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General Technical
Report PSW-36

Measuring Moisture Content in Living Chaparral:

a field user's manual

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PREFACE

In 1977, the Forest Service, U.S. Department of Agriculture established a research and development program at this Station titled "Vegetation Management Alternatives for Chaparral and Related Ecosystems." This 5-year program, headquartered at Riverside, California, is an intensive effort to develop, test, and demonstrate a wide range of options for maintaining or increasing the productivity of chaparral and related ecosystems in southern California.

This manual is based on a report by the Physical Dynamics Corporation, Bellevue, Washington, as part of its contract with the program. It is intended for field use. Supplementing the manual are two short slide-tape training programs that describe the procedures for collecting and drying chaparral samples.

Comments about the manual should be directed to:

Program Manager
Chaparral Research and Development Program
Forest Fire Laboratory
4955 Canyon Crest Drive
Riverside, California 92507

Copies of the slide-tape training program may be ordered from:

National Audio-Visual Center
General Services Administration
Washington, D.C. 20409
Request: Fuel Moisture Sampling—A01013-5500 (contains two programs); price: $36 U.S. Make check, money order, or purchase order payable to *National Archives Trust Fund.*

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This manual standardizes procedures for determining the moisture content of living chaparral for use in a proposed statewide system of monitoring living fuel moisture. The manual includes a comprehensive examination of fuel moisture variations in California chaparral, and describes techniques for sampling these variations. Equipment needed to sample and determine living fuel moisture is discussed. Detailed procedures for collecting living fuel samples and processing the samples for moisture content are provided.

Retrieval Terms: fire management; chaparral; prescribed burning; fuel moisture; living wildland fuels; chamise; manzanita.

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The strong influence that variations in the moisture content of living material in chaparral has on fire behavior has long been recognized by wildland fire managers and fire scientists. However, uniform and valid techniques for measuring living chaparral moisture and incorporating this fuel parameter into the various aspects of fire management have not been generally available for field use.

This manual describes the factors affecting living chaparral moisture, the requirements for establishment of fuel moisture sampling areas, and the procedures for collecting fuel samples and determining their moisture content using conventional laboratory drying ovens.

The basis of living fuel moisture determination has been a recurring problem, frequently appearing in the form of a question as to how the fuel can have more than 100 percent moisture. Moisture content of many substances is given as the proportion of water in the substance, and therefore must always be less than 100 percent. However, it is more appropriate to express the moisture content of wildland fuel in relation to dry weight, since it is the dry material that provides the heat to evaporate the water so that the fuel will burn. Also, fuel loading is expressed in terms of dry weight; if wet weight were used, adjustments in the energy potential would have to be made for moisture content. Consequently, expressing moisture content as percent of dry weight is consistent with the method of measuring fuel loading.

Although living fuel moisture is a major influence on fire in chaparral, it is only one of several fuel and environmental parameters affecting fire behavior. Consequently, living fuel moisture alone cannot be used to evaluate adequately potential fire hazard and fire behavior. Used in conjunction with the effects of other fire behavior influences, however, knowledge of the level and trends of living fuel moisture can greatly improve the accuracy of appraisals of fire hazard and the prediction of fire behavior for use in fire control, fire prevention, and prescribed fire activities.

Typically, 55 to 75 percent of the total standing fuel in mature chaparral is living material. The amount of moisture in this living material is almost always much greater than that in the dead material during the fire season. Because of its high moisture content, living fuel will seldom burn by itself in its natural arrangement. Heat from burning dead fuel is needed to dry the living material sufficiently to allow it to burn and add to the heat output of the fire. Since a relatively small amount of dead fuel is usually uniformly distributed through the chaparral shrub crowns, it does not burn well by itself under normal conditions; the distance between dead fuel elements is too great for intense combustion. For a hot fire to develop in chaparral, then, a large part of the living material must also burn along with the dead fuel. But the combustibility of living fuel is strongly influenced by its moisture content, and this varies greatly with time and place. Consequently, the moisture in living fuel is a major determinant of chaparral fire behavior. It may sometimes determine if the chaparral will burn at all.

MOISTURE VARIATION IN LIVING FUEL

The moisture content of living chaparral in California follows a distinctive annual pattern *(fig. 1)*. When spring growth starts, the moisture content of the new plant material rises rapidly to a peak, often to more than 200 percent of its dry weight—for some species, to greater than 300 percent. The moisture in older foliage and twigs also increases during this period, although to a lesser degree than for new growth. In larger shrub stems and trunks, the increase in moisture is relatively small. Consequently, most of the change in moisture that affects fire behavior is in the foliage and small material. As the long, nearly rainless season progressively sets in, the moisture content of the shrubs decreases, reaching a minimum when the shrubs become dormant in the fall. The moisture then remains at a relatively low level until growth resumes in the spring.

Although the moisture content of living chaparral usually follows the same general annual pattern, significant variations occur between years and from place to place. Changes in moisture content are related to the physiological activity of the shrubs, and this activity is greatly influenced by soil moisture and the temperature of the soil and the air. When precipitation is deficient in winter and early spring, less new growth is

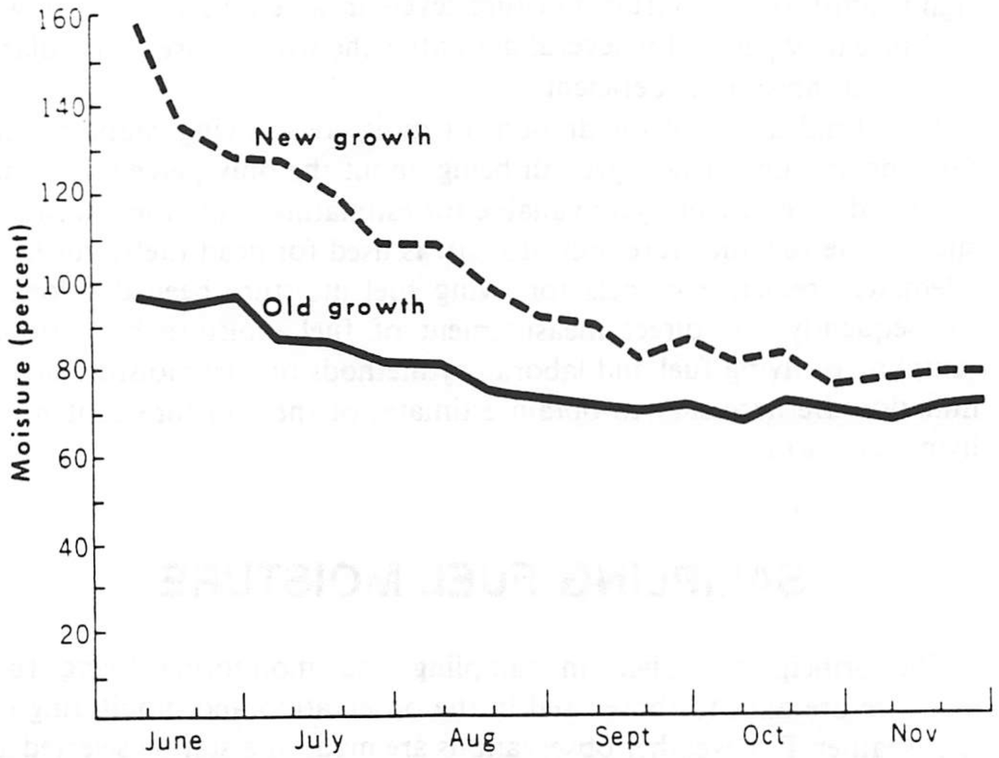

Figure 1 — Twelve-year average seasonal variation in chamise moisture content in the Angeles National Forest.

produced and peak moisture in the living material is less than in other seasons when soil moisture is more plentiful. If soil moisture deficiency persists through the summer, shrub moisture drops more rapidly and may reach a lower point in the fall than when soil moisture is normal.

Soil and air temperatures affect the time new growth starts and the level of moisture attained by the shrubs. The new growth will start earlier and often reach a higher level of moisture when the weather in late winter and spring is warm than when the weather is cold. Other factors that affect soil and air temperatures, such as slope aspect, slope, steepness, and site elevation, also affect the amount of new growth, the time it starts, and the level of moisture in the living material.

The moisture patterns of different chaparral species vary somewhat, particularly in the peak moisture reached in the growing season and in the moisture content at dormancy. Moisture variations are also found between shrubs of the same species in the same locale, and often in material taken from different heights and aspects on the same shrub. Site quality also affects shrub moisture: shrubs on good sites tend to produce more new growth, have higher moisture levels, and decrease in moisture content more slowly during the summer than shrubs on poor sites. Dry foehn winds, such as the Santa Ana winds of southern California, and the Mono winds in the northern part of the State can significantly reduce shrub moisture levels in a few hours. This lower moisture may persist for several days after the winds cease, particularly when soil moisture is deficient.

Visual indicators of the amount of moisture in living chaparral are few, the amount of new growth being about the only perceptible one. Analog devices are not yet available for estimating living fuel moisture, such as the fuel moisture indicator sticks used for dead fuels, nor have adequate predictive models for living fuel moisture been developed. Consequently, the direct measurement of fuel moisture by periodic sampling of living fuel and laboratory methods of fuel moisture determination are necessary to obtain estimates of the moisture content of living chaparral.

SAMPLING FUEL MOISTURE

The principles applied in sampling and monitoring living fuel moisture are akin to those used in the observation and monitoring of fire weather. Fire weather observations are made at a station selected as being typical in weather characteristics of the geographical area of interest. Because of geographical variability of local weather, however, observations at the station at any given time are not likely to correspond precisely to weather conditions at other points within the area. Therefore, a weather observation at the station is actually only a sample of the weather for the larger geographical area, and this sample may only approximate weather conditions over the area as a whole.

Observation of living fuel moisture requires an area of a few acres that is deemed representative of a more extensive geographical area for those conditions affecting living fuel moisture. Samples of the living material are then collected from this small area for moisture determination. Thus, this fuel moisture sampling area serves the same function in fuel moisture monitoring as does the weather station in the monitoring of fire weather. Like the fire weather sample, the fuel moisture sample may only approximate the living fuel moisture conditions over the larger geographical area because of the spatial variations in influences affecting living fuel moisture.

Comparability of fire weather observations between stations is effected by standardization of weather instruments, the exposure of these instruments to weather conditions, observation procedures, and the specific time that observations are made. Comparability of living fuel moisture observations is achieved by standardization of fuel sample collection and moisture determination procedures, limitation of individual samples to one species, and by specification of sampling conditions.

Selecting Sampling Areas

The moisture in living chaparral is controlled chiefly by the local climate and the physiological response of the shrubs to that climate, as determined by the characteristics of separate species and individual plants within that species. Consequently, both the climatic variations and the response of the shrubs to those variations must be considered when sampling living chaparral for moisture content.

Establishing a system for the observation and monitoring of living fuel moisture first requires the selection of areas for which moisture information is required. Climatic variation is the primary parameter to consider in setting the boundaries of these areas. Differences in moisture between species can be accounted for in the selection of species to be sampled. Variations in sample moisture resulting from differences in shrub characteristics can be minimized by proper sample collection procedures.

Local climates in California are influenced by numerous factors, including elevation, latitude, slope steepness and aspect, precipitation patterns, and location of the area with respect to synoptic weather pattern tracks and proximity to the ocean. Outlining the boundaries of local climatic zones ideally is accomplished through a detailed climatic analysis of the State. However, this would be a major endeavor that could not be done immediately. Until such an analysis could be made, delineation of climatic zones must be based on general knowledge of local climatic variations. The fire danger rating areas used in the California Wildland Fire Danger Rating System were based on a partial climatic analysis; therefore, these areas can provide a guide to delineate climatic zones for fuel moisture sampling.

At least one fuel sampling area must be established for each climatic zone. These areas should be chosen as best representative of the general characteristics of the zone regarding elevation, slope aspect and steepness, site quality, and chaparral species; or representative of the same influences in that portion of the zone where the primary fire problems exist.

Key Sampling Areas

The primary purpose of fuel sampling areas in climatic zones is twofold: to provide living fuel moisture information for local use in fire control and prevention and to improve fire danger ratings. Living fuel moisture information, however, has effective broader statewide applications — comparison of fire hazards between different parts of the State as a guide to special fire prevention actions, such as area closures; the reallocation of firefighting resources to those areas of greatest hazard at different times during the fire season; and statewide monitoring of living fuel moisture as a guide in establishing opening dates of the fire season in different areas.

These broad uses of living fuel moisture information require that comparisons be possible between different parts of the State, defining fuel moisture levels and trends as affected by changes in weather patterns from year to year and within a fire season. A special system of key sampling areas is needed to meet this requirement. As in local climatic areas, statewide comparison of climatic variation is the primary parameter to be considered in establishing key sampling areas. Climatic variation must only be evaluated on a broader scale. Each *major* climatic pattern in the State should be represented by a key sampling area. California's climate varies from west to east and from north to south, and is also strongly influenced by the State's mountain ranges. As a minimum, separate key sampling areas should be established for coastal areas, west and east slopes of the major inland valleys, and the east side of the Sierras in both northern and central California. In southern California, coastal areas and inland mountain slopes should each be represented by separate key sampling areas.

To preserve climate as the primary variable between key sampling areas, the topographic features of the areas should be similar and preferably representative of the more severe climatic conditions. Thus, the key sampling areas should be located on south-facing slopes and at lower elevations. Site quality should also be similar. Ideally, the same single chaparral species should be sampled in all key areas. In practice, this is not possible, since a single species does not predominate throughout the State. However, either chamise or upright growing manzanita usually abounds in most areas and the sampling should be limited to these species whenever possible. Where the ranges of the two species overlap, both chamise and manzanita can be sampled in a key area to provide a bridge for the evaluation of weather effects on living fuel moisture between key areas. If necessary, this same bridging technique can be used to add a third species for some key sampling areas.

Some of the sampling areas in the climatic zones may also meet the specifications for the key sampling areas; these may be used for both key area applications and local uses. For some of the broad climatic patterns, however, separate key sampling areas are likely to be necessary to meet the uniformity requirement of key sampling areas.

Year-to-year comparison of fuel moisture levels and trends is an important function of all sampling areas. Therefore, both the key sampling areas and local climatic zones should be located on sites likely not to be disturbed over a period of years.

Fuel Moisture Sampling Period

Moisture sampling in the key areas should begin before new spring growth starts and continue until the end of the fire season. This permits monitoring of living fuel moisture from shrub dormancy to peak moisture, through the decline of moisture during the summer, and into the often critically low moisture period in the fall. For southern California, year-long moisture sampling in the key sampling areas may sometimes be necessary.

The time of year that sampling of local areas should begin is dictated by the use and need for moisture information. If the same kind of information as provided by the key areas is desired, the sampling should commence before new growth starts and continue to the end of the fire season, as with the key sampling areas. For areas at low elevations, the time to start sampling will be about the same as for the nearest key sampling area. Sampling at higher elevation areas can begin later. Over much of California, new growth is usually delayed 7 to 10 days for each 1000-foot increase in elevation. In climatic zones where prescribed burning programs are being conducted, year-long sampling is desirable to provide a guide to the optimum time for the burns.

For some applications of living fuel moisture data in the local climatic zones, season-long monitoring of fuel moisture may not be necessary. It is often of primary interest only to know when the living fuel moisture is approaching a critically low level, so that intensified fire prevention and other precautionary fire control actions can be initiated to offset the increased hazard. Since key areas are located where fuel moisture can be expected to first approach the critical level, moisture data from the nearest key area will indicate when to start sampling the local area.

Living fuel moisture usually changes slowly, therefore sampling periods about 10-14 days apart normally will be sufficient to indicate moisture trends; however, additional samples during prolonged heat waves or foehn wind periods may be desirable.

Number of Samples

The new and old growth should be sampled separately as long as they can be distinguished, owing to large differences in moisture content between new and old growth material during much of the year and the highly variable amount of new growth from year to year. At least three samples each of new and old growth for each species sampled in a given area should be collected for each sampling period. Multiple samples will provide a better estimate of the average moisture for the sampling area than will a single sample. As a data bank of fuel moisture information is collected, multiple sampling will permit statistical analysis of moisture variation within the sampling area and the limits of accuracy of the average moisture contents obtained.

Size of Sampling Areas

Each sampling area should contain an ample number of shrubs so that only a few twigs need to be removed from each shrub during a sampling period. Otherwise, repeated sampling of only a few shrubs can soon deplete the supply of sample material and may adversely affect shrub growth and, consequently, the accuracy of the moisture sample. In areas sampled over a large part of each year, 7 to 10 acres normally will contain enough shrubs. However, if the shrubs are small or sparse or more than one species is to be sampled, a larger area may be needed. Areas sampled for only a few months each year can be smaller—3 to 5 acres will usually be adequate.

Documentation

The boundaries of both key and local sampling areas should be marked with durable wood or steel posts. Plot the location on a general area map and provide sufficiently detailed written information of location and access routes—highway number or name, distance from easily recognized landmarks, etc.—to permit the area to be readily found. A written description of the sampling area, giving elevation, slope aspect and steepness, size of the area, predominant species, and the age of the chaparral, is of major importance in making maximum use of the collected moisture data. Pictures of the area are also desirable. Each sampling area must be given an identifying name or number.

SAMPLING FOR PRESCRIBED BURNING

In prescribed burning, representative estimates of living fuel moisture must be obtained for the planned burn area, instead of for a climatic zone as in the monitoring of general levels and trends of fuel moisture. Temporary line transects, rather than sampling areas, are best suited to sampling fuel moisture for prescribed burning. Differences in soil moisture, slope aspect, slope steepness, elevation, site quality, and chaparral species all can cause variations in living fuel moisture over the planned burn area. Consequently, the number of transects needed to adequately sample a planned burn area depends on the amount of variation in these parameters. For example, a burn area that is predominately on a slope of one aspect and steepness which contains mostly a single chaparral species can be adequately sampled with a single transect running from the bottom to the top of the slope, in an area generally representative of the burn area; but if major differences in aspect, slope, or species exist, additional transects are desirable. In general, the number of transects needed will increase with the size of the burn, primarily because variations in the parameters controlling living fuel moisture are more likely to be encountered as the burn size increases. If evaluation of probable fire behavior in different parts of the burn is desired, then transect sampling of major variations in the controlling parameters will be needed.

Transects to be sampled more than once should be marked so that fuel samples are collected from the same area each time. The transects should also be plotted on the burn area map to aid postburn evaluation of fire results and fire behavior. For prescribed burning, fuel sample collection procedures and the number of samples are the same as for permanent sampling areas.

Fuel moisture information from the permanent climatic zone and key areas can serve as a guide to start of sampling in the prescribed burn area. Burn area sampling should begin first along a transect that will define general fuel moisture conditions in that area. More detailed transect sampling can then begin as the fuel moisture level approaches that of the burning prescription. High detail sampling usually is not required until a few days before the burn date.

PROCEDURES

Of the several methods available for determining the moisture content of wildland fuels, drying the fuels in a conventional laboratory drying oven appears to be best for monitoring living chaparral moisture levels and trends. Determining moisture content by oven drying has long been a standard technique in science and industry, and equipment designed for the purpose is readily available. The method is very simple: freshly collected samples of foliage and twigs are weighed, dried in an oven for a specified period at a temperature slightly above the boiling point of water, then weighed again. The moisture content of the fuel sample can then be calculated, based on the weight measurements obtained before and after oven drying. Since the drying process does not require monitoring, the cost in technician hours for the moisture determination process is low. Safety problems are few—the process is not any more hazardous than using a domestic oven for cooking food.

By using the equipment and techniques described herein, reliable moisture content estimates of chamise and manzanita (and of species with similar characteristics) can be obtained within a drying time of 15 hours. Thus, if fuel samples are collected during the day and placed in the oven by 1700 hours, the samples can be removed from the oven and their moisture content determined by 0800 on the next day.

EQUIPMENT

Drying Ovens

Two general types of electrical drying ovens are available—mechanical convection ovens and gravity convection ovens. Mechanical convection ovens use a fan or blower to circulate and to vent moist air from the oven. Gravity convection ovens depend on the natural upward movement of heated air for circulation and ventilation. Good quality ovens of both types have dual temperature controls. The secondary control is set a few degrees higher than the primary control; if the primary control fails, the secondary control will regulate the temperature and thereby prevent damage to the oven and its contents.

Mechanical convection ovens with dual temperature controls *(fig. 2)* are recommended where samples are processed on a regular basis. Gravity convection ovens cost 15 to 20 percent less, but the superior performance of the mechanical convention type makes the additional investment worthwhile. Because of forced circulation in a mechanical convection oven, vertical and horizontal temperature gradients are small and the drying of the fuel samples is more uniform than in a gravity convection oven. Temperature recovery after the samples are placed in the oven is much faster in a mechanical convection oven—20 to 30 minutes, compared with 4 to 10 hours in a gravity convection oven. Because of better circulation and more rapid temperature recovery in mechanical convection ovens, the drying time of fuel samples is 3 to 5 hours less than in the gravity convection type.

The required oven size will depend on the number of fuel samples to be processed at one time and the dimensions of the sample containers.

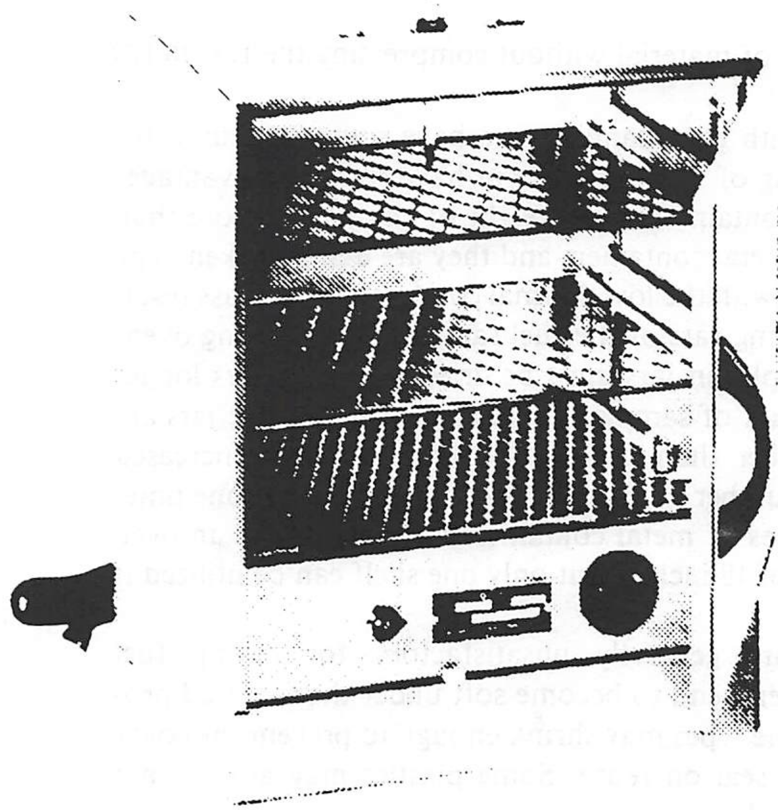

Figure 2 — Laboratory drying oven.

At least 370 cubic inches of oven volume and approximately 40 square inches of shelf space must be allowed per sample to permit effective air circulation and moisture venting. Sample containers must be at least 3 inches from the bottom of the oven and not closer than 3 inches from the top. If more than one shelf is used in the oven, the tops and bottoms of the containers on the different shelves should be separated by 1½ to 2 inches. The smallest mechanical convection ovens generally available have a working volume of about 4500 cubic inches—sufficient volume for 12 fuel samples. However, because of the shelf area and vertical spacing requirements for the containers, the interior dimensions of an oven of this size may limit sample capacity to less than 12. In selecting a drying oven, then, attention must be paid to the dimensions of the sample containers and the oven interior as well as to oven volume.

Sample Containers

One-quart metal paint cans are recommended for the collection and drying of fuel samples. These containers are available through most paint stores or can be ordered in quantity from the manufacturer. The container can be reused several times if a paint can opener and reasonable care are used. Drying time is very sensitive to the compactness of the fuel sample, and the quart-sized containers permit collection of the required amount of material without compressing the fuel in the container.

One-quart, wide-mouth glass canning jars have often been used for the collection and drying of fuel samples but have some disadvantages compared with metal containers. The weight of the jars is more than three times that of the metal containers and they are easily broken. The large mass of jars along with the low thermal conductivity of glass result in a relatively slow heating rate of the fuel samples in the drying oven. Consequently, fuel samples in jars must be dried about 3 hours longer than for the same amount of samples in metal containers. The jars are also about 3 inches taller than the metal containers. This increased height may affect the number of samples that can be dried at one time. For example, two shelves of metal containers can be dried in an oven with an interior height of 18 inches, but only one shelf can be utilized if glass jars are used.

Plastic containers are generally unsatisfactory for drying fuel samples. These containers tend to become soft under the required prolonged heating, and some types may shrink enough to prevent the cover from providing a tight seal on reuse. Some plastics may also release toxic vapors when heated.

Collecting samples in containers different than those in which they will be processed for moisture determination is not recommended. Because of the high moisture content of living fuel, moisture almost always condenses on the interior of the container and its cover. This moisture cannot be transferred from one container to another and accounting for it greatly complicates the moisture determination process. Any loss of fuel material during the transfer may also cause significant error in the moisture content.

Laboratory Balances

Either beam or torsion-type balances may be used to weigh fuel samples. The balance must have a capacity of at least 300 grams if metal containers are used and 600 grams for glass canning jars. The balance used must be direct reading to 0.1 gram; balances requiring the estimation of weight between 1-gram increments are not satisfactory. Top-loading balances *(fig. 3)* are easier to use and preferable to the hanging pan-type balance, since some kinds of hanging pan balances will not accommodate the sample containers.

Electronic balances are very easy to use, permit rapid weighing, and tend to reduce weighing errors. These balances are expensive, however, and their use in fuel moisture determination is probably not justified unless large numbers of fuel samples are weighed frequently.

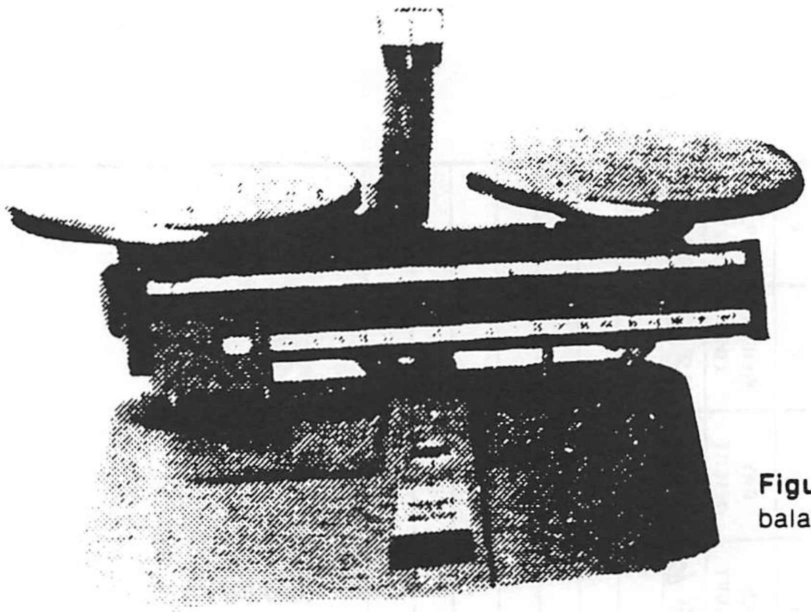

Figure 3—Laboratory balance.

COLLECTING LIVING FUEL SAMPLES

Uniform and systematic fuel sample collection procedures are essential for securing valid and useful living fuel moisture information. Haphazard collection of samples will produce erratic and inconsistent results leading to erroneous assessments of the fire hazard. Fuel samples for monitoring the levels and trends of living fuel moisture in California chaparral are to be taken from preselected and demarcated sampling areas. Normally, these areas will range in size from 3 to 10 acres. Only a single species of chaparral will be collected in most areas, but in some areas two species may be specified.

Preparing Sampling Area

It is important to ensure that the moisture content derived from fuel samples best represents the average moisture for the sampling area; the material must be collected from as many of the shrubs of the designated species as possible, and this material must be collected from the entire sampling area each time that samples are collected. Collection routes providing access to all parts of the sampling area must be established before collection begins. These routes may meander through the area or may follow more or less straight lines, whichever best suits the topography. Some pruning and slashing may be necessary in dense

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LIVING CHAPARRAL FUEL SAMPLE

AGENCY	ADMIN. UNIT	CLIMATIC ZONE	SAMPLE AREA
USFS	LOST RIVER R.D.	#10	HIGH MTN.

COLLECTION RECORD — **MOISTURE DETERMINATION RECORD**

BY	DATE	TIME	BY	TIME IN	DATE	OVEN LOCATION
E.Z.	7/21/79	14:30	I.R.	1700	7-21-79	LOW ROCK R.S.

OVEN TYPE (*Circle One*) (M.C.) G.C. — TIME OUT 0815 — DATE 7-22-79

NO.	CONDITION OLD	CONDITION NEW	SPECIES	CAN NUMBER		CHECK CAN NUMBER ACTUALLY WEIGHED	A GROSS WEIGHT WET	B GROSS WEIGHT DRY	C CAN WEIGHT	D DRY WEIGHT	E WEIGHT LOSS	F % MOISTURE
1	X		CHAM	4	→	4	207.8	165.3	134.6	30.7	42.5	138.4
2		X	"	12	→	12	211.7					
3	X		"	8	→	8	205.2					
4		X	"	6	→	6	202.0					
5	X		"	3	→	3	212.3					
6		X	"	10	→	10	217.9					
7					→							
8					→							

PHYSICAL OBSERVATION

NEW GROWTH: STARTING ☐ CONTINUING ☒ COMPLETE ☐ NONE ☐

FLOWERING: STARTING ☐ PEAKING ☐ DECLINING ☐ DRYING ☒ NONE ☐

FRUIT: PRESENTING ☐ RIPE ☐ NONE ☐ FALLEN ☒

WEATHER

DRY BULB 81° RELATIVE HUMIDITY 21 %

WET BULB 59° % CLOUD COVER 0 %

(B - C) = D; (A - B) = E; (E ÷ D) X 100 = F

REMARKS: 165.3 - 134.6 = 30.7
207.8 - 165.3 = 42.5
$\frac{42.5}{30.7} \times 100 = 138.4$

TEMPORARY FORM R5-5100-1 (ISS. 3/79)

Figure 4—Living chaparral fuel sample form.

stands to provide access, but care must be taken to avoid unwarranted disturbance to shrubs of the designated species. Conspicuously mark the collection routes, such as with flagging, so that the same route can be followed each time the area is sampled. Fuel sample collection is facilitated if the collection routes are divided into three parts, each containing approximately one-third the total accessible shrubs of the designated species.

Equipment

The following equipment is needed to collect the fuel samples:

- Sample containers (1-qt. paint cans)
- Small pruning clippers
- Fuel sample collection record forms *(fig. 4)*
- Portable ice chest
- Paint can opener *(fig. 5)*
- Plywood disk
- Sling psychrometer *(fig. 6)*
- Map showing location and name or number of the sampling area

Figure 5—Paint can opener.

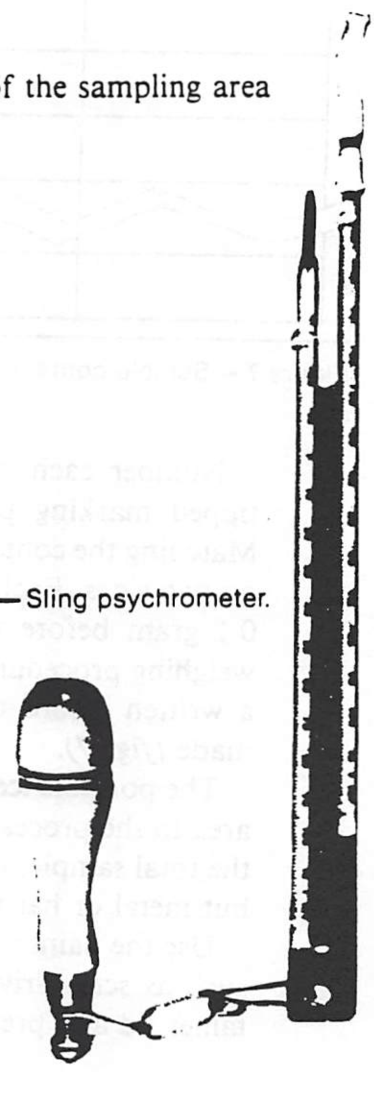

Figure 6—Sling psychrometer.

SAMPLE CONTAINER WEIGHT RECORD

Container Number	Weight	Type	Date Weighed
54	134.6 G	1-Qt. CAN	6/29/79

Figure 7—Sample container weight record.

Number each one-quart metal sample container and its lid. (Felt tipped marking pens with semipermanent ink work well for this.) Matching the containers and lids is easier if the containers are numbered on two sides. Each container *with its lid* must be weighed to the nearest 0.1 gram before use (see moisture determination section below for weighing procedures). The weight may be marked on the container, but a written record of the container numbers and weights also must be made *(fig. 7)*.

The portable ice chest is used to transport samples from the sampling area to the processing center. The chest should be large enough to hold the total samples collected on each trip. Styrofoam chests are adequate, but metal or hard plastic-covered types are more durable.

Use the paint can opener to open the sample containers. Other tools, such as screwdrivers and bottle openers, are likely to distort the container lid and prevent a tight seal.

Collecting Fuel Samples

Time of Day

Fuel samples should be collected during the normally hottest part of the day, usually between 1100 and 1500 hours in the spring and summer and between 1100 and 1400 hours in the fall. *Do not* collect samples when the chaparral foliage is wet from rain, dew, or fog; fuel moistures derived from samples collected under such conditions can be greatly in error. Wait for a more favorable day if necessary.

Material Collected

Collect only twigs with the foliage attached. *Maximum size of the twig must not exceed ⅛ inch diameter where it is cut from the shrub.* Smaller material usually can be collected. Cut off any flowers, seed pods, nuts, berries, and similar material *(fig. 8)*. Also remove any dead material. Only the live twigs and foliage should be put into the sample container.

Figure 8—Remove flowers, seed pods, nuts, berries, and any other unwanted living or dead material from sample live twigs and foliage.

Sample Size

The *dry weight* of the sample should be 25 to 35 grams. But since dry weight can be determined only after oven drying, the amount of material to be collected must be judged from the depth of the fuel in the sample container. A larger volume is needed when the moisture content is high. Also, the volume must usually be greater for species with rigid twigs that give a very loose pack in the container. New growth manzanita and chamise at the peak growing season require that sample containers be filled about three-quarters full to give the required dry weight. For old growth manzanita and chamise during the same period, filling the containers a little over one half usually provides the correct amount of dry material. As the season progresses and moisture in the chaparral decreases, the volume of material collected can also be decreased, particularly for new growth. Check the dry weight of the samples after they are processed and, if necessary, adjust the volume collected at the next sampling period.

Collection Procedures

Unless otherwise specified for a given sampling area, three samples of old growth and three of new growth material (as long as they are distinguishable) will be collected for each species at each sampling period. *Do not* mix species or old and new growth in the same sample container. Collect the old and new growth samples in pairs, each sample pair containing material from approximately one third the accessible shrubs along the collection routes; thus, all shrubs will be represented about equally in the three pairs of samples.

Collect twigs and foliage only from the upper half of the shrubs. Each sample should contain nearly equal amounts of material from all sides and tops of the shrubs, but it is not necessary to collect material from all parts of each shrub. A properly selected sampling area will contain enough shrubs so that only a few twigs need to be taken from each during a sampling period. Consequently, taking twigs from all sides and the top of each shrub will likely produce too much material. If twigs are taken from the north side of one shrub, collect from the south side of the next, the east side of the next, and so on until the sample is completed.

After removing unwanted material from each twig, cut it into pieces 2 or 3 inches long so that the material fits easily into the container. The fuel pieces should be arranged to fill the container evenly. *Do not* compress the sample; drying times are based on loosely arranged fuel. The fuel begins to lose moisture as soon as it is removed from the shrub, so keep the container lightly sealed except when material is being added. After the sample is completed, brush off any debris from around the sealing lip of the container and seal it tightly. (Make sure the lid and container numbers match.) The containers can best be sealed by putting them on the ground or other solid surface and then pressing the lid on firmly and evenly with the plywood disk. *Do not* pound the lids onto the containers with any solid object — the lid and container are likely to be damaged beyond further use. Record the required sampling data on the collection record form as samples are collected.

After all samples have been collected, put them in the portable ice chest for transport to the sample processing center. Place the chest in a part of the vehicle where it will not receive direct sunlight or cover it with a blanket or tarpaulin. If the containers become too hot, enough air pressure may develop to loosen the lids or the samples may begin to decompose in the hot, moist atmosphere in the containers. It is important that samples be weighed as soon as possible after collection, preferably within 2 or 3 hours. Before leaving the sampling area, complete the following: (1) observe the wet and dry bulb temperatures with the sling psychrometer and record these data along with the amount of cloudiness on the collection record form, and (2) circle the descriptions that best describe the physical condition of growth on the plants just sampled *(fig. 4)*. This is an average condition; do not be influenced by a few uncharacteristic situations. Use the following definitions:

New growth:

Starting — First appearance of new leaves or flower buds. Depending on the species sampled, flowering may be the first indication of the beginning of growth.

Continuing — New growth or flowering has progressed enough to provide more than a ½-inch new growth on most growing stems, or most flowers are developing seeds. Starting and continuing may both be circled.

Complete — New growth and flowering is complete. Old growth is no longer distinguishable from new growth.

None — Growth completed was shown at some previous sampling. No growth or very little growth is occurring.

Flowering:

Starting — First appearance of flowering, only occasional flowers are seen. This stage may be observed on more than one sampling date.

Peaking — Flowers are observed on most flowering stems. Starting and peaking can occur on the same sampling date and can be observed more than one time.

Declining — Few new flowers are seen and some flowers are turning color, dropping petals, or dropping intact. In a few instances, both peaking and declining may occur.

Drying—New flowers are absent or rare. Nearly all flowers are turning color or dropping. Declining and drying may occur together in some seasons.

None—Flowers are absent or isolated on a few unusual plants. If a few plants have some flowers, make a note under remarks.

Fruit:

Presenting—Seeds, berries, or nuts can be seen but most are green and/or soft.

Ripe—Seeds, berries, or nuts appear to be mostly ripe and are beginning to fall.

Fallen—Most seeds, berries, or nuts are gone.

None—Fruit is gone or is rare and isolated to a few plants.

DETERMINING FUEL MOISTURE[1]

Equipment

1. Laboratory drying oven—see note below
2. Laboratory balance with a direct reading to 0.1 gram
3. Paint can opener
4. Moisture determination record forms *(fig. 4)*
5. Set of balance weights *(fig. 9)*

Procedures

1. Weigh the *sealed* samples to the nearest 0.1 gram to obtain the gross weight *wet*. Record this under the gross weight wet, column A, on the record form. The samples should be weighed immediately after they are brought in from the field and *before* the container lids are removed for any reason. Clean the containers of any dirt and dust before weighing them, paying particular attention to the grooves around the lid and top of the container.

2. Carefully remove the container lids after the samples have been weighed.[2] Using the paint can opener, pry the lids up slowly around

[1]The procedures are established for moisture determination using a mechanical convection oven and metal paint can-type sample containers. See appendix if convection ovens or glass sample containers are used.

[2]If the samples are not dried the same day they are collected, see appendix A for storage instructions.

Figure 9 — Set of balance weights.

the perimeter to minimize distortion. Set the lids aside; they do not need to be placed in the oven.

3. Set the oven between 103° and 105° C (217° to 221° F) and preheat it for at least 1 hour at this temperature before placing the samples inside. Place the *open* containers in the drying oven. The oven temperature will decrease by 15 to 25 degrees because of heat absorption by the samples and the cooling effect of the evaporating moisture. It is not necessary to adjust the oven controls to compensate for this temperature change. A properly adjusted oven will regain the correct temperature as the samples are heated.

Do not overload the oven. Too many samples in the oven at one time will slow the drying process, result in nonuniform drying of samples, and may cause the oven controls to fail to maintain the proper oven temperature. Allow approximately 40 square inches of shelf space for each sample, and space the samples about equal distances apart and from the oven walls. If only one shelf is used, it should be placed so that the sample containers are near the middle of the oven. When using more than one shelf, the samples should be at least 3 inches from the bottom of the oven and not closer than 3 inches from the top. The space between containers on different shelves should be at least 1½ to 2 inches.

4. Dry the samples in the oven for 15 hours.[3] Avoid opening the oven door during the drying period, since the oven temperature will drop substantially each time the door is opened. However, the oven vent must always be fully open during the drying period to allow moisture to escape.

5. Remove the samples from the oven at the end of the drying period. Use gloves, since the containers will be hot. Seal each container immediately after it is removed, making sure that the container lid and container number match. The very dry fuel quickly absorbs moisture from the air, so it is important that sample removal and sealing be done rapidly.

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[3]See footnote 1.

6. Allow the sealed samples to cool to room temperature. The warm containers create convection currents that cause large weighing errors if samples are weighed before they are cooled.

7. After the samples have cooled, weigh them to the nearest 0.1 gram. Record this weight in the gross weight *dry,* column B, of the record form.

8. Put aside the unopened weighed samples until after the moisture content computations have been made.

Moisture Content

The moisture content of the samples is obtained from the equation:

$$\text{Percent moisture} = \frac{\text{Sample weight loss}}{\text{Sample dry weight}} \times 100$$

Remember that moisture content for living chaparral fuels is expressed as a percentage of dry weight. Solution of the equation requires the following steps (an example is shown on the sample record form, *fig. 4*):

1. Record the empty container weights in column C, on the moisture determination record form. If the container weight is not marked on the container, secure it from the container weight record.

2. Subtract the empty container weight, column C, from the gross weight *dry,* column B, to obtain the *dry* weight of the sample. Record this dry weight in column D on the record form.

3. To determine the sample weight loss, subtract the gross weight *dry,* column B, from the gross weight *wet,* column A. Record the weight loss in column E on the record form.

4. Divide the weight loss, column E, of each sample by its dry weight, column D. Carry this calculation to three decimal places.

5. Multiply the quotient obtained in step 4 by 100 by moving the decimal point two places to the right. The result is the moisture content of the sample in percent, and this value is to be recorded under percent moisture, column F, of the record form.

6. If any samples have a dry weight in excess of 50 grams or an indicated moisture greater than 275 percent, it is possible that they are too compact or moist to dry completely in 15 hours. Open such samples and dry them an additional 6 hours in the oven. Repeat steps 5 through 7 of the drying procedures, then recalculate the moisture content.

Preparing Containers for Reuse

1. Sample containers may be emptied after the moisture computations have been completed. Make sure that all fuel particles are removed. The interior and exterior of the containers usually can be wiped clean with a damp cloth. Occasionally, however, pieces of foliage may adhere to the sides or bottom of the interior—this occurs most frequently with new growth samples. Soaking the containers in soapy water may be necessary to remove this material.

2. Inspect the containers and the sealing lips on lids. Discard any damaged lids or containers. From the remaining lot, match as many good lids and containers as possible. Once this is done, remove the numbers and any weight markings from both the lid and container. Renumber and reweigh the container and lid.

3. Ensure that all containers are thoroughly dry, then replace the lids tightly enough so that they will stay in place while being transported to the field. Make sure that the lid number and container number match.

Care and Use of Laboratory Balances

Accuracy of fuel moisture determination by oven drying is highly dependent on precise weight measurements. In the foregoing procedure, weights must be determined to the nearest 0.1 gram. This is a very small unit of weight (a single manzanita leaf weighs between 0.1 and 0.2 gram). Weighing to the necessary degree of accuracy is not difficult, but special heed must be given to minimizing external influences that affect weight measurements.

The balance must be set up on a level, solid surface. A balance will not weigh accurately if it is not level, and vibration will make accurate weighing difficult or impossible. Place the balance where it will not receive direct sunlight, and in a part of the room that is free of air currents, such as those from heating and air conditioning vents or open windows and doors. A corner of a room is often a suitable location for the balance. A corrugated paper box can also be used to provide a still-air environment for weighing. The box should be large enough to house the balance and provide sufficient room to weigh the fuel samples. Remove the top flaps from the box. Place the box on its side with the opening toward the observer. Cut a piece of plywood or similar material slightly smaller than the box and put this inside the box to provide a solid surface on which to place the balance. The corrugated paper tends to compress somewhat under the weight of the balance and may make leveling and zeroing of the balance difficult if the hard surface insert is not used.

Check the zero setting of the balance before each weighing session and adjust it according to the manufacturer's directions, if necessary. Recheck the balance zero after each five or six samples are weighed; the zero on some balances tends to change slightly with temperature variations and as the balance is "exercised."

Before placing the sample container on the balance, make sure that the weighing pan is clean. Always center the sample container on the weighing pan. Beam-type balances usually have notches on the beams for proper placement of the major weights, and all of these weights must be in a notch. Even a slight misplacement of the weights will cause a large error. Double check the weight reading before recording it on the record form. Misreading the balance is one of the most common causes of weighing errors.

A properly used quality balance will seldom need accuracy adjustments. However, an inaccurate balance is not easily detected in normal weighing operations; consequently, its accuracy should be checked periodically. This is done by weighing standard balance weights on the weighing pan. Check the balance reading near the low and high ends of its range and at least one point between. If the balance is inaccurate, make adjustments according to the manufacturer's instructions or return the balance to the manufacturer for adjustment or repair.

A laboratory balance is a delicate instrument and should be kept covered when not in use to protect the bearings and knife edges from dust and dirt. Avoid frequent moving of the balance from place to place.

APPENDIX

A. Drying Time Adjustments

1. If 1-quart glass canning jars are used for sample containers, increase the basic drying time of the samples to 18 hours for a mechanical convection oven.

2. The basic drying time for samples in metal containers placed in a gravity convection oven is 18 hours. Increase this drying time to 21 hours if 1-quart glass canning jars are used for sample containers.

B. Sample Storage

Best results will be obtained when the sample drying process is started on the same day that the samples are collected. If this is not possible, the samples may be stored for short periods as follows:

1. Weigh the sealed containers and record the weight in the gross weight wet column of the record form. The sample containers should then be opened. Samples in open containers can be stored up to 48 hours at room temperature and up to 5 days in a refrigerator. Do not reweigh the samples when they are placed in the oven for drying; weight loss during storage will appear as part of the weight loss in the oven. Samples that cannot be processed within 5 days after collection should be discarded.

2. Samples that cannot be weighed the day they are collected may be stored unopened in a refrigerator for periods up to 24 hours. Allow the samples to warm to room temperature before they are weighed. Make sure that there is no condensation on the exterior of the container. Discard samples that are not weighed within 24 hours.

C. Checking Oven Temperatures

Temperature within most laboratory drying ovens is monitored with a mercury-in-glass thermometer inserted in top or side of the oven. Thermometers are of the long-stemmed type, with a mark indicating the portion of the thermometer that should be within the oven cavity.[4] Moni-

[4]Some low-cost ovens may be equipped with standard mercury-in-glass thermometers. These thermometers should be inserted into the oven so that the bulb is at least 3 inches from the oven's interior top or wall.

toring thermometer should be left in place while drying the fuel samples.

Temperature control on most ovens is marked with numbers or letters for different temperature settings or may only have an arrow to indicate which direction to adjust the control for a higher or lower temperature. For convenience in using the oven to dry fuel samples, the control should be marked at the setting that will give 104° C (220° F) on the monitoring thermometer. Oven temperature should be checked each time, as a small adjustment of the control may be needed to attain the correct drying temperature.

Temperature of the modern mechanical convection oven of good quality is quite uniform over most of the oven cavity. Therefore, samples loaded in the oven as specified in the drying procedures will be subject to the same temperature. Convection drying ovens, however, often have large temperature variations within the cavity, particularly older and many low cost ovens. Temperature variation of such ovens must be checked before they are used to dry fuel samples, as part of the oven volume may not be within allowable temperatures.

An electrical temperature probe with a strip chart recorder is best suited for checking temperature variations in the ovens. The following procedure is used:

1. Insert the probe to the center of the oven cavity.
2. Turn on the oven and adjust the control to give a temperature of 104° C (220° F) at that point. The recorder trace will show an initial rapid rise in the oven temperature. The indicated temperature will then vary by 2 or 3 degrees around the set point as the heating element is cycled on and off by the control. Use the average temperature in this latter variation to establish the proper control setting.
3. Allow the oven temperature to stabilize for at least 1 hour after the final adjustment of the control.
4. Using the probe, make temperature measurements along a vertical line at the center of the oven at 2-inch intervals, beginning 2 inches from the bottom of the oven and ending about 2 inches from the top. Also, make a temperature measurement at the level of the bulb of the monitoring thermometer. Leave the probe at each point through 4 or 5 on-off cycles of the heating element, and clearly mark the location of the probe on the recorder trace. *Do not* change the temperature control setting during these measurements.
5. Make similar temperature measurements along a vertical line 2 inches from one wall of the oven, and also along a vertical line midway between the center and that line.
6. Determine the average temperature at each point from the recorder trace.

7. Drying temperatures of the fuel samples should not vary by more than 3 ° C (6 ° F) from the standard temperature of 104 ° C (220 ° F). The temperature in the oven cavity is usually fairly symmetrical around the center point; therefore, the three lines of temperature measurements can be used to establish the usable volume by interpolating between the measured temperatures. This process is facilitated by plotting the temperature measurements on a scale drawing of the oven cavity. Use the temperature obtained at the level of the monitoring thermometer bulb to establish the thermometer reading that will give the proper operating temperature at the center of the oven. Post this temperature and the usable volume of the oven near or on the oven.

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