# USE OF X-RAYS IN MEASURING RING WIDTHS FROM INCREMENT BORINGS

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ABSTRACT

An X-ray source was used to produce a radiograph of 5.1mm wood cores. Ring widths were measured much faster and more accurately from the radiograph than directly from the wood core. Where the density variation between earlywood and latewood was not great enough, radio-opaque solutions were infused into the latewood cells to improve contrast on the radiograph. A wood moisture content of 30% gave the best results without any shrinkage. The radiographic method had a maximum inherent error of less than 0.3%, due to linear deformation.

## INTRODUCTION

The conventional method of measuring ring widths from 5.1mm increment cores is slow and tedious. The increment cores are usually placed on the micrometer scale of a movable low-power microscope. To see rings in this manner it is also necessary to wet the cores. In the measurement of rings on cores from close-grained species and branches, planing and wetting are necessary. The application of alumina powder is equally slow as the surface needs careful preparation. A method which could both speed up and increase precision in the measurement of growth rings would be a great asset in this field.

Lenz (1957) showed that X-rays could aid measurement of increment cores from tree borings. He found that accurate results could be obtained as long as there was about 1m distance between the X-ray source and the object, and as long as the object was in contact with the film. Low voltage X-rays (20 to 70 kV) were used and he showed that the major errors were caused by the wood properties rather than the radiographic method. Goossens (1967) showed not only that X-rays could be an aid in measurement of increment cores but also that great accuracy was possible. He examined the errors caused by the breadth of the anode, the eccentric situation of the annual ring and the thickness of the core; he gave a final equation for the error in the measured breadth of the annual ring. Polge (1966) used an X-ray tube producing soft X-rays (10 to 15 kV) emitted through a beryllium window to produce a radiograph of an increment core 5.1mm in diameter. The radiograph of the core was scanned by a microdensitometer.

X-ray photography has several advantages over the manual method:

1. Little preparation of the wood cores is needed; planing and wetting of the cores is eliminated.
2. Speed at which wood cores can be read and measured is many times greater than by using microscope and micrometer.
3. Storage of wood cores is always a problem. They are bulky and unstable in their original condition. Special conditions are required for storage. X-ray photographs or negatives are stable and not bulky. A permanent record of the cores in their original state can be kept.
4. Errors in recognising rings are reduced because they are seen on one plane with the light source underneath the film. False rings can be recognised more easily because the whole cross-section can be studied at one time.

The X-ray method uses the properties of wood when exposed to X-rays, i.e., a body of high density will absorb more X-rays than a body of low density. The radiograph shows the difference in density between latewood and earlywood and there must be sufficient contrast between these two to show growth rings clearly in the increment core. The boundaries of these rings must be clear for precise measurements. Clarity varies greatly with the way the core is lying on the film and whether it has good contact with the film. The moisture content of the wood core both alters its properties under X-rays and its size in a radial direction.

## METHOD

The 5.1mm wood cores to be radiographed were placed on an X-ray film as shown in Fig. 1. Kodak Type M, a double-coated industrial film was used. Three other double-coated X-ray films were tested but the Kodak Type M film was chosen because of its very fine grain. Fine detail could be seen from this film with no grain showing when it was enlarged up to 10 times the original dimensions. A single-coated film (Kodak Type R) that is probably highly suitable was not available at the time. (It has a 0.5% penetrometer sensitivity and can be magnified more than 50 times without grain showing); the film that was used (Type M) had a sensitivity of 1.0%. About 20 wood cores can be arranged on a 204 × 254mm film. The film is wrapped in a paper folder and enclosed in an opaque envelope (Fig. 2). The three layers are only 0.64mm in total thickness and the wood core rests only 0.22mm from the upper light-sensitive layer and 0.44mm from the lower light-sensitive layer (the emulsion is on both sides of the transparent base of the film). A perpendicular distance of 1.016mm from the anode to the centre point of the film was chosen.

## ERRORS IN THE TECHNIQUE

There are two small errors in the radiographic method. The first is caused by the effective focal spot being 0.3mm × 0.6mm in size and not a point source. This error

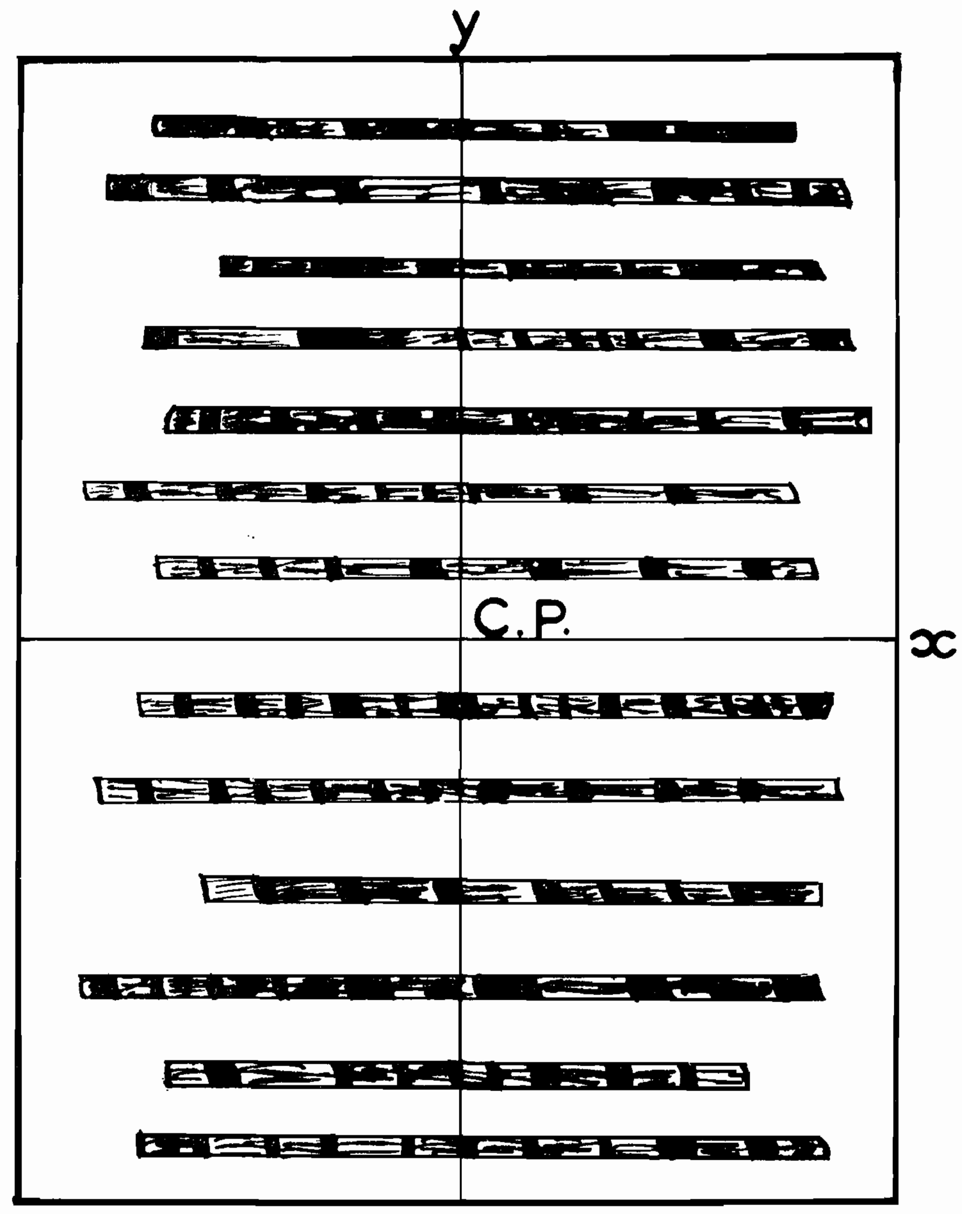


FIG. 1—Cores arranged on upper side of Kodak X-ray film (204mm × 254mm).

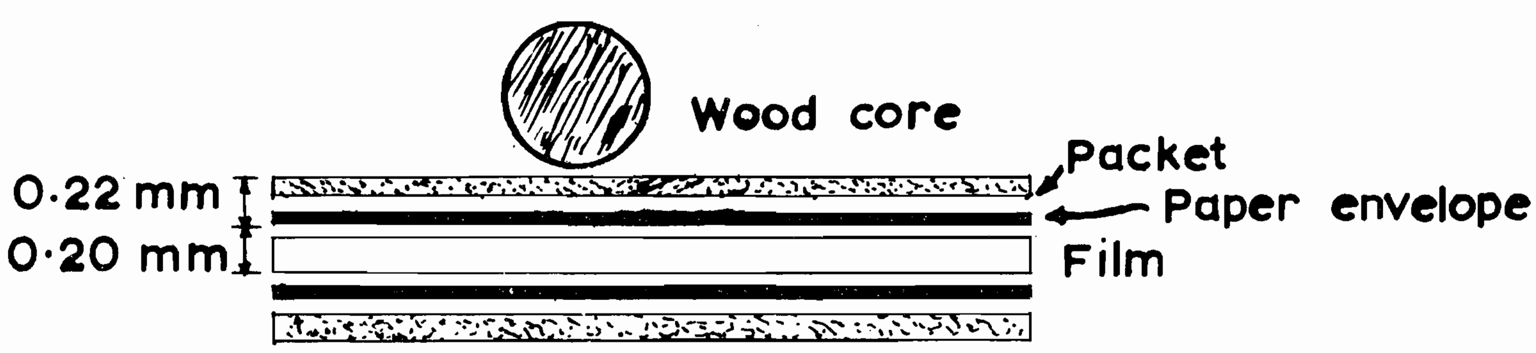


FIG. 2—Cross section of Kodak X-ray film in the envelope and packet, with a wood core resting on it.

causes a blurring of the image and is at a maximum of 0.0033mm when the wood core is closest to the centre of the film. The maximum error (e) in the formation of the image of an annual ring boundary is calculated as follows:

$$e = \frac{2ak}{d - a}$$

where a = distance from upper side of core to lower film plane,
k = distance from centre point of effective focal spot to its further perimeter,
d = distance from focal spot to lower film plane.

The second error is more serious and is known as linear deformation. This occurs where the X-rays do not enter the wood core at right angles to the film. The further the object is from the centre point of the film the greater the error. With the size of film used the maximum distance the wood core could be from the centre point was 150mm in an oblique direction, 102mm radially and 127mm transversely. The extension in the width of the core was only 0.014mm and was ignored. The other two directions have small errors in the width of annual rings and larger errors over the whole length of the core. The maximum extension $\{E_1\}$ in the length of a core was 0.3mm and an error $\{E_2\}$ of 0.05mm in reading a ring of 15mm in width only occurred at the edge of the film. These errors are calculated as follows:

$$E_1 = \frac{b \times c}{d - b}$$

$$E_2 = \frac{15b}{d - b}$$

where b = distance from centre of core to lower film plane,
c = distance from centre point of film to end of core,
d = distance from focal spot to lower film plane.

The maximum error due to linear deformation was 0.3% along the x axis (*see* Fig. 1). There was no error in total length or ring widths along the y axis. On the diagonal between the x and y axes the error was only 0.15% (on the extreme corner of the film). Linear deformation is accentuated by the thickness of the core. An annual ring is circular in section and when it is projected on to the film plane it causes blurring of the image.

A rectangular metal collimator was used to restrict primary radiation and therefore limit scattered radiation. The result is that better contrast can be obtained on the film. The area covered by radiation is a 420mm × 469mm rectangle. The resultant film image is a negative one (because the film receives less radiation from the denser wood than from the less dense wood). The lighter rings on the radiograph of the wood core are latewood bands. Measurements were taken from the negative on a table with the light source underneath. A thin transparent scale, superimposed on the negative, was a good aid to measuring ring widths. A ruler was also used but needed careful use to obtain good results. For finer detail a low-power microscope with a movable scale could be used.

Other sources of error that were not quantified are discussed below.

### *Quality of Wood Cores*

It is most important that the wood boring is taken at right angles to the main axis of the stem. With leaning or malformed trees a poor core may result in very poor definition on the radiograph. This is due to the circular section of the annual ring being projected on to the film plane or in bad cases to one ring being superimposed on another.

### *Position of Wood Cores on the Film*

The increment cores were laid on the film with the transverse section uppermost so that the X-rays penetrated the wood longitudinally. If the cores are radiographed with the radial longitudinal side uppermost the arc of the annual ring shows a blurred image of the latewood band. (cf. *Pseudotsuga menziesii* in Fig. 3a with radial longitudinal side uppermost, with the same core in Fig. 3b, which rays penetrated longitudinally.)

Good contact with the film had to be ensured for a clear picture. Contact was improved by pressing cores down on the film so that the envelope contained no air

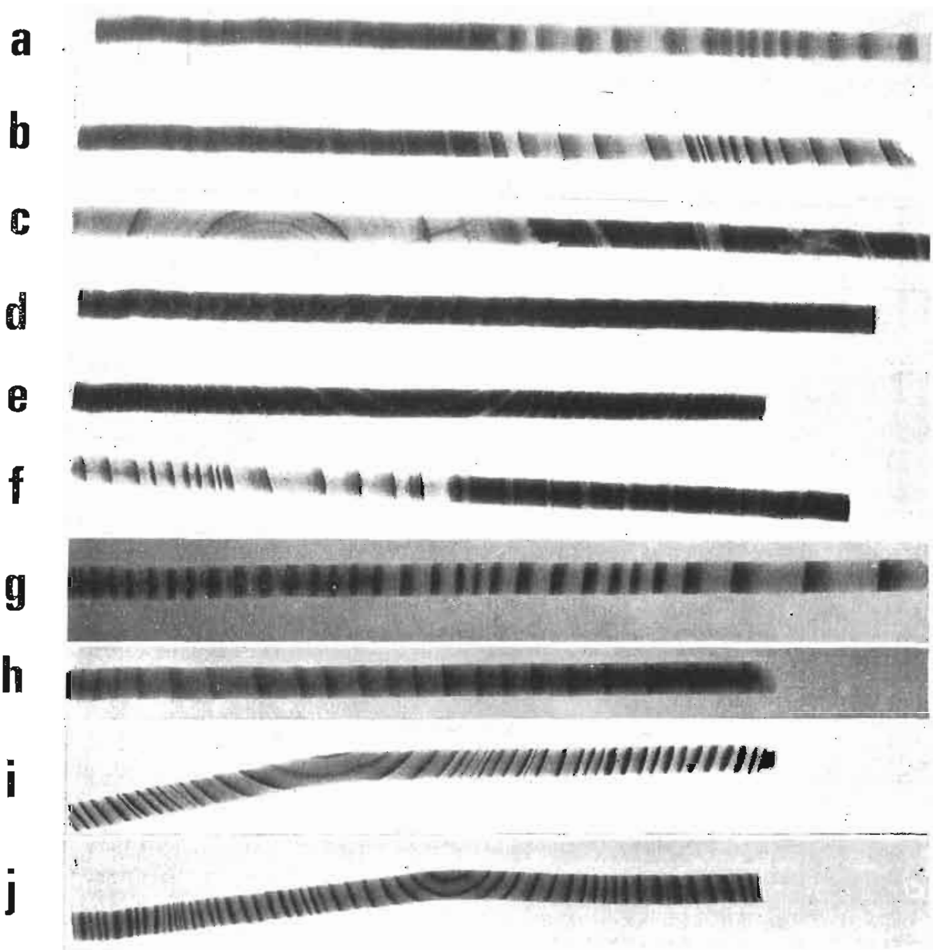


FIG. 3—The effect of the position of the cores and their moisture content on the quality of the radiograph.

a: **Pseudotsuga menziesii** with radial longitudinal side uppermost and showing a blurred image of the latewood bands.
b: Same core as (a) turned so that rays penetrated the wood longitudinally.
c: Wet green core of **Pinus radiata** in which the earlywood of the sapwood appears denser than the latewood because of its greater cell-water content. The drier heartwood on the left appears less dense.
d: **P. radiata,** as for the sapwood of (c) above.
e: **P. ponderosa,** as for the sapwood of (c) above.
f: **Pseudotsuga menziesii** in which the heartwood (left) appears less dense because it contains less water than the sapwood (right).
g. **Ps. menziesii** at 52% moisture content with heartwood showing on left.
h: **Pinus radiata** at 94% moisture content, showing correct density characteristics.
i and j: **P. ponderosa,** oven dry.

space between it and the light-sensitive layer. A sheet of perspex was laid on top of the cores and lead weights were placed on the ends to press this down. The absorption of X-rays by the perspex was slight, and constant over the whole film area.

The envelope on the X-ray film is quite firm and the small cores were likely to roll from their proper position while being placed on the film. This is caused by the air between the envelope and the film; without this gap stress marks could show on the film after storage. Cellulose tape was used to position the cores on the film to prevent them rolling over. Although the tape absorbed some of the X-rays it was almost impossible to see on the radiograph.

### *Moisture Content and its Effects on the Image*

Medical radiography uses cell water as an aid to interpretation. Free water in the cells of wood cores is undesirable for radiography. Where the mass of water in a core is greater than the mass of wood the water absorbs more X-rays than the wood. This was strikingly evident in latewood and earlywood. In a wet green core the earlywood appeared denser than the latewood because of the greater cell water content in the earlywood. (See *Pinus radiata* (Figs. 3c and 3d), *P. ponderosa* (Fig. 3e) and *Pseudotsuga menziesii* (Fig. 3f). A further complication arose in the presence of heartwood. Because there is less cell water in heartwood than in sapwood the heartwood appeared less dense as a whole, but the latewood bands showed as denser bands (see *Ps. menziesii* in Fig. 3f).

As an experiment, the cores were dried slowly, so that radiographs could be taken over a range of different wood moisture contents. The anomalies mentioned in the above paragraph are present in the green-wet cores. When the cores have between 90% and 100% moisture content (MC) (percentage of anhydrous weight), they have lost enough water for the X-ray negative to show the correct density characteristics, i.e., heartwood denser than sapwood and latewood denser than earlywood. (In Figs. 3g and 3h respectively *Pseudotsuga menziesii* is at 52% and *Pinus radiata* is at 94%.) The differences became more pronounced as the cores dried out: they were at their best (size unchanged) just above 30% MC. At this level the water has gone from the cell lumina but the cell walls are still saturated. (In Fig. 4 the part of a *Pinus ponderosa* core is shown where the X-ray film image was enlarged seven times.) Drying below 30% MC caused the water in the cell walls to evaporate and shrinkage of the core resulted, especially radially. Shrinkage in latewood and earlywood emphasised their density differences (see *P. ponderosa* in Figs. 3i and 3j). It was desirable to radiograph cores as near to 30% MC as possible, to have no shrinkage and no free water in the cells. But when *P. radiata* was at 30% MC there was not enough contrast between densities in earlywood and latewood in some trees. In medical radiography, when there is not enough contrast to show a particular organ, a radio-opaque is infused to improve contrast on the radiograph, e.g., a radio-opaque, Urografin, is infused into the kidneys. A way was therefore sought of adapting this principle to infuse a radio-opaque into the latewood of wood cores to improve contrast. At a 30% MC the bordered pits of earlywood tracheids are closed but the bordered pits of latewood tracheids are still open. Thus it was possible that when a core was immersed in a radio-opaque liquid the latewood cells would be filled with liquid and the earlywood cells would not; consequently a 30% aqueous solution of "Urografin" (sodium and methyl-glucamine

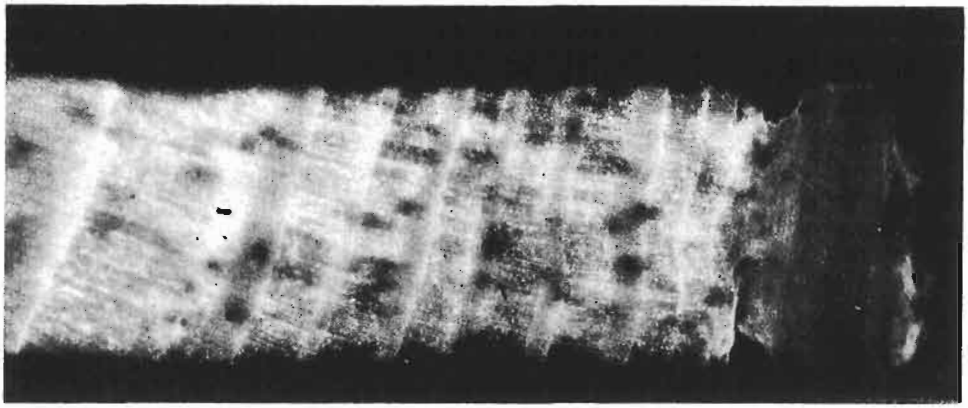

FIG. 4—Radiograph of part of a **Pinus ponderosa** core magnified seven times (dosage 25 kV, 300mA, 1.2sec.; light areas show greater X-ray absorption).

salts of 3, 5 diacetylamino-2, 4, 6-tri-iodobenzoic acid) was used. A method was then evolved for infusing *P. radiata* with Urografin but still keeping the moisture content down to 30% so that free water was not present.

*P. radiata* cores were conditioned to about 11% MC. They were then immersed for a brief period (15 to 45sec), in 30% Urografin solution, which was long enough for the liquid to enter the latewood. A shorter immersion period meant that Urografin did not enter the latewood in the centre of the core and a longer immersion had the effect of infusing Urografin into the damaged earlywood cells. The cores were then conditioned to a moisture content of at least 30%, to ensure the dimensions were approximately the same as the original ones. This was done by putting them inside an airtight container with a saturated atmosphere around them. Radiographs were taken after the conditioning. The latewood bands again showed up as lighter bands. In compression wood only the outermost, true latewood tracheids in each growth layer absorbed sufficient Urografin to show clearly on the radiographs, though the dense compression wood bands can be detected as lighter areas. Compare the *P. radiata* cores in Fig. 5

a
b
c
d
e

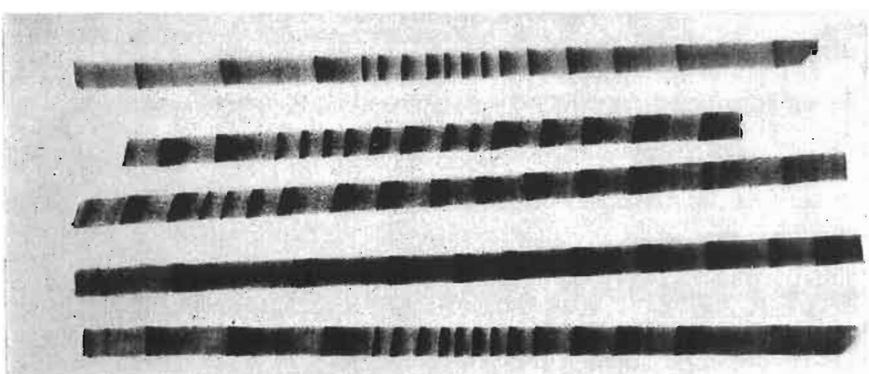

FIG. 5—Radiographs of **Pinus radiata** cores infused with Urografin, 25kV, 300mA, 1.0sec. dark areas show greater X-ray absorption. The dark latewood bands are extended to the right by the compression wood. The core in Fig. 5d was not taken at right angles to the main axis of the stem.

a-e, which were dipped in 15% Urografin for 45sec (a) and in 30% Urografin for 15, 25, 35 and 45 sec (b-e respectively), with the *P. radiata* core in Fig. 3d which was not dipped.

## CONCLUSIONS

The method used standardised the X-ray dosage to 25kV at 300mA for 1.2sec. That voltage is the lowest the equipment could give (soft X-rays) and the contrast in a wood core 5.1mm thick was not as great as could be expected using equipment capable of giving lower voltage X-rays (Polge 1966). There was, however, sufficient contrast with the inclusion of a radio-opaque in some cases, to enable annual rings to be measured more accurately and easily than by conventional methods.

## ACKNOWLEDGMENTS

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