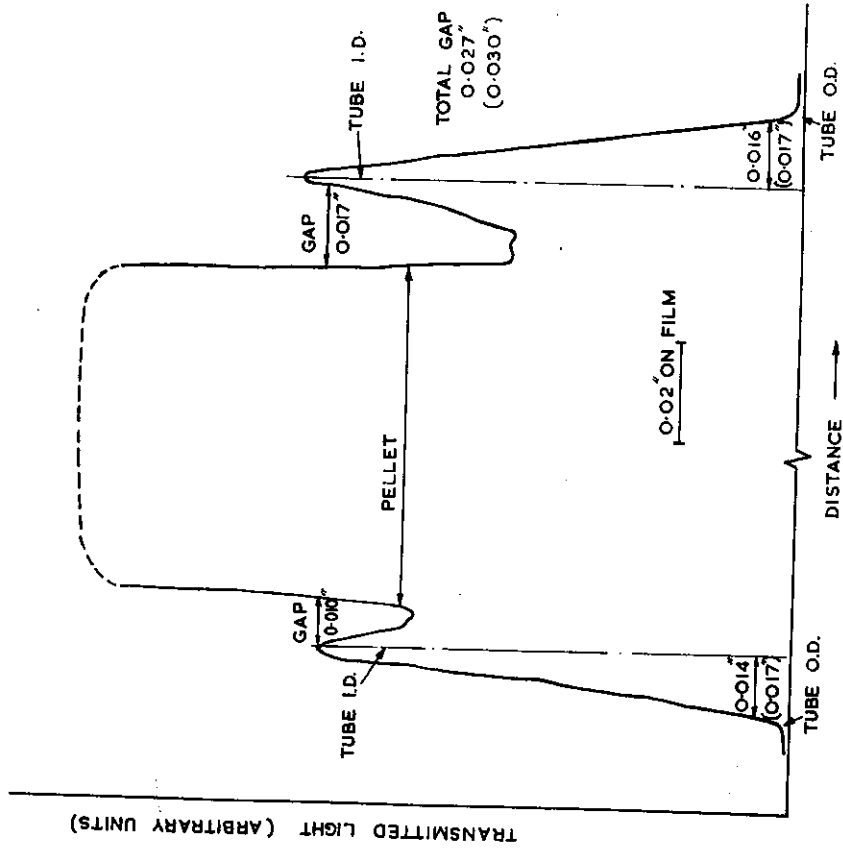
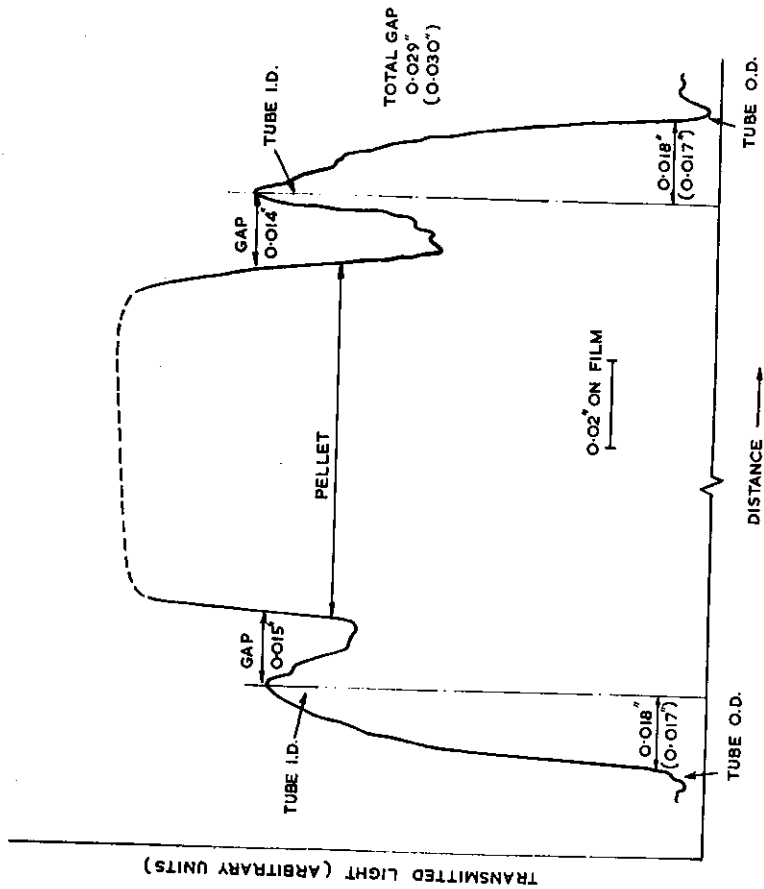


FIGURE 7 MEASUREMENTS OF TUBE o.d., TUBE i.d. AND WALL THICKNESS TAKEN FROM COLOUR RADIOGRAPHS OF STEPPED ZIRCONIUM TUBE. THE DOTTED LINES GIVE THE CORRESPONDING MICROMETER MEASUREMENTS.



TRANSMITTED LIGHT (ARBITRARY UNITS)

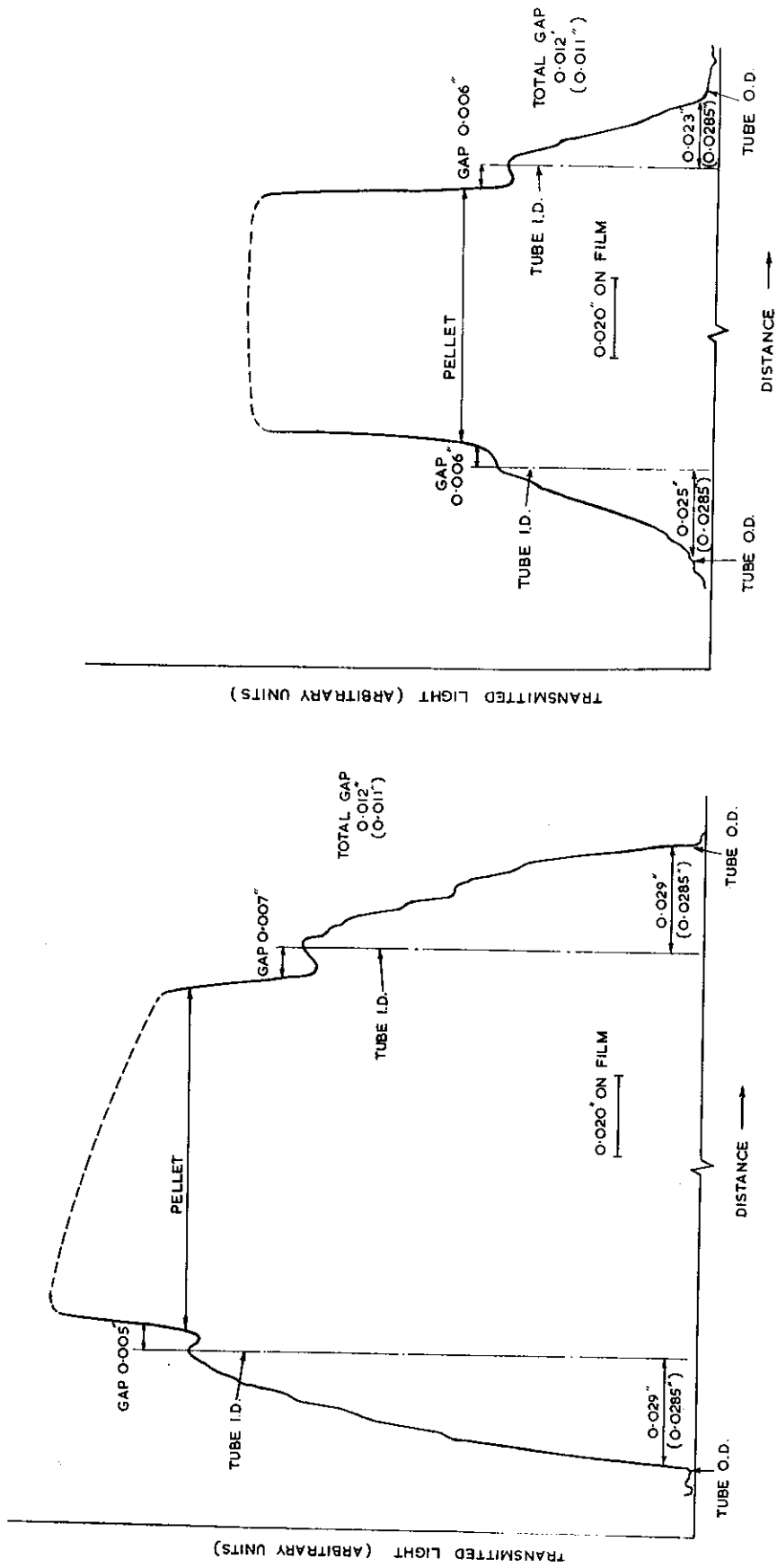


TRANSMITTED LIGHT (ARBITRARY UNITS)

(a) N5-31 PRINT OF COLOUR RADIOGRAPH

(b) BLACK AND WHITE RADIOGRAPH

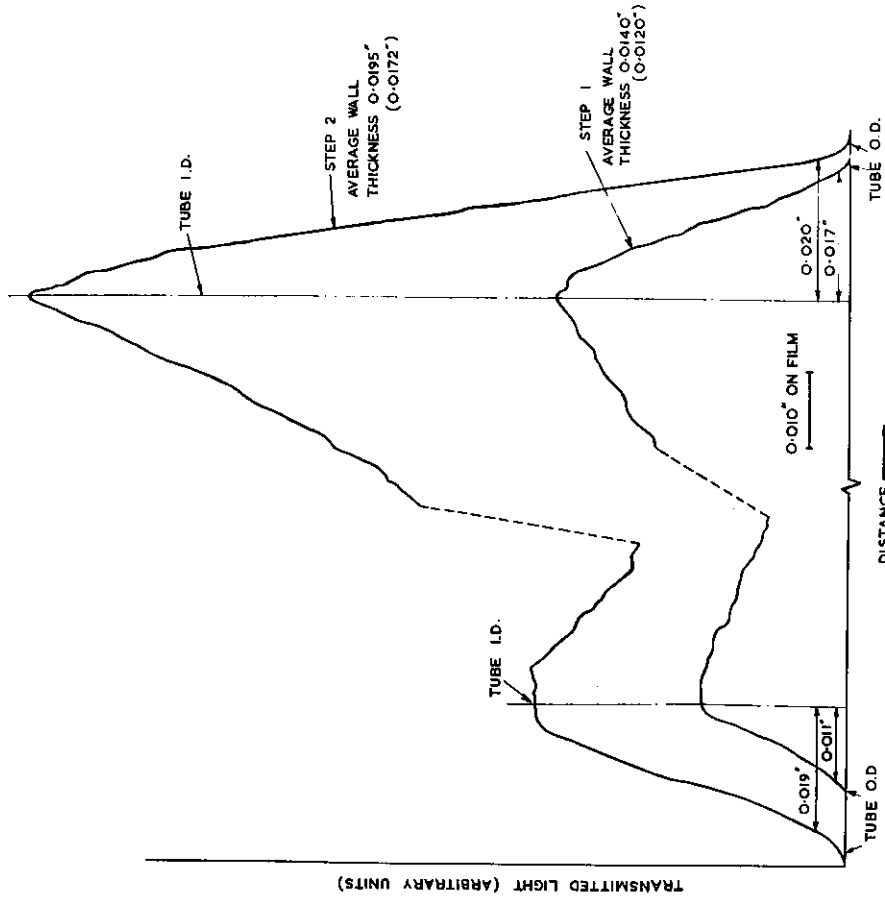
FIGURE 8 MICRODENSITOMETER TRACES FROM EACH SIDE OF THE DUMMY FUEL PIN SHOWN IN FIGURES 2 AND 3. NUMBERS IN BRACKETS ARE MICROMETER MEASUREMENTS INCLUDED FOR COMPARISON.



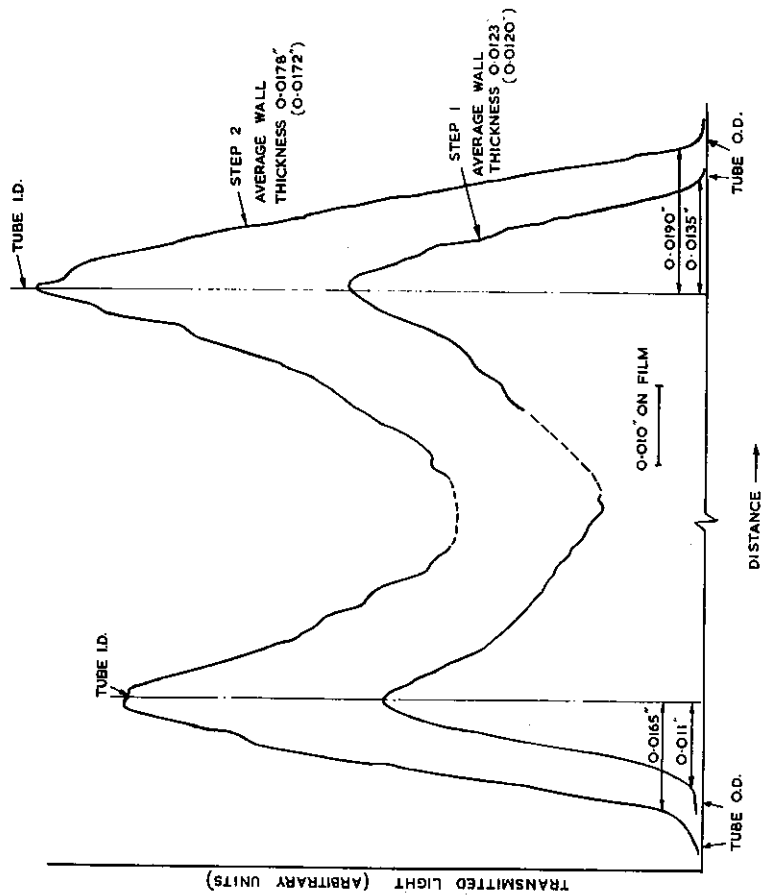
(a) 55-31 PRINT OF COLOUR RADIOGRAPH

(b) BLACK AND WHITE RADIOGRAPH

FIGURE 9 MICRODENSITOMETER TRACES FROM EACH SIDE OF WAISTED PELLET FUEL PIN. THE TRACE WAS TAKEN AT THE CENTRE OF THE PELLET WHERE THE TUBE/PELLET GAP IS A MAXIMUM. MICROMETER MEASUREMENTS (IN BRACKETS) ARE INCLUDED FOR COMPARISON.



(b) BLACK AND WHITE RADIOGRAPH



(a) N5-31 PRINT OF COLOUR RADIOGRAPH

FIGURE 10 MICRODENSITOMETER TRACES FROM EACH SIDE OF FIRST TWO STEPS OF THE STEPPED TUBE. MICROMETER MEASUREMENTS (IN BRACKETS) ARE INCLUDED FOR COMPARISON.

