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Sustained Combustion of an Animal Carcass and Its Implications for the Consumption of Human Bodies in Fires*

REFERENCE: DeHaan JD, Nurbakhsh S. Sustained combustion of an animal carcass and its implications for the consumption of human bodies in fires. J Forensic Sci 2001;46(5):1076–1081.

ABSTRACT: When a human body is found with significant portions of its torso and limbs destroyed yet with comparatively minor damage to head, hands and feet, the mechanism of such destruction defies ready explanation, since exposure to external fires, particularly those involving flammable liquids, usually results in the destruction of hands, feet, limbs, and head prior to significant combustion of the large mass of the torso. Previous tests by these authors have demonstrated the conditions necessary to promote combustion of a body: the presence of adequate body fat, presence of a porous, rigid char to act as a wick, and an external flame source sustained for several minutes to char the body and cause the subcutaneous fat to begin rendering.

In the test reported here, a freshly-slaughtered pig carcass with a net weight of 215 lb. (95 kg) was wrapped in a cotton blanket and placed on a carpet-covered plywood panel. The fire was initiated using 1 L of gasoline poured on the shoulder area of the blanket-wrapped carcass. The gasoline burned off within 4 min, having ignited a large area of the blanket and adjoining carpet. Flames from those fuel packages resulted in the establishment of a steady-state fire sustained by the rendering of the body fat, with the necessary wick provided by the charred cotton blanket and carpet. The heat release rate of this fire was 60 $\pm$ 10 kW, with flames less than 12 in. (0.35 m) high for its duration. The fire sustained itself by the rendering process for more than 6½ h from ignition, at which time it was extinguished. An average mass loss rate of 1.5 g/s (5.3 kg/h) was observed during the self-sustained fire. Extensive destruction of the carcass (more than 60% by weight) included reduction of large bones to a fragile, ashen state. Other test data will demonstrate the similarity between subcutaneous fat from human and porcine sources. The implications for the reconstruction of accidental and homicidal fires involving such destruction will be discussed.

KEYWORDS: forensic science, criminalistics, fire, arson, death, combustion, animal model, bodies

In a very limited number of fire death cases, the body of the victim is found with intensive fire destruction of the torso (including the muscles and bones) while damage to surrounding furnishings and other fuels is minimal. Such cases are often described as spontaneous human combustion because it is thought that a "normal" accidental fire intense enough to consume a body would necessarily be large enough to involve an entire room. Previous tests by these authors (1) demonstrated that animal tissue in the form of pork skin, subcutaneous fat and muscle, could be burned in a hot but localized fire fueled by rendered fat absorbed into a charred porous substrate. The substrate acts like the wick in a kerosene lamp. This previous work showed that the size of the fire is controlled by the rate of mass loss which is in turn determined by the surface area of the wick involved. Fires of 20 to 130 kW heat release rate (HRR) were produced from wick areas (of carpet and charred cloth) between 0.1 and 0.5 m^2 in area. Such fires involved a mass loss rate of fuel of 1 to 3 g/s (3.6 to 10.8 kg/h). The duration of these fires was dependent on the amount of fuel available and tests involving small pig carcasses of around 50 kg revealed that the modest amount of subcutaneous fat tended to limit the duration of the fires to less than 1.5 h before self-extinguishment. It had been suggested that a test using the same experimental protocol as before but using a larger (~100 kg) carcass that would more closely resemble an adult human body would be useful in establishing the fire conditions produced when a body is involved in a prolonged fire of limited size (i.e., with HRR less than 150 kW). Further tests comparing the combustion properties of human fat and pork fat using a cone calorimeter would validate the equivalency of using pig carcasses rather than human cadavers for such tests.

Experimental

The room calorimeter at the California Department of Consumer Affairs—Bureau of Home Furnishings (BHF) provided the basic experimental requirements for this test. The room, 3 m $\times$ 3.6 m $\times$ 2.5 m high, had a single door 2.2 m high $\times$ 0.9 m wide that is fitted with an exhaust hood. Analytical equipment fitted to the hood exhaust measured the O_2, CO, and CO_2 concentration of the exhausted air and allowed the entire room to be used as an oxygen depletion calorimeter. Data were recorded 12 times per minute for the first 10 min of the test, then twice per minute to 1:22:00 (1 h, 22 min), then once every 82 s for the balance of the test. This was done to conserve file space on the logging computer.

On the concrete floor of the compartment was mounted a load cell with a capacity of 200 kg ($\pm$ 0.06 kg). A 1 m $\times$ 1 m section of gypsum board was used to protect the load cell and a 4 $\times$ 8 ft (1.2 $\times$ 2.4 m) panel of ¾ in. (19 mm) plywood was laid as a base on top of the gypsum board. A layer of ½ in. (12 mm) rebond polyurethane foam carpet pad was installed over the plywood followed by a layer of short pile synthetic carpet.

A fresh refrigerated pig carcass (dressed, i.e., gutted and cleaned) weighing 95 kg (215 lb) was obtained from a local meat packing plant. (Logistics and cost considerations made it impracti-

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cal to obtain a human cadaver. The composition, mass and proportions of an adult pig were considered sufficiently similar to an adult human.) The carcass was wrapped in a single thickness of cotton blanket and placed centrally on the carpeted plywood platform. One thermocouple (Type K) mounted centrally in the compartment near the ceiling captured the hot layer temperature in the compartment. A portable thermocouple/pyrometer was used to measure average plume temperature of the flames produced. The load cell was monitored continuously, as were the gas conditions and the heat release rate (HRR) calculated by the analytical instrumentation. The test was recorded by video camera. The fire was started by manually igniting 1 L of automotive gasoline poured over the shoulder region of the blanket wrapped carcass.

Radiant Heat Ignition (Cone Calorimeter) Tests

A Stanton-Redcroft Oxygen Depletion Cone Calorimeter (Polymer Laboratory, Epson, Surrey, UK) was used to compare the heat of combustion and combustion rate of pork fat against those of human fat. A 10 cm × 10 cm × 3 cm aluminum foil tray was filled with segments of fresh refrigerated pork fat and skin or segments of fresh (thawed frozen) human subcutaneous fat obtained from the University of California—Davis, Medical School. Based on tests previously reported, it was known that such materials could not be ignited at an incident radiant heat fluxes of 35 kW/m^2 in the absence of a suitable wick, so a single layer of clean cotton cloth towel was wrapped around the fat and skin in each tray. The wrapped samples were then exposed to an incident heat flux of 35 kW/m^2 and the resulting plume was ignited with a high voltage arc source. The resulting HRR was calculated by the calorimeter and, along with the load cell data, was used to calculate the effective heat of combustion for each sample. A portable thermocouple/pyrometer was used to measure the flame plume temperature during each test. The calorimeter test results are found at the end of the "Results" section.

Results

Carcass Test

The HRR measured (ignition was at 0:00:30 (0 h, 0 min, 30 s) of the data record) during this test is shown in Fig. 1. As expected, the gasoline fire flared to a maximum HRR of approximately 293 kW at 00:01:05 (00:00:35 after ignition), dropping to a minimum HRR of 35 kW at 00:05:34 (00:05:04 after ignition). This fire served to char the cotton blanket, ignite the carpet beneath the carcass and scorch the exposed skin of the carcass (producing third degree burns of very limited depth). At this point, the fire in the synthetic carpet and pad began to grow, reaching peak HRR of 280 kW at 00:23:30 and 249 kW at 01:06:27.

During this time, the fire spread across the blanket, charring it quite completely, leaving a porous ash adhering to the carcass in many areas. The carpet in the vicinity of the carcass became heavily involved in open flames, producing most of the heat detected during this interval. The two large HRR peaks were associated with two periods of active fire growth in the carpet and pad, apparently the result of a draft effect in the compartment spreading the fire along the flanks of the carcass. This process produced a large irregular area of charred and melted carpet and pad (eventually penetrating the plywood deck beneath) centered on the position of the carcass. After the maximum burning rate at 01:06:00, the fire in the carpet died back to a very small but persistent series of flames at the margins of the burned area. These small flames persisted until nearly the entire area of carpet was burned, a behavior seen in the previous tests. The external fire supported by the burning of the blanket and carpet was sustained long enough to penetrate large areas of the skin along the chest, flanks and limbs of the carcass and cause the skin to split and the subcutaneous fat to render. This fat was seen to flow into the charred blanket and drip onto the charred carpet to support areas of burning that eventually merged into a fire that surrounded most of the carcass. The splitting and rendering process was observed to begin about 10 to 15 min after ignition and

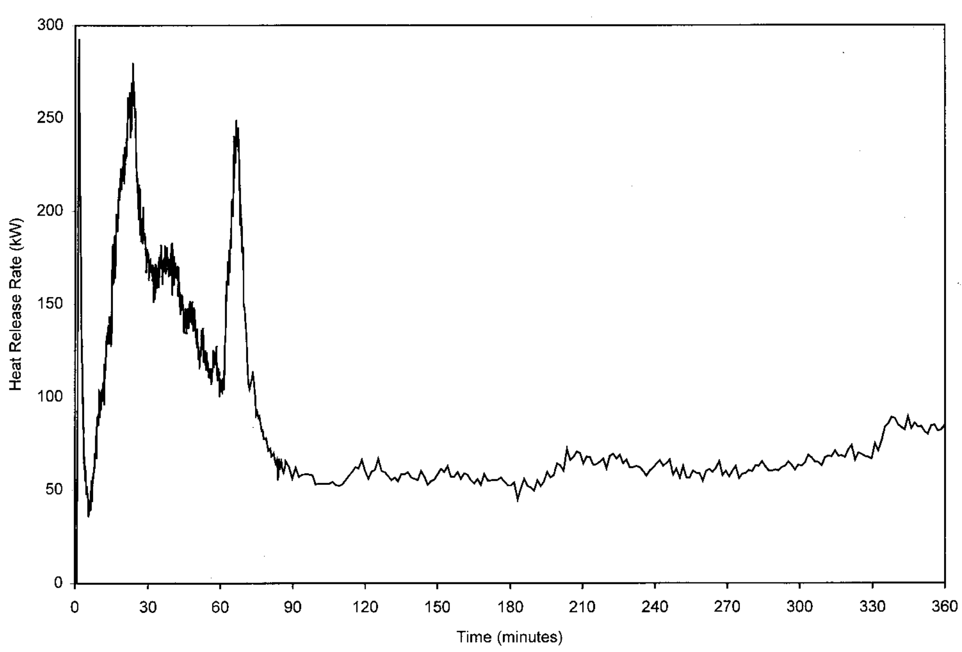

FIG. 1—*Heat release rate (HRR) of carcass test. Initial peak at 1 min is gasoline flame, peaks at 20 to 85 min are from carpet and pad. HRR from 85 to 330 min is from pork fat fire.*

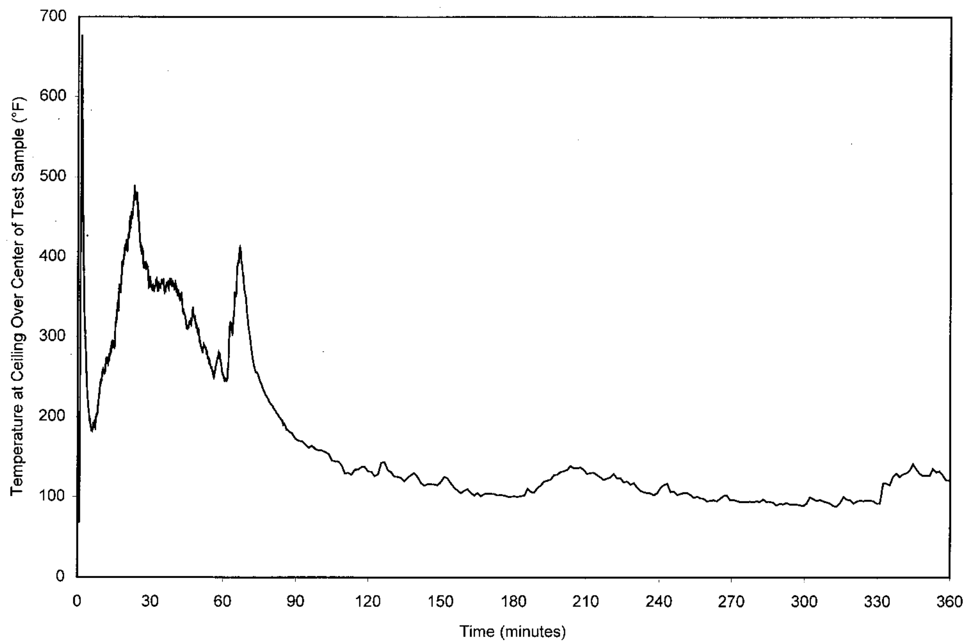

FIG. 2—*Ceiling temperatures 1 in. (2.5 cm) below ceiling of compartment (centered over sample) reflect the fluctuations in HRR and the maintenance of a steady-state warm smoke layer by the prolonged combustion of the carcass.*

was well established by the time the carpet fire reached its maximum HRR at 01:06:00.

As the burning of the carpet and pad died away after 01:20:00, the flames supported by the melted body fat became the predominant combustion and the HRR achieved a steady 55 to 60 kW which it sustained from 01:20:00 to 05:32:00 (331 min from ignition). At that time the plywood deck was seen to be perforated allowing extra ventilation from beneath and through the wood. During that period, the HRR grew to 84 kW where it stabilized about the end of the data collection at 6:00:00. At one stage, flames were observed under the wood deck.

The ceiling layer temperatures recorded above the center of the carcass (sample) are shown in Fig. 2. Maximum temperatures coincided in time with the maximum heat release rates discussed earlier. The rapid combustion of the gasoline produced a maximum ceiling temperature of 677°F (358°C) recorded at 00:01:20 (50 s after ignition) and a flame plume with an estimated height of 1.5 m. The two maxima of HRR from the blanket and carpet corresponded to maximum temperatures of 365°F (185°C) at 00:16:49 and 411°F (211°C) at 01:06:50. As the HRR decreased from that maximum, so did the ceiling temperature, stabilizing at 100 to 125°F (38 to 52°C) for the remainder of the test. Temperatures recorded at the top of the door opening closely paralleled those of the ceiling layer, indicating that the hot gas layer was at least 0.5 m deep (down from the ceiling) during the test, but cooling by the time the gases exited the room. While the temperature in the normal air layer was not measured, the experimenters were in and out of the compartment numerous times and often spent many minutes sitting or crouching in the compartment without exposure to high temperatures or smoke products. Near the end of the experiment, a television interview was conducted alongside the burning carcass.

The total mass of the carcass, blanket, plywood, carpet, and pad was 241.5 lb (109.6 kg). The load cell data is shown in Fig. 3. The addition of 1 L of gasoline adds a "blip" of 650 g (1.6 lb) just prior to ignition. The mass recording shows the periods of most rapid fuel consumption during the 30 to 80 min time period where the carpet was burning most enthusiastically.

Between 90 and 330 min, the rate of consumption (determined by the consumption of carcass) is almost perfectly linear. A total of 46.52 lb (21.12 kg) was consumed in 4 h, resulting in an average mass loss rate of 11.63 lb/h (5.3 kg/h, 1.5 g/s).

As the destruction of soft tissue proceeded, more and more of the bones of the thorax and limbs were exposed. These assumed a white to light gray color and appeared at first to be otherwise unchanged. As the fire progressed, it was discovered that these bones had become quite friable and were easily broken or even crushed by light mechanical pressure. The carcass burned into two pieces at mid-thorax about 4.5 h into the test. The head and forequarters remained relatively intact, the hindquarters and flanks were supporting steady combustion until the end of the test at 6.5 h, when the flames were extinguished by application of water spray. During the last 40 min of the test, the plywood platform was losing structural integrity and the weight loss data became unreliable after 345 min, as some of the weight was then supported by the floor rather than the load cell.

Cone Calorimeter Data

The effective heat of combustion of pork fat burning with a cotton wick was measured and the results are shown in Fig. 4. It had been previously observed that without a cloth wick, fuels such as candle wax or fat would not produce a sustainable flame under standard cone calorimeter conditions. Once a cloth wick was provided, the cloth charred within 10 s (with incident heat flux of 35 kW/m^2) and the fat beneath it quickly melted and absorbed into the wick, producing a stable, self-sustaining flame. During the early stages of each test, moisture trapped within the fat was released beneath the wick and caused boiling that is evidenced in the data by sharp, irregular spikes in the load cell measurements. The effective heat of combustion (EH_c) is calculated

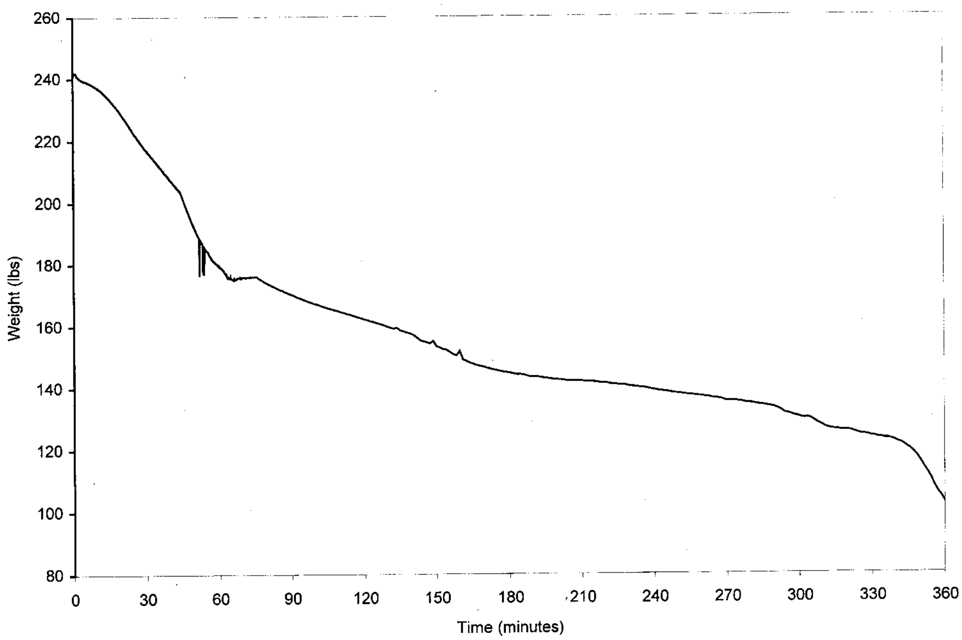

FIG. 3—*Load cell data (total weight of carcass, carpet, pad, and plywood) showing a constant mass loss rate of 11.63 lb per hour (5.3 kg per hour) over the period of 90 to 330 min.*

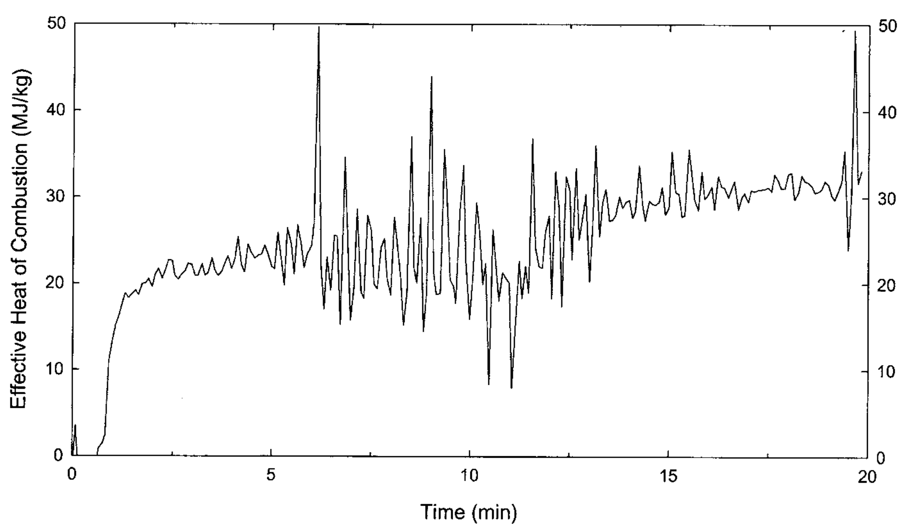

FIG. 4—*Effective heat of combustion of pork fat with a cotton cloth wick as measured in the cone calorimeter. Spikes in data are due to boiling of water and fat under wick.*

by dividing the HRR measured by the mass loss rate (kg/s). Once stabilized, the EH_c for pork fat averages out to approximately 34 MJ/kg. The EH_c for human fat under the same conditions averages out at approximately 32 MJ/kg (Fig. 5). Another useful calculation the cone calorimeter produces is the rate at which heat would be released from a burning sample per unit area. For pork fat, the rate of heat release is between 240 and 280 kW/m^2 at an incident heat flux of 35 kW/m^2 (Fig. 6) and 340 to 380 kW/m^2 at an incident heat flux of 50 kW/m^2. The equivalent measurement for human body fat was 250 to 280 kW/m^2 at an incident heat flux of 35 kW/m^2.

Flame temperatures of 813°C (1495°F) were measured during the carcass test and 880°C (1616°F) were measured during the cone calorimeter test of pork fat. A flame temperature of 913°C (1675°F) was measured during the cone calorimeter test of human fat.

Discussion

While it was not possible to accurately measure the surface area of the wick involved during the carcass combustion test, observations indicated that at any one time some 0.2 to 0.3 m^2 of carpet and blanket were involved (during the stable burning period from 80 to 330 min). From the cone calorimeter data, an area of 0.2 m^2 would be expected to sustain a fire of approximately 50 to 60 kW which is very close to what was observed.

With an average mass loss rate of 1.5 g/s and an effective heat of combustion of 34 kJ/g as measured in the cone calorimeter, a fire of 51 kJ/s (51 kW) would be expected and this in very good agreement with the observed rate of 55 to 65 kW.

The area of the combustion, being extended along the flanks of the carcass was basically a line fire of indeterminate length rather than a pool fire (and in some areas involved the vertical surface of the charred blanket wick). This complex geometry makes a Heskestad (flame height versus heat release rate) calculation impossible. The flames observed in the vicinity of the carcass ranged from 3 to 10 in. (7 to 25 cm) in height and were based both on the carpet and on the charred blanket remnants adhering to the carcass. This small size and localized nature would minimize the chances for fire to spread unless additional fuels came into direct contact with the flames.

The flame temperatures observed are in the same range as those of most other fuels (and also in the range of temperatures in commercial crematoria). It has been observed that excessive damage to bones is not a result of simple exposure to high temperatures since bone does not become more brittle or oxidize simply due to high temperatures. Bone in a fresh carcass is a complex material, involving moisture, blood and marrow (with a high concentration of fat). Exposure of fresh bone to high temperatures then could produce complex series of reactions. It must be noted that the flames observed here were not only in direct contact with bone, they were fluctuating and turbulent. Such turbulent flames cause very high temperatures one moment with a reducing (oxygen deficient) atmosphere, and lower temperatures the next moment as they flicker away from the bone, exposing the heated surface to cooler, oxygen-rich air. These conditions could be expected to cause spalling of the moisture-laden surface of the bone as well as ignition of the fat within the bone. Such effects would not occur in bones that have dried out prior to exposure to fire. These conditions are also very different from the steady-state fire to which bodies are exposed in commercial crematoria where high temperatures and constant oxidation conditions are maintained by natural gas jets or electric radiant heaters. It is thus not surprising that, given enough time, such exposures in accidental fires can result in more complete fragmentation of even massive bones than is common in cremated remains.

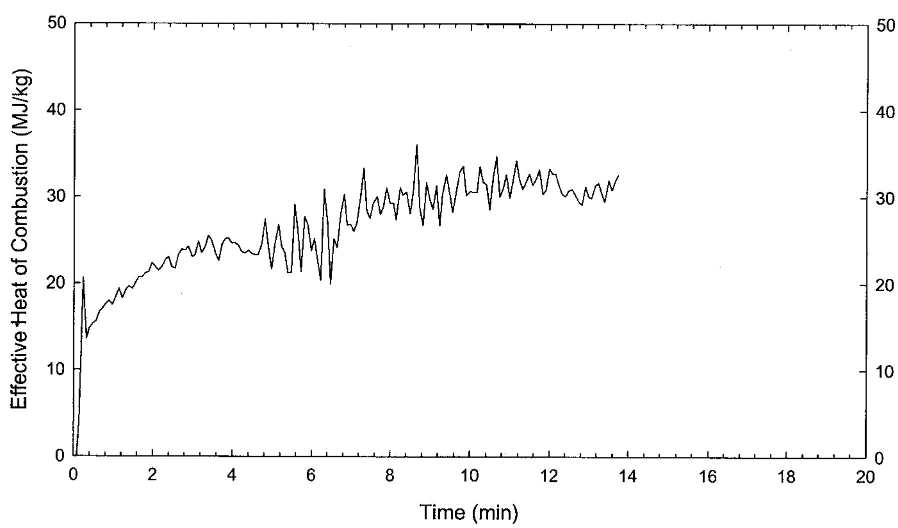

FIG. 5—*Effective heat of combustion of human fat with a cotton cloth wick as measured in the cone calorimeter. Spikes in data are due to boiling of water and fat under wick.*

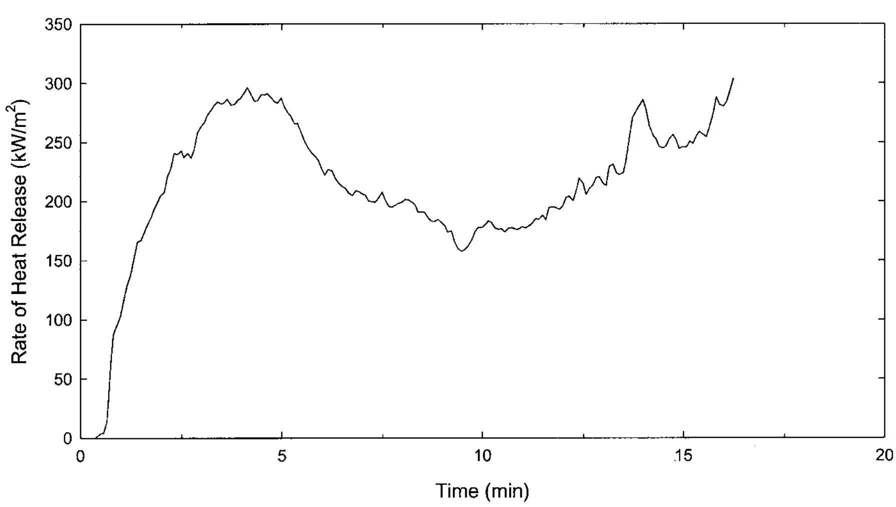

FIG. 6—*Rate of heat release (kW per square meter of fuel surface) of pork fat with a cotton wick, as measured in the cone calorimeter.*

Conclusion

It has been demonstrated that given a source of external ignition of some duration (10 to 15 min or longer) such as a fire in clothing or bedding, the skin of a body can char and split and the melted subcutaneous fat be released. If that fat can be absorbed onto a suitable porous rigid substrate that can act like a wick, it can support flaming combustion for as long as fuel is available. The size of the resulting fire is controlled by the surface area of the wick, but for reasonably-sized bodies the fires will be very modest in heat release rate, with 20 to 50 kW being typical. Such fires are unlikely to exhaust the available oxygen in the average compartment (room) or to produce enough heat to create a hot smoke layer capable of igniting other fuels in the room by radiant heat. Fuels that come into direct contact with the flames can, of course, be ignited, possibly spreading the fire. The rate of combustion is typically moderate (1 to 4 g/s or 3.6 to 14 kg/h). Given enough time and an adequate wick, such fires can sustain themselves for many hours, accomplishing a great deal of damage including fragmentation and powdering of bone. The portions of a body that do not have an adequate supply of subcutaneous fat, such as the distal limbs, will not support continuous combustion. The presence of an ignitable liquid is not required for such occurrences since it would typically not be sustained long enough. (It was used in this test simply to ensure ignition of enough carpet and blanket). Such fires are rare because they require the confluence of several factors (fuel, external ignition, adequate wick and, especially, *time,* but they do *not* require any extraterrestrial or unnatural forces or unexplainable phenomena.

Acknowledgments

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Reference

1. DeHaan JD, Campbell SJ, Nurbakhsh S. Combustion of animal fat and its implications for the consumption of human bodies in fires. Sci Justice 1999;39(1): 27–38.

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