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Debunking the Spontaneous Human Combustion Myth: Experiments in the Combustibility of the Human Body

Angi M. Christensen
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Angi M. Christensen entitled "Debunking the Spontaneous Human Combustion Myth: Experiments in the Combustibility of the Human Body." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

William M. Bass, Major Professor

We have read this thesis and recommend its acceptance:

David J. Icove, Richard L. Jantz, Lyle W. Konigsberg

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis
Presented for the
Master of Arts Degree
The University of Tennessee, Knoxville

Angi M. Christensen
May 2000

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Dedication

This thesis is dedicated to my dad, Captain Chet Christensen, whose courageous career as a firefighter sparked my interest in the subject.

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Abstract

Human combustion has been described as "the nearly complete combustion of living human beings in the apparent absence of sufficient external fuel" and it has been inferred from this that either the "human body is unexpectedly combustible of itself or, more controversially, some unrecognized external energy source is acting on the body" (Corliss 1993). Advocates of the phenomenon of spontaneous human combustion, or SHC, have hypothesized everything from potables to poltergeists to pyrotrons to account for the unusual circumstances surrounding these deaths.

Mainstream science, however, contends that although strange, a scientific explanation for the phenomenon does exist. Several studies have suggested that once ignited by an external source, the combination of melted fat and a carbonaceous wick (in the form of clothing, carpet or upholstery) can sustain a small, localized fire capable of a significant degree of bodily destruction. Advocates of SHC argue that the "candle effect" or "wick effect" as this hypothesis is known, has failed in past experiments to replicate (and therefore account for) the degree of bone incineration common to many of these cases. This failure, however, may be due primarily to the use of inappropriate subjects. While pigs (previously the most commonly used subjects for this type of research) may be similar to humans in terms of body fat content, they fail to represent the profile of alleged SHC victims in many ways.

It is hypothesized here that victims of alleged SHC, being largely elderly females, are predisposed to more complete incineration because of both a relatively greater body fat content and a relatively lower bone density. It has long been observed by those who work in crematoriums that the time it takes to incinerate a body is largely dependent on

the condition and size of the body. Those individuals with more body fat tend to burn hotter and faster than those with less body fat (Fred Adamat, personal communication 1999). Furthermore, elderly individuals tend to take much less time to cremate than younger individuals. One funeral director indicates that the average time for cremation is about 2-2.5 hours, with some young, well-built individuals taking up to 3.5 hours to completely cremate while elderly individuals often take less than one hour (Helen Taylor, personal communication 2000).

This research lends further support to the "wick effect" hypothesis through two experiments. Both experiments used human rather than pig or other animal subjects. This has not been done frequently in the past due to inaccessibility of human subjects by many researchers, but because the circumstances surrounding these deaths require very specific conditions, I think the use of human materials is essential to replicating these conditions as nearly as possible. An experiment on the heat of combustion of human tissues strongly suggested that the constituents of the human body will sustain a low heat, localized fire capable of consuming a significant amount of mass. Additionally, experiments conducted burning "healthy" versus osteoporotic human bone demonstrated that less dense bone has a propensity to incinerate more quickly and more thoroughly than normal, healthy bone.

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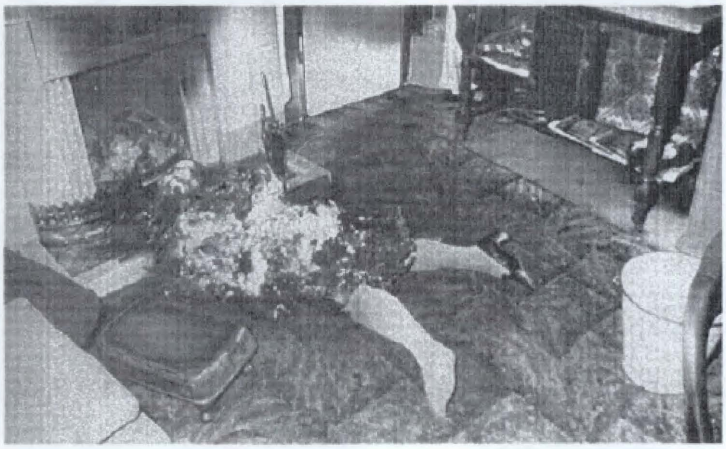
Chapter 1: Introduction

Fire is the third leading cause of accidental death in the Unites States claiming more than 4,000 lives each year (DeHaan 1997). This gives the U.S. one of the highest fire fatality rates in the developed world (Marshall et al. 1998). Nearly three quarters of these fatal fires are residential (Federal Emergency Management Agency 1997). Investigative standards vary as to forensic analyses of these deaths, particularly when there are a number of unusual features. For example, in some rare cases, victims are found devastatingly consumed, with bones partially to nearly completely incinerated without destruction of the dwelling and little involvement of other combustibles in the vicinity (see Figure 1).

Often, investigations of these bizarre deaths are incomplete, failing to include recommended investigative procedures including detailed photography and autopsies (National Fire Protection Association 1995; National Guidelines for Death Investigation Research Report 1997). Confronted with such an information gap, less informed members of the general public have often attributed these unusual scenes to unknown, bizarre sources such as "spontaneous human combustion" or SHC. Even some trained investigators, not understanding the complex fire dynamics of these cases and lacking modern investigative tools (Seaton 1997), have mistakenly labeled these deaths as resulting from SHC, contributing to the persistence of the SHC myth into the present day.

Figure 1: A Body Consumed by Fire Without Involving Nearby Combustibles*



*Reprinted from Randles and Hough 1992

SHC in the Literature

Literary references to SHC, particularly in the early 19th century, are not uncommon. Many well-known novelists have used SHC in their works including Charles Brockden Brown (1798), Herman Melville (1849), Nikoli Gogol (1842) and Charles Dickens (1853). An analysis by Croft (1989) suggests that regardless of the status of explanation of SHC at the time, authors have used SHC as a means of "...commenting on the human condition with the hope of improving it", and as a "...method to show how individual or institutional corruption is inevitably fated to a reward in kind."

While scientific references to SHC were high prior to 1900 or so (Becker 1894; Booth 1888; Fontanelle 1828; Stockwell 1889 and Thurston 1938 to name a few), SHC virtually never appears in mainstream scientific journals today. There has, however, been a surge of popular publications on various paranormal events including SHC. Titles such as "The Fringes of Reason" (Schultz 1989), "Encyclopedia of Unsolved Mysteries" (Wilson and Wilson 1987), "Strange and Unexplained Mysteries of the 20th Century" (Randles 1994) and "Strange Stories, Amazing Facts: stories that are bizarre, unusual, odd, astonishing and often incredible" (Reader's Digest Association, Inc. 1976), all of which include chapters on SHC, have met with great success. Entire books have even been devoted to the subject of SHC (Arnold 1995; Harrison 1977; Randles and Hough 1992; Wilson 1997), as have recent television shows (A&E Television Newtworks 1997; British Broadcasting Company 1989), web sites (Haslam 1999), and newspaper articles (Ament 1990; Banks-Smith 1998; Jacobson 1993; Mathews and Blundel 1998; Robinson 1994; Sieveking 1997). The apparent popularity of these publications, coupled with the pervasiveness of paranormal subject matter in media and entertainment, make it clear that people want to know about the mysterious. It also suggests that a significant percentage of the population still believes in SHC.

While many modern publications simply recount gruesome details of some of the more highly publicized cases of alleged SHC, skeptics are trying to be heard as well. Joe Nickell, one of the more vocal skeptics, has published several articles and chapters attempting to expose the SHC myth (Nickell 1988; Nickell 1989; Nickell 1996; Nickell 1998a; Nickell 1998b; Nickell and Fischer 1984). Other authors including Benecke (1998) and DeHaan (1998b) have tried to demystify SHC by suggesting scientific explanations, one of which will be described in detail later on.

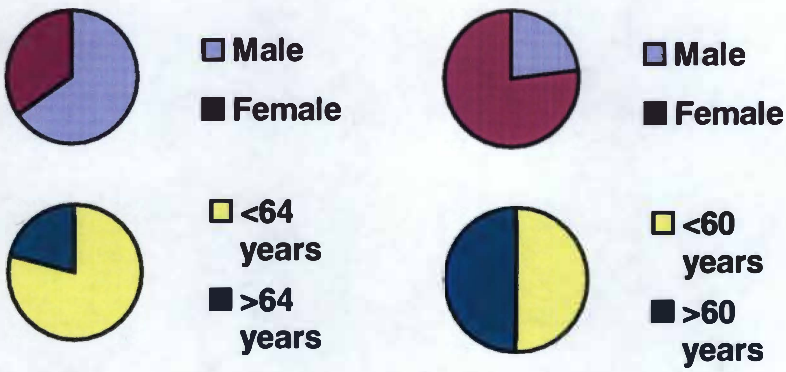
Common Features of SHC Cases

As indicated previously, cases of alleged SHC are mercifully rare. Only about 200 cases have been reported worldwide since the 1600s. There are several features common to most, if not all, cases. Most notably, there is unusually extensive destruction of the body (including bones) with little damage to surrounding combustibles except those furnishings, bedding or carpet in direct contact with the victim. If body parts do remain, they tend to be distal limbs, especially legs and feet. This contrasts with "normal" fire deaths where limbs are typically the first to be consumed by the fire. (Here, "normal" refers to those fire deaths that involve the destruction of a structure such as a house or car, consuming the body along with it. These deaths occasionally result from thermal injuries sustained from the fire itself, but normally result from asphyxia.) A vast majority of SHC cases occur indoors leaving a smelly, oily, brownish-yellow residue on furniture and walls and greasy, ashy remains. They also tend to occur in the evening hours or overnight, allowing potentially eight or more hours for the fire to take place, though some cases are reported to occur within minutes or even instantaneously. Many victims are discovered in or near beds or chairs and most were home alone at the time of the fire. With respect to the worldwide distribution of these peculiar deaths, SHC appears to be a largely Western European and North American phenomenon.

Victims of alleged SHC also share many features. A study of "normal" fire deaths in North Carolina reported that about 65% of the total decedents were male and the mean age of victims was 39 years (Marshall et al. 1998). In contrast with this report, however, a majority of alleged SHC victims are elderly females. Randles and Hough (1992) compiled a rather thorough database of 111 cases of alleged SHC, nearly 60% of which involved female victims. Nearly a quarter of the victims in their database were 70 years or more, and more than half were 50 years or more. This contrasts with Marshall et al.'s study which found that only about 21% of victims of "normal" fire deaths are more than 64 years old. Nickell and Fischer (1984) compiled a smaller database of 30 cases that exhibit classic characteristics of SHC. Their victims were 77% female; 25% of those whose ages were known were 70 years or more, 50% were 60 years or more, and greater than 80% were 50 years or more (see Figure 2).

While many accounts lack details about the victim's build, a number of SHC victims were known to have been overweight in life. Many SHC victims (nearly 30% of those in Nickell and Fischer's database) were also known to have consumed alcoholic beverages or other sedatives prior to their deaths. This, however, does not conflict with the profile of "normal" fire death victims, 53% of which were found to have blood alcohol levels of more than 22mmol/L in Marshall et al.'s (1998) study. This statistic

Figure 2: Age and Sex Profiles of "Normal" vs. "SHC" Fire Deaths



"Normal" fire deaths
(from Marshall 1998)

"SHC" fire deaths
(from Nickell and Fischer 1994)

from Nickell and Fischer's database, however, should be read with caution as many "alleged drinkers" were so reported because it was thought at the time that one must have consumed alcohol in excess for SHC to occur.

Another characteristic of SHC is the increasing frequency of reported cases (see Figure 3). The number of fatal cases reported in the last 50 years is equal to the number of cases reported in the previous 350 years. This increase is probably largely due to better documentation but may result in part from secular changes in body composition. Europeans and Americans are becoming increasingly fatter, and a larger number of overweight individuals means a greater number of people who fit the SHC victim profile.

Theories

A variety of explanations for SHC have been proposed (see Figure 4). Spontaneous ignition (of some materials) is a well-understood event and not a paranormal phenomenon. Drysdale (1985) explains that "...certain combustible solids can ignite as a result of internal heating which arises spontaneously if there is an exothermic process liberating heat faster than it can be lost to the surroundings". This phenomenon, he indicates, is associated with large masses of material with combustion beginning deep inside the material, giving rise to a smoldering wave that slowly propagates outwards. Many, including retired industrial chemist Cecil Jones, believe that SHC results from this type of spontaneous ignition within the body (Randles and Hough 1992). Advocates of this theory suggest that gases such as methane and phosphine (which are normal products of anaerobic bacterial decomposition of vegetable matter and commonly found within human digestive tracts) may be involved in "freak" internal chemical reactions resulting

Figure 3: Frequency of Reported SHC Cases

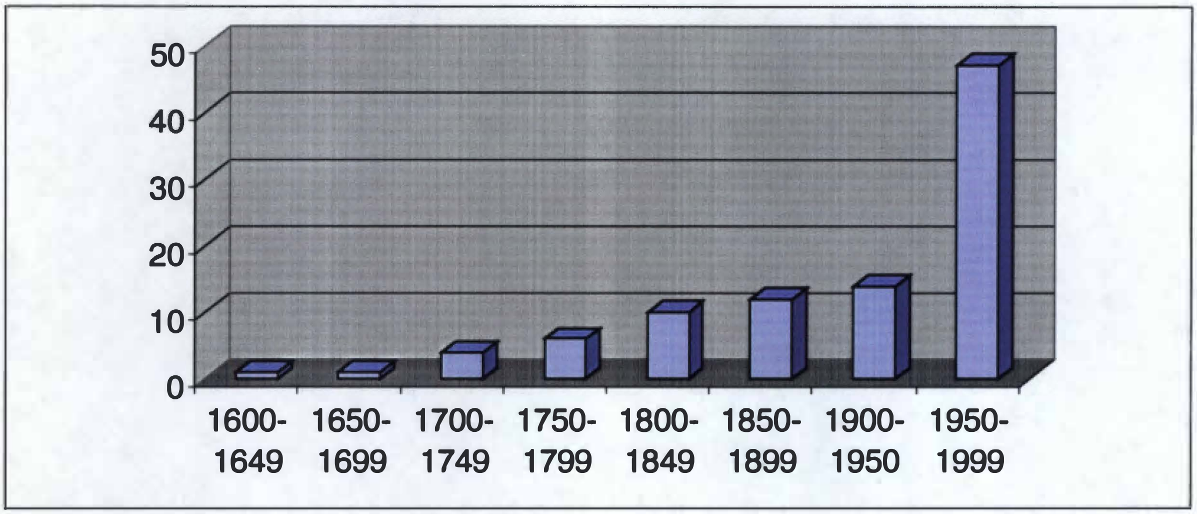
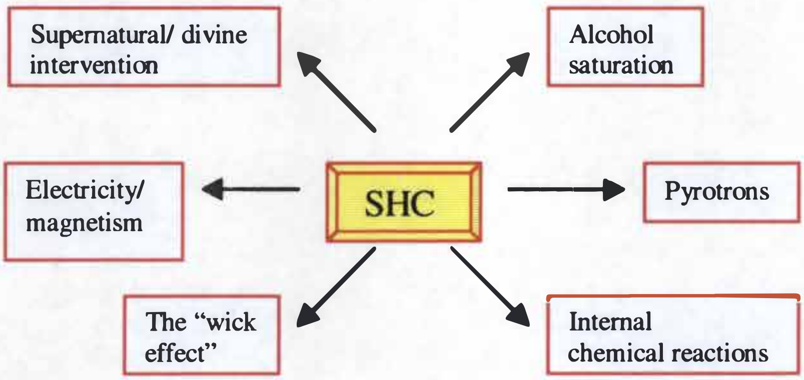


Figure 4: Commonly Proposed Explanations for "SHC"



in spontaneous ignition. The exact reactions, however, have yet to be described. In addition, as Randles and Hough (1992) point out, this theory begs the question as to why there do not appear to be established reports of spontaneous combustion in animals such as cattle which are known to have intestinal build-ups of methane gas.

Some suggest that forms of electricity and magnetism may be responsible (Harrison 1976; Meaden 1990; Wilson 1997). Proposed electrical sources include regular as well as ball lightening (Meaden 1990; Randles and Hough 1992), build-ups of static electricity and "short-circuiting" of electrical fields within the body (Randles and Hough 1992; Wilson 1997). Others have observed correlations of SHC with geomagnetic fluctuations (Gearhart 1975) and leys (energy pathways that criss-cross the earth, generating strange phenomenon at their points of intersection) and suspected a possible relationship (Persinger and Lafreniere 1977).

Beginning in the early 1600s in Europe, it was widely accepted by the general public as well as legal and medical professionals that excessive consumption of alcohol would result in SHC because alcohol saturation made the body more flammable. This idea coincides well with what would later be termed "preternatural combustibility", a condition under which the cells of the body reach a critical state of ignition and require only an outside spark to cause them to burst into flame. French physiologist Julia-Fontanelle (1828), however, demonstrated that lumps of flesh that had been immersed in alcohol would not burn, casting doubt on this prominent theory of the time. Dupuytren was another to deny that alcohol enhanced combustibility, suggesting that alcohol's role was that of rendering the victim semistuporous and liable to be more careless with fire as well as diminishing their capacity to appropriately respond to fire (Bondeson 1997).

Theories of supernatural origins and divine intervention have also emerged (Harrison 1977; Randles and Hough 1994; Wilson 1997), suggesting that aliens, UFOs, or poltergeists are responsible for these unusual deaths, or that victims suffered the wrath of God.

Larry Arnold, the leading proponent of the "pyrotron" theory, calls upon the field of particle physics to account for his explanation of SHC. Arnold's "pyrotron" is an inconceivably tiny energy unit 1×10^{20} times smaller than a gamma ray with enough energy to thoroughly "burn up" whatever it impacts. He suggests that these particles are constantly zipping through the universe and are so infinitesimally small that they usually pass right through our bodies. He theorizes that occasionally these particles fission or fuse with an atom in the body beginning a chain reaction that releases enough energy to disintegrate a human body in a split second or less (Arnold 1995). The most obvious argument against this theory is its failure to account for the distribution of alleged SHC cases. According to Arnold's theory, every atom in the universe should be equally susceptible to spontaneous combustion in this manner. However, curiously, humans from Western Europe and North America seem to remain most vulnerable.

The Scientific Method and Forensic Fire Scene Reconstruction

Many researchers believe that SHC is a myth and has a rational, testable, scientific explanation. The myth persists, however, in part due to a public fascination with the mysterious and resulting media attention and also because rational explanations of these mysterious events inevitably reach fewer ears than the initial unexplained occurrence.

Many advocates of SHC object to ordinary, scientific explanations, doubting that the course of such an event can be demonstrated in retrospect. Modern forensic research, however, has succeeded in discovering numerous methods for revealing clues to past events including fires (Icove 1995). Icove (1995) indicates that at least four major factors are taken into account in forensic fire scene reconstruction: *identifiable fire pattern damage*, or changes to exposed surfaces by heat transfer, *human factors* including witness accounts, detection, behavior and escape paths, *physical forensic evidence of human activity* including burn injuries, wounds, latent fingerprints, shoe prints and blood spatter, and the *application of the scientific method* based upon relevant scientific principles and research including fire testing, dynamics, suppression, modeling, pattern analysis and historical cases.

An alleged SHC scene, as any other fire scene, is readily analyzed using the above factors. The damage pattern is noted in many reported cases, and is usually described as one of its unique features. Witness accounts and victim behavior are also regularly documented. Physical evidence in cases of alleged SHC is typically in the form of burn injuries on the victim and any remnants of the ignition source. The scientific method comes into play when developing and testing a hypothesis with the goal of developing a theory (based on *observations* of the fire scene, *predictions* of the hypothesis, and objective, replicable and reliable *tests* of those predictions based on established knowledge or new research) as to the origin, development, damage, and cause of the fire. Thus, even unusual fire scenes such as those discussed above are candidates for forensic reconstruction.

The "Wick Effect"

With respect to the spontaneity of alleged SHC cases, many investigations reveal that, though anomalous, there is no need to resort to bizarre, paranormal explanations of human ignition and combustion. In more cases than not, ignition sources such as cigarettes, open fireplaces, lamps, candlesticks, stoves and room heaters are readily obvious, and where a source was not initially apparent, it was later discovered or reasonably hypothesized to have been consumed. In a study of fire deaths within the state of Tennessee, nearly 65% of deadly residential fires with known causes resulted from blanket fires, smoking in bed or clothing catching on fire (Icove 1977). This fact casts doubt on the supposed spontaneity of SHC. There still remains, however, the question of the seemingly unusual combustibility of the human body.

DeHaan (1998a) indicates that there are 3 major combustible constituents of the body. First, tissues such as skin and viscera, while not the best fuels, will burn if dehydrated and exposed to a direct flame. Second, bone will add to the fuel of a fire by contributing marrow and tissue, though is not readily combustible. The third and best source of fuel on the body is fat. This fact helped lead many modern skeptics of SHC to conclude that the "candle effect" or "wick effect" is responsible for the seemingly peculiar circumstances surrounding these unusually destructive deaths. French surgeon Guillaume Dupuytren appears to be the first to suggest that once an individual's clothing caught on fire, body fat would melt, fueling a slow and complete combustion of the entire body (Bondeson 1997). Fire officials, in fact, have observed that clothed bodies tend to be destroyed more quickly in structure fires than unclothed ones (Richards 1977).

This idea has intrigued many modern researchers and inspired several lines of research. D.J. Gee (1965), following an encounter with a case similar to other alleged cases of SHC, conducted a series of experiments and found that melted human body fat will only burn when at a temperature of about 250° C. A cloth wick in the liquid fat, however, would continue to burn even when the temperature of the fat had fallen as low as 24° C, supporting the notion that when aided with a wick, human fat is more readily combustible. Another experiment involved a rough model. Gee enveloped a test-tube in a layer of human fat, covered it with skin, and enclosed the entire system in cloth. A Bunsen flame was used to ignite the model, and combustion of the fat, skin and cloth proceeded slowly along the length of the 8-inch roll, producing a smoky yellow flame and soot, consuming the entire roll in about one hour. These results suggest that human body fat will, indeed, fuel a smoldering fire that will continue to consume more flesh and fat.

Dr. John DeHaan took this line of inquiry one step further. In an experiment conducted for the British Broadcasting Company's QED program (1989) intended to lay the myth of SHC to rest, DeHaan wrapped the carcass of a pig in a blanket, doused it with gasoline and set it alight in a mock living room. Two minutes later, the petrol had burned off, but melting fat that had soaked into the clothes and carpet continued to fuel the fire. After three hours, the fire was still burning at temperatures greater than 800°C. Five hours into the experiment, the carcass began to show classic signs of SHC with some bones burning while the rest of the living room remained untouched by flame. While the pig never actually burnt completely to ashes, DeHaan considered the experiment a success, demonstrating both that fire can be supported by animal fat, and that these long lasting fires can remain localized.

In a somewhat more controlled environment, DeHaan et al. (1999) conducted several experiments measuring the combustion of pork tissues under a variety of conditions. In an experiment burning cotton wrapped pork fat, DeHaan and colleagues measured maximum flame temperatures of 911°C using a handheld thermocouple probe. This 120-130kW fire, however, would quite likely to spread to nearby combustibles. Tests involving lean pig carcasses produced fires of 40-50 kW and were thought to be more typical of burning human remains where less efficient fuels such as skin and muscle are also involved. This is a relatively small fire, and according to DeHaan et al., unlikely to spread.

Another important conclusion reached by DeHaan et al. was that this fat-aided combustion was highly dependent upon both preheating by an external source and the presence of a rigid, porous wick of charred cellulostic material (such as cotton clothing, upholstery or carpet) which sustained combustion by increasing the effective vapor pressure of the liquefied fat. If these two factors were present, DeHaan et al. (1999) concluded, combustion would proceed at a rate of about 1-3 g/s (3.6-10.8 kg/h). Also of note, DeHaan and colleagues noted a time lag of about 500s from the time the fire was started until the rendered fat contributed measurably to the fire.

It is relevant here to point out an interesting fact about animal fat: when it burns, it does not do so cleanly. A 10-20% water content by weight reduces the effective heat of combustion and the unburned pyrolysis products condense on nearby surfaces (DeHaan 1997). This condensation is the oily brown soot often observed on furniture and walls at the scenes of alleged cases of SHC. Water content also keeps the heat output of these fires low since a considerable amount of the heat generated by the flames goes to driving moisture from adjacent fat before it will ignite (DeHaan 1998b).

The "wick effect" may also account for the pattern of bodily destruction in these cases which differs from the pattern seen in "normal" fire cremation deaths. The "wick effect" would predict that the body would be most heavily burned in areas where fat content is the greatest. Body fat is typically distributed as follows: men tend to accumulate fat around the neck, upper arms and lower back, women carry fat in the breasts, hips and thighs, and both men and women have high concentrations of fat near the groin, sides, and buttocks with fat dominating large areas of the pericardial and abdominal cavities (Martini and Timmons 1995). In other words, the fattiest region of the body is the torso, with little fat being carried in the distal limbs and especially the hand and feet. This distribution corresponds precisely with the damage pattern observed in many cases of alleged SHC.

Krogman (1949) has suggested that the amount of destruction in a fire is more a function of the conditions of combustion than of the combustibles themselves. Thus, another factor contributing to the combustibility of the human body in these cases may be the furniture upon which victims are typically found. DeHaan (1997) indicates that when a body is supported by metal furniture or springs, it is better exposed to surrounding flames, leading to a much more thorough combustion of the body than might be expected. This situation is most commonly observed in car fires, but may also arise in a bed or armchair supported by metal springs.

An Example of the "Wick Effect"?

DeHaan (1998b) describes a case of an individual who appeared to be the victim of incineration by the "wick effect". The case involved a "well-nourished" adult female who was discovered burning in the woods by two hikers in Medford, Oregon. It does not typify other alleged SHC cases since this case occurred outdoors and the victim was set alight by her murderer rather than by accident, but the victim profile and pattern of bodily destruction are consistent with reported cases of SHC. The body had been nearly completely consumed between the knees and mid-chest, and the hip and upper leg bones were destroyed to the point of being unrecoverable. Surrounding dead leaves, however, were not consumed. It was determined (based on witnesses who had seen the victim hitchhiking earlier) that the fire had burned for no more than 5 hours. When authorities arrived, the fire was still burning and photographs were taken.

As DeHaan (1998b) indicates, these photographs provided a unique opportunity to estimate the heat output of a body being consumed by the "wick effect". Using the Heskestad relationship:

$$H = .23Q^{0.4} - 1.02D$$

where H is the height of the flame in meters, Q is the heat output in kilowatts and D is the diameter of fuel (burning in a pool) in meters (Drysdale 1985), it was estimated (based on visual estimation of H and D) that the heat output for this photographed case was approximately 25-30 kW (although by my calculations, Q in this case would be closer to 11-23 kW). This is quite a bit lower than the heat output observed in DeHaan et al.'s experiments involving pig carcasses. This example, thus, strongly supports previous notions regarding the low heat output of combusting human remains. However, good experimental data using human material is still much needed.

Combustion Of Osteological Material

Advocates of SHC often deny that the "wick effect" can account for the degree of destruction witnessed in these cases, commenting on the extremely high temperatures, sufficient air flow and considerable time that must be required to completely incinerate human bones by "normal" means. Indeed, complete legal incineration of a human body requires temperatures of about 1800-2100°F (950-1100°C) to consume a body within 1-2 hours (Petty 1968). In a cremation, the collagen fibrils and other fibers that tie together the calcium phosphate crystals and make up about one third of the bone are burned, leaving only crystals (Angel 1974). Eckert et al. (1988) observes that complete cremations (leaving only ashes) are rare, whereas incomplete cremations (which leave some bone pieces) are more usual. Others (Bass 1984) suggest that *complete* consumption of a body in a fire (that is, lacking any identifiable elements) is not possible.

Beginning with Krogman, who appears to be the first to conduct experimental cremations for the purpose of seeking answers about cremated remains (Stewart 1979), many studies have been conducted on the effects of heat and fire on osteological material. Many of these studies were carried out by anthropologists and aimed at classifying burned bone for the purpose of learning more about ancient cremation or resource procurement practices (Baby 1954; Binford 1963; Buikstra and Swegle 1989; Gejvall 1963; Stewart 1979; Thurman and Willmore 1981). Other studies have involved analyzing burned skeletal remains in order to improve forensic investigations of cremation deaths and/or aid in positive identification of fire victims (Angel 1974; Eckert et al. 1988; Herrmann 1977; Nelson 1992; Richards 1977; Stevens 1977; Stewart 1979; VanVark 1974a,b; Warren and Maples 1977). Shipmann et al. (1984) examined the effects of heat on several properties of osteological material including color, morphology and crystal structure.

Many of these studies have arrived at the same conclusion: below about 800°C, the combustion of osteological material is incomplete. Increased exposure to temperatures in excess of about 800°C, however, can result in calcined bone. Shipmann et al. (1984) noticed that the neutral white color indicating incineration predominated in samples of goat and sheep mandibles and astragali that were heated from 645-940+°C for 4 hours in a Norman Test Kiln. Buikstra and Swegle (1989) burned fleshed human humeri and femora in a gas incinerator and found that most combustion took place between 700 and 900°C, reaching a calcined condition in 50 to 70 minutes. These temperatures correspond roughly with the temperatures for burning pork fat reported by DeHaan. It seems that pork fat, then, burns at temperatures sufficient to calcine bone. But what about burning *human* fat plus surrounding (less efficient) fuels? Why do these (supposedly) lower heat fires still succeed in incinerating bones?

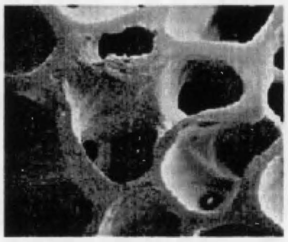
The Weak Bone Hypothesis

Despite previous research results regarding the effects of heat on human remains, the most common criticism leveled against the "wick effect" hypothesis by advocates of SHC is the inability of researchers to replicate (and therefore account for) the unusual degree of bone incineration often seen in alleged cases of SHC. Indeed, the reduction of bones remains perhaps the most difficult factor of fire cremation deaths to explain. While the above studies suggest that burning pork fat reaches temperatures sufficient to calcine bones, DeHaan's pig failed to burn to ashes as hoped. I would like to suggest that previous attempts such as these have failed not because the "wick effect" hypothesis is lacking, but because a fully appropriate research design with appropriate subjects has never been used.

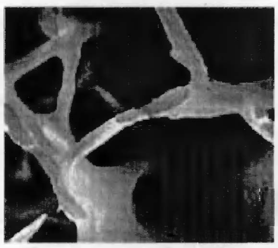
It seems clear that because the circumstances surrounding these cases require very precise conditions, the use of human materials which approximate the victim profile is essential to replicating these conditions as nearly as possible. One of the reasons DeHaan may have failed to see the desired degree of bone incineration in his BBC experiment may be because his pig did not resemble alleged SHC victims in many ways, the most important of which may be bone density. It is hypothesized here that the reason these fat-fueled cremation fires are so successful in destroying the bones so thoroughly is because victims of alleged SHC also fit the profile of those at high risk for osteoporosis. Having less dense bones, their skeletons are thus predisposed to quicker, more thorough destruction should their bodies catch on fire.

Osteoporosis, or porous bone, is characterized by structural deterioration of bone tissue resulting in lowered bone mass and consequent bone fragility (National Osteoporosis Foundation 2000). Figure 5 shows a comparison of normal and osteoporotic bone, which clearly demonstrates this deterioration. According to the National Osteoporosis Foundation (2000), 8 million American women and 2 million American men have osteoporosis and millions more have low bone density. Osteoporosis occurs in those who are immobilized or who have hormonal imbalances, but it is most

Figure 5: Comparison of Normal and Osteoporotic Bone*



Normal bone



Osteoporotic bone

*Reprinted from Dempster et al. 1986

commonly seen with aging (Vander et al. 1994). Approximately one in two females and one in eight males over the age of fifty will suffer from an osteoporosis-related fracture in their lifetime (NOF 2000).

While everyone loses bone when aging, women are more susceptible to osteoporosis for several reasons. First, women simply tend to have a smaller bone mass to begin with, so the effects of bone loss are relatively greater. Second, loss occurring with aging takes place more rapidly in females with the removal of the bone-promoting influence of estrogen after menopause (Vander et al. 1994). Women can, in fact, lose up to 20% of their bone mass in the 5-7 years following menopause (NOF 2000).

Other risk factors for osteoporosis include a family history of osteoporosis, eating disorders, a low calcium diet, certain medications including corticosteriods and anticoagulants, low testosterone levels in men, an inactive lifestyle, smoking and excessive alcohol consumption (NOF 2000). While significant risks have been reported in people of all ethnic backgrounds, Caucasians appear to be at highest risk for the disease (NOF 2000).

There are several characteristics common to both SHC victims and those at risk for osteoporosis. The two most important are being female and being older, particularly post-menopausal. While race is not indicated in many of the SHC case reports, the prevalence in Western Europe and North America suggests that Caucasian ancestry may be another important similarity. Likewise, while lifestyles of SHC victims are seldom mentioned, one could infer that overweight victims led more sedentary lifestyles. Alcohol consumption is yet another factor common to both. These similarities are seen as suggestive that alleged victims of SHC were very likely also suffering from osteoporosis. Thus, this disease may be partially responsible for the degree of bone destruction by fire following their deaths. It has also been suggested that the different fire dynamics which involve more "turbulent" exposure to oxygen and resulting variable flame temperature near the bone may contribute to the degree of destruction (John DeHaan, personal communication 2000).

Chapter Summary

In summary, it would appear that the "wick effect" is a feasible explanation for the phenomenon of SHC—one which does not require mysterious forces or defiance of any physical laws. There are, however, a couple of areas that warrant further investigation. First, as noted previously, experimental data on the combustion of human fat and surrounding tissues are desperately lacking. Specifically, it would be useful to confirm the long-speculated low heat of combustion responsible for nearly consuming a human body but failing to spread to other nearby combustibles. Second, a simple experiment could determine whether osteoporotic human bone is more susceptible to combustion than healthy bone, lending support to the weak bone hypothesis. The following chapter describes the materials and methods of two such experiments which could provide even more meaningful support to the "wick effect" hypothesis.

Chapter 2: Materials and Methods

Human Heat of Combustion Experiment

In order to obtain additional experimental data on the combustion of human tissues including body fat, a human tissue sample (which consisted primarily of skin and subcutaneous fat with some muscle) was combusted in an attempt to determine the effective heat of combustion. The heat of combustion was selected as the variable of interest because this is a value that is known for many common materials including animal fat and is a variable frequently used in many fire engineering calculations. Furthermore, effective heat of combustion calculations take the size (surface area) of the sample in to account versus other variables such as heat output which is largely dependent on the surface area of the sample.

The experiment was conducted at the outdoor Anthropology Research Facility in Knoxville, Tennessee. For safety and accuracy, this experiment was conducted under the supervision of Dr. David J. Icove who is an arson investigator for the TVA Police and is experienced in conducting such tests.

Two amputated legs were obtained from the Histology Department at the University of Tennessee Medical Center in Knoxville, Tennessee. Because approximation of the victim profile was seen as essential, the limbs of two elderly females were selected. When the limbs were taken back to the Anthropology Department and unwrapped for dissection, it was discovered that one of the limbs seemed to have been preserved and was consequently not appropriate for this study. The sample for this experiment, therefore, was taken from the remaining limb which was amputated from a 72-year-old female.

In order to determine the effective heat of combustion, the following formula will be used:

$$\Delta h_c = \frac{Q}{m \bullet A}$$

where Δh_c is the effective heat of combustion in kilojoules per gram (kJ/g), Q is the heat release rate in kilojoules per second (kJ/s), m is the mass burning rate in grams per square meter second (g/m^{2}s), and A is the area burning in square meters (m^2) (SPFE 1995). Heat release rate (Q) will be determined using the formula:

$$Q = \left(\frac{H_f + 1.02D}{.23}\right)^{2.5}$$

where H_f is the flame height in meters (m) and D is the fuel diameter (which assumes the fuel is burning in a circular pool) in meters (m) (SFPE 1995). The variables m, H_f, D, and A were determined experimentally in the following manner:

A sample measuring 10cm by 5cm was dissected from the lower thigh region of the amputated leg. The sample was then placed atop a flat rock inside an aluminum bowl atop a postal scale (see Plate 1). The purpose of the bowl was to retain any fat that melted off but did not combust, and the rock's purpose was to keep the sample out of direct contact with the bowl so that heat released would not be conducted throughout the bowl. The weight of the sample was determined to be 150g using the postal scale (all measurements were recorded in inches and ounces and later converted to centimeters and grams).

Plate 1: Human Heat of Combustion Experiment

From past experiments, it is known that it is very difficult to ignite tissue samples such as this one without the aid of a "wick", which contributes little to the heat released, but provides the necessary dynamic to start and maintain the fire (John DeHaan, personal communication 2000), so the sample was topped with a 10cm by 7.5cm piece of 100% cotton cloth which was ignited with a Scripto Views butane lighter (model HD650-C7). Because the experiment was conducted outdoors, a slight breeze that day made initial ignition difficult, but once ignited, the cotton readily burned, followed by combustion of the sample.

In order to measure flame height, a ruler was placed vertically next to the burning sample and the event was recorded on a Sony Digital Video Camera Recorder (model DCR-TR103/TRV110). By doing this, the video could be played back and freeze-framed to capture the flame height at any given time. This proved to be a very useful methodology particularly since the breeze frequently prevented the flame from being vertical making measuring difficult otherwise. Freeze-framing the video allowed for measuring the flame during a period when it was vertical.

In a similar fashion to flame height, the diameter of the fuel and burning area were determined by observing the size of the charred cotton wick atop the sample (which was significantly smaller than the initially cut fabric sample) compared to the ruler captured on video. The burning area was calculated as the product of the length and width of the charred wick area. Since the wick was rectangular in shape, the diameter of the fuel (which assumes a circular shape to the fuel) will be calculated by determining the diameter of a circle with the same area as the rectangle.

As was the case in previous experiments of this kind, the sample continued to burn, fueled by the melting fat absorbed by the charred cotton wick. The sample burned for 45 minutes before self-extinguishing. The change in mass of the sample was calculated by subtracting the remaining weight (as measured by observing the postal scale reading after the sample had extinguished) from the original weight of the sample.

Bone Density Experiment

In order to assess whether density is a factor in the susceptibility of bone to incineration, bones of differing densities were burned and then observed. Human tibiae and calcanei were used for the experiment primarily because of the availability of osteoporotic and normal examples of these elements. Bone samples, which were non-provenience elements from the University of Tennessee Anthropology Department collection, were initially selected based on gross observation; 1 right tibia and 1 left calcaneous were selected simply because they felt lighter than other elements of the same size. "Normal" counterparts (i.e. 1 additional right tibia and 1 additional left calcaneous) were selected. An effort was made to select normal counterparts that resembled the light element in every way except for weight (see Plate 2). In order to confirm their similar sizes and differing weights, measurements were taken according to the Data Collection Procedures Manual for Forensic Skeletal Material (Moore-Jansen et al. 1994). These measurements are displayed in Tables 1 and 2.

These measurements alone, which show that the dimensions are nearly identical while A elements are less than half as heavy as B elements, suggest that tibia A and calcaneous A are less dense than tibia B and calcaneous B. However, they do not

Plate 2: Tibial and Calcaneal Samples

Table 1: Tibial Measurements

Measurement:	A (light tibia)	B (heavy tibia)
Length of Tibia	361mm	360mm
Maximum Epiphyseal Breadth of the Proximal Tibia	75mm	71mm
Maximum Epiphyseal Breadth of the Distal Tibia	52mm	52mm
Maximum Diameter at the Nutrient Foramen	34mm	32mm
Transverse Diameter at the Nutrient Foramen	24mm	24mm
Circumference of the Tibia at the Nutrient Foramen	95mm	93mm
Weight	92.6g	199.2g

Table 2: Calcaneal Measurements

Measurement:	A (light calcaneous)	B (heavy calcaneous)
Maximum Length of the Calcaneous	79mm	79mm
Middle Breadth of the Calcaneous	39mm	39mm
Weight	13.1g	28.6g

distinguish whether this is due to a difference in cortical thickness or a difference in the density of cortex present or both.

In order to further verify the differences in density, two procedures were performed, one of which examines cortical thickness and the other of which looks at cortical density. First, radiographs were taken of each element using a model GE Prestige SI X-ray. These radiographs, shown in Plates 3 and 4, give a clear visual demonstration of the differences in cortical thickness. While these films do not quantify overall density, it seems reasonable to conclude based on a visual analysis that tibia A is less dense than tibia B and that calcaneous A is less dense than calcaneous B.

Second, Dual Energy X-ray Absorption (DEXA) scans were performed on each proximal tibia. This procedure, which utilizes the Lunar DPX-IQ pictured in Plate 5, is intended to determine the cortical bone density of live individuals and diagnose osteoporosis. Because the machine is designed to scan known, live individuals and the samples for this study were dry bones from unknown individuals, several adjustments had to be made. Because the computer program that calculates density requires age and build of the patient, these statistics had to be fabricated but were kept consistent for both tibiae (the machine was programmed to scan a 50 year old female who was 5’6” and weighed 140 lbs). Furthermore, because DEXA scans are typically conducted on hip bones, vertebrae and forearms, there was no reference sample for tibiae. Being the only long bone region routinely scanned, the forearm was used as a model. The scans encompassed about the proximal half of each tibia except for the very top of the tibial plateau. (DEXA scans were not performed on the calcanei because the machine failed to

Plate 3: Radiographs of Tibial Samples

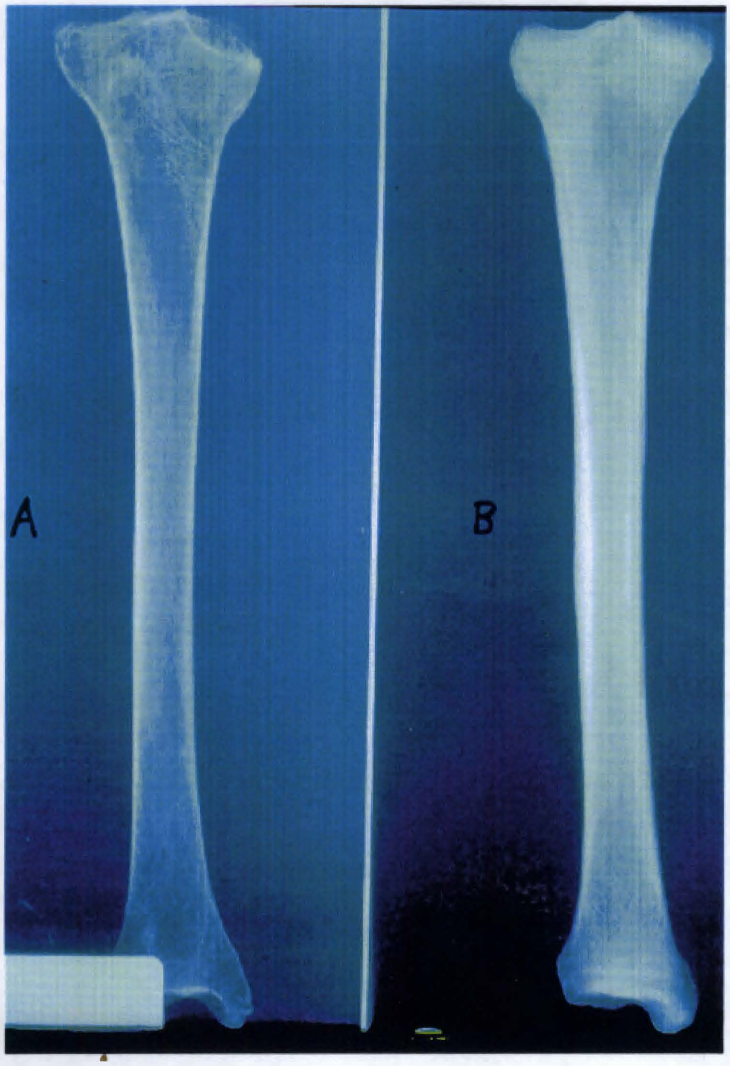


Plate 4: Radiographs of Calcaneal Samples

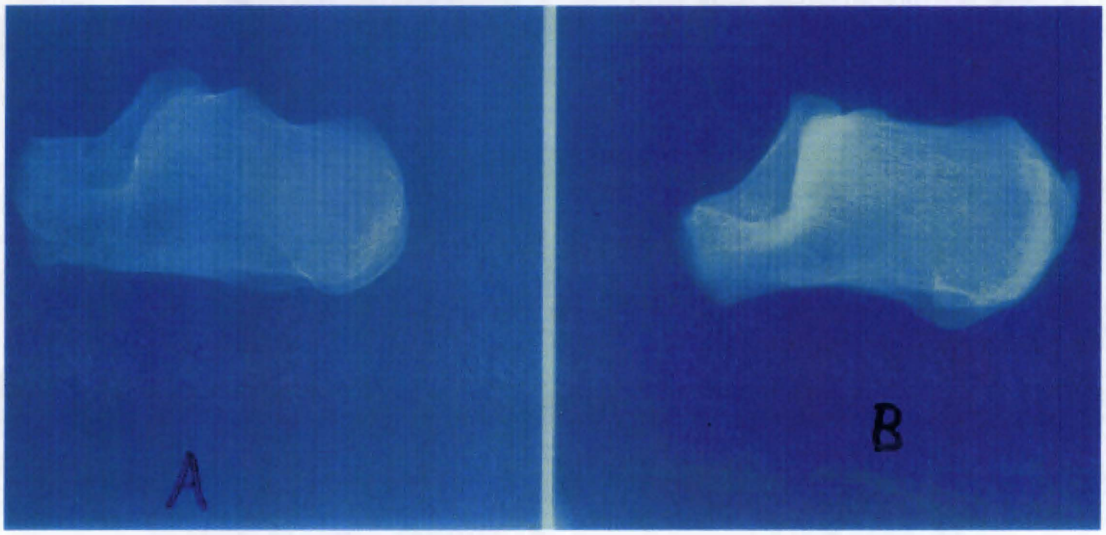
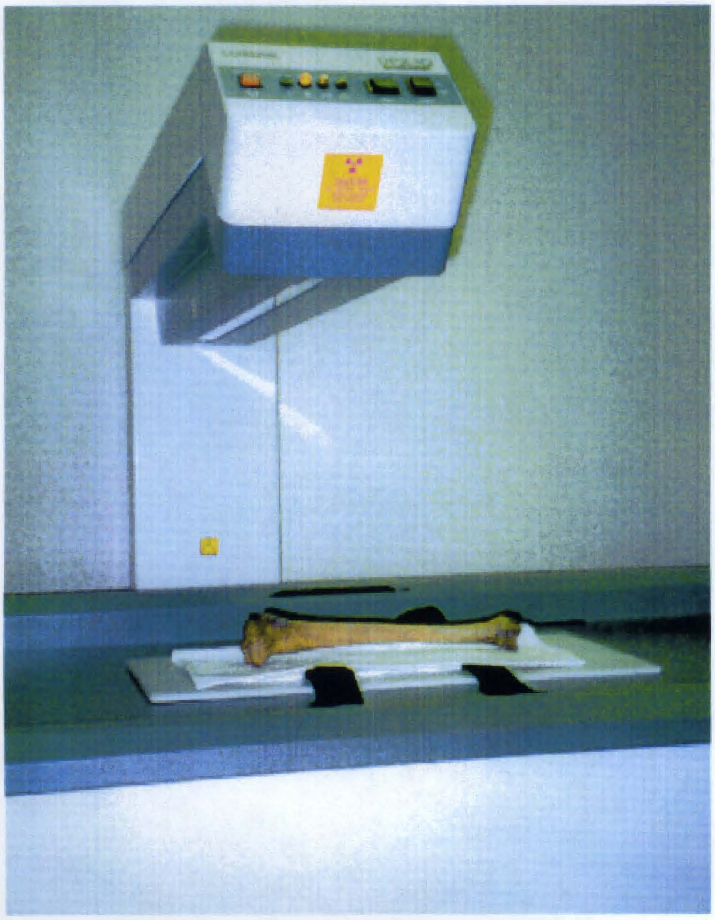


Plate 5: Lunar DPX-IQ DEXA Scanner



recognize the bones when scans were attempted and in any case, there seemed no appropriate model.)

The results of DEXA scans are given as Bone Mineral Density, or BMD, in g/cm^2. According to the World Health Organization criteria for osteoporosis, an individual within one standard deviation below the average young-normal BMD (where one SD is equivalent to 10-12% of the average young-normal BMD) is considered healthy, those between 1 and 2.5 standard deviations below are considered osteopeniac (low bone density), and those greater than 2.5 standard deviations below are classified as osteoporotic (World Health Organization 1994). DEXA scan results are generally given to the patient in the form of a T-score representing the number of standard deviations below average young-normal BMD. The BMD and T-score output is shown in Table 3.

The above statistics for BMD suggest that tibia B is nearly twice as dense as tibia A, and the T-score indicates that tibia B would be considered in the healthy range for bone density while tibia A would be considered extremely osteoporotic. Caution must be exercised when interpreting these results, however, as the scanner may be reading these elements slightly incorrectly since it is designed to scan fleshed bones and because it believed it was scanning forearms rather than tibiae. However, given the extremely large discrepancy and the fact that this bias is consistent, it seems reasonable to conclude that tibia A is significantly less dense than tibia B.

Prior to cremation, each tibia was cut into two pieces 150mm below the lateral aspect of the tibial plateau using an oscillating saw. This was done for two reasons. The first reason was to increase the number of cremations from 2 trials

Table 3: DEXA Scan BMD and T-score Output

Element	BMD (g/cm^2)	T-score
Tibia A	.363	-5.0
Tibia B	.694	-0.25

(calcaneous and tibia) to 3 trials (calcaneous and 2 tibial segments) without destroying more osteological material. The second reason was to be able to isolate and separately cremate the section of tibia that was previously scanned so that the possibility of varying density within the same specimen did not affect cremation results or interpretations. The proximal and distal segments (shown in Plate 6) were then weighed separately (see Table 4).

Three cremation trials were run. The first consisted of the two calcanei, the second involved the distal tibiae and the third involved the proximal tibiae. This particular order was selected in case adjustments needed to be made in the procedure, and being the only area to have a DEXA scan performed on it, it was seen as essential that the cremation procedure be successful on the proximal tibiae.

For cremation, the elements were placed on a silicon carbide kiln shelf coated with a 50:50 mix of kaolin (white clay) and flint. These shelves are use for firing ceramics and can withstand temperatures up to 1650°C (3000°F). The elements were then placed into the Power-Pak II Cremation System (by Industrial Equipment & Engineering Co. in Orlando, Florida) shown in Plate 7. Due to prior use that day, the cremation system was already at a temperature of 315°C (600°F) when the experimental cremations began. Each element was fired until either or both elements fragmented upon contact with the tool used for removing the remains. The times and temperatures of firing are displayed in Table 5. Each element was also weighed after cremation. The results are displayed in Table 6.

Plate 6: Proximal and Distal Tibial Segments

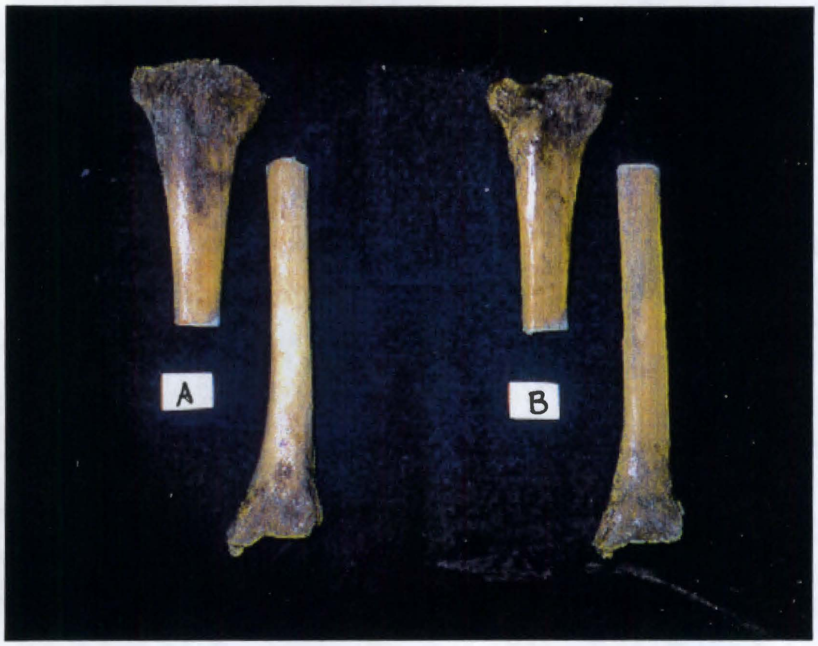


Table 4: Tibial Segment Weights

Segment	Tibia A weight (g)	Tibia B weight (g)
Whole tibia	92.6	199.2
Proximal tibia	49.2	91.8
Distal tibia	43.0	106.6

Plate 7: Cremation System

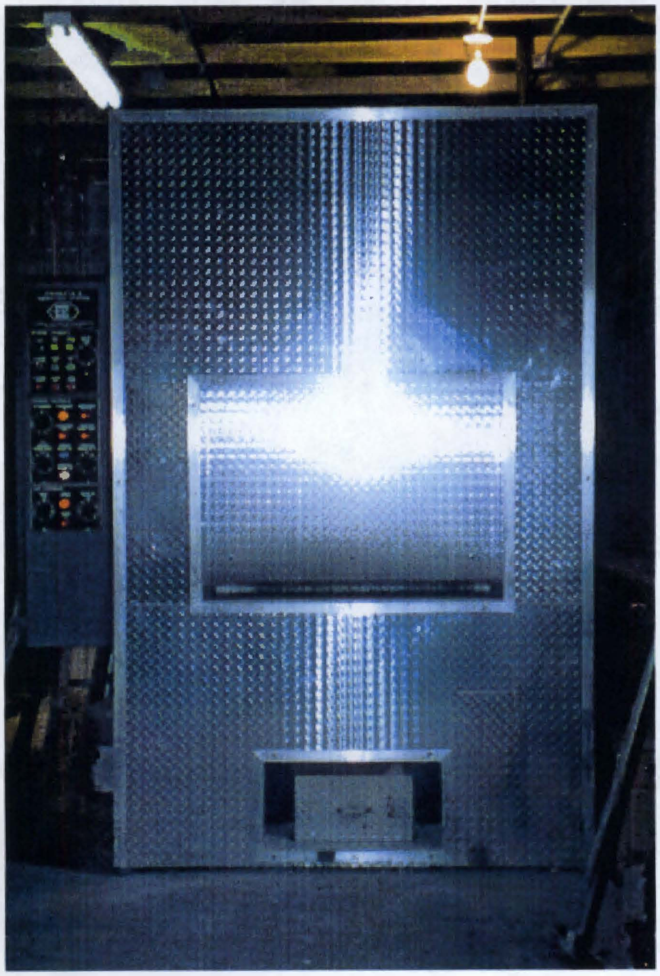


Table 5: Cremation Times and Temperatures

Element	Time (min)	Temperature (°C)
Calcaneous	0 (in)	315
	4	625
	8	745
	10 (out)	780
Distal Tibiae	0 (in)	680
	2	685
	4	705
	7 (out)	730
Proximal Tibiae	0 (in)	705
	4	775
	5 (out)	790

Table 6: Post-Cremation Weights

Element	Weight (g)
Calcaneous A	5.3
Calcaneous B	15.4
Distal tibia A	25.3
Distal tibia B	68.3
Proximal tibia A	27.9
Proximal tibia B	59.2

Chapter 3: Results

Human Heat of Combustion Experiment

Through the above described method, the flame height (H_f) was determined to be 0.075m, and the fuel area (A) was determined to be 0.075m x 0.05m, or 0.00375m^2. From the area, the fuel diameter was derived using the equation for the area of a circle (A = πr^2), replacing A with the area of the rectangle, and solving for r:

$$\pi r^2 = 0.33575$$

$$r = .034.$$

Since the diameter is twice the radius (2r), D was calculated to be:

$$D = 2r$$

$$= .068$$

The heat release rate (Q), using the previously discussed equation:

$$Q = \left(\frac{H_f + 1.02D}{.23}\right)^{2.5}$$

was calculated to be:

$$Q = \left(\frac{(0.075) + (1.02)(0.068)}{.23}\right)^{2.5}$$

$$= .32 \text{ kJ/s}.$$

The burning rate, m, is the mass loss per second over the burning area. The original sample was 150g, and after a 45 minute (2700 second) period, the remaining mass was 100g, so 50g of the sample was lost to combustion. Thus,

$$m = \frac{50g}{(2700s)(0.075m)(0.05m)}$$

$$= 4.9 g/m^2 s.$$

Inserting the above values into the formula:

$$\Delta h_c = \frac{Q}{m \bullet A}$$

the effective heat of combustion of the sample was calculated to be:

$$\Delta h_c = \frac{0.31\text{kJ/s}}{(4.9\text{g/m}^2\text{s})(0.00375\text{m}^2)}$$

$$= 17\text{kJ/g}.$$

According to the Handbook of Fire Protection Engineering (SFPE 1995), the effective heat of combustion of animal fat has been calculated to be 39.8kJ/g. This is, expectedly, much higher than the result observed here where there were the less efficient fuels of skin and muscle involved. In fact, 39.8kJ/g exceeds the effective heat of combustion of various other common materials such as charcoal and wood which themselves have relatively high heat of combustion values (33.2-34.2kJ/g and 17.8-20.4kJ/g, respectively). Indeed, the heat of combustion of animal fat approaches that of gasoline and paraffin (43.7kJ/g and 46.2kJ/g) and one would hardly expect that the human body could burn as hot as gasoline and not affect surrounding combustibles! 17kJ/g, or just less half that of fat alone, is thus a reasonably low value to expect for the heat of combustion of a human body. A fire of this magnitude is still quite capable of consuming a good deal of tissue, as was demonstrated by the 33% reduction of the sample combusted for this experiment.

It would be very useful to compare these results to the effective heat of combustion of the observed Medford, Oregon case, but unfortunately, burning area and mass loss rate were not available and thus Δh_c could not be calculated. In retrospect, it would also have been very useful to have measured the flame temperature of the combusting sample in order to determine whether this temperature is lower than the ignition temperature of many household furnishings, thus establishing a relationship between the low heat of combustion and the failure of the fire to spread to nearby combustibles.

Ideally, several trials of the above experiment should be run in order to confirm values for effective heat of combustion of a human body and it would no doubt vary depending on the body fat content of the specimen. This experiment, however, was intended as a benchmark to determine whether human samples, indeed, behave in a way similar to previously tested pig (and other animal) fat. The results, in fact, are *not* really consistent with experiments conducted using pig fat, but *are* consistent with what one would *expect* given the addition of less efficient fuels such as skin and muscle. Thus, the results are seen as highly suggestive (thought not proof positive) that when the human body burns aided by cotton clothing as a wick, it does so at a very low heat but nonetheless succeeds in perpetuating and consuming a significant amount of mass. This experiment, therefore, supports previous notions about the process of human combustion via the “wick effect”.

Bone Density Experiment

Admittedly, each of the cremated elements suffered greater destruction than anticipated and hoped. Because the temperature of the cremation system could be monitored but not controlled, it was difficult to anticipate when the elements should be removed. The extremely high temperatures combined with the dryness and fragility of the specimens led to very quick and thorough incineration with decisions having to be made very quickly. Nonetheless, because each pair of elements was cremated side by side and therefore subject to the exact same conditions for the same amount of time, the results are still viewed as meaningful.

Upon examination of the temperatures in Table 5, one will notice that most combustion took place between 625 and 790°C. As indicated previously, past studies have typically revealed that the combustion of osteological material is incomplete below about 800°C. All samples in this study would be considered completely calcined. The above temperatures, however, do closely approach this threshold and this study, therefore, is seen as being in agreement with and in support of the results of previous studies.

While the temperatures and times of each of the cremations varied slightly (due to increasing temperature of the cremation system as a result of further use), the results were essentially the same. Upon removing the elements from the cremation system, osteoporotic (A) elements always showed greater thermal damage than their healthy (B) counterparts when examined for fragmentation, mass loss and color (see Plates 8, 9 and 10).

Fragmentation In each case, the osteoporotic element crumbled when removed from the cremation system while the healthy element (though also damaged) remained more intact. Calcaneous A hardly retained a recognizable morphology while calcaneous B still remained nearly complete. Neither distal tibia remained intact, but distal tibia A was significantly more fragmentary than distal tibia B, being in more and smaller pieces while its healthy counterpart, though also fragmentary, retained larger fragments. The

Plate 8: Post-Cremation Calcanei

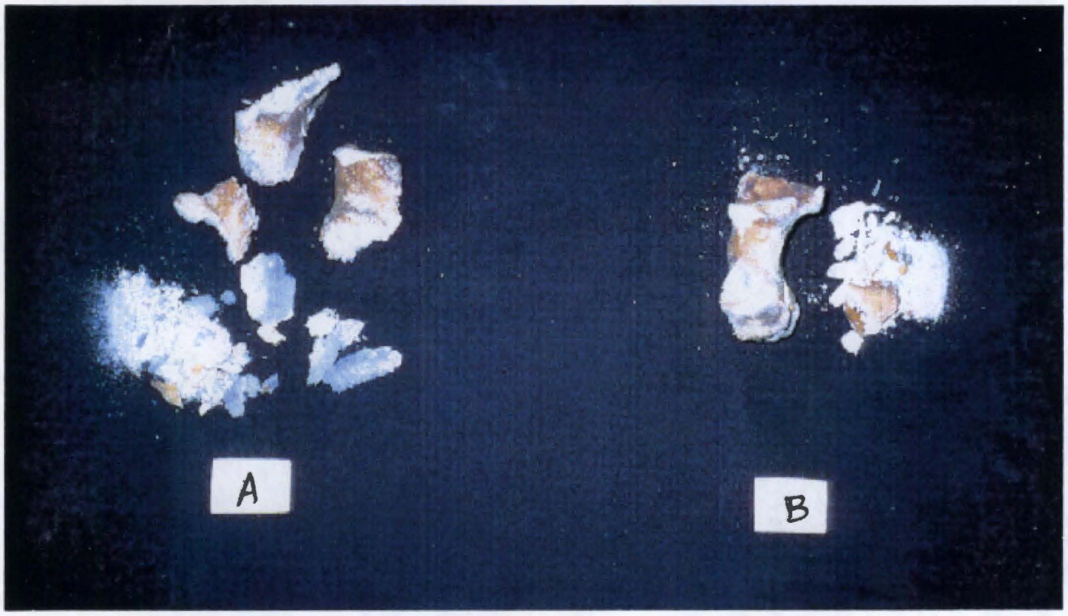


Plate 9: Post-Cremation Distal Tibiae

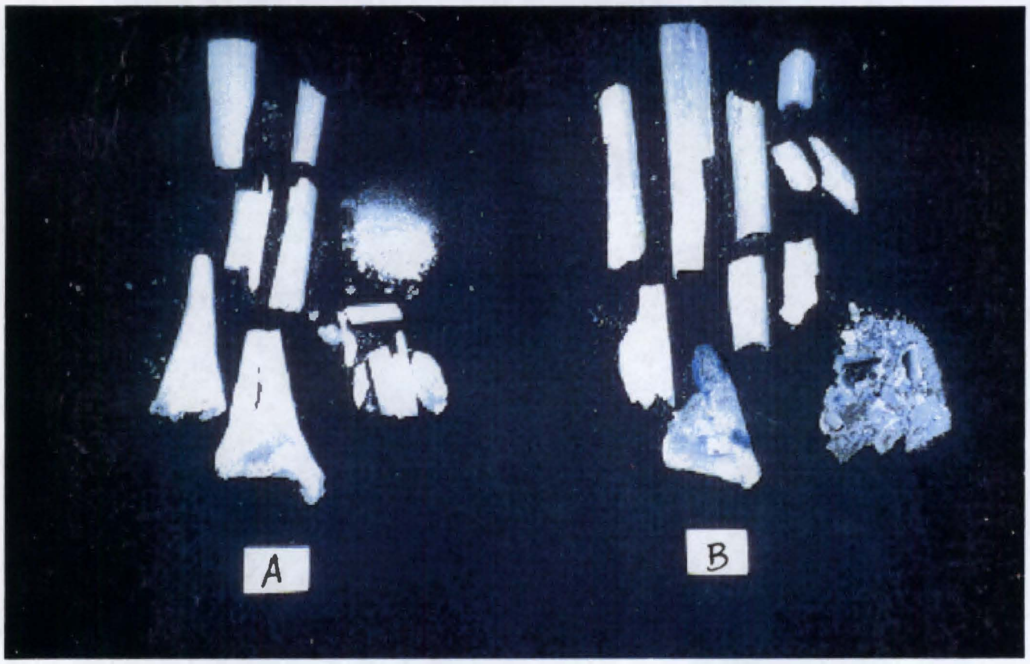
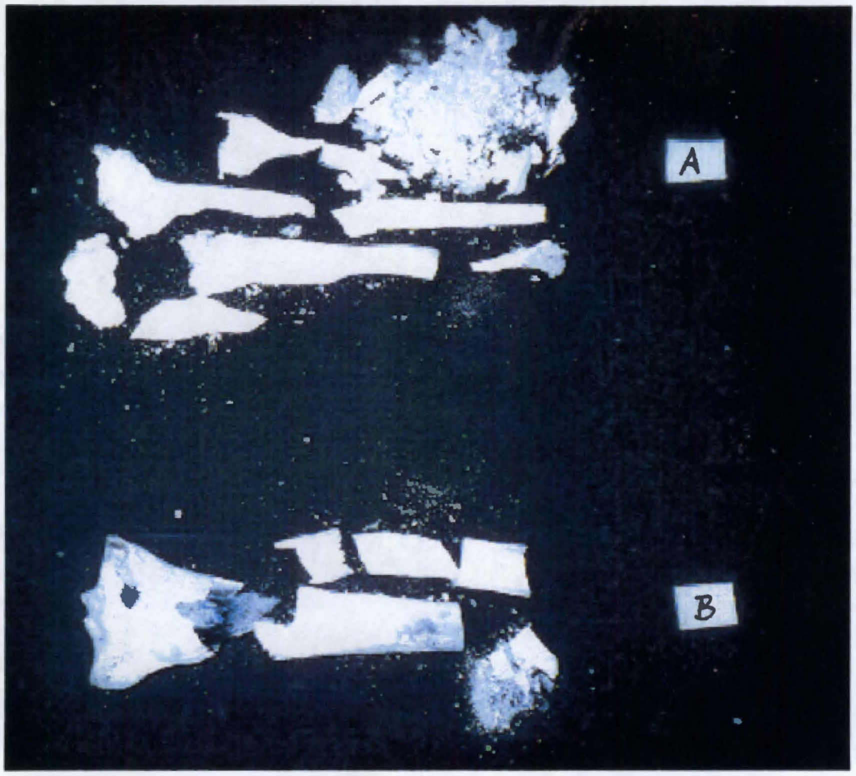


Plate 10: Post-Cremation Proximal Tibiae



most significant difference was seen with the proximal tibia. The osteoporotic specimen was extremely damaged, fragmenting into many small pieces upon initial contact and deteriorating further with subsequent (even careful) handling. The healthy proximal tibia, in contrast, broke into only 4-5 large shaft fragments with the condyles and tibial plateau remaining largely intact.

Mass Loss Rate Osteoporotic elements also experienced a higher rate of mass loss during cremation (see Table 7). The osteoporotic calcaneous lost 0.54g/min more mass than the healthy calcaneous due to thermal damage and the osteoporotic tibia lost, on average, 2.6g/min more mass than the healthy tibia. The higher rates (in general) for the tibia over the calcaneous are most likely at least partially a result of the increased cremation temperature. One may speculate that due to the more fragmentary nature of the osteoporotic elements, fewer pieces were recovered (affecting the post-cremation mass) and while this may be the case to a slight degree, care was taken to recover even the "dust" that remained for all elements.

Color Osteoporotic elements also showed signs of greater thermal damage when examined for color changes known to be associated with thermal exposure. In order that observations be standardized, Munsell Soil Color Charts (Munsell Color Company, Inc. 1954) were used in analyzing the color of specimens following cremation. The internal surface of calcaneous A maintained a combination of white (N8/), bluish gray (10B6/1) and pink (7.5YR8/4) while light brown (7.5YR6/4) and reddish brown (5YR5/4) dominated the external surface. Calcaneous B showed only white (N8/) on the internal surface though it retained some weak red (10R4/4), light reddish brown (5YR6/3) and pinkish gray (7.5YR6/2) on the exterior.

Table 7: Cremation Mass Loss Rate

Element	Pre-Cremation Mass (g)	Post-Cremation Mass (g)	Absolute Mass Loss (g)	Mass Loss Rate (g/min)
Calcaneous A	13.1	5.3	7.8	0.78
Calcaneous B	28.6	15.4	13.2	1.32
Distal tibia A	43.0	25.3	17.7	2.5
Distal tibia B	106.6	68.3	38.3	5.47
Proximal tibia A	49.2	27.9	21.3	4.26
Proximal tibia B	91.8	59.2	32.6	6.52

Distal tibia A was predominantly white (N8/) with some small areas of bluish gray (10B5/1) and pinkish white (5YR8/2). Distal tibia B was primarily white (N8/) on the external surface, retaining some light yellowish brown (10YR6/4) while the internal surface remained predominantly black (N2.5/) with areas of dark bluish gray (5PB4/1) and bluish gray (5PB6/1).

Proximal tibia A was predominantly white (N8/) on both the internal and external surfaces with some small areas of light bluish gray (5PB7/1). Proximal tibia B had white (N8/) dominating the exterior, speckled with reddish yellow (5YR6/6) and bluish gray (5PB6/1). The interior was predominantly gray (N6/, N7/) with areas of black (N2.5/) and dark bluish gray (10B5/1).

As indicated by previous research (Buikstra and Swegle 1989; Shipman et al. 1984), the sequence of thermal discoloration proceeds along a color continuum beginning with normal bone color (unburned) to some blackening (non-incinerated) to blackened and dark brown (incompletely incinerated) and finally to bluish white or gray (completely incinerated). In each of the above cases, A elements lie further along the continuum of thermal damage than B counterparts suggesting greater thermal destruction even though each element was subjected to the exact same thermal conditions. The results of this color analysis as well as the more fragmentary condition and greater relative mass loss of the osteoporotic elements are seen as indicative of the greater susceptibility of osteoporotic bone to thermal damage than healthy bone.

Chapter 4: Discussion and Conclusions

Discussion

The above results strongly support the "wick effect" as a likely explanation for many of the circumstances surrounding alleged cases of SHC. Many characteristics of these cases thought inexplicable appear to have rational explanations. Some of these characteristics, mentioned earlier, include extensive bodily destruction even to bones, little damage to surrounding combustibles, leaving only distal limbs remaining, leaving a residue on furniture and walls, occurring indoors, usually in or near beds or chairs, occurring largely in Western Europe and North America, and finally, happening to primarily elderly females who may have been overweight and/or consuming alcohol or other sedatives before the fire occurred.

Each of these features can be accounted for by the "wick effect" and related observations. The extent of bodily destruction is a result of at least one of many possible factors. Several studies have already suggested that the body itself provides fuel in the form of fat (Gee 1965; British Broadcasting Company 1989; DeHaan et al. 1999), and DeHaan et al. (1999) demonstrated that the combustion of animal fat aided by an external wick is capable of consuming 3.6-10.8kg/h. Furthermore, given that many victims are discovered in beds or chairs, the dynamics of fires if these locations, as noted by DeHaan (1997), can lead to a greater amount of destruction than expected. DeHaan also demonstrated that such fires, though destructive, will remain localized and avoid involving surrounding combustibles (British Broadcasting Company 1989). Given that fat is the primary fuel in these fires, the distribution of fat on the human body explains the pattern of bodily destruction. The residue often reported adhering to surrounding furniture and walls has been explained by the properties of burning fat.

The current study demystifies several other factors previously unexplained or attributed to paranormal or unusual sources. In examining the SHC victim profile, it was noted that this profile was very similar to the profile of those at risk for osteoporosis. The supposition that those with osteoporosis are more likely to be victims of this degree of cremation is explained by both the victim profile and the worldwide distribution of cases. It also accounts for the degree of bone destruction, previously thought to be too extensive to be due to scientifically explicable causes. Furthermore, the result of the tissue combustion experiment demonstrated the previously suspected low heat of combustion of human body tissues.

With respect to other proposed theories (several of which were mentioned earlier), many fail to meet the criteria of a scientific theory because they lack testability. Without subjecting a hypothesis to possible falsification, the strength of that hypothesis cannot be assessed. Unlike these other suggested explanations, the "wick effect" hypothesis lends itself to scientific inquiry, and indeed, it appears that the "wick effect" has met the outlined criteria for a scientific theory: aspects of the fires were observed and documented; several predictions based on the hypothesis were tested by comparing them with established knowledge, previous research and the experiments conducted here; and each of these tests *supported* the hypothesis, while none of them refuted it. Moreover, given the objectivity, replicability and reliability of these tests, it seems appropriate to elevate the hypothesis to the status of a theory until such a time as some other test supports the contrary or a different hypothesis with more explanatory power is suggested.

There are several (occasionally) reported features that this theory does not explain such as those cases which are reported to occur instantaneously or where it was reported that absolutely no outside ignition source was possible. It is important to remember, however, that in many reported cases of SHC, data is woefully lacking, and much of the data that is available is largely anecdotal (particularly in earlier cases). These reported features or characteristics are therefore suspect and most likely exaggerated, misdocumented or nonexistent.

To further summarize, the following outlines a likely scenario of a fire cremation death that exhibits characteristics typically associated with SHC: An older, perhaps overweight female who has possibly consumed some kind of sedative accidentally ignites her clothing. Her capacity to respond appropriately is diminished due to advanced age, obesity, stupor, or all of the above. Furthermore, she is home alone so no one is there to help. As the body begins to burn, fat is melted and absorbed by the clothing, carpet or furniture which acts as a wick, helping to sustain the fire. Because she is overweight (or at least possesses a substantial amount of body fat simply because she is female), there is sufficient fuel to maintain the fire for several hours. The destruction is concentrated around the torso where the fuel supply is the greatest. As the fat burns, byproducts condense on surrounding furniture and walls. The fire is a small, smoldering one and therefore does not spread. Once the flames finally reach the bones, they are easily destroyed due their existing weakened and deteriorating condition. After several hours, the fuel supply is exhausted and the fire ceases to burn.

Conclusions

Humans do not spontaneously combust, though they are surprisingly combustible given the conditions discussed above. In spite of previous research, and no doubt in the face of these results as well, the debate about the reality of SHC will continue due to the morbid fascination of many with the gruesome phenomenon. While most mainstream scientists probably give it little thought or attention, SHC advocates continue to argue its legitimacy. Nickell and Fischer (1984) raise an interesting point about this debate when they note that skeptics of SHC largely emphasize cause, frequently dismissing effect, while SHC advocates commonly concentrate on effect, often giving no hypothesis for (or completely ignoring) cause. If cause is ignored, as Nickell and Fischer point out, then the phenomenon is destined to forever remain mysterious. I believe the results of previous research combined with the results of the experiments conducted here provide sufficient evidence to suggest that these fires and subsequent deaths are not the result of mysterious external forces, but rather, unfortunately, are the result of tragic accidents followed by predictable, explainable destruction.

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