I. The Home as Emergency Fire Shelter

Every home constructed in fire prone areas should be so sited, constructed, and maintained that it could be considered a shelter-in-place for natural disasters inclusive of wildland fires. Such was the case with the Spanish haciendas that had fireproof tile roofing and fireproof exterior walls and extensive fire-safe landscape buffers around their structures. However, after WWII when construction expanded rapidly into the wildland-urban interface areas, such lessons were quickly forgotten and homes were often sited in high-risk fire topography and quickly built with the easiest available material: wood. Quite predictable, wildland fire disasters grew bigger and bigger and burned more and more homes even in seemingly fire-safe areas as firebrands carried the wildland fire from wood roof to wood roof, burning thousands of homes even within the city, as was the case in the 1991 Oakland Tunnel Fire. When the November 6, 1961, Bel-Air Fire burned or severely damaged over 500 homes, the fire was ranked only second in the Western states to the San Francisco Fire that followed the earthquake of 1906, as the insurance loss was estimated at $24 million. Because of the high risk and exposure to insurers, private fire insurance had pretty well dried up by 1968 and the insurance companies were then forced by the State of California to form a FAIR PLAN umbrella insurance pool that spread the shock losses of brush fires among all insurance companies. Because of its generally low cost relative to the risk insured, it was a key incentive to continue development in high risk fire areas often without meaningful fire safe changes in land use, planning, and construction, as FAIR PLAN subsidized insurance for homeowners living in such areas. Consider that two-thirds of the homes destroyed by wildfire since state-wide public records were kept in 1923 have been burned since 1980.[1] The new density of hillside housing has shifted from a policy of the home as an emergency fire shelter to wholesale evacuation and with it a greater loss of homes during fires (K. Radtke, unpublished research).

Research was conducted as far back as the early 1980s in the Santa Monica Mountains[2] by UCLA researchers pertaining to residents' beliefs regarding fire hazards, their adjustments to the threat of fire, and the expectations regarding the level of fire services provided to them. Results indicated that they were well aware of the hazards, were uncertain of what technological safeguards are likely to be the most effective, and may have unreasonable expectations regarding their individual protection via fire service organizations.

However, it is not too difficult to build and maintain a fire-safe designed home. First, it must be located in an area where it is not exposed to convection and radiation heat sources. This means that it must be set back from slopes, not located side-slope, not located in fire chimneys such as narrow canyons, not in saddles, and not in or at the confluence of narrow canyons. Given the steep topography of the Santa Monica Mountains and the insistence on their property rights when people want to build on otherwise wildfire-exposed lots, such constraints are often hard to meet. However, building with truly fire-safe construction and designing homes that don't catch convection and radiative heat sources but rather let them slide over the house where possible can often greatly mitigate some of the siting problems. Add to this the proper clearance of all flammable materials around the house while working with your neighbors to do the same and you have created a pretty safe fire shelter for yourself and them. But keep your diligence up on a year-round basis.

Many of the even more recent fire losses in the Santa Monica Mountains were still related to causes such as fire-trap constructed homes (wood roofs, wood decks, homes so located and built as to being exposed to convective and radiative heat sources (fire catchers), flammable accessory structures, wood fences, railroad ties, improper clearance of native and ornamental vegetative fuel sources, accumulation of other flammable materials around

[1] Davis, Mike. Let Malibu Burn: "A political history of the Fire." *L.A. Weekly* 1996. Internet Report Oct. 24, 2007.

[2] Loeher, Larry Fire Hazard: "The Dimension of Resident's Attitude." in *Living in the Chaparral of Southern California-an Integrated Approach to Public Safety*. Proceedings of the Conference and Public Workshop sponsored by the National Foundation of Environmental Safety and the National Park Service. 1985. pp. 51-55.

the homes, and ease of fire entry. When even seemingly fire-safe construction, such as newer homes with stucco siding, enclosed eaves and fire-safe Class A roofs, catches on fire there must be reasons. Totally overlooked Achilles heels of such homes are wooden decks, the vents required at the base of their stuccoed walls and the still-permitted use of wood along the outside of homes such as wooden railroad ties for steps to reduce the overall cost compared to fireproof steps such as stone or concrete. The vents are soon forgotten or overlooked and soon covered with landscaping. When the railroad ties slowly ignite or such vegetation burns on unattended homes (such as fire-evacuated homes), firebrands or flames have plenty of time to creep into the wooden frame covered by the stucco and slowly ignite the house from the inside. An initial tell-tale sign of this is often a warm or hot exterior or interior wall of the house, soon perhaps a smoky room, and finally often smoke coming from the chimney on a hot day.

This author, as one of the board members of the then National Foundation for Environmental Safety, conducted free of charge many homeowner inspections in Los Angeles County's wildland areas during the 1980s-1990s, often after homeowners had passed their yearly "brush clearance" inspections and thought they were safe. Wildfires and their causes as well as home losses were also investigated when time permitted and fire safety seminars were held throughout California.

To his dismay the author found that most of the homes inspected were not really fire-safe, as flammable landscape vegetation, flammable household items, or flammable accessory structures were never really addressed during brush inspections. To his knowledge, none of the residences of homeowners that diligently followed his advice were lost in wildfires even when they were located in the center of a firestorm such as in central Las Flores Canyon during the 1993 Old Topanga Fire. The owner of the property wanted to build a home on a lot inherited from his parents where their previous summer home had burned down during the 1943 Las Flores Fire. He attended the Symposium Chaparral-Fire & Man this author had organized with the Los Angeles County Fire Department Forestry Division and other agencies such as U.C. Berkeley extension services at Tapia Park in Malibu in June 1978. Because of potential fire exposure to steep slopes in a fire-funnel canyon, the owner of this particular home built a compact one-story overall fire-safe designed home with stucco siding, a low pitch Class A roof so as not to be exposed much to convective and radiative heat sources, and added a stand-alone garage. Because windows and the code-required vents near the roof and at the base of the stucco walls presented dangerous places of fire entry, he then hand-fabricated 1/2-inch-thick plywood shutters with handles to fit the windows and also constructed small wooden shutters to fit every opening or vent within the stuccoed walls of the home and garage as the house was being completed (see 1982 *Homeowner's Guide*... p. 15; 2004 *Homeowner's Guide*... p. 19). The fire-safety emergency devices were put in place whenever a fire potentially threatened the neighborhood. He then also taught his neighbors the lessons he had learned. During the 1993 Old Topanga Fire, when a firestorm overran the house, small wooden shutters at the rear of the garage facing the steep slopes were charred but did not burn through during the burnout period of the low-growing coyote brush on the steep and long slope located within 15 feet of the rear of the garage. This was reported by the *Los Angeles Times* and other news media at this time. Others in the neighborhood had installed roll-down metal fire shutters along fire-exposed windows. Being educated to the potential fire danger and knowing what to do and following through paid off in all instances investigated.

Further research has indicated that home losses can be effectively reduced by focusing mitigation efforts on the structure and its immediate surroundings. Those characteristics of a structure's materials and design and the surrounding flammables that determine the potential for a home to ignite during wildland fires (or any fires outside the home) from direct flame impingement as well as the ever-present firebrands are being referred to as home ignitability[3]

The Stanford Research Institute report (1973) is a think-tank" report based largely on raw data provided by the

[3] Cohen, Jack D. "Reducing the Wildfire Threat to Homes and How Much?" Paper presented at the Fire Economics Symposium in San Diego, CA. April 12, 1999.

City and County of Los Angeles Fire Departments and the U.S. Forest Service. In carrying out a comprehensive economic analysis for protecting the Santa Monica Mountains from wildfire the report proposed and analyzed the following three alternatives:

1. To reduce the number of wildland conflagrations.
2. Given the number of wildland conflagrations, to reduce their extent.
3. Given the number of wildland conflagrations, to reduce the damage (to structures).

The fire-adapted vegetation in the mountains and the fire weather patterns make wildland fires inevitable. Reducing the number of wildland fires and reducing their size would require lateral fire barriers such as firebreaks of at least 200 feet in width or wider fuel breaks that require a large labor input for maintenance of even greater width. Attempting to stop the frontal advance of wildland fires to the beach would require horizontal ((E-W) of at least ½ mile in width. But even then there would be no guarantees that wild-driven wildland fires could be stopped because of spotting of firebrands. As such, alternative 3 was the only one economically feasible with benefits to society overall. It uses the fire loss data of the 1961 Bel Air Fire in predicting future fire losses in the Santa Monica Mountains. In using the least cost plus loss planning method the conclusion was that, with then approved (fire-retardant) roofs and "brush" clearance of 100 feet the average home destruction rate could be limited to 7 homes per year for the whole Santa Monica Mountains stretching from Ventura County to Griffith Park.

To accomplish this, the three final recommendations were:

1. Public Education - Fire agencies should emphasize that occasional large scale fires are inevitable in the Santa Monica Mountains and urge that steps be taken to minimize the loss when the conflagrations occur.
2. Insurance Surcharge Rates - The brush surcharge rates should be set to reflect expected losses. If present rates do not meet this criterion, they should be revised.
3. Planning For Fire Protection – Fire protection agencies should use the least cost plus loss economic planning methods as illustrated in the report; fire research and planning groups should continue to develop them.

The report also noted that brush clearance is inadequately enforced and only applies to "brush" and that flammable landscape vegetation that often replaces flammable brush is not required to be cleared. The report then suggested that research should also be directed towards the role of ornamental shrubbery in the spread or containment of fires. It also stated that additional steps should be taken to protect individual homes from fires aside from the first step of installing fire-retardant roofs (whose meaning has now been replaced with the more stringent requirement of nonflammable and preferably Class A roofs as well as Class B roofs) and clearing the "brush" should include:

1. Reducing overhanging roofs and closing other openings to the house to prevent flying embers from entering it
2. Installing fireproof shutters, especially on the sides of the house that get direct fire exposure.
3. Having auxiliary pumps for swimming pools
4. Eliminating flammable objects from the yard
5. Improving access driveway standards
6. Initiating programs to train able-bodied citizens to defend their houses during periods of moderate fire exposure.

If all the above listed items would have been diligently followed up and enforced, the report estimates that fire losses could perhaps have been reduced to that approaching the average of 7 homes per year. However, the Stanford Research Institute report did not foresee the continuous permitting of homes (inclusive of the proliferation of accessory structures and barns, flying decks, wooden balconies and wooden fences) in high fire risk areas. The siting and density of such homes added structural fuel components that increased the spread and reduced the containment of fire. Also, the role of topography was not yet addressed in "brush" clearance requirements, and (as even shown today in most brush clearance publication) most fire department pamphlets still show the house situated on level land with proper ingress and egress that includes the building pad as well as a flat 100 to 200 feet clearance distance with no surrounding homes. The real problems faced by homeowners struggling with living in steep mountainous topography with often limited ingress and egress and with other homes nearby is often an instant disconnect when they are provided with such unrealistic guides.

Lee and Bonnicksen,[4] in evaluating brushland watershed management policies in southern California, came to their somewhat surprising findings that increasing monetary losses in wildland fires appear to have resulted from the increases of property values at risk and not from the increases in number of acres burned. This holds also true for wildland fires in the Santa Monica Mountains and indicates that the Stanford Research Institute report (1973) that recommended its alternative 3, reducing the damage (to structures) through fire-safe construction and clearance of flammable vegetation, is still the most cost-effective bio-social consideration.

Further requests for studies on solving the fire problems in the Santa Monica Mountains, often urged by the public, elected officials as well as fire chiefs such as County Fire Chief Houts himself, continued and quite some time and became more urgent with every uncontrollable large-scale fire. One such study by Lowden and Degenkolb (1972)[5] recommended the development of a strong fire research program within the Los Angeles County Forester and Fire Warden Department. One such program was then initiated soon thereafter with cooperative research programs between the County of Los Angeles and the U.S. Forest Service Riverside Fire Laboratory and expanded in 1976.

The 1976 5-year research and development program called Vegetation Management Alternatives for Chaparral and Related Ecosystems, headquartered at the Riverside Fire Laboratory, was initiated by the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station and the Pacific Southwest Region, Forest Service, U.S. Department of Agriculture (A comprehensive report of its findings, recommendations and management guides produced was published in 1986).[6] The County of Los Angeles, through the Los Angeles County Forester and Fire Warden continued to be one of the grant-receiving cooperators with Radtke continuing as its cooperating scientist. Several then state-of-the art publications were produced by this author and others during the five-year period such as his *Living More Safely at the Chaparral-Urban Interface* and a *Homeowner's Guide to Fire and Watershed Management...*, published at the insistence of the Forest Service. However, many of the recommendations were not seriously addressed and were started to be implemented only reluctantly by local agencies before the wildfires of 1978, 1982 and 1993 that burned 230, 85 and 333 homes respectively and 202, 11, and 112 structures that included barns, sheds, detached garages, etc.

Research was hampered and then generally shut down within the Fire Department because of concerns raised by an post tax cutting-Proposition 13-related audit that attempted to streamline the department. This audit, among other more items, recommended that up to 25% of fire department rank and file jobs be filled by civilians (with great salary and retirement savings) as they are not directly involved in firefighting but that the wildfire prediction research carried out within the Forestry Bureau (by Radtke) be prioritized.

Since, in response to this audit, the efforts of foresters in fire-related work were further marginalized, cooperative wildfire-related research within the Fire Department was largely continued "under the radar" by this author. Non-published research still focused on assisting firefighters with evaluating potential home losses given a fire start in the area and supporting a then controversial triage system for predicting home losses in a fire,

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4 Lee, Robert G. and Thomas M. Bonnicksen. Brushland Watershed Fire Management Policy in Southern California: Biosocial Considerations. California Water Resources Center. University of California. Contribution No. 172. August 1978. 73 p.

5 Lowden. Merle S., and John G. Degenkolb. Fire in the Malibu. U.S. National Bureau of Standards. 1972. 16 p.

6 Conrad, C. Eugene, George A. Roby, Serena C. Hunter. "Chaparral and Related Ecosystems: a 5-year Research and Development Program." Gen. Tech. Rep. PSW-91, Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986. 51 p

defending defensible homes with limited resources available and bypassing predictable indefensible homes in a fire conflagration.[7] Some studies focused on predicting a fire's path given a fire start and recommending its containment (largely along flanks in a large-scale fire) based not only on man-made barriers such as firebreaks and roads but also types and age classes of native woody chaparral vegetation.[8] Efforts were also made to disseminate public safety information when feasible.[9]

The summary of one such report, filed away somewhere in County files, reads as follows:[10]

> Six fuel management alternatives were proposed to meet the objectives of reducing large-scale fire conflagrations as well as the damage to property and watershed values. It was shown that the best long-range fuels management alternative for the Santa Monica Mountains may be Alternative F.
>
> Alternative F presupposes that all agencies adhere to a land use plan that incorporates fire-safe zoning ordinances and building codes that are vastly improved. This land use plan must also recognize the interrelationship of fire and watershed management (of vegetation and topography) and must not favor one over the other. Lack of multiple purpose management may be witnessed throughout the mountains when local brush clearance ordinances are strictly enforced by the fire services on steep terrain to which they may not be applicable. Additionally, the land use plan requires that public agencies update their ordinances to assure that they are not in conflict with one another (and public safety).
>
> Alternative F also presupposes that homeowners are made aware of the fire and watershed management problems in fire prone mountainous areas so that they can effectively manage their land as well as their home.
>
> Prior to the establishment of large-scale mosaics of different vegetation classes in woody chaparral (which could be largely accomplished through effective wildland fire management), intensive research has to be completed throughout the mountain range on fire behavior, fire corridors, (fire topography), fire climate and vegetation. This information must then be assimilated to create an effective fire barrier system for the Santa Monica Mountains which could act as backbone for the mix of fuel management methods that is going to be used by the different agencies. The additional value of such studies is that it provides quantitative data to answer many related questions that arise in effective fuel management.
>
> Fast moving fires of low to moderate intensity (as measured in environmental terms) in annual or soft chaparral may be a fact of life which public agencies have to accept given the restraint on aggressive firefighting due to past haphazard development. Any management alternative should be careful not to increase these vegetation types at the expense of chaparral so that large-scale fires and their frequency are not changed or increased from one vegetation type to another.

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7 Radtke, Klaus and Martin Gubrud. "Evaluation of Roof Types from Infrared Aerial Photographs." Unpublished document prepared under Cooperative Research Agreement 21-436 between the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture and the County of Los Angeles and its Department of Forester and Fire Warden. On file, County of Los Angeles, Department of Forester and Fire Warden, Los Angeles. July 11, 1980. 14 p.

8 Radtke, Klaus. 1982. The Oat Fire of October 31-November 1, 1981. Unpublished report prepared under Cooperative Research Agreement 21-436 between the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture and the County of Los Angeles and its Department of Forester and Fire Warden. On file, County of Los Angeles, Department of Forester and Fire Warden, Los Angeles; 22 p. 1map.

9 Radtke, Klaus. An Urban Viewpoint of Wildland Fire Problems. In: Proceedings of the 1980 national conference of the Society of American Foresters. Oct. 5-8, 1980. Spokane, Washington. Society of American Foresters; 1981: 117-122.

10 Radtke, Klaus. "Fuel and Fire Management in the Santa Monica Mountains." Unpublished document prepared under Cooperative Research Agreement 21-436 between the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture and the County of Los Angeles and its Department of Forester and Fire Warden. 1980. 54 p.

After 1982, Radtke, in private practice, continued to oppose non-fire-safe development in the Santa Monica Mountains[11] and supported fire-safe community standards that must include safe and adequate ingress and egress.[12] In 1984, with Judge Baker of the National Foundation for Environmental Safety as moderator, a professional seminar was held at the Malibu Civic Center's Library attended by Fire Department personnel from Los Angeles County, Los Angeles City, and Ventura County Fire Department as well as research professionals and interested homeowners. The meeting highlighted unpublished research carried out under the Chaparral Research and Development Agreement. Fire history, vegetation type and age class maps were displayed on overlays and historic fire corridors were outlined. It was shown how the lessons gained from such research could predict fire pattern given a fire start and where and how fires could be fought effectively under different fire weather regimes because of less resistance to containment. Such knowledge gained by fire chief officers let, for example, to the containment of the eastern flank of the 1993 Old Topanga Fire along Topanga Canyon Road.[13] However, such knowledge gained has to be continuously updated to be applicable to current field conditions.

There are firebreaks within the Coastal Sage Scrub areas of, for example, Corral Canyon that have not been maintained in the recent past and are slowly being revegetated naturally. If not maintained, the lower faces of such firebreaks will become vegetated with a mixture of highly flammable annual weedy species and highly flammable Coastal Sage Scrub components. One may ask when and why were such firebreaks established in the first place and why have they not been vegetated with “nonflammable” or “low fuel” vegetation. The following quote taken from the introduction to a 1938 research publication pertaining to test plots established in the Santa Monica Mountains by the Department of Los Angeles County Department of Forester and Fire Warden for revegetating firebreaks answers these questions:[14]

> “The many miles of firebreaks constructed during the past two decades produced an annual maintenance problems of major proportions. Firebreaks were constructed primarily to assist in rapid influx of firefighters to the conflagration, as a front line of defense from which to set backfires and to retard the spread of fire if burning against the wind. The firebreaks, in order to be effective, must be free of vegetation in order to rob the area of fuel. Following initial construction, annual weeds and grasses appear as though from nowhere, which had to be removed by hand and on more favorable slopes by motive power. Areas where cleaning may be performed by caterpillars make up a very small percent of the firebreak“.

Extensive test plots with more than 30 species of succulents were established in the 1930's throughout the southland in cooperation with the L. A. County Department of Forester and Fire Warden, the U. S. Forest Service, arboretums and nurseries as well as the University of Berkeley. One such plot was also established after the 1935 Fire adjacent to Latigo Canyon Road about one mile north of the Lechuza Fire Patrol Station. Results indicated that the plants would be eaten by deer and rodents if not fenced, would largely freeze in the higher elevations, would require supplemental watering and could not compete with the native vegetation as they were more suited for the immediate coastal areas.

As the wildland-urban interface extended more and more into the mountains and mingled often highly flammable structures and flammable landscape vegetation with highly flammable native vegetation the options for

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[11] Radtke, Klaus. Re: Rancho Malibu Estates (Vesting Tentative Tract Map No. 46277. Document addressed to Los Angeles County Board of Supervisors raising concerns about this unsafe development. Geo Safety, Inc. 10 p.

[12] Radtke, Klaus. Public Hearing on the Adoption of a Permanent Community Standard District, Malibou Lake. Document addressed to Los Angeles County Regional planning Commission. Geo Safety, Inc. 3 p.

[13] Personal communication in 1994 at Fire Camp 2 by the chief in charge of this section.

[14] Gerhardy, Carl O. “Succulent Plantings at Lechuza Plot, Santa Monica Mountains March 1936.” *Department of Forester and Fire Warden, Los Angeles County*. December 23, 1938.

maintaining and using firebreaks for backfiring and effectively fighting wildland fires diminished greatly. While lateral firebreaks have proven effective in the past to contain the flanks of even wind driven fires, the emphasis is now on mass or forced evacuation during wildland fires. Unfamiliarity with the area by out-of-town fire fighters, structural fire fighters exposed to wildland fire fighting in unfamiliar territory, and the lack of effective firefighting due to crowd control and evacuation has already affected fire patterns of recent fires, will undoubtedly increase the acreage burned in the area and has increased structural losses. The latter has been well documented for the Santa Monica Mountains. Homes unattended by either homeowners, friends or residents, or fire fighters have a much greater probability of burning than attended homes as many homes slowly ignite and become fully engulfed after the fire front has passed.

The opening of the coast road and highway from Santa Monica to Oxnard at the close of the Rindge Ranch area by the early 1930's started a Real Estate boom that also saw development in the riparian areas of lower Corral Canyon. For example, the 1950 Los Angeles County Forester and Fire Warden base map identifies only one structure located along a permanent road leading more than 750 feet along the creek from the highway into the canyon as the Parmalee residence.[15] However, the 1950 Malibu Beach Quad map[16] based on aerial photos, shows 3 structures within the riparian area of lower Corral Canyon with a permanent road extending now to 1,500 feet through and along the creek unto the canyon. Dirt roads branching off from it lead west, then east up to and across the Coastal shelf and north along the riparian boundary and up a short distance into the hills towards a relatively flat area.

When the western flank of the 1943 Woodland Hills Fire burned across the Corral Canyon area, it did not reburn a thin strip of riparian vegetation within lower and central Corral Canyon. While this often gives residents the false hope that they can also by luck, divine intervention, preparedness or firefighter intervention survive the next fire, this is often not the case unless they have a truly fire-safe home built in an area where it can be easily protected or can serve as a stand-alone fire shelter. These lessons were then learned (but generally soon forgotten) when the 1958 Liberty Fire, in burning 74 homes in its path, also burned 17 homes in the Corral Canyon area.

Rebuilding and new construction becomes easier after the vegetation is cleared by fire and the 1967 Point Dume quad[17] map now shows an additional structure further along the dirt road that leads to north into the canyon as well as at the terminus of the dirt road leading west out of the canyon that is now connected to Corral Canyon Road. The photo-revised 1981 Point Dume Quad map[18] now only shows the original (now uninhabited?) three (rebuilt) structures from the 1950 quad map. The unimproved roads west to Corral Canyon and east from no longer exist and the access road from the highway is also eliminated. Such roads became overgrown with native as well as weedy, exotic vegetation such as Black Mustard. When walking the area, remnants of Rindge Ranch range fencing is still in evidence along the hillsides.

II. Understanding the Purpose and Effectiveness of (Emergency) Fire Shelters

As the number of civilians moving to the wildland-urban interface and enjoying the outdoors increases, the number of wildland fires associated with disasters and injuries both among civilians and fire fighters also increases.

The most common cause of thermal injury is direct contact with flames. Although a significant amount of radiant

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15 Los Angeles County Forester and Fire Warden. 1950 base map. Santa Monica Mountains. Scale 1" = 2,000 feet.
16 USGS (United States Geological Survey). Malibu Beach 7.5 minute quadrangle topographic Map. 1950
17 USGS (United States Geological Survey). Malibu Beach 7.5 minute quadrangle topographic Map. 1950 (photo-revised 1967).
18 USGS (United States Geological Survey). Malibu Beach 7.5 minute quadrangle topographic Map. 1950 (photo-revised 1981).

heat can be created in wildland fires, firefighter clothing is usually enough to offset serious burns. Temperatures may be extreme at the fire front but they are of short duration. The worst burn events typically involve civilians who are inexperienced with wildland fire behavior or with rapid, unanticipated changes in fire behavior and do not have the proper equipment and clothing to protect themselves from such extreme exposure. Immediate death is primarily due to incineration. Of the 133 firefighter fatalities during 1990-1998 studied by Mangan[19], the most common cause of death with 29% was turnovers. It occurs when a firestorm burns over the individuals in the path of an advancing fire front. Volunteer firefighters experienced the most fatalities with heart attacks being the most common.

Another type of burn is the inhalation burn. Mostly seen in firefighters, this is when the patient has inhaled superheated air. One good indication that the patient may have a supraglottic (above the glottis) heat injury is swollen lips. In this case, advanced airway interventions may have to be done soon. If the patient has severe shortness of breath he may have to be treated with high flow oxygen. Protecting the airway from extremely hot air is always a firefighter's primary concern. Breathing through a wet shroud or bandana exposes the airways to hot, moist air, which can be more harmful than hot, dry air. Avoid breathing through wet cloth but protect your face. A wet bandana or wet cloth can be used to cover the nose and mouth to reduce inhaling smoke after the flame and heat of the fire have passed.

As explained by Robert Franz in the book *Disaster Medicine*[20], contact with superheated air brings the risk of respiratory tract injury. Respiratory tract injury should be suspected with burns around the face, neck, and upper body. Physical findings that have a high correlation with upper respiratory burns include facial burns, nasal hair singeing, facial edema, stridor, and early respiratory distress. Serious respiratory burns are most often seen in those casualties whose history includes being trapped in the burning area. These people have no choice but to breathe the smoke and hot air. The level of injury is directly correlated with the amount of time spent in the burning area and the actual temperature of the air being breathed.

Fire tents–As understood by fire fighters, an emergency fire shelter is a stand-alone, compact, aluminum foil and fiberglass tent-like structure employed by firefighters as a last resort in a wildfire life-threatening situation to protect them from burning from radiant heat sources. The fire shelter is basically a one-person pup tent, minus the floor, made from fiberglass cloth covered with a reflective aluminum coating. It takes a minimum of 15 to 20 seconds to deploy a shelter under ideal conditions, longer in turbulent winds and when an area has to be cleared. As explained by Anderson the new post 2003 generation fire shelter protects primarily by reflecting radiant heat and trapping breathable air.[21] It has two layers. The outer layer is aluminum foil bonded to woven silica cloth. The foil reflects radiant heat and the silica material slows the passage of heat to the inside of the shelter. The aluminum can reflect up to 95 percent of the fire's radiant heat but generally does poorly against moving, windborne (convection) heat. Unlike radiant heat, convective heat (from flames and hot gases) is easily absorbed by the fire shelter, allowing the temperature of the material to rise rapidly. At 470^{o} F such fire shelters generally fail as glue holding the outside together melts. People can survive inside temperatures up to 175-190^{o} F. But for how long?

Initially it is difficult to understand how anyone can survive breathing **dry** hot air in a fire shelter until one understands that air, fortunately, is a poor conductor of heat and the upper airway is very efficient in thermal or

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19 Mangan, R. “Wildfire Fatalities in the United States 1990-1998” *United States Department of Agriculture, Forest Service.* 1999. As quoted with permission by Robert Frantz in Chapter 20 “Fire Storms and Wildfires” in the book “Disaster Medicine.”

20 Frantz, Robert E. “Firestorms and Wildfires” (Chapter 20) in *Disaster Medicine* authored by Hogan, David E. and Jonathan L. Burstein.

21 Anderson, Leslie. Project leader. “The new generation fire shelter.” NWCG PMS 411. Boise, ID: *National Wildfire Coordinating Group, Fire Equipment Working Team, National Interagency Fire Center*. 2003. 30 p.

heat exchange. As further explained by Robert Franz, for this reason a person can breathe air at a temperature of 199^{o} F (92^{o} C) for 30 minutes and of 482^{o} F (250^{o} C) for 3 minutes without serious injury. Although most of the injuries to the respiratory tract are therefore generally mild and they involve only the upper airways, anyone with a significant history of exposure should receive a medical evaluation as soon as possible. Thermal injuries to the respiratory tract can be insidious, with a delayed onset of respiratory distress after contact with superheated air. Significant respiratory distress may be present as late as 24 hours after the exposure. Thermal airway injury is always associated with edema, which can rapidly occlude the airways.

In stark contrast to the higher temperatures generally required for respiratory tract injuries soft body tissue thermal burns can already occur when the skin is exposed to temperatures above 115^{o} F (46^{o} C). At temperature exposure greater than 120^{o}F for three seconds, a child's skin is burned severely enough to require surgery.[22]

On September 26, 2010, a heat wave started to engulf parts of California with Los Angeles recording its highest temperature of 113^{o} F the following day at which its official temperature gauge malfunctioned. To have an understanding and appreciation of the danger of radiant heat exposure (such as one receives from the sun) local residents could have conducted their own research by walking in the sun without a hat and being lightly dressed. While only limited radiation heat injury would have been received by such persons because most soft body tissue would have been covered by clothing because of modesty concerns, fatigue, irritation, disorientation and poor judgment were probably felt by many persons at the end of their walk even if they took a bottle of water along to offset the cooling effect of the body through sweating. Such experience may just mirror the initial exposure phase of facing a wildland fire in the open without a shelter.

While emergency fire shelters reduce the risk of death and injury for fire fighters, they are not fail-safe and carrying a fire shelter should never be considered an alternative to safe firefighting.

But what about smoke inhalation during wildland fires? While lightweight breathing devices occasionally carried during prescribed burn operations can protect from smoke inhalation they are not generally carried during wildland fires. In reviewing the literature about smoke exposure among wildland firefighters Timothy and Otmar (1997)[23] found that overexposure to carbon monoxide and respiratory irritants is likely among firefighters when direct control of fires is required and smoke production is intense. Such over exposures are brief events but sometimes poor atmospheric dispersion or rigorous work schedules cause hours or even days of unhealthy working conditions. During such exposures increased respiratory health problems have been measured in wildland firefighters. Small but statistical significant reductions in lung functions have been observed, across both work shifts and seasons. Specifically, smoke exposure is likely to be the highest during initial attack, during direct attack on fires in high winds (as the smoke lays low on the ground), and large fire situations that suffer from poor atmospheric dispersal. Hazards in smoke seems to be limited to respiratory irritants and carbon monoxide. Ambient wind speed is a key factor in controlling smoke exposure potential, with smoke exposure proportional to wind speed at both wildland fires and prescribed burns. Prescribed burns may increase exposure because of the higher moisture in the fuels.

Fire trucks/vehicles–Since the 1950s mechanized fire equipment such as fire engines have been more widely used in wildland fire suppression, and by necessity often became emergency shelters. Because of firefighter deaths as well as “close-calls” when using fire trucks as emergency fire shelters, research is being conducted continuously to evaluate their effectiveness during a burn over (where a fire escapes beyond the fire lines). Such

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22 http:/emedicine.medscape.com

23 Timothy E. Reinhardt and Rogar D. Otmar. Smoke Exposure Among Wildland Fire Fighters- A Review and Discussion of Current Literature. USDA Forest Service Pacific NW Research Station General Tech Report PNW-GTR-373 Febr. 1997.

a vehicle entrapment study was conducted by the Missoula Fire Laboratory in 1996 with the Los Angeles County Fire Department and other fire services throughout the country as collaborators.[24] Some of the research results important for survival in a real-world fire entrapment are listed below:

a. In most fuel types (besides grass and light brush), the temperature and radiant heat flux generally increase with the height above the ground. This is consistent with the principle that heat rises. This observation has special relevance considering the height of an engine cab compared to the height of a fire shelter.

b. Heat from the passage of the fire front appears to be retained in the vehicles longer than in the fire shelter or other items of PPE, indicating that the metal in an engine may act as a “heat sink.”

c. Moving just a few feet back from the oncoming flaming front–especially on a road cut on steep slopes–appears to significantly reduce the effect of temperature and radiant heat flux on both the individual firefighter and fire engine.

d. During the moderate-intensity, short duration exposure of the Los Angeles County tests, exterior components of the engines either caught fire or experienced some melting (See Figures 27 and 28 of the Mangan report referred to in the above footnote). Under higher intensity or longer duration exposures, the fire engine could catch fire and continue burning when conditions outside would be harmful to a firefighter attempting to leave the engine.

e. When a fire comes up a steep side slope, it appears to go over and under the engine, creating an eddy on the back side that draws heat and flame. A firefighter taking shelter behind an engine parked on a steep slope would not be protected from heat or flame. This effect was demonstrated in October 1996 when an engine was burned over during the Calabasas Fire in Malibu.

f. When the outside doors of an engine cab are subject to high radiant heat loads, the petroleum-based plastics and sound-deadening materials in the door panels and dashboard volatilize. The smoke generated by this volatilization may cause both short-term and long-term health effects on firefighters without respiratory protection, and will create conditions that force them from the cab into the fire area.

g. Under high heat loads, tempered glass in the cab's windows may break out. This may occur when the difference in temperature inside the cab and the temperature outside is only 4°C. Consideration should be given to using safety glass for greater levels of protection.

h. The temperature difference between the 1-inch (3-cm) and 12-inch (30-cm) levels in the fire shelters reinforces the need to encourage entrapped firefighters to get on the ground and to keep their face and mouth as close to the ground as possible, protecting their respiratory system.

Based on such results, it is prudent for firefighters operating fire trucks to also carry emergency fire shelters that they employ inside their trucks to escape the heat and toxic smoke, or deploy it outside along a road cut or other surrounding areas that protect from convective, radiant, and conductive heat sources.

Open ground fire safety zone–All firefighters that are working on or near a fire line, or hikers and campers suddenly exposed to a wildland fire line, must be able to identify a survival safety zone and need to know how big is “big enough.” Such a zone is defined as providing freedom from danger, risk, or injury. Research conducted by Butler and Cohen indicates that an open ground safety zone should be large enough (and therefore cleared of all flammable vegetation) so that the distance between the person and the flames is at least four times

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[24] Mangan, Richard, Project Leader. “Surviving Fire Entrapments. Comparing conditions inside vehicles and fire shelters.” *USDA Forest Service Technology and Development Program.* Missoula, Montana. Fire. September 1997.

the maximum flame height.[25] The research compared the causes of fire fatalities and near fire fatalities of firefighters wearing largely protective Nomex clothing in severe fire conditions even in those cases where crowning in forest fires could produce flames in excess of 200 feet.

The authors further stated that radiant energy travels in the same form as visible light, that is, in the line of sight. Therefore, locating safety zones in areas that minimize firefighters' exposure to flames will reduce the required safety zone size. For example, topographical features that act as radiative shields are the lee side of rocky outcroppings, ridges and the tops of ridges, or peaks containing little or no flammable vegetation. Since safety zone size is proportional to flame height any feature or action that reduces flame height will have a corresponding effect on the required safety zone size. Some examples are burnout operations that leave large "black" areas and thinning or fuel-reduction operations that reduce fuel. The authors emphasized that the research results only address the results of radiant heat, and convective heat transfer from gusts, fire whirls or turbulence could increase this required zone.

The Stanford Research Institute's 1973 report, in analyzing fire protection strategies for the Santa Monica Mountains[26], quotes the yet unpublished report by Green (1973) that lateral firebreaks (those containing the flanks of the fire) must be at least 200 feet wide to provide adequate safety for suppression crews (as it provides a 200 feet distance from flames in emergencies)[27]. According to the above quoted research by Butler and Cohen, flame length would have to be limited to 50 feet in length to provide adequate protection during extreme fire events. However, fire behavior modeling by many different authors since then has indicated that flame length can greatly exceed this length under extreme fire weather conditions, especially in steep topography with flames being pushed uphill by convection currents.

Wilson[28], in investigating the common denominators of fire behavior on fatal and near-fatal forest fires in the U.S. from 1926 to 1976 involving firefighters, found unexpected factors. He stated that firefighters were surprised to learn that fatal and near-fatal incidents often occur in fairly light fuels, on small fires or isolated sectors of large fires, and that fire behavior is relatively quiet before the incident. The general belief is that the high intensity crown fire in timber or heavy brush is most likely to trap and kill firefighters. Yet, with rare exceptions, such as the Sundance Fire of 1967 in Idaho, the Blackwater Fire of 1937 in Wyoming, and the King's Canyon Fire of 1967 in Western Nevada, most of the fires in his study were innocent-appearing just before the accidents.

Wilson then asked himself the question. Why, then do such tragedies and near-fatalities occur under so-called "easy" fire behavior conditions? He answered it by stating that fire spread and intensity can change much more quickly in light fuels than in heavier fuels.   Fine fuels tend to be more quickly responsive to changes in atmospheric conditions than heavier fuels. Second, hot, dry Santa Ana (or foehn-type) winds dry out the lighter fuels with the result that any change of wind, slope, or other environmental factor may lead to a drastic and unanticipated change in fire behavior. Since dry fuels burn with little or no smoke the obvious signs of change in fire behavior, such as smoke and crackle of flames, are only noticeable once the situation has become critical. He then concluded that there are four major common denominators of fire behavior in fatal or near-fatal fires. These often occur:

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25 Butler, Bret W. and Jack D. Cohen "Fire Fighter Safety Zones: How Big is Big Enough." *Fire Management Notes*. Volume 58. N. 1. Winter 1998. pp. 13-16.

26 Stanford Research Institute. Decisions Analysis of Fire Protection Strategy for the Santa Monica Mountains: An Initial Assessment. Prepared for Forest Service. US Department of Agriculture. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. Stanford Research Institute. Menlo Park, CA. Oct. 1973. 159 p.

27 Green, Lyle. R. Developing Fuel-Breaks for Wildland Fire Control in California. Review draft of the U.S. Forest Service, Riverside Fire Laboratory. June 1972.

28 Wilson, Carl C. "Fatal and Near-Fatal Forest Fires. The Common Denominator." In: *The International Fire Chief* 43(9). 6 p. March 1976 (portions of this paper were first prepared for the National Advanced Fire Behavior Course, Sunriver, Oregon, April 1974 and for the National Fire Behavior Officers Training Course, Marana, Arizona, March 1976).

1. on relatively small fires or deceptive quiet sectors of large fires.
2. In relatively light fuels such as grass, herbs, or light brush.
3. When there is an unexpected shift in wind direction or wind speed.
4. When fire responds to topographic conditions and runs uphill

But Wilson also cautioned that, with a sudden change of wind, the fire may change direction, regardless of the topography.

A common sense approach for hikers when caught in the open without a shelter and with a fire approaching is to look for a road cut or ditch (firefighters have even survived in deep wheel well ditches or deep ruts on dirt roads). Lie face down in the ditch or road cut on its uphill side at the base of the (hopefully tall) bank and cover yourself with anything that will shield you from the heat of the fire. If you do not have protective clothing, cover yourself with dirt as much as you can as it is a good insulator. If there are no road cuts look for large rock outcroppings and shield yourself from the approaching radiation heat behind these rocks. However, if you have time, remove all fuel from around the rocks. If time is more limited first remove all finer dead fuels as these will carry the fire and provide a quick heat release that may be fatal. Even hiding in the depression under large fallen logs and covering exposed parts of your body with soil will help protect you. However, be aware that you may share such shelters with rattlesnakes and other critters. Also carry lightweight heat-reflecting blankets with you wherever you go.