Non-Destructive Method of Detection of Rotten State in Standing Trees and Wood Materials Utilizing Radioactive Isotopes

By

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I. Introduction

As a method of detection of the rotten state in standing trees and wood materials without their destruction, X-ray photography has been employed. However the X-ray apparatuses generally suffer from the disadvantages of high cost and of bulk, so it cannot be said that this method can be used everywhere.

The method which the authors have found to be concise and available easily in forest or anywhere is the utilization of γ-ray of radioactive isotopes such as Co^{60} or Cs^{137}. Recently artificial γ-ray sourses as a means of detecting internal flaws, cracks of metals are being used. On the same principle it was concluded after investigation that they are also highly useful for detection of the inner rot of wood materials.

The principle, apparatus for this method and results obtained are described below.

II. Principle

When a flux of γ-rays of a given energy passes through matter, in this case wood materials, the number of quanta N' in the primary beam decreases exponentially with the thickness x' of the absorbing material. It is seen that

$$N' = N'_0 e^{-\mu x'} \qquad (1)$$

where μ is the absorption coefficient of the material and N'_0 is the number when $x'=0$. The absorption in thick layers of wood materials is affected by their thickness, density and water content. In usual standing trees and wood materials if there is a rotten and corrupt

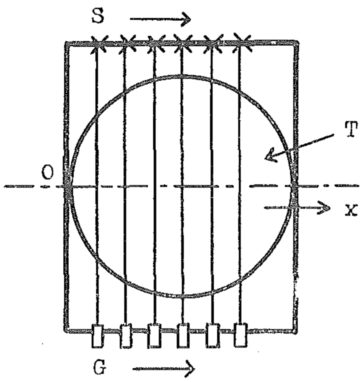

Fig. 1.
Figure showing the principle of this detecting method. S: γ-ray source, G: G–M counting Tube, T: tree trunk.

part, the density of tht part is smaller by its slightly greater porosity than the unrotten part. So the absorption of γ-ray and then the value of μ will become smaller in such corrupt part.

As seen in **Fig. 1** the γ-ray source S and Geiger-Müller tube G are positioned facing each other at the opposite sides of a tree trunk T and are moved on parallel lines at the same time and in the same direction.

If the trunk is unrotten and has a perfect circular sectional form, the counting rate (cpm) N in G–M counting tube should show the value accoroding the next formula:

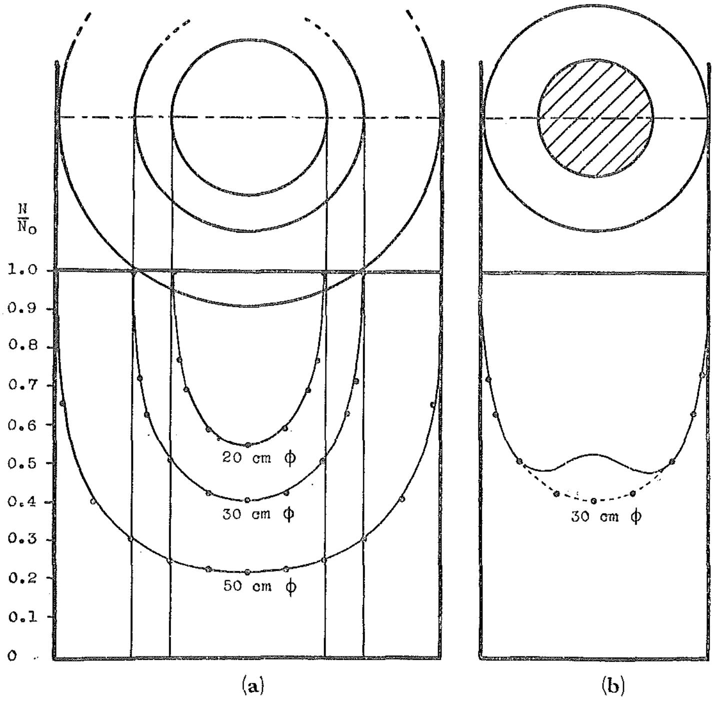

Fig. 2. γ-ray absorption curves in tree trunk having a perfect circular sectional form.
a) unrotten trunk, b) inner rotten trunk.

$$N = N_0 e^{-2\mu\sqrt{2ax-x^2}} \qquad (2)$$

where a is radius of the trunk, x is a distance from the original point 0, N_0 is a counting rate in G–M tube without absorption by the wood material.

Fig. 2 (**a**) indicates how the curve of the counting rate N varies smoothly with the thickness in unrotten trunk. Here, the ratio of N_0 to N is shown and as the diameter of tree trunk is larger, the curve becomes more flat at the central part. If the centre of the trunk is rotten, the curve should become irregular as shown in **Fig. 2** (**b**). From the curve the inner rotten state, location and extent in the tree trunk can be found. (In **Fig. 2** the value of μ is taken 0.0335 per 1 cm thickness of "Todo" fir tree which is later described).

The sectional form of the trunk, however, is not always perfectly circular, but it must be expected to be fairly irregular on the outer side. In this case the next treatment should be applied on measurements. When the γ-ray source and G–M counter are faced toward each other at points, 1, 2, $\cdots$, n in **Fig. 3**, the distances through which

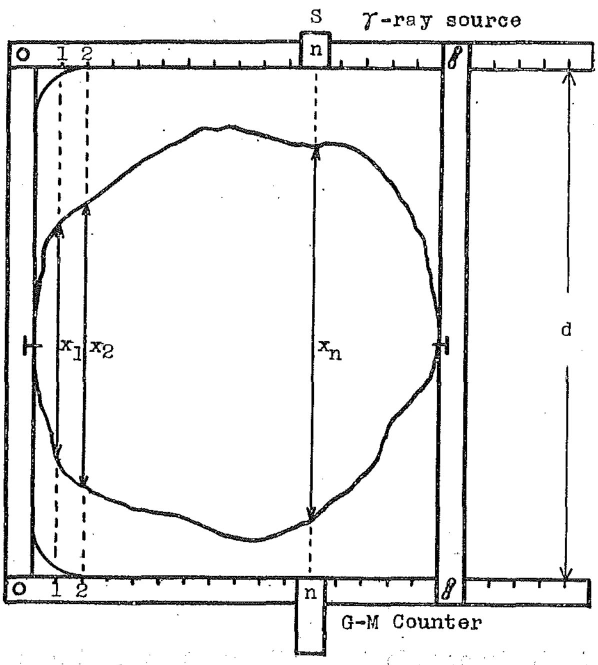

Fig. 3. Measurement for a trunk having a fairly irregular sectional form.

the radiations are passing are $x_1, x_2, \cdots, x_n$. So the counting rates obtained at these points are strictly

$$\left.\begin{aligned} N_1 &= N_0 e^{-\mu_1 x_1} \\ N_2 &= N_0 e^{-\mu_2 x_2} \\ &\cdots\cdots\cdots\cdots \\ N_n &= N_0 e^{-\mu_n x_n} \end{aligned}\right\} \qquad (3)$$

where $\mu_1, \mu_2, \cdots, \mu_n$ are coef. of absorption respectively considered at these paths. However, in order to simplify, substituting the mean counting rate by absorption per unit passing distance $\overline{N}_a$, one can calculate $\overline{N}_a$ as follows:

$$N_a = \frac{\sum_1^n (N_0 - N_n)}{\sum_1^n x_n} = \frac{n N_0 - \sum_1^n N_n}{\sum_1^n x_n} \qquad (4)$$

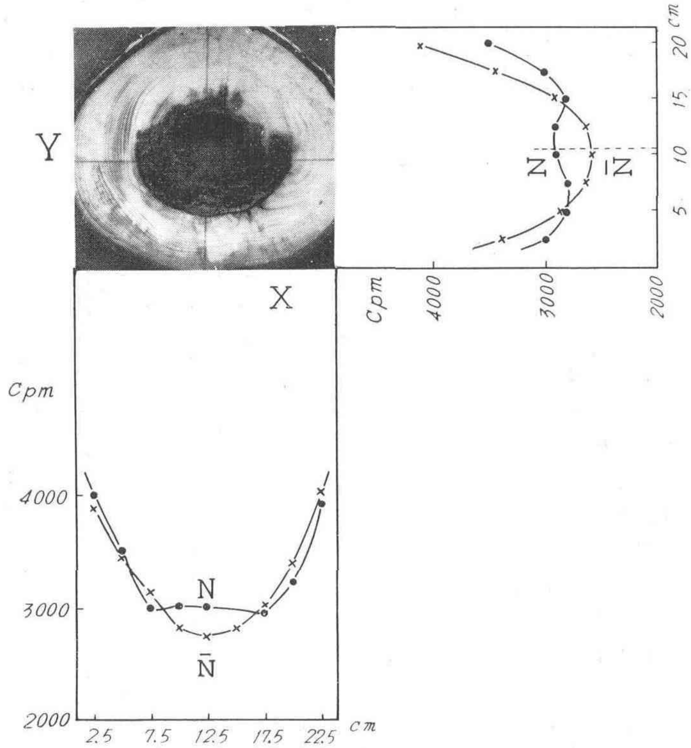

Fig. 4. An example showing the result measured from two perpendicular directions X, Y on a "Todo" fir tree having inner rotten part.

Using (4) the mean counting rates $\overline{N}_1, \overline{N}_2, \cdots, \overline{N}_n$ considered respectively at the point $1, 2, \cdots, n$ are

$$\left.\begin{aligned} \overline{N}_1 &= N_0 - x_1\overline{N}_a \\ \overline{N}_2 &= N_0 - x_2\overline{N}_a \\ &\cdots\cdots\cdots\cdots \\ \overline{N}_n &= N_0 - x_n\overline{N}_a \end{aligned}\right\} \qquad (5)$$

The actually measured counting rate $N_1, N_2, \cdots, N_n$ and the calculated mean counting rate $\overline{N}_1, \overline{N}_2, \cdots, \overline{N}_n$ are plotted on curves N and $\overline{N}$ in **Fig. 4**, and from the inspection of deviations between them one can know the inner state of the wood material qualitatively with good accordance. As shown in **Fig. 4** also, if these measurements and calculations are carried out about two perpendicular directions, X and Y, the better results are obtained in location and decision of inner rot states.

III. Experimental

1. Apparatus and results.

Co^{60} 1–3 mC or Ra 1 mg was used as the γ-ray source. It was kept in a suitable lead cylindrical case of 3 cm diameter, 4 cm height and 1 cm thickness. The radiations were measured by Geiger-Müller tube and Scale 100 Counter apparatus and Scintillation Counter in room measurement. In field measurement the G–M tube and portable rate meter were used actually; aluminium-made rules were framed by screw and nut, across the standing tree trunk. These are shown in **Fig. 3** and **Fig. 5**. The measurements have been made to date on "Todo" fir (Abies mayriana Miyabe et Kudo) and "Ezo" spruce (Picea jesoensis Carr). Similar results are obtained by the three types of measuring apparatus, (1) G–M tube and Scale 100 Counter, (2) Scintillation Counter, (3) portable rate meter with G–M tube. The results obtained by (1) and (2) have more accuracy, but a longer time for the measurement is

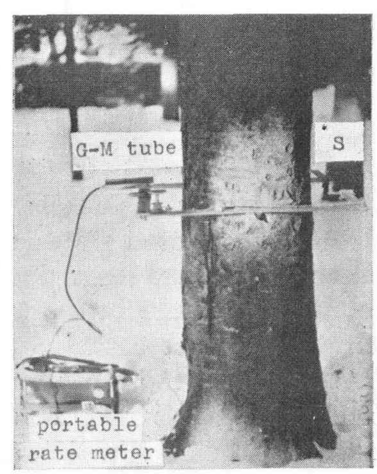

Fig. 5.
Photograph showing apparatuses and actual field measurement in natural forest in winter.

necessary. On the other hand the results by (3) are slightly inaccurate, but it is sufficiently useful in field measurement and convenient for surveying. For example, the results on "Todo" fir using (1) and (2) apparatus are shown in **Fig. 6** and the results using (3) apparatus are in **Fig. 4**. It is seen that the rotten state in tree trunk is detected easily.

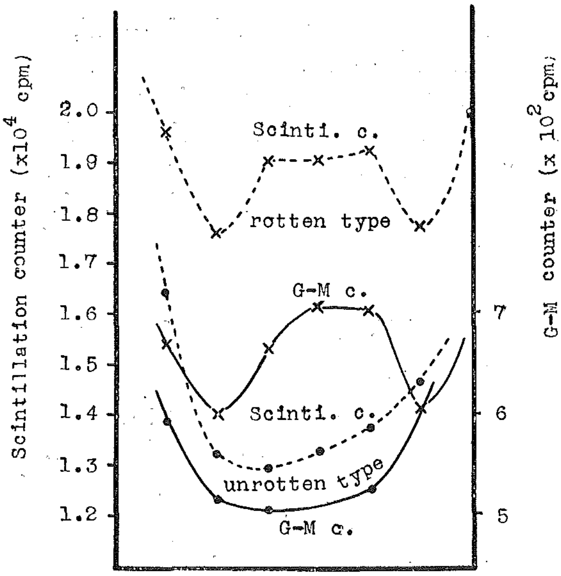

Fig. 6. Comparison of obtained curves between a scintillation counter and a G-M counter.

2. On judgment of rotten state from the curves.

The example which is seen in **Fig. 4** shows typical curves demonstrating the rotten state in wood trunk. The special features of the curves are in the large deviation of $\overline{N}$ and N at the part of minimum counting rate and in the tolerable irregularity of curve N. Another special point for notice respecting the curves is shown in **Fig. 7.** In this figure curve N has a convex part in its concave inclination. If the angle of this part α is less than 90°, it nearly certain that some rotten part exists in this tree trunk.

However, care must be taken in judgment of curves since there are large effects of wood node and water contained in trunk as discussed in the next section.

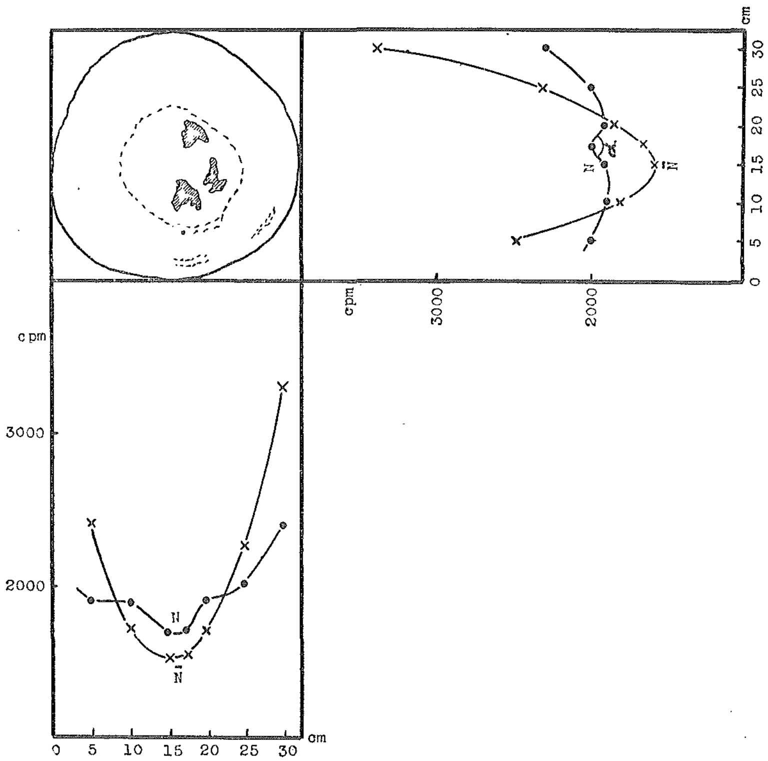

Fig. 7. An example which has a typical form for easy judgment of rotten state from the obtained curves.

3. On the effect of wood node and water contained.

Existence of node in tree trunk exerts a large effect upon the curves as shown in **Fig.** 8. The point n on the curve N in **Fig.** 8. corresponds to the place of node and the marked absorption of γ-ray is observed here because of its high density of wood substance. To avoid this node disturbance in measurement and to obtain better results, it may be recommended that tests to find out the node on the surface of trunk be made before the measurement. As a situation on a tree trunk which had the fewest node, authors decided a measuring point at the height of one meter from the earth when the diameter breast high of trunk was 60 cm. On other trees of different diameter, they determined the height for measuring from the trunk diameter using the volume table and mean tree height.

Next consideration and experiment were made on the effect which

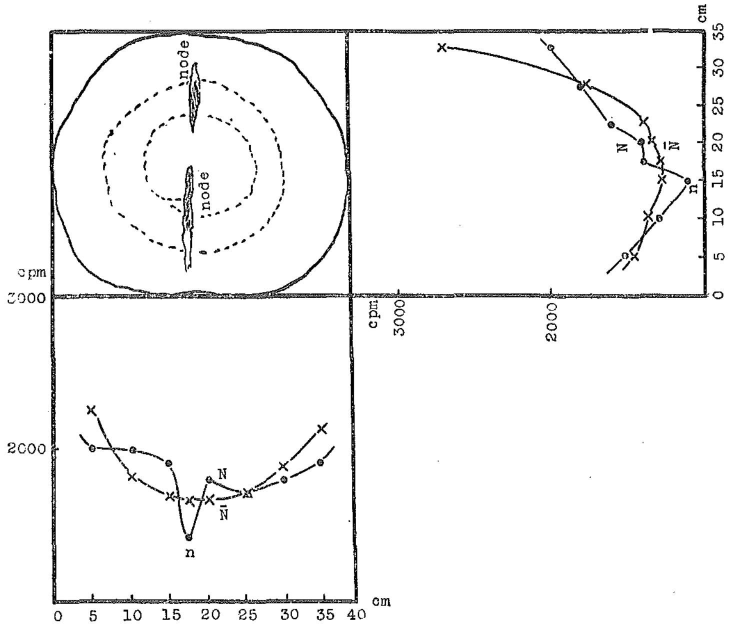

Fig. 8. Effect of existence of wood node in trunk.

water contained in standing tree may have upon the interpretation of measurement results. The method of inspection employed in this study is based on the porosity of wood material in rotten state and on the absorption of γ-ray radiations at this part. So if water filled this interval of the porous part, it may well be that the result obtained from the measurement will become ambiguous, because the absorption of γ-ray by water is fairly large. According to the calculation by the authors on standing trees, the absorption of γ-ray was 55% by wood material and 45% by water in it (where water content in "Todo" fir tree was taken at about 50%, the cellulose content at 27.5%, lignin content at 12.5%. It waw taken as a basis of calculation that the absorption of γ-ray was proportional to 3 orders of atomic number of those constituent elements).

To investigate the actual effect of water contained, an experiment was carried out with a log, which had an inner rot, immersed in water. Thus, the water content was altered variously. The results obtained by such a treatment are shown in **Fig. 9**. Curves I and II are of 15% and 31% water content respectively and have similar values, but curve III which is 56% water content has a lower value of counting rate because of the effects of absorption of water. From such a curve it becomes difficult to find out the inner rot state.

However, in the natural standing tree such a high water content state is unusual with the exception of the periphery of trunk and water-rich wood in marsh, so it has been concluded that the effect of water does not impede the judgment of the inner state of trees in ordinary field measurements. The effect of water contained in periphery of trunk has been shown already in many examples, **Fig. 4, 7, 8** and **9.** In these figures the measured curve N is fairly lower than mean value curve $\bar{N}$ at the periphery of trunk, and as it is well known the periphery of trunk is more rich in water than the central portion of the tree, the results above shown can be explained without difficulty. Using such data one can also observe the state of water distribution in wood materials and water-rich wood. On these problems further studies are being curried on by the authors.

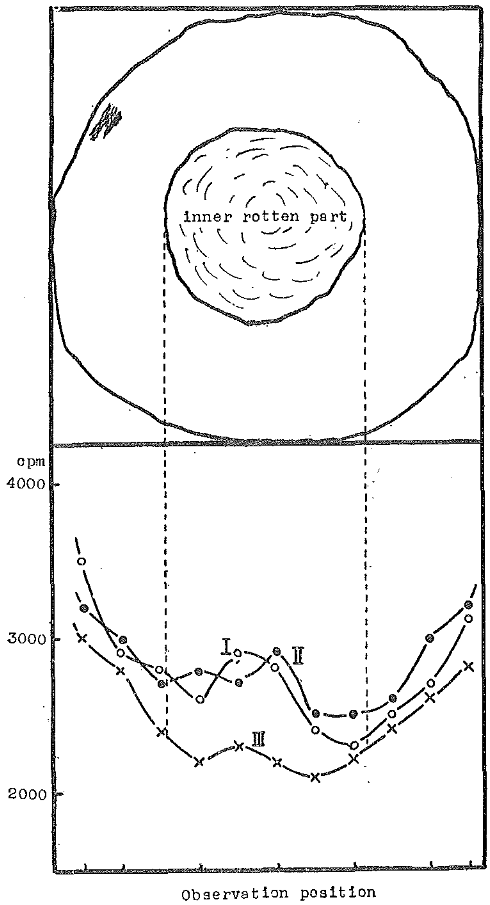

Fig. 9. Effect of highly water content in trunk. I : 15%, II : 31% and III : 56% water contained.

4. About the obtained performances on standing trees in field, hit-percentage.

Taking care as to various points as above described, the authors have been examined practically 34 "Todo" fir trees in a natural forest using their apparatus. After the measurement was over, the tree was cut down at once at the measuring height. Comparing the cut end of the tree with the estimation from the measured curves good hit-percentages have been obtained as follows: 100% (Observations above 0°C) and 80% (Observations below 0°C) for unrotten tree samples, 93% (Observations above 0°C) and 75% (Observation below 0°C) for rotten tree samples. As the reason of lowering of hit-percentages at low temperature (below 0°C) it is considered that the G–M tube having alcohol as quenching gas was used in this reserch. In this respect apparatus can be improved by using halogen gas filled counter tube or scintillation counter.

The time that is necessary for such a measurement of one tree trunk in field is about 10 to 15 minutes; it is considered that that time may be shortened by using a high stable rate meter or survey meter having scintillator and by skilled handling.

IV. Summary

γ-rays of radioactive isotope Co^{60} were used in detection of rotten state in standing trees and wood materials. The method of detection and the results obtained were as follows:

1. Measurements of counting rates (rpm) of γ-rays passing through wood substances were made at each observation position from left to right as in **Fig. 1.** Next, a curve of the counting rates for each position was drawn. From the form of curve the inner state of wood materials was known.

2. In general about the standing tree with irregular peripheral form a calculation of mean counting rate by absorption per unit passing distance was made as shown in Eq. (4). Using this result the mean counting rate $\bar{N}$ and actually measured counting rate N for each position were plotted as in **Fig. 4.** By inspection of deviation between them and the forms of these curves on many trees, a general rule was formulated for judgment whether a standing tree had inner rot or not.

3. Effects of wood node and water contained in tree trunk on the obtained curves were investigated. It was concluded that the former effect could be excluded by selecting a suitable measuring height without node, and that the latter effect does not impede the judgment of the inner state of tree trunk within the limits of these experiments, because in natural standing trees such a high water content as to effect the measurements is not usually found.

4. Good results have been obtained in hit-percentages of judgment on inner rot state of 34 natural standing trees as follows: 100%

(Observations above 0°C) and 80% (below 0°C) for unrotten samples, 93% (above 0°C) and 75% (below 0°C) for rotten samples. It was considered that the reason of lowering of hit-percentages at lower temperature was in the use of G–M counting tube having alcohol gas.

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