ANALYSIS OF A DOUBLE FATALITY FIRE ALLEGEDLY CAUSED BY A PORTABLE ELECTRIC HEATER

HOW POOR METHODOLOGY CAN LEAD TO THE WRONG CONCLUSION

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ABSTRACT

This paper discusses the utilization of the systematic process outlined in NFPA 921 to properly investigate and analyze a particular fire incident. In the subject case, an improper and incomplete fire scene investigation combined with erroneous fire and engineering analysis resulted in the incorrect conclusion that a portable electric heater in a recreational vehicle (R.V.) caused a fire. As a result of the fire, two children died and the parents of the children were injured. A proper origin and cause analysis including evaluation of fire patterns, witness observations, fire dynamics, electrical arc mapping, laboratory examination and testing, and appropriate engineering analysis methods is discussed. Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) are presented and utilized in the cause evaluation and presented.

INTRODUCTION

The Importance of Scientific Methodology in Fatal Fire Investigations

It is important to perform a proper and complete scientific fire investigation in order to render correct opinions regarding the origin and cause of a fire and to properly allocate responsibility for the fire loss. Proper investigation is particularly important when serious injuries or fatalities have occurred.

Data from fire patterns, witness observations, fire dynamics and arc-mapping must be utilized; to the extent they exist, to establish, if possible, an area of origin. Ignition and fuel sources identified within that area of origin, as well as the potential circumstances that might bring together a particular ignition source and fuel must be evaluated for causation. Incomplete and improper scene processing, documentation and evidence collection, failure to interview pertinent witnesses, as well as a failure to understand the operation of any particular appliance being considered for causation significantly inhibit the investigator[s] from coming to the correct conclusion as to the origin and cause of a fire.

"There is no easy way to do a hard thing."[1] A proper fire investigation requires diligent and comprehensive hard work in the collection, analysis and testing of the data. Presumption of cause and investigative bias lead to short cuts, incomplete data collection, the ignoring of relevant data and ultimately the likely wrong understanding and conclusion as to the cause of the fire.

Exemplar Testing and Failure Analysis

Very often exemplar testing and analysis of appliances are incorporated into the fire investigation to determine *"if it [the appliance] is capable of causing the fire."*[2] Such testing is useful in establishing *"the validity of the proposed ignition scenario."*[3]

Some general observations can be made concerning exemplar testing. First, before an ignition scenario is proposed, it should be established that the appliance is within the defined area of origin. As such, the importance of correctly identifying the area of origin is underscored. Second, the ignition scenario proposed must match the known or expected progression of the fire from initiation, development, and spread (fire dynamics). Fire patterns, witness observations, and arc-mapping further assist with understanding the progression of the fire. Third, comparative analysis of the appliance involved in the fire, and the tested exemplar(s), must be made relevant with similar or dissimilar conditions between the two units documented and considered in the failure and fire cause analysis.

NFPA 921 Chapter 20, *Failure Analysis and Analytical Tools,* identifies and discusses several established scientific methodologies for evaluating potential failures in appliances and equipment. Such methodologies are not exclusive to NFPA 921 but are previously established scientific methodologies incorporated into NFPA 921. In this present paper, both Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) are incorporated into evaluating potential causes of the fire. As indicated in NFPA 921, *"FMEA is a technique used to identify basic sources of failure within a system, and to follow the consequences of these failures in a systematic fashion."*[4] NFPA 921 also indicates a FTA diagram *"places, in logical sequence and position, the conditions and chain of events that are necessary for a given fire or explosion to occur."*[5] Important to note is that identifying a potential source of failure in a system in and of itself is inadequate, as a failure mode for any system can be hypothesized. The *consequences* of the failure, including logical connections between multiple failures, must be followed through in a *systematic fashion.*

FIRE INCIDENT AND BACKGROUND

Circumstances of the Fire Incident

A family of four, two adults and two children, in the interim of moving from one primary residence to another, was utilizing a motor home R.V. as a weekend residence. During the week, the family resided in the primary residence of their relatives. On a cold February Sunday morning around 4:20 a.m. while the family members were all asleep, a fire occurred inside the R.V. that resulted in the deaths of the two children, burn injuries to the stepfather and destruction of the R.V.

On the evening prior to the fire, the children went to bed around 9:30 p.m. in the extreme forward part of the R.V. in an elevated bed positioned over the cab of the vehicle. The parents of the children went to bed between 10:30 and 11:00 p.m. in the extreme rear part of the R.V. in a fold out bed. The stepfather testified that he was first awakened by heat from the fire and that he "looked up and the fire was towards the kids…up close to them." He got his wife up and forced her out the rear door which was immediately adjacent to the bed in which they were sleeping. He then attempted to reach the children by traveling along the narrow passage between the rear and the forward ends of the R.V. He was almost all the way to the children before having to turn back due to the flames and heat of the fire. He made several trips down the passage to the forward part of the R.V. in an attempt to rescue the children but was unable to save them. He then exited the R.V. through the rear door. The fire department responded and extinguished the fire. The two children perished in the fire.

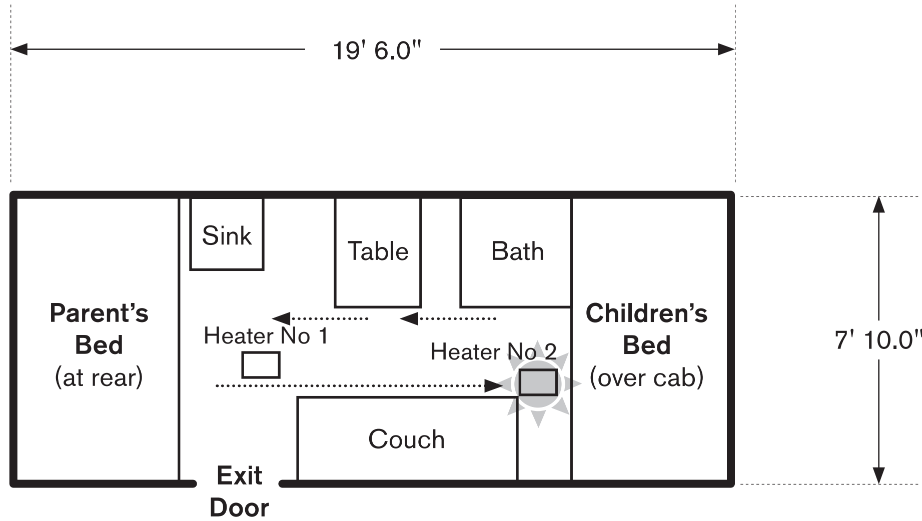

FIGURE 1 // R.V. LAYOUT
The fire was first observed near the children in the area where the second heater would have been located. The dotted block arrows indicate the travel path of the stepfather as he attempted to reach the children during the fire.

Description of the R.V.

Figure 1 depicts the general layout of the small R.V. The incident R.V. was purchased used approximately 1-1/2 to 2 years before the fire. Sometime in October or November (approximately 3 to 4 months before the fire), the R.V. was moved from storage and set up as a weekend residence. The R.V. was of wood framed construction and aluminum siding with wood floor decking. The R.V. was 19 1/2 feet long by 7 feet 10 inches wide.

In addition to use as a weekend residence, the small R.V. was used for the storage of clothing and personal belongings of the family as they were in the process of moving to a new home. Furthermore, there was furniture and other furnishings inside the R.V. including but not limited to beds, seating, table, couch, counters, and a bathroom. There were no gas appliances associated with the R.V. or in use in the R.V.

Electrical power was supplied to the R.V. via non-metallic sheathed cable from a circuit breaker panel mounted near a utility shed on the property where the R.V. was located. From deposition testimony, it is understood that there were a number of electrical circuits, devices, receptacles and appliances within the R.V. There were two portable electric heaters that were being used to heat the R.V. on the night of the fire. One of the heaters was located in the forward part of the R.V. on a table near the children's bed. The second heater was located in the rear portion of the R.V. on the floor near the bed of the parents in the narrow passageway between the rear and forward ends of the R.V. Electrical power was supplied to the portable heater located in the forward part of the R.V. via a duplex outlet. Electrical power was supplied to the portable heater located in the rear portion of the R.V. via an extension cord plugged into a duplex outlet. The exact configuration and extent of the complete electrical system on the interior and exterior of the R.V. is unknown.

The Fire Scene Investigation

An incomplete fire scene examination with very limited documentation was performed by a local municipal investigator. Both of the parents were hospitalized following the fire. In an attempt to get rid of the bad memories, the R.V. was removed from the family members' property and buried in a landfill before any other investigators had the opportunity to properly examine, process, and document the scene. As a result, very little scene data was available.

The municipal investigator who went to the scene immediately following the fire discovered the remains of the metal housing of the portable electric heater that was located in the rear portion of the R.V. near the bed of the parents. Finding one of the heaters in the face up position and observing burn patterns on the floor beneath the heater, the investigator improperly concluded that the heater did not have a tip-over switch and that it tipped over and started the fire. He collected the remains of the heater as evidence. No other evidence was collected.

Fire scene debris excavation was limited to a small portion of the flooring around the heater in question. Only a small portion of the power cord associated with the heater was still attached to the heater and the disconnected portions were never excavated or recovered. The extension cord that was connected to the power cord was not excavated or recovered. The electrical system in the small R.V. was not properly excavated, examined, or documented. The portable electric heater that was known to be in operation in the forward portion of the R.V. near the children was twitnessed circumstances of the fire or that there was a second heater in operation and located in the R.V. because he never interviewed the surviving occupants.

Description of the Portable Electric Heater in Question

As previously discussed, there were two heaters in the recreational vehicle (R.V.) at the time of the fire. The heater near the children, identified in Figure 1 as "Heater No. 2", was purchased from Lowe's and had a plastic case. The municipal investigator never knew about this heater and did not recover any of its artifacts from the fire.

The heater nearest the parents and alleged to have started the fire was a UL listed, electric, Airtech utility heater, Model No. 01013. This heater, identified as "Heater No. 1" in Figure 1 had a steel case and was distributed by Aloha Housewares, Ltd. and sold by Wal-Mart. The heater was purchased in February 2003, approximately one year before the fire. The 110 120 volt heater, which had experienced limited use since it was purchased, had two thermostatically controlled elements.

An electric fan circulated air over the two electrical resistance heating coils. A selector knob on the front of the heater allowed the user to select "low" or "high" heat. The heater elements were 1.22 mm diameter, coiled wire type, resistance elements. The elements were routed around and secured through ceramic support brackets. At low heat, a long element that had approximately six vertical legs produced 1300 watts. At high heat, a second, short booster element connected in series with the long element produced an additional 200 watts. The short element ran horizontally across the heater box close to, but not normally touching, the six vertical legs of the long element. The nominal cold resistance was 10.8 and 1.7 ohms for the long and short elements, respectively. The resistance elements normally did not get hot enough to glow red during operation. Figures 2, 3 and 4 depict various components of the exemplar heater.

The heater in question was equipped with two safeties to prevent a fire hazard. The first was a combination regulating thermostat and tip-over switch. The tip-over switch was designed with a pendulum weight attached to a polycarbonate plastic arm that opened the electrical circuit if the heater tipped over in either the forward or backward direction. The thermostat also opened the electrical circuit if the desired room temperature was reached. The second safety was a thermal fuse element that would open the electrical circuit due to high temperature.

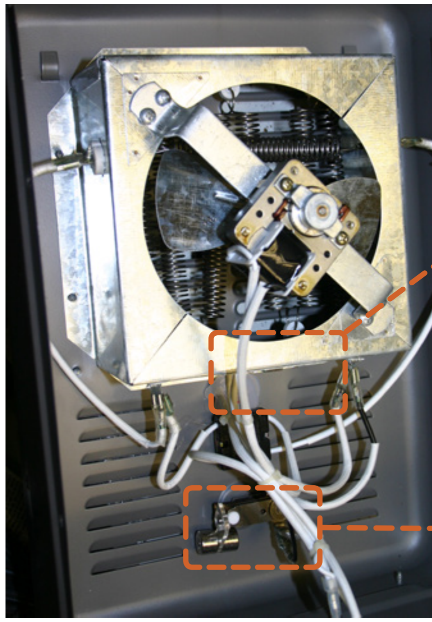

FIGURE 2 // EXEMPLAR HEATER
with back cover panel removed

FIGURE 3 // THERMAL FUSE

FIGURE 4
Combination thermostat/tip-over switch with polycarbonate plastic arm and arm-pin

Fire Origin Area Allegations Put Forth

The municipal fire investigator incorrectly concluded on the basis of fire patterns alone that the heater had no tip-over switch and that the fire originated in the floor beneath the tipped over heater. He interviewed no witnesses. He performed no arc mapping. He analyzed no fire dynamics and did not consider the first fuel ignited, the fuel load analysis, the fuel distribution, a scene reconstruction, or any consideration of witness observations concerning the location and spread of the fire or movements of the witness during the fire.

Fire Cause Allegations Put Forth

The heater in question was transferred to an engineer hired by the attorney for the family (plaintiff) to perform failure and causation analysis. The distributor (defendant) of the heater was placed on notice of a potential claim and their attorney hired The Warren Group to analyze the origin and cause of the fire. A joint laboratory examination of the heater included real time video x-rays of the heater in question and an exemplar heater followed by the disassembly and internal examination of both units. Although the heater in question sustained extensive fire damage, significant data was obtained during the joint laboratory examination.

There was no electrical arcing on either the internal circuitry or the small remaining section of the power cord of the heater in question. Both the long and short heating elements were found to be separate, completely intact and continuous without any breaks and with no electrical arcing activity or other substantial damage. Additionally, the remains of a combination thermostat/tip-over switch were found within the heater housing. Furthermore, there was a high temperature thermal fuse located within the remains of the unit.

Sometime after the laboratory examination, a lawsuit against the distributor of the heater was filed and the plaintiff's engineer issued a report indicating the heater was defectively designed and the defective design of the heater was a cause of the fire. The engineer further concluded that the fire originated on the upper left corner of the heater on the basis of burn patterns on the heater. He also agreed with the municipal fire investigator's findings that on the basis of fire patterns beneath the heater on the floor and the tipped over position of the heater post-fire, the heater must have been pushed or fallen over, and started the fire.

In addition to a number of other allegations, the engineer concluded on the basis of a visual examination alone of exemplar units that the contact arm pin of the tip-over switch was fabricated of "low grade", clear acrylic, plastic type material which fractured and broke as it came into contact with a "sharp", pin stop when the unit was tipped over. The plastic components were consumed in the fire and no evidence was produced to confirm the alleged failure, or alleged design and manufacturing defects of the tip-over switch.

The engineer performed no materials analysis of the plastic on an exemplar unit nor was he able to identify the specific plastic that was incorporated into the design. The engineer performed no cyclic loading analysis. Additionally, the engineer was unaware that the heater was approximately a year old and had only been used a limited number of times. Otherwise, it had been in storage.

The plaintiff's engineering expert conducted a number of tests during his investigation. These tests measured external casing temperatures and cordset temperatures during operation. Interestingly, during one test in which the tip over switch was bypassed and the heater was operated on its back, a sweatshirt under the heater was ignited. According to the engineer, during the test, the heating elements glowed red, made a "pop" sound, and the sweatshirt auto ignited.

ANALYSIS OF THE FIRE ORIGIN

Figures 5, 6, 7 and 8 depict the burned R.V. and the portable heater in question.

FIGURE 5
Right side view of burned R.V.

FIGURE 6
Right side view of burned R.V. looking towards cab

FIGURE 7 // HEATER NO. 1 PRIOR TO EXCAVATION
The arrow points to the heater beneath debris

FIGURE 8
Heater No. 1 and floor beneath post-excavation

Fire Patterns

The R.V. unit with its contents and furnishings formed a small volume with a large fuel load, all of which were fully involved and largely consumed during the fire, with floor level burning occurring throughout the R.V. The ceiling and walls, with the exception of the rear wall, were completely destroyed. There were no fire patterns that provided a scientific basis for establishing the origin area of the fire.

Witness Observations

The stepfather first observed the fire "towards the kids…up close to them." He did not observe fire at any other location inside the R.V. During deposition testimony, he identified on a diagram the location of where he first observed the fire (see Figure 1); which was on the forward side of the R.V. nearest the children. He was able to travel almost all the way to the children before having to turn back. The heater in question was located in the aisle and near the bed of the parents. In fact, one could reach out and touch the heater while lying in the bed. Had the fire originated at the heater in question, the narrow aisle would have been obstructed by flames from the burning couch, cabinetry, and stored items on either side of the aisle. The stepfather had to have stepped over or right beside the heater in question each time he traveled down the aisle. Based on the stepfather's ability to travel up the narrow aisle in the R.V. and alongside the couch and his first observations of the fire location, the fire originated somewhere on the end of the R.V. near the children.

Arc-mapping

Electrical arc-mapping is a key element useful in analyzing and determining the area of origin of fires. The electrical circuits, components and devices in the R.V. were not excavated, recovered, examined, or documented, and no arc-mapping was performed. Arc-mapping could have and should have been performed. Careful gridding, excavation and sifting of the scene and debris for the electrical circuits and components would have provided relevant and valuable data.

The only, yet very significant, physical electrical evidence that was available was the absence of any electrical arcing within the heater unit in question or to the remains of the power cord of the heater. The evidence indicates the fire did not likely originate within or around the heater.

Fire Dynamics

There was no scientific basis for saying that the burns on the floor beneath the location of where the heater was found or that the burn patterns on the heater itself indicate the fire originated at the heater or that the heater caused the fire. The entire structure and contents burned extensively and nearly to completion in this incident. The high temperatures at the floor level generated either by flashover conditions, a fully involved fire, or by fall down burning, will clearly damage the flooring and heat up metallic objects such as the housing of the heater. Metallic objects heated during a fire can transmit heat via conduction heat transfer into combustible materials such as the carpeting that is in contact with it, causing subsequent pyrolysis, charring and ignition of the combustibles. Furthermore, the heater is not a solid appliance but has vent openings on both the front and the back sides. Consequently, heat can also be transferred via convection and radiation through the heater openings to the flooring.

The position of the heater, as reportedly found after the fire, does not indicate that it was in a tipped over position prior to the fire. The structure was destroyed by the fire. With the exception of one wall, all of the walls and the ceiling/roof structures and sheathing burned and collapsed. It is well known that falling debris in a structure fire will impact and move or shift objects that it comes into contact with as it is falling. The heater housing was bent and deformed and therefore clearly sustained impact damage during the fire incident. Given the level of fire destruction and collapse incurred to the R.V. structure and the condition of the heating element coils and internal wiring of the heater, it is most probable that the heater first lost electrical power and was sometime later knocked over during the course of the fire event or during extinguishing efforts, and not before the fire.

The R.V. is a small, confined space, and as indicated in witness testimony, the heater was placed in the aisle and stepped over or around during the day. The stepfather, in the process of traveling towards the children during the fire, could certainly have knocked over the heater.

FAILURE ANALYSIS AND EXEMPLAR TESTING

Failure Analysis

Although the origin area analysis clearly indicated that the portable electric heater was not within the area of origin, extensive failure analysis and laboratory testing was conducted by The Warren Group to determine the potential for an overturned heater to cause a fire. This laboratory testing focused on understanding the heater's normal operation and its response to a number of "failures" such as being overturned or having a failed safety device like a defective tip-over switch. NFPA 921, 2008 edition, Chapter 20 discusses several failure analysis tools that can help the fire investigator *"organize information collected during the documentation of the incident into a rational and logical format."*[6] Two systems analysis techniques specifically mentioned in NFPA 921 are failure modes and effects analysis and fault tree analysis. Each of these methods can be utilized to examine and organize the information found during an investigation such that the investigator can understand the relationships between the separate observations and reach the correct conclusion. These tools are especially helpful in larger or more complex investigations with a large amount of information.

At its simplest, failure modes and effects analysis is a technique wherein a table is created for a specific product or process that lists various "failure modes" and their "effects." More elaborate tables can be created that include additional information such as necessary conditions for occurrence of the failure or a measure of the likelihood of the failure's occurrence or its severity. The analysis commits to paper the process most investigators mentally conduct, that is, considering what could have gone wrong and what its effect would be. Additional information on the application of failure modes and effects analysis to fire investigation is given in Chapter 20 of NFPA 921.

FIGURE 9
Rearward tip over endurance test

FIGURE 10
Heater at moment of element shorting and fracturing

FIGURE 11
Burned spots on sweatshirt under heater with fractured coil

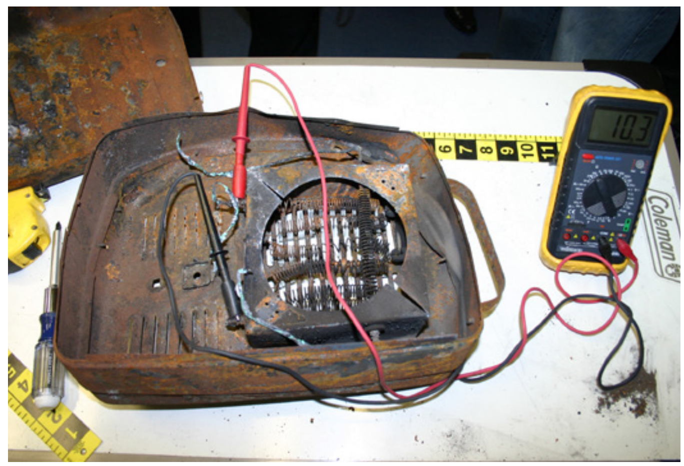

FIGURE 12
Testing of subject heater showed no evidence of shorted heater coils

Exemplar Testing

In the subject case, a series of over 20 individual laboratory tests was conducted to determine the normal operation of the heater and its response to various failures. A summary of each of the tests forms a simple failure modes and effects analysis table, a portion of which is shown in Figure 13. Due to space limitations, this paper discusses only some of the tests and the significant results from the testing. Figures 9, 10, 11 and 12 illustrate some of the testing. A variable voltage transformer was used during testing to ensure that the power supply voltage was at a full 120 volts and hence the heater was at full output. Baseline testing with the exemplar units (that is with no safety mechanisms by-passed) indicated that the unit's tip-over switch would cut off power to the heater coils when the units were tipped about 48 degrees in either a forward or rearward direction. In normal orientation, the maximum casing temperature on the air outlet side of the heater was found to be 163°F.

In one set of tests, the unit's tip-over switch was bypassed to determine the maximum casing temperature and flooring temperature when the heater was fully tipped over in both forward and rearward directions. These tests indicated that the maximum casing temperature occurred when a rearward tip-over occurred. The maximum casing temperature was found on the front of the heater which was facing up and in this condition was 301°F. The temperature of the rear face in contact with the floor was only 102°F. The maximum flooring temperature occurred when a forward tip over occurred. The maximum flooring temperature found in this condition was 192°F.

In another series of tests, it was noted that when the unit was forcefully tipped over and the heating element is hot, on some occasions, sections of the short and long heater elements can come in contact with one another. This effectively creates a new shorter section of heating element which glows red hot. These tests indicated that by either multiple forceful blows to the heater or during an extended period of tipped over operation the heater elements could short, turn red hot, fracture and eject hot particles. This fracture and ejection is accompanied by a "pop" sound.

Additional tests were run to determine the effect of a failed fan motor in both normal upright conditions and forward and rearward tipped over conditions. In normal orientation without the fan working, it was found that the one shot thermal fuse would activate and switch off power to the heating elements. In a rearward tip-over orientation with a disabled fan and with the tip-over switch bypassed, in two tests the heating elements were found to fail after a period of operation of 30 and 406 minutes. The elements failed by short circuiting with subsequent fracture and ejection of hot fragments of heating element. These fragments melted and charred the sweater and carpet under the heater but did not result in noticeable flaming combustion.

In further analysis, the metallic remains of the tip-over switch of the incident unit were ultrasonically cleaned and a model number for the switch was obtained. The model number corresponded to the model number for the tip-over switches installed in the exemplar heater units. An exemplar switch was removed from a heater and submitted to a materials laboratory at MIT for testing of the pendulum material. The materials engineer reported that the plastic arm pin was constructed of polycarbonate. "Polycarbonate (PC) is a high performance amorphous engineering thermoplastic with exceptionally high impact strength, clarity, heat resistance and downward dimensional stability." The materials engineer opined that the engineer hired by the plaintiff had an unfounded opinion regarding the failure of the cutoff switch due to impact. He stated that polycarbonate is one of the least brittle, if not the least brittle, plastics known. It is used in critical situations where high toughness is required such as bullet proof glass or canopies for jet fighter aircraft or safety helmets. It would never fail in a brittle manner due to handling stress. The incident heater was approximately one year old, had been used very little and according to deposition testimony had never been tipped over or otherwise damaged. It is highly unlikely that the plastic arm pin of the tip-over switch failed as suggested by the plaintiff's engineer.

ENGINEERING ANALYSIS & CONCLUSIONS

The extensive testing, some of which was described above, allowed an understanding of the way the heater and its safety controls react to various failures. The charting of these tests and their results form a simple failure modes and effects analysis. A partial failure modes and effects analysis table for the subject case is shown in Figure 13. The complete analysis showed the heater was capable of starting a fire external to its casing by ejection of hot fragments on fracture of a shorted heating element. This phenomenon explains the fire that occurred during the plaintiff's engineering expert's testing. No other condition of abnormal operation tested resulted in circumstances likely to cause a fire.

Failure Mode	**Cause of Failure**	**Effect of Failure**
Heater tips over while operating.	Impact from occupant of R.V.	Heater tip-over switch turns off power to heating elements.
Tip-over switch fails to turn off power to elements on overturned heater.	Defective, broken or bypassed tip-over switch.	Heater runs with maximum casing temperature reaching 301°F until either one shot thermal fuse cuts off power or elements short and fracture.
Heating elements short together and fracture.	Continued operation in tipped over condition with failure of both tip-over switch and one shot thermal fuse.	Red hot fragments can exit heater casing and land on adjacent combustible materials possibly causing a fire.

FIGURE 13 // PARTIAL FAILURE MODE & EFFECTS ANALYSIS

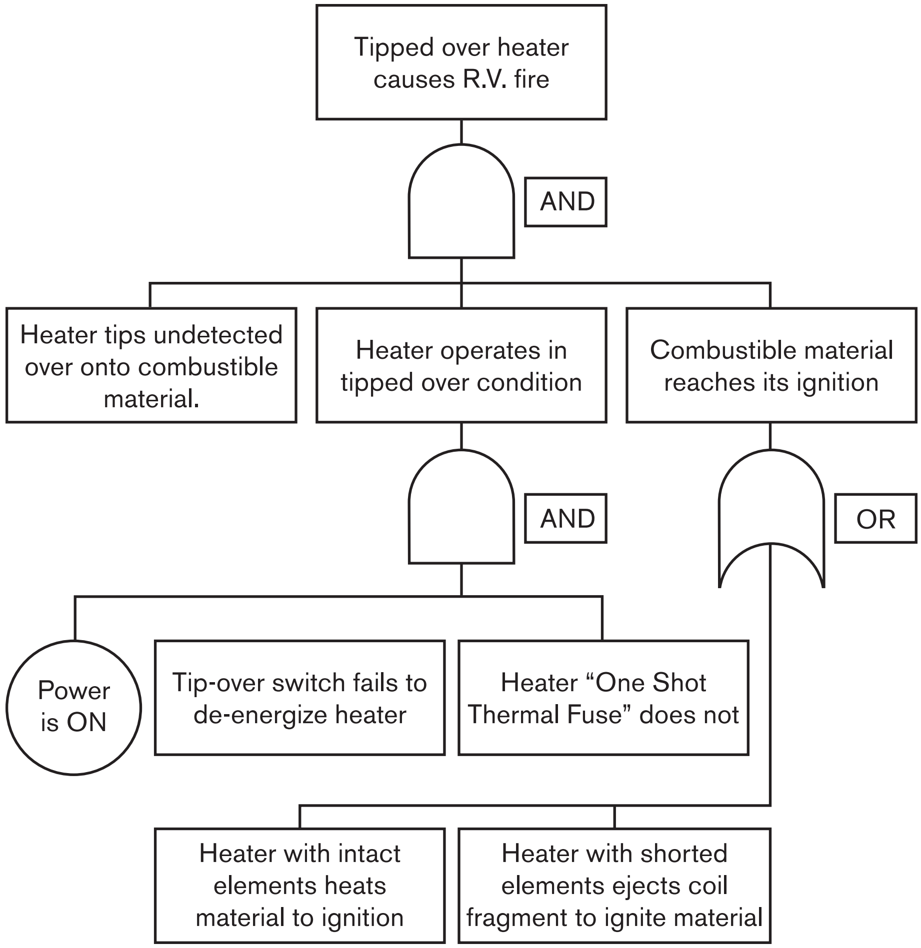

FIGURE 14 // SIMPLIFIED FAULT TREE ANALYSIS CHART

For the heater to have actually caused the subject fire, a number of unique conditions must simultaneously occur. To better understand the complete circumstances that are necessary for causing a fire, fault tree analysis can be used to visually document the logical connections between the separate conditions. A simplified fault tree analysis chart is shown in Figure 14. From this it can be easily seen that a number of simultaneous failures must occur for the heater to cause a fire. These include the heater being tipped over onto combustible material, failure of the tip-over switch, one shot thermal fuse, and the elevation of the combustible material's temperature above the material's ignition temperature.

In the subject case, the heater's safety controls were damaged in the fire to the extent that a determination of their status at the time of the fire was impossible. However, it is certainly extremely unlikely that all the safety features would fail to work at the same time. More problematic to the theory that the heater caused the subject fire is that a tipped over heater with an un-shorted coil was unable to elevate the temperature of its casing above 301°F or the flooring under the heater to above 192°F. These temperatures are well below the ignition temperature of combustible materials that may have been around the heater. Testing did determine that the heaters coils could short and eject hot coil fragments that could start a fire; however, examination of the subject heater clearly showed that the coils had not shorted; therefore, this ignition sequence did not occur. Furthermore, there was no evidence of electrical arcing on the internal circuitry or the remains of the power cord of the heater indicating power to the heater had been interrupted before the fire reached the unit. The heater in question clearly was not in the area of origin and did not cause the fire.

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ENDNOTES

1. Dr. Warren Wiersebe, sermon: *Vocations in the Bible*
2. NFPA 921 Guide for Fire and Explosion Investigations, 2008 edition, Section 16.10.4.2
3. NFPA 921 Guide for Fire and Explosion Investigations, 2008 edition, Section 24.4.6
4. NFPA 921 Guide for Fire and Explosion Investigations, 2008 edition, Section 20.3.2
5. NFPA 921 Guide for Fire and Explosion Investigations, 2008 edition, Section 20.3.1
6. NFPA 921 Guide for Fire and Explosion Investigations, 2008 edition, Chapter 20

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