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Development
Program**

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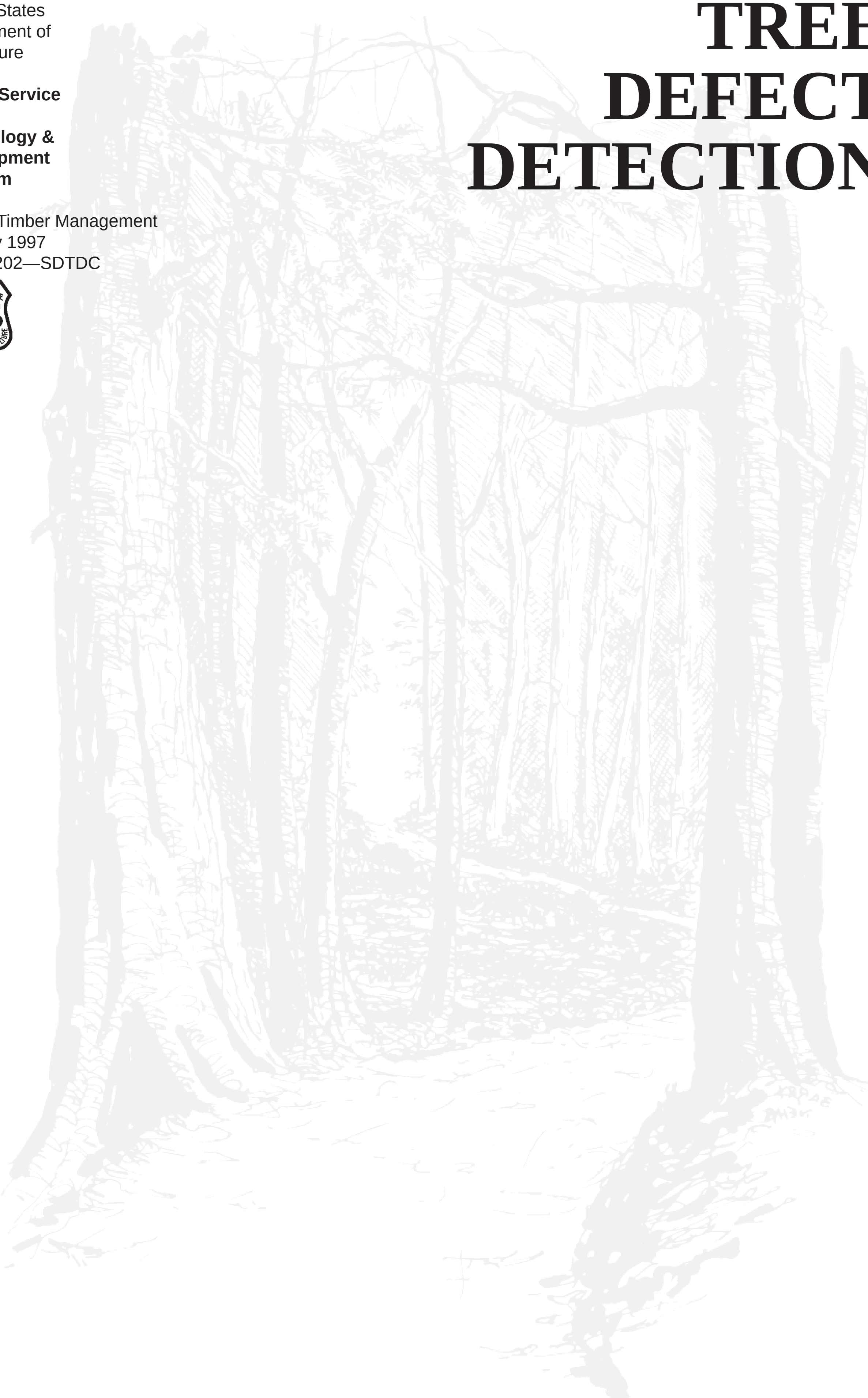
# TREE DEFECT DETECTION



# TREE DEFECT DETECTION



**Skip Garrett, P.E., Senior Project Leader**
*San Dimas Technology & Development Center*

**January 1997**

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## INTRODUCTION

For centuries, woods workers have wished for a way to know what the inside of a particular tree might look like. Until recently, the only way to determine the condition of the wood in a standing tree, and consequently what products could be produced from it, was to cut the wood into sections and inspect it. Even then, internal defects could be hidden from view.

The ability to quantify defect or decay in timber stands prior to management decision-making could have significant impacts on silvicultural and land use planning as well as the appraisal and marketing of timber sales. Traditionally, defect has been estimated subjectively with varying success. The type and amount of defect determines the potential for and value of a particular finished product. Partial cutting requires the designation of residual trees to meet visual, silvicultural, or other biological needs and potential-product values can be used to determine which trees to leave in a stand. Better estimates of defect leads to better forest management decisions and enhanced revenue.

Critiques or reviews by the wood products industry of Forest Service timber sale programs often site concerns relating to miscruising of defect. An increase in the number of lump-sum sales has made the estimation of defect even more important. Effective tools and techniques to accurately survey and characterize the extent of defect in a timber stand would be beneficial.

The goal of this San Dimas Technology & Development Center (SDTDC) project is to develop tools to help Forest Service timber personnel identify and quantify defect in standing trees. The first objective was to gather information and perform a market search for instruments or devices that can detect defect in trees. The purpose of this report is to summarize the findings from efforts supporting this objective.

## DETECTING DEFECTS

Tools to help detect and characterize defect in trees would be extremely useful within the Forest Service. The ability to sense defect or non-sound wood in trees would assist product designation and grading. Den trees or wildlife trees, or trees that potentially fall into these categories, could be identified. Hazard trees near logging sites or recreation areas could be evaluated and removed only if necessary. Hidden metal or ceramic foreign objects could be potentially identified prior to the timber sale or falling operation. A device is needed that would be portable, lightweight, rugged and weather resistant.

Defect detection can be broken into two categories: invasive and non-invasive. This means the object being inspected for defects is either penetrated or not. For trees, further definition is required for these terms relative to the xylem (the wood) and the bark (the protective outer layer). Defect detection devices for trees will be either xylem invasive or xylem non-invasive. This definition is based on the fact that for potential wood products, penetrating the xylem could cause damage and affect the value of that piece, while penetrating only the bark usually would not.

## XYLEM INVASIVE TECHNIQUES

### Increment Borer

Xylem-invasive techniques for detecting defects in trees will involve penetrating and damaging the wood. The increment borer is a common forestry tool that falls into this category. These devices cost about $100 to $150. The tool is used to extract a core from a tree so the core can be visually inspected and measured to determine tree growth rate, age, and soundness. Borers are similar to a drill bit except they are hollow. A range of sizes are available providing wood sample cores with diameters ranging from 0.169 inch (4.3mm) to 0.500 inch (12mm), with 0.200 inch (5.15mm) the most common size. The cutting edge is pulled through the wood by the threads allowing a core to be removed.

Increment borers are screwed into the tree by hand and take a considerable amount of time to use. The ease at which the borer penetrates the wood depends on wood hardness and friction properties, as well as the strength and capability of the user. Borers are specifically designed and engineered for use with supplied handles and often have warnings that the warranty will be voided if used with power drills. However, it is possible to develop a borer for use with a portable electric drill which would speed up the process of collecting core samples. Also, by measuring the torque required as the borer or a drill bit moves through the wood, it may be possible to estimate the density and strength of the material and determine the amount of decay present.

Determining the type and extent of the defect involves close visual inspection by knowledgeable people and involves boring more than one hole and possibly many holes around the circumference at different angles and at various heights. A torque-measuring devise also requires multiple drill holes. The only decay that will be detected is at the point of drilling - decay pockets could be missed by a fraction of an inch and thereby avoid detection.

### Borescope

Borescopes are commonly used for remote visual inspection (see figure 1). They are precision test and inspection tools employed to examine internal structures in manufacturing processes, quality control inspections, preventative maintenance, hidden damage or corrosion assessment, and as an aid in research and development projects. These tools make visual inspection simple and reliable. Borescopes provide bright, sharp, full-color images and allow probing inside pipes, structural voids, and other inaccessible places. Both rigid and flexible probes are available. Flexible probes can be snaked through labyrinths inside machinery such as engines, turbines, pumps, and valves.

*Figure 1. Borescope.*

A wide range of rigid and flexible borescopes are available with different diameters, working lengths, directions of view, and fields of view. A standard borescope kit includes the scope itself, a light source, and a light transmitting cable. The price of a kit starts at $1,000 and goes up from there depending on capability and quality. Accessories including small video cameras, zoom lenses, VCRs, and monitors can be added for video documentation purposes.

Borescopes can be used to visually inspect the inside of a tree for defect. This requires drilling a hole, or several holes, into the xylem. Borescopes with diameters as small as .047 inch (1.2mm) are available, allowing the holes to be very small. Like the increment borer, borescopes require a knowledgeable operator and may require multiple holes at various angles and heights to find and define defect in trees.

## Wood Hardness Tester

The Forest Engineering Research Institute of Canada (FERIC) has developed an advanced prototype wood hardness tester to assist the Alberta, Canada forest industry make accurate surveys of decay levels in aspen stands. The tester has a spring-loaded needle that penetrates the wood to a depth related to its hardness (see figure 2). The penetration needle is .062 inch (1.6mm) in diameter and can penetrate up to 1.57 inch (40mm). Measurements are taken along two perpendicular axes of the exposed surface of a stem sample. The readings are indicators of wood hardness and are used to determine the extent of the decay (defect boundary) and, using a standard formula, the volume of defect. Developmental field tests showed it was possible to clearly distinguish nonpulpable decayed fiber from pulpable decayed fiber. (It is important to note developmental testing was done on samples of the stem cut from felled trees, not standing live trees.)

*Figure 2. Wood hardness tester.*

FERIC designed their prototype to be light, compact, rugged, resistant to moisture and dirt contamination, and easily manufactured. As this version of the wood hardness tester approaches the production stage, FERIC is considering using integrated circuits and installation of a microprocessor to reduce the size of the electronics package and improve the tool's accuracy. At this time, the possibility of adapting this tool to other tree species appears promising. Changes to the design such as the length and diameter of the penetrating needle or to the characteristics of the main spring may be necessary. Other design changes and developmental work may be necessary for use on standing trees rather than sections of the tree.

## Decay Detecting Drill

The Silbert Instruments model DDD200 Decay Detecting Drill is available from Shannon Technology of Phoenix, AZ. The unit costs approximately $9,000 and additional drill bits cost about $100 each. The DDD200 instrument uses a 0.040 inch (1mm) diameter drill, 8 inches (200mm) long to probe the wood (see figure 3). At a light, constant drilling pressure (the operator judges the correct amount of force to apply by monitoring a series of light emitting diodes (LEDs) mounted on the instrument), the narrow, flexible, telescopically supported drill bit, rotated at high speed, rapidly penetrates hard or soft wood. A graphic record of the rate of penetration is produced on a slowly rotating drum and decay is detected by a sudden change in bandwidth between the lines on the trace record.

*Figure 3. Decay Detecting Drill.*

SDTDC did not test this device. The manufacturer claims that it will take about 30 seconds to drill one hole in a typical yellow pine tree and another 45 seconds to prepare for a second sampling and that the rechargeable battery pack is capable of providing a full day of sampling. The complete instrument with all accessories (including extra drill bits, battery pack and charger, plotter paper, metal detector, small tools, and transport case) weighs 35 pounds (16kg). Like the other invasive techniques, this tool will require a knowledgeable operator and may require multiple holes at various angles and heights to defence the extent of defect.

### Shigometer

The Shigometer is a battery-operated, lightweight field ohmmeter developed over many years by Alex Shigo of the USDA Forest Service Northeastern Forest Experiment Station (see figure 4). This instrument generates a pulsed direct current and registers (in thousands of ohms) the resistance to the current as it passes through the wood or bark. Before wood begins to decay, it becomes wetter and contains more ions, which will directly affect the resistance to current. The resistance is also affected by temperature and the Shigometer will not work on frozen wood. Internal decay is detected with the use of a twisted-wire probe. A 0.1 inch (2.4mm) hole is drilled into the stem section to be measured and electrical resistance readings are monitored as the probe is inserted. In sound wood tissue, relatively high resistance readings are obtained and as wood becomes discolored or decayed, electrical resistance progressively decreases.

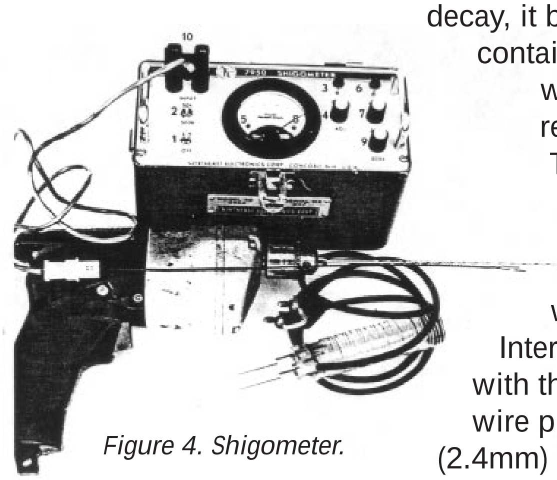
*Figure 4. Shigometer.*

SDTDC did not test the Shigometer, but extensive research has been conducted concerning its uses and limitations. It is agreed that the Shigometer is a valuable tool for determining the current vigor of trees and forests (cambium testing), but since resistance changes begin prior to damage caused by decay (xylem testing), the Shigometer technique for decay detection requires careful application and interpretation. Basic biological knowledge of the material being evaluated is essential. Skill in instrument use increases with greater awareness of local biological principles and practice with the instrument.

The Osmose Wood Preserving Co., Inc. of Buffalo, NY sells a version of the Shigometer that uses a digital ohmmeter.

## XYLEM NON-INVASIVE TECHNIQUES

### X-Ray

X-rays are a form of electromagnetic radiation, similar to light but of shorter wavelength, capable of penetrating solids. X-ray scanners create x-rays using electrical power - usually a great deal of electrical power (on the order of hundreds of kilowatts) - to penetrate sizable objects including logs. The need for substantial power and image enhancement and analysis hardware and software, make these systems non-portable. Typical x-ray scanners are similar to those used for airport security and for use on trees would require a large portable power supply. SDTDC conducted a demonstration test on a prototype x-ray scanner developed by MacMillan Bloedel Research Ltd. of Canada. (Refer to SDTDC Report 9224-1206 of December 1992 titled “Detection of Foreign Objects in Logs”.) MacMillan Bloedel developed a x-ray system with image enhancement and analysis software that successfully improved sawmill yield by optimizing saw patterns based on the location of knots in the log. SDTDC concluded the x-ray system, with the proper custom imaging software, could be used to detect foreign objects in logs at the mill. However, at the present time, x-ray systems for use on live trees are neither portable nor practical.

## Gamma Ray

Gamma rays are high-frequency, highly energetic, penetrating radiation similar to x-rays. The difference is gamma rays are emitted from the nucleus of a radioactive atom. This means gamma-ray testing devices are portable and do not require a power source. They are used in the non-destructive testing industry to inspect large objects or structures (that cannot be x-rayed) for voids or defects. The amount of radiation passing through an object is based on the density of the material it passes through. The image is recorded on x-ray film.

Inspection or test devices using gamma radiation to penetrate solid objects utilize a radioactive substance like iridium-192 or cobalt-60 to produce the penetrating rays. The radioactive substance is held inside a shoe-box-sized container that is heavily shielded with lead and weighs about 75 pounds (34 kg). The container has a remote controlled aperture to allow radiation to escape through a flexible, shielded hose. The amount of radiation exposure is controlled by the distance from the hose nozzle to the test object and the amount of time that the aperture is open. The amount of radiation needed is based on the density of the test object and the sensitivity of the x-ray film used.

SDTDC conducted a demonstration test of gamma-ray technology with the help of MQS Inspection, Inc. in Santa Fe Springs, CA. Four logs ranging in size from 16 to 24 inches (0.4 to 0.6 m) in diameter with various amounts of decay, defect, and imbedded foreign objects were provided for gamma-ray inspection. Sheets of x-ray film were attached to the logs with bungee cords. A skilled operator, with extensive training in handling radioactive substances used a combination of expertise and trial-and-error to produce images of sections of the logs on 14 by 17 inch (0.36 by 0.43 m) x-ray film. Pockets of decay, voids, knots, and nails were seen when the x-ray film was viewed on a light table.

Gamma-ray inspection is somewhat expensive. X-ray film costs 9 cents per square inch (645 $mm^2$) or about $22 for a 14 by 17 inch sheet (0.36 by 0.43m). A radiation source in a properly shielded container and a skilled operator are also required. The demonstration test of four 6-foot-long (1.8m) logs took several hours and required 15 x-ray images at a cost of $500.00. The test took longer because MQS had no experience working with wood. The testing was conducted inside a chamber with very thick concrete walls. Outdoor use would require people to move back at least 200 feet (61 m) from the radiation source for each “shot.”

## Ultrasound

Ultrasound is a collective term for all sound-like waves whose frequency is above the range of normal hearing. The human ear can detect sound frequencies from about 30 to 20,000 hertz, so ultrasound frequencies are in excess of 20,000 Hz.

Ultrasonic test devices measure the time of travel of ultrasonic pulses through test materials to evaluate quality and detect flaws or irregularities. Ultrasonic testing of concrete for defects such as cracks and voids is an established and well-accepted practice. In concrete structures, measurement of ultrasonic pulse velocity are used to evaluate piles, pillars, panels, floor slabs, beams, and pipes. The depth of surface cracks can be estimated and the severity and extent of deterioration due to cracking, fire, and freezing can be evaluated.

*Figure 5.*
*Pundit Pulse Velocity Meter.*

The Pundit Pulse Velocity Meter is a popular instrument in the non-destructive test community (see figure 5). It is a portable device weighing about 17 pounds (7.8 kg) and is equipped with a 54kHz emitter and receiver transducers and a digital display which shows pulse travel time in microseconds. The price is about $4500 and thousands are in use around the world. The manufacturer's brochure claims it can be used to locate rot and other defects in standing trees, utility poles, and pilings. This instrument is available from the Gilson Company, Inc., Worthington, OH. (800-444-1508).

SDTDC conducted a demonstration test on the Pundit with the help of CH&A, a non-destructive testing outfit, in San Diego, CA. The same four logs used in the gamma-ray demonstration were used. CH&A personnel had not had much experience with wood and none with logs so some trial-and-error was required. The testing of the four 6-foot-long (1.8m) logs took more than two hours and cost $500. The demonstration showed ultrasonic pulses took longer to penetrate the wood with cracks or rot but was unable to quantify what was present. While the results of the testing were not excellent, it was proven that ultrasonic techniques could be used for defect detection in wood. Further research has shown these techniques work better in live wood than in dry logs.

## ARBORSONIC DECAY DETECTOR

The Arborsonic Decay Detector (ADD) is the only device found by SDTDC specifically designed to detect decay in trees. The ADD costs approximately $4600, depending on the exchange rate. Originally designed in Japan 10 years ago to detect decay in telephone poles, it was modified two years ago following an initial idea from the British Forestry Commission's Research Station to assess live trees. Since then it has been developed and tested by the manufacturer, Fujikara Europe Ltd. of Wiltshire, England (see figure 6).

*Figure 6. Arborsonic Decay Detector.*

The ADD device itself is about the size of a car radio, with two leads to a small transmitter and a receiver (the transducers). The transmitter and receiver are placed on opposite sides of a trees trunk; the transmitter "fires" an ultrasonic pulse through the xylem to the receiver and the elapsed time is displayed digitally on the screen in microseconds. The pulse signal has a velocity of approximately 2000 meters per second via the cell walls in the tree. The velocity makes calculations simple when the tree diameter is measured in metric units. The diameter in millimeters is divided by two to give the expected reading in microseconds for a sound tree. If the tree is sound, the ultrasonic pulse can pass in a straight line to the receiver giving a predictable reading. If the tree is decayed, ultrasound cannot pass though decay and will have to pass around it, taking longer and giving a higher reading.

Using the ADD is simple. First, measure the diameter of the tree at the test point using the metric D-tape provided with the unit. The diameter in millimeters is divided by two to get the expected reading in microseconds for a sound tree. Then, two plugs of bark approximately 35mm (1.4 inches) in diameter are removed from opposite sides of the tree using a hammer and punch. This allows good contact with the wood and "ultrasonic coupling gel" (petroleum jelly). The gel is used to improve contact by filling in voids on rough xylem surfaces. (It is possible on some smooth-barked trees to leave the bark intact.) The two transducers are placed against the wood which actuates them for a short time before the time reading is displayed.

If the time reading is close to what was expected for that diameter, then the tree is sound (at least at the test point location). If the reading is up to 50% higher than expected, this indicates the presence of incipient decay. Readings more than 50% higher indicate advanced decay. At this point further testing is required to determine the extent of the decay. This is done by conducting another test 90 degrees from the first test, and then doing what the manufacturer calls quadrant testing. This means taking four more readings (using the same bark holes) with the transducers 90 degrees to each other (i.e. 12, 3, 6, and 9 o'clock). From these readings the extent and location of the decay can be determined.

Trees that are totally rotten show a reading of 999. The ADD can handle trees up to 55 inches (1.4 m) in diameter. It comes with all needed accessories and the only consumables are petroleum jelly and batteries, which are both commercially available and inexpensive. The same testing parameters can be used on any type of tree at any time; seasonal variations and moisture content have little effect. Also, since ultrasonic signals travel by way of the cell walls, and cell wall material is similar in both soft and hard woods, these signals are not a factor in this application.

SDTDC tried this machine on several trees, both sound and with various types of decay. These trees were later felled for visual inspection. Each time the ADD proved correct. It confirmed suspicions or helped quantify the amount of defect where there were external indicators. However, the ADD also found decay in a few trees that knowledgeable foresters had inspected and judged sound.

In a perfect world, it would be possible to place the transducers on the bark and send the signal through the tree. However, with thicker bark, the ultrasonic signal is absorbed by the pulpy bark material. Bark plugs can be removed rather easily and are replaced mostly for cosmetic reasons, but this will also help protect the cambium layer from moisture loss and parasites. The cambium can regenerate if it does not dry out and therefore the wound will only be temporary. This minimal wounding is probably acceptable, especially when compared to the quality of information obtained by ultasonic testing.

The Arborsonic Decay Detector is simple to use and interpret; it takes about 10 to 15 minutes to test each tree at the stump. When no defect is found in the stump, move to the next tree. If defect is detected, further testing is required to determine the extent of the defect. This device must be used by personnel competent in their understanding of trees and decay types/ mechanisms. The ADD relies on the user to identify the test points which are selected using careful visual examination of the tree and background knowledge of local conditions.

## CONCLUSION

In today's technology conscious world, opinions that are not supported by scientific fact are often disputed. If reliable and accurate equipment that can detect and define tree decay is available, professionals will be expected to utilize such equipment in order to support and justify their decisions. Therefore, further development and testing of tree-decay-detection devices is warranted and needed.

This publication is the result of a preliminary market search and product review, conducted by the San Dimas Technology and Development Center, of potential devices to detect defect in trees, and improve the management of National Forest resources.

The Defect Detection project was initiated by the Timber Sale Technology Committee. This group meets annually to discuss field needs in the area of timber sales, ranging from initial sale layout to the transport of forest products. Work is prioritized and future projects are developed to address needs which appear to be multi-regional in scope.

Field personnel are encouraged to contact their Regional representative on this committee if they see a need for the distribution of information, the application of new technology, or have ideas for new product development.

The current Timber Sales Technology Committee representatives are:

| | |
|---|---|
| Dan Castillo | R01A |
| Don Martinez | R02F03A |
| Alan Lucas | R03A |
| Gerry Thompson | R04A |
| Alan Quan | R05F15A |
| Rick Toupin | R06C |
| Jim Sherar | R08F11A |
| Tom Peterson | R09A |
| Don Golnick | R10A |
| Rod Sallee | W01C |

BOB SIMONSON, W07A
Program Leader, Timber

**PROJECT PROPOSAL**
**USDA Forest Service**
**Technology and Development Program**

SDTDC solicits input from the field for suggestions for future projects. Your suggestions are important to us, so please take a few moments to complete this form and return to the address provided.

Project Originator: Name ______________________________ Date ________________

Title ________________________________________________

Unit ________________________________________________

Mailing address ________________________________________

DG address _____________ Telephone ________________________

**Project Title:** ______________________________________________

**Current Problem/Need**
Describe how work is currently being done; current problem/need, location; why improvement is needed.

**Proposed Solution**
Describe your concept of the end product, i.e., new equipment design, video production, handbook, etc.

**Potential Benefits**
Describe how this product will improve safety, resource management; increase efficiency, customer satisfaction, productivity; reduce cost, time.

- affix here -

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USDA, Forest Service
SDTDC
Attn:Timber Program Leader
444 E. Bonita Avenue
San Dimas, CA 91773-3198

**User Feedback Survey**

User Name (optional) ________________________________
Title___________________________________________
Unit __________________________________________

**Tree Defect Detection**
**#9724 1202**

| Benefits | YES | NO | Amount |
|---|---|---|---|
| Improves safety | | | |
| Saves money | | | |
| Saves time | | | |
| Increases efficiency | | | |
| Other | | | |

How effective or relevant is this information?

What would you change?

General comments: