Chapter 3

ACCIDENTAL FIRE CAUSES

INTRODUCTION

The causes of shipboard fire may be purely accidental or may be the result of purposeful act. Many fires have resulted from the acts or omissions of crewmembers. Carelessness and irresponsible or ill-advised actions have caused disastrous fires. And omissions--not taking the proper preventive measures when hazardous situations are discovered--have allowed many fires to "just happen."

There are so many possible sources of shipboard fires that they cannot all be enumerated. However, this chapter will present some of the more common sources of shipboard fires with the intent to provide the investigator with some basic knowledge regarding shipboard fires and preliminary areas of inquiry.

No matter how a shipboard fire starts, it could result in the loss of the ship, and perhaps the loss of lives. It is therefore extremely important that the cause of the fire be identified so that it may be prevented from happening again in the future. The determination of the cause of any fire requires the clear identification of those conditions necessary for the fire to have occurred. These conditions include, but are not limited to, the device or equipment involved, the presence of a competent ignition source, the type and form of the material first ignited, and the circumstances or actions that brought all the factors together.

Classifications of Fire Cause

The cause of any fire may be classified as accidental, natural, incendiary, or undetermined.

Accidental fires are those in which the proven cause does not involve any deliberate human act to ignite or spread the fire. While in most instances, this classification is clear, some deliberately set fires can be accidental.   For example, an engineer lighting off a boiler is purposely lighting a fire. If through some equipment malfunction, or personal oversight there is a flashback fire that spreads to involve the entire engineroom, the spread of the fire is accidental even though the initial fire was deliberate.

Natural fires involve events such as lightning, wind, and the like and do not involve any direct human intervention. They are sometimes referred to as "Acts of God."

Incendiary fires are deliberately set under circumstances in which the individual knows that the fire should not be set.

An undetermined fire cause means that the cause cannot be proved. The fire still might be under investigation, and the cause might be determined at a later date.

The term suspicious should not be used to describe a fire cause. Mere suspicion concerning a fire's cause is an unacceptable level of proof and should be avoided.

Source and Form of Heat of Ignition

The source of ignition will be at or very near the point of origin of the fire. Remaining physical evidence of the ignition source may be found at the point of origin, or such evidence may be heavily damaged or even destroyed by the fire. Regardless of its condition, the source of ignition should be identified for the cause to be determined. If the source can only be inferred, then the cause will be the most probable one.

A competent source of ignition requires sufficient temperature and energy and contact with the first fuel ignited long enough to raise it to its ignition temperature. The ignition process involves generation, transmission, and heating.

Once the area or point of origin is identified, the investigator must identify the heat-producing device, substance, or circumstance that could have resulted in ignition. Heat-producing appliances include heating equipment, appliances, and lighting equipment.

Heat Sources

There are four basic heat sources.

Chemical Heat Sources

- Heat of combustion is heat released during complete oxidation. It is the heat given off by a burning object, also referred to as the caloric fuel value.
- Spontaneous heating is an increase in temperature that does not draw heat from the surroundings. This also has several forms.
- Heat of decomposition comes from the decomposition of an organic substance.
- Heat of solution occurs when a substance is dissolved in liquid.

The most common chemical heat source in shipboard fires is probably spontaneous heating that leads to spontaneous ignition. Spontaneous ignition is often overlooked as a cause of fire aboard ship. Yet many common materials are subject to this dangerous chemical phenomenon. They include materials that are carried as cargo and materials that are used in running the ship. An example of spontaneous ignition that could easily occur aboard a vessel might be a rag soaked with vegetable oil or paint that has been discarded in the corner of a workshop, storage area or engine room. The area is warm, and there is no ventilation. The oil on the rag begins to oxidize---to react chemically with the oxygen in the warm air around it. Oxidation is a natural process that produces heat. The heat causes the remaining oil to oxidize faster and produce still more heat. Since the heat is not drawn away by ventilation, it builds up around the rag. After some time, the rag gets hot enough to burst into flames. It then can ignite any nearby flammable substances, perhaps other rags or stored materials, so that a major fire is very possible. All this can and does occur without any outside source of heat.

Careless disposal or storage of materials can lead to spontaneous ignition.

Materials Subject to Spontaneous Ignition

Ship's Materials -- As noted in the previous section, oily rags and paint-soaked rags are subject to spontaneous ignition. In this case, fire prevention is simply a matter of good housekeeping. However, some materials that are not usually subject to spontaneous ignition will ignite on their own under certain conditions. Wood is one such material.

Wood, like every other substance, must be heated to a certain temperature before it will ignite and burn. And most steam pipes do not get hot enough to ignite wood. Yet if a piece of wood is in constant contact with a steam pipe or a similar "low-temperature" heat source, it can ignite spontaneously. What happens is that wood is first changed to charcoal by the heat. Then the charcoal, which burns at a lower temperature than wood, is ignited by the steam pipe. Even though the change from wood to charcoal may take several days to occur, it could easily go unnoticed. The first sign of a problem would be smoke or flames issuing from the wood.

Cargo -- Many materials that are carried as cargo are subject to spontaneous ignition. Ignition occurs through the chemical interaction of two or more substances, one of which is often air or water. Precautions for stowing many of these substances are included in the Hazardous Materials Regulations of the Department of Transportation (DOT), which are enforced by the U.S. Coast Guard. These regulations may be found in

Title 49 of the Code of Federal Regulations (CFR). Additionally, many items that may ignite spontaneously are mentioned in the current edition of the National Fire Protection Association's (NFPA) *Fire Protection Handbook.*

Types of Combustible Cargo. Chlorine produces a violent reaction when it combines with finely divided metals or certain organic materials, particularly acetylene, turpentine and gaseous ammonia. Title 49 CFR 172.101 cautions: "Stow in well-ventilated space. Stow away from organic materials."

The metals sodium and potassium react with water. Hence, 49 CFR 172.101 cautions: "Segregation same as for flammable solids labeled Dangerous When Wet."

Metal powders such as magnesium, titanium, calcium and zirconium oxidize rapidly (and produce heat) in the presence of air and moisture. Under certain conditions they can produce sufficient heat to ignite. The NFPA cautions "Moisture accelerates oxidation of most metal powders." In the DOT regulations, metallic aluminum powder is listed with the following requirements: "Keep dry. Segregation same as for flammable solids labeled Dangerous When Wet."

According to the NFPA, dry metal turnings do not tend to ignite spontaneously. However, piles of *oily* metal borings, shavings, turnings and cuttings have caused fires by igniting spontaneously. As in the case of oily rags, heat is produced by oxidation of the oil within the pile of shavings. Eventually enough heat is produced and held in the pile to ignite the most finely divided metal. Then the coarser shavings and other combustible materials, if present within the pile, ignite and compound the fire problem.

Soft coal may heat spontaneously, depending on several factors.

1. Geographic origin
2. Moisture content
3. Fineness of particles and ratio of fine particles to lump coal
4. Chemical makeup, including impurities
5. Whether or not the coal is newly crushed.

Both coal and metal shavings are regulated cargo, which means they must be handled and transported according to regulations in Title 49 CFR. In addition, the following present a danger of fire through spontaneous heating: alfalfa meal, charcoal, cod-liver oil, colors in oil, cornmeal feeds, fish meal, fish oil, fish scrap, linseed oil, oiled and varnished fabrics of all kinds, redskin peanuts, and tung-nut meals. (Note the number of oils.)

Electrical Heat Energy

The next source of heat is electrical energy. The most common form is resistance heating. The heat is produced by the flow of electrons through a conductor that impedes the flow. This impediment (resistance) produces heat. Electric space heaters, cooking appliances, and clothes dryers are but a few examples of this form of electrical heat.

Induction heating is another type of electrical energy producing heat. Again the heat is produced by the electrons' movement. This type of heat is produced by passing electrons through the heated object. The microwave oven is the most common example. The electrons are in the form of an alternating magnetic field that fluctuates at such a high rate that it is no longer contained within a conductor. This is called radio frequency (RF), and is also the basis of radio and television transmission. In a microwave oven this RF energy is contained within the oven and passes through the object to be heated.

Electrical heat also is produced by arcing. An arc is produced when the flow of electrons is interrupted by separating the conductors. This can be as simple as opening a switch or breaking a wire.

Static electricity also can produce arcs and heat. Ungrounded moving objects will produce static electricity. Walking across a carpet, a moving belt, a hovering helicopter all can produce a shock and arc.

Lightning is also a form of static electricity and is a special hazard for tank vessels loading or discharging cargo.

Faulty Electric Circuits and Equipment

For properly insulated and wired equipment, electricity is a safe and convenient source of power. However, when electrical equipment wears out, is misused or is poorly wired, it can convert electrical energy to heat. Then the equipment becomes a source of ignition and thus a fire hazard. In sifting through a fire scene, the investigator should be on the look out for any electrical appliances or equipment that is found in the area where the fire is suspected to have originated. Such items may have to be sent to a laboratory for close scientific examination. Before removing such items from the fire scene, they should be photographed in place and their location within the compartment accurately documented.

Replacement Parts and Equipment

Standard residential or industrial electrical equipment does not last very long at sea. The salt air causes corrosion; the ship's vibration breaks down the equipment; and the steel hull can cause erratic operation or short-circuiting. As a result, the equipment or its wiring may overheat or are, causing a fire if flammable materials are located nearby.

Approved electrical equipment is, however, specially designed and constructed for shipboard use. Given reasonable maintenance, it will withstand the strenuous conditions at sea. Thus, only approved replacement parts and equipment should be installed aboard ship--and only for the use for which they have been approved. The investigator should verify that electrical equipment found at the fire scene is of approved marine type.

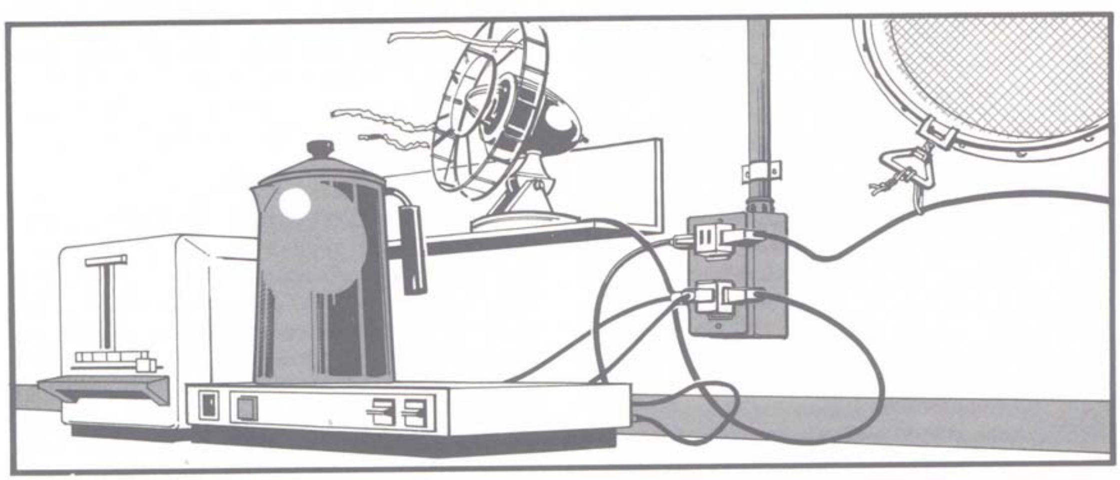
Wiring and Fuses

The insulation on electrical wiring, particularly the type used for appliances, electric hand tools and cargo and drop lights, will not last forever. With age and use, it can become brittle and crack. It may be rubbed through or broken by abuse or by the vibration of the vessel. No matter how it happens, once the insulation is broken, the bare wire is dangerous. A single exposed wire can result in a fire under the right conditions. If both wires are exposed, they can touch and cause a short circuit. Either could produce enough heat to ignite the insulation on the wiring or some other nearby flammable material.

Further, if the fuse or circuit breaker in that particular circuit is too large, it will not break the circuit. Instead, an increased current will flow, and the entire circuit will overheat. Eventually the insulation will begin to burn and ignite combustible material in its vicinity.

Jury-Rigging

The "jury-rigging" of electrical outlets to serve additional appliances, particularly in crew's quarters and galleys, is a dangerous practice. The wiring in every electrical circuit is designed to carry a certain maximum load. When this wiring is overloaded with too many operating appliances, it can overheat and burn its insulation. The hot wiring can also ignite flammable materials in the area. Cabins have been burned out by such fires, even though the need for jury-rigging can easily be avoided by planned use of appliances.

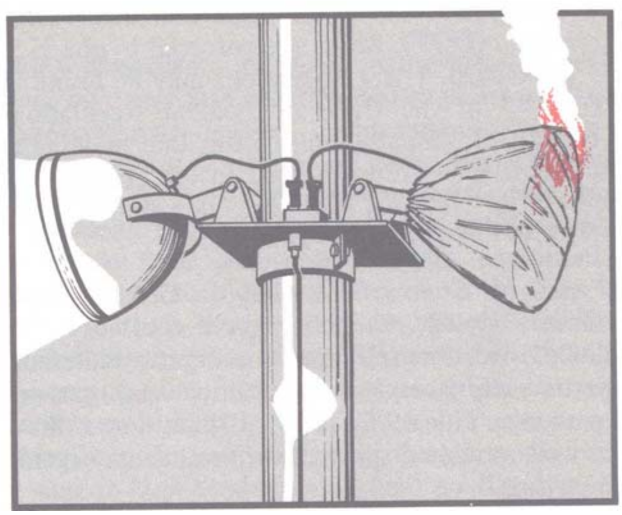


Overloading is dangerous. Only one appliance should be connected to each outlet in an electric circuit.

Exposed Light Bulbs

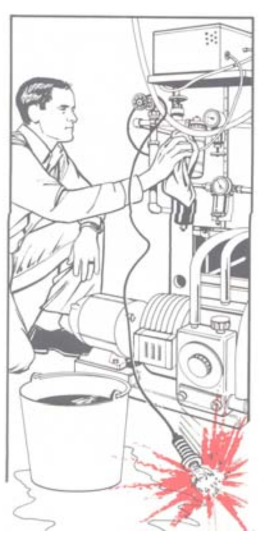
An exposed, lighted electric bulb can ignite combustible material by direct contact. A number of shipboard fires have started when a crewmember left a lamp lit in unoccupied quarters. As the ship rolled, curtains or other flammable material came in direct contact with the hot bulb and ignited. The result in most cases was destruction of the crewmember's quarters.

On weather decks, high-intensity floodlights are usually protected from the elements by canvas or plastic covers. The covers are desirable when the lights are not in use. However, if cover is left in place while the light is on, the heat of the lamp can ignite the material.



The heat of the lamp can ignite covers left in place over floodlights.

Improperly protected droplight or cargo-light bulbs could similarly ignite flammable materials, by contact or by breaking and arcing. They should never be permitted to burn while unattended. What appears to be a safe situation in a calm sea could quickly become dangerous in a rough sea.



An unprotected droplight bulb can easily break, allowing the live electric circuit to ignite nearby flammable material.

Vapor-tight Fixtures

Vapor-tight fixtures are protected against the effects of sea air. The vapor protection is designed to keep moisture out, but it also holds heat in. This causes the insulation to dry out and crack more rapidly than in standard fixtures. Thus, vapor-tight fixtures should be examined after a fire to check for short circuits as a possible source of ignition.

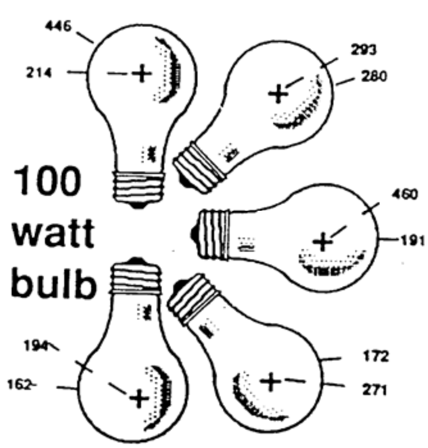
Incandescent Lamp Temperatures

(This table taken from A Pocket Guide to Arson and Fire Investigation, Factory Mutual Engineering Corp., Norwood, Massachusetts, 1992.)

Wattage	Bare Bulb Temperature (^{o} F)	Bare Bulb Temperature (^{o} C)
	110	43
40	252	122
60	260	127
100	261	127
200	307	153
300	374	190
500	389	198

Note: The above temperatures are based on mounting with base up, in a 77^{o}F (25^{o}C) ambient temperature. The temperatures vary, however, depending on the mounting position and the particular point on the bulb. For example: A 200 watt bulb would reach 307^{o}F (153^{o}C) with base up mounting; with a side mounting the bulb could reach 493^{o}F (256^{o}C).

The following chart is taken from the IES Lighting Handbook, 5th Ed.



This diagram shows the various hotspots of a light bulb mounted in various positions. Note that when a light bulb is mounted in the upright position, the tip of the light bulb can reach temperatures in excess of 446^{o} F (230^{o} C). The tip of the same light bulb mounted horizontally will probably only reach 194^{o} F (90^{o} C).

Electric Motors

Faulty electric motors are prime causes of fire. Problems may result when a motor isn't properly maintained or when it exceeds its useful life.

Motors require regular inspection, testing, lubrication and cleaning. Sparks and arcing may result if a winding becomes short-circuited or grounded, or if the brushes do not operate smoothly. If a spark or an are is strong enough, it can ignite nearby combustible material. Lack of lubrication may cause the motor bearings to overheat, with the same result.

Engine Rooms

Engine rooms are particularly vulnerable to electrical hazards. Water dripping from ruptured seawater lines can cause severe short-circuiting and arcing in electric motors, switchboards and other exposed electrical equipment. This, in turn, can ignite insulation and nearby combustible materials. Probably even more serious are ruptured fuel and lubrication lines above and near electrical equipment. In investigating engine room fires, the investigator should trace fuel and lubrication lines in the vicinity of major fire damage and examine closely any connections and/or fittings in these lines that are located in the immediate area.

FUEL OIL TRANSFER AND SERVICE OPERATIONS

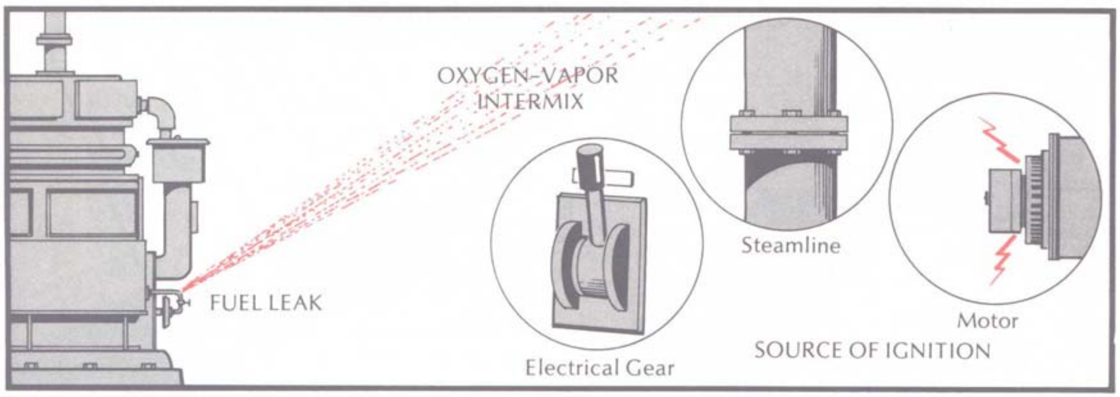
Fuel oil for the ship's propulsion is stored in double-bottom tanks, deep tanks, and tanks in the vicinity of the engine room. The types of fuels most commonly used are No. 6 fuel oil, bunker C and diesel oil. Bunker C and No. 6 fuel oil are both heavy, tarry substances that require preheating before they can be transferred or burned. Both have flash points of approximately 65.6 ^{o} C (150 ^{o} F) and ignition temperatures of 368.3 - 407.2 ^{o} C (695-765 ^{o} F). Double-bottom tanks and deep tanks are fitted with steam pipe grids and coils near the suction pipe, to preheat the oil. Diesel oil does not require heating to be transferred and burned. Its flash point is 43.3 ^{o} C (110 ^{o} F), and its ignition temperature is 260 ^{o} C (500 ^{o} F).

Transfer of Fuel

When fuel is taken aboard, it is stored in double-bottom or deep tanks. If necessary, the fuel is heated, and then it is pumped to the service tanks or settling tanks. From there, it moves to a gravity or day tank, or to a fuel oil service pump, from which it is pumped to the fuel oil burners or diesel engines.

Overfilling. If a tank is overfilled, the fuel will rise through the overflow pipe, and eventually through the vent pipe that terminates topside. The engine room crew should monitor the transfer process carefully and constantly, to prevent overfilling.

Leaks in the Transfer System. If there is a leak in the transfer piping, the pressurized fuel will be sprayed out through the break. Spraying tends to vaporize the fuel, and the vapors are easily ignited. Thus, line breaks can be very hazardous if there are steam pipes, electric motors, electric panel boards and so forth in the area. (This is also true of lubricating oil leaks near steam pipes).



Fuel line leaks can spray vaporized fuel far enough to be ignited by steam lines or electrical equipment located nearby.

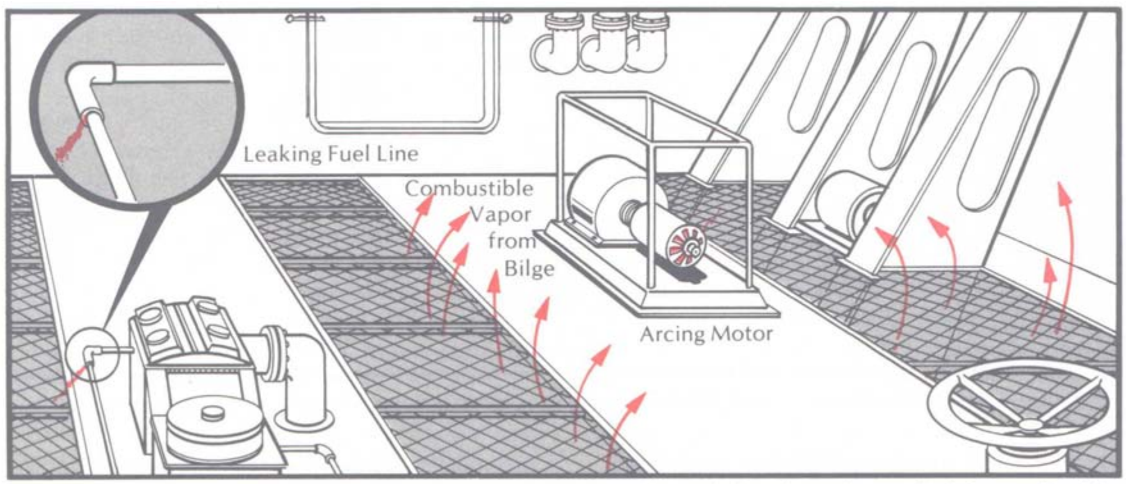
Oil Burner Maintenance

For proper atomization and operation, oil burner tips require regular cleaning and maintenance. An improperly operating oil burner tip can cause incomplete burning of the fuel and a buildup of unburned fuel in the windbox of the boiler. This fuel will eventually ignite. If sufficient fuel is present, the flames can spread away from the boiler and involve other materials and equipment. After a fire involving an oil burner, the investigator should examine the burner tips and review the maintenance practices to see if they have been cleaned and maintained properly. Further, installation procedures should be reviewed, since improper installation can also cause fuel buildup and ignition.

Bilge Area

Fires occur in bilge areas because of excess accumulations of oil. Most often, the oil leaks into the bilge from an undetected break in a fuel or lube oil line. The oil vaporizes, and the flammable vapors build up in and around the bilge area. Once these vapors are mixed with air in the right proportion, a carelessly discarded cigarette or cigar butt, a match or a spark can ignite them and cause a fire. Bilge fires can move very quickly around machinery and piping, and for this reason they are not easily controlled. They are more difficult to extinguish than most engine and boiler room fires.

Bilge areas should be examined by investigators to detect the presence of excess oil. Areas around oil/water bilge separators should also be checked for possible overflow, which can also be a source of large accumulations of oil in the bilges.



Fuel from leaking oil line collects in the bilge. Combustible fuel vapors from the bilge mix with air as they move toward the arcing motor. Ignition of the fumes by the motor can cause an explosion followed by fire.

WELDING AND BURNING OPERATIONS

Welding and burning operations are hazardous by their very nature. This can best be appreciated by noting that the flame from an oxyacetylene torch can reach a temperature of 3315.5^{o} C (6000^{o} F). Welding temperatures are reached either by burning a mixture of gas and oxygen or by using electricity. The most common welding gas is acetylene; others include hydrogen, LPG and natural gas. In electric welding, commonly called arc welding, the required heat is produced by an electric arc that is formed at the work piece. In welding operations, dangerous, high-temperature sparks and slag are thrown off which can easily ignite nearby combustible materials.

Burning is a gas-fueled operation and is more hazardous than welding. In gas burning, or gas cutting, the temperature of the metal is raised to the ignition point, and a jet of oxygen is introduced. This forms a metal oxide that melts, and the oxygen jet removes the molten metal.

Unsafe Burning and Welding Practices

The high temperature, molten metal, and sparks produced in welding and burning operations can be an extremely serious fire hazard. During burning and welding operations, unsafe conditions, unsafe acts, oversights or omissions may result in shipboard fires. The investigator should be familiar with proper welding and burning procedures and should be sensitive to common safety deficiencies, including:

- Failure to provide a competent fire watch in the immediate work area, below the work area and on the opposite side of a bulkhead that is being welded or burned. The fire watch should have no other duties and should inspect and re-inspect the area for at least one-half hour after the operation. This is crucial, as hot metal and slag retain heat for a long time.

- Failure to move combustible materials (or to protect them if they cannot be moved). Materials in the work area and the areas below deck and on the opposite side of a bulkhead should all be protected. Hot sparks and slag can travel great distances, and heat moves quickly through metal decks and bulkheads.

- Burning near heavy concentration of dust or combustible vapors such as those emitted by fuel oil, lubricating oil and other flammable liquids.

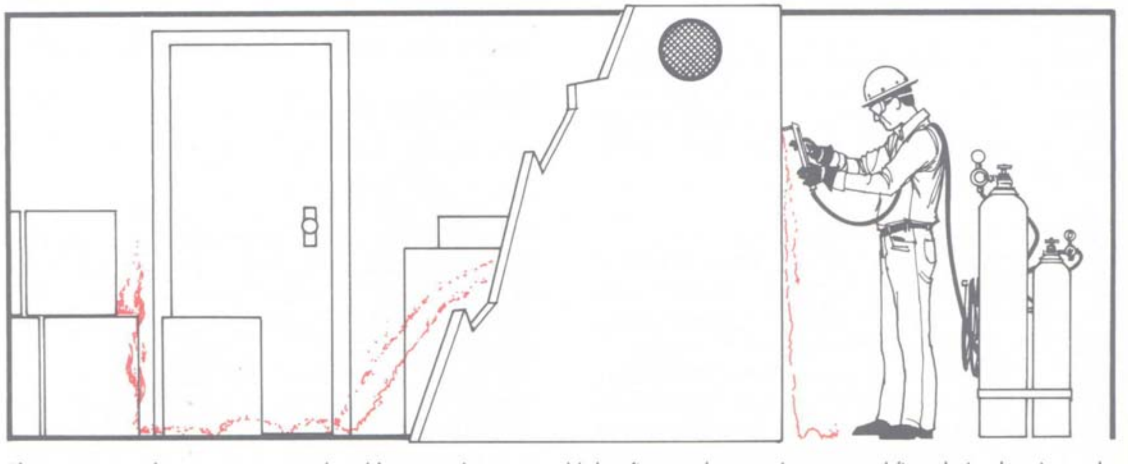
- Failure to remove flammable vapors, liquids or solids from a container, pipe or similar work piece and to obtain the proper clearance (including a certificate) from an NFPA-certified marine chemist or an officially designated "competent person."

- Failure to have the proper type of fire extinguisher at the scene, along with a hose line charged with water to the nozzle and ready for immediate use.

- Failure to secure oxygen and gas cylinders in an upright position.

- Failure to protect the gas and oxygen hoses from mechanical damage, or damage from the flying sparks, slag and hot metal resulting from the operation.

- Failure to provide a shutoff valve for gases outside a confined space.



Failure to remove combustible materials or to establish a fire watch may be factors in fires ignited during burning and welding operations.

Charging Storage Batteries

When storage batteries are being charged, they emit hydrogen, a highly flammable gas. A mixture of air and 4.1% to 74.2% hydrogen by volume is potentially explosive. Hydrogen is lighter than air and consequently will rise as it is produced. If ventilation is not provided at the highest point in the battery charging room, the hydrogen will collect at the overhead. Then, any source of ignition will cause an explosion and fire.

In investigating fires that include areas where batteries may be charged, check that the area is well-ventilated to prevent entrapment or build-up of explosive gases and look for signs of smoking or other sources of ignition nearby, such as machinery that might produce sparks.

GALLEY OPERATIONS

On a small harbor tug or a large passenger liner, a ship's galley is a busy place, and it can be a dangerous place. The intense activity, the many people, the long hours of operation, and the basic hazards--open flames, fuel lines, rubbish and grease accumulations--all add to the danger of fire due to galley operations.

Energy Sources

For cooking, the most common energy source is electricity. Diesel oil is used to a lesser degree, and liquefied petroleum gas (LPG) is used on some smaller vessels, such as harbor tugs. Electric ranges are subject to the same hazards as other electrical equipment. These include short circuits, brittle and cracked insulation on wiring, overloaded circuits and improper repairs.

When liquid fuels are used for cooking, fuel lines may be vulnerable to being damaged. Further, fittings and connections in fuel lines may be faulty or improperly installed. The investigator must examine fuel lines, fittings and connectors to see if such items were involved in the ignition sequence in a galley fire.

Cooking equipment, like heating units, is designed to provide safe, reliable service. It is manufactured to current industry standards and must be installed in accordance with the manufacturer's instructions. Again, people are the unpredictable factor. When cooking equipment is misused, incorrectly installed, or not properly maintained, it can become an ignition source.

If cooking equipment is a suspected cause, check the positions of the controls. They will usually survive even a severe fire, and such examination can establish their position at the time of the fire. Also check the contact points of the controls, switches, and thermostats for malfunction, signs of pitting, and arcing.

Ranges present a twofold fire danger: The heat of the range can cause a galley fire, and its fuel can be involved in one. Galley personnel should exercise extreme care when they are in the vicinity of an operating range. Clothing, towels, rags and other fabric or paper used in the galley call be ignited through carelessness. No material should be stowed above a range. At sea, the range battens should be used at all times. Investigators should attempt to assess the housekeeping practices in the galley and look specifically for evidence of improper stowage of combustibles near heating surfaces.

Pilot lights must be operative, and the main burners must light when they are turned on. Otherwise, fumes will leak into the galley, and any source of ignition will cause an explosion and fire.

Automatic drip coffeemakers can be potential sources of ignition. There are two basic types of these appliances; one has a brewer element that also serves as the warmer element, and the other has separate brewer and warmer elements.

The component that is most commonly an ignition source is the brewer element. In order for this to occur two things must happen: the operating thermostat must fail, and the safety fuse(s) (TCO or thermal cutoff) also must fail. Tampering with the unit (or improper repairs) also can cause the unit to become an ignition source if the TCO is bypassed.

Those units that use the brewer element as the warmer element have the heating element located under where the pot normally sits. If this unit overheats, the heating area assembly will take on the shape of the top of a cupcake. There also will be severe charring under the appliance.

Deep fryers can also be a source of both heat and fuel for a galley fire. The fryer should be stationary, so that it cannot shift with vessel movement. The frying basket should never be filled so full that the grease splatters or overflows. Once ignited, the grease will burn rapidly. Nothing should be stowed above the fryer. Most important, the fryer should never be left unattended while it is operating.

Housekeeping

The activities within a galley generate plenty of fuel for carelessly caused fires. Thus, good housekeeping is of the utmost importance. Used boxes, bags and paper, and even leftover food, should be placed in covered, noncombustible refuse cans where a carelessly discarded butt or match cannot ignite them.

Grease accumulations in and around the range, particularly in the hoods, filters and ductwork, can fuel a galley fire. If the ductwork becomes involved and there are heavy grease accumulations, the fire can extend to other areas and decks. Therefore, hoods, filters and ductwork should periodically be thoroughly cleaned.

In investigating a galley fire the investigator should closely examine the cooking and electrical appliances in the area of greatest fire damage. The area near ranges and deep fryers should be carefully examined by the investigator to document the combustible materials in the immediate area, or stowed immediately over them. The positions of burner, oven, and fryer controls should be recorded and, if suspected to be improper, photographed. The pilot light assemblies and any electrical components should be examined, keeping in mind that some parts may need to be removed for detailed examination in a suitable laboratory ashore. Should such removal be necessary, the part should be photographed before removal to document its “as found” condition. It should then be properly tagged or marked for identification, and proper chain of custody maintained.

Check controls and fuel lines for prior trouble with equipment. Look for previously attempted repairs. The presence of fresh, tool marks may indicate that someone had recently attempted a repair. Check for signs of fuel leakage in the area of the unit. When combustible fuels leak, they may soak into deck coverings and leave stains or liquid burn patterns.

Valves and controls for fuel may malfunction allowing unburned fuel to escape. Gas valves on both LP and natural gas appliances and equipment may fail to operate properly for several reasons. A valve also may fail when debris enters the system and prevents it from properly closing. Anytime that a gas valve is determined to have been-or is suspected to be involved in the cause of a fire or explosion, it should be x-rayed prior to being disassembled.

Mechanical Heat Energy

Mechanical heat energy takes three basic forms. The first is friction heat. This is the heat from direct mechanical contact between moving objects, such as rubbing sticks together to make fire. Another form of mechanical heat energy is friction sparks. A familiar example of this type is a grinding wheel.

The third form is the heat of compression. When a gas is compressed, the molecules are forced closer together and heat is produced. Filling SCBA air tanks is one form of this heat. A diesel engine is dependent on this form of heat to run. The spark plugs are replaced with a very high compression ratio (over 20 to 1). The compression of the air in the cylinders increases its temperature above the ignition point of the diesel fuel. When the fuel is injected into the cylinders, it ignites and the engine runs.

First Material Ignited

The first material ignited (the initial fuel) is that which sustains combustion beyond the ignition source. The physical configuration of the fuel plays a critical role in its ability to be ignited. The initial fuel also can be part of the device that malfunctioned and/or may be an item that was too close to a heat-producing device. The determination of the initial fuel ignited is a very important element in properly understanding the events that caused the fire.

Ignition Factor or Cause

The mere presence of an ignition source and an initial fuel, by themselves, does not create a fire. The fire is the direct result of bringing together the fuel and ignition source. The sequence of events that led to the combination of these two elements establishes the cause.

Consider a fire that originated in a deep fat fryer in a galley. The proper cause determination is much more than "the deep fat fryer caused the fire." It is necessary to establish more precisely what occurred. Did the controls fail? Was the thermostat set too high? Was the unit too close to combustible materials?

Potential causes should be ruled out *only* if there is clear and definite evidence that they could not have caused the fire.

Certainty of Opinions

Opinions formed by the fire investigator must stand the challenge of reasonable examination. NFPA 921, *Guide to Fire and Explosions Investigations* has defined *four* specific levels of confidence against which opinions can be measured. These are also based upon guidelines established by the American Academy of Forensic Sciences.

1. Conclusive. At this level of confidence, all reasonable alternatives to the hypothesis are considered and eliminated, leaving only that hypothesis under consideration as true.

2. Probable. This level of confidence corresponds to being more likely true than not. At this level of confidence, the chance of the hypothesis being true is more than 50 percent.

3. Possible. At this level of confidence, the hypothesis can be demonstrated to be feasible but cannot be declared probable.

4. Suspected. This level of confidence corresponds to a perception that the hypothesis may be true, but there are insufficient data to draw a conclusion to the exclusion of any other reasonable conclusion.

Quite often the report filed by the local fire department, local fire marshal, or state fire marshal will be used by a plaintiffs lawyer to file suit against the manufacturer, supplier, and/or installer of various types of equipment when that report indicates that some type of equipment was responsible for causing the fire. The investigator must remember that the mere presence of an item at the point of origin does not *necessarily* mean that it was the fire cause. All reports should indicate the degree of certainty of the investigator's opinion. Any time the degree of certainty is either possible or suspected, the cause should be listed as undetermined.

Heat Tape

Heat tapes, used to prevent the freezing of water lines, also can become ignition sources. There are two types of these tapes. One comes pre-assembled in certain lengths that are ready to be used. With other types the heat tape is cut to length, with the male attached plug placed on one end and a termination cap on the other. The first type can become an ignition source if the thermostat fails or if the tape is installed improperly. Improper installation includes wrapping the tape over itself, thus insulating the tape (unless recommended by the manufacturer). In addition to these conditions, the second type can fail if water enters the tape. This can cause the tape to burn like a fuse.

On many vessels that work in Arctic Seas, such as fish processing vessels, which have refrigerated holds, use electric heat tape extensively to keep drain lines ice free during defrost cycles of the refrigeration process. Typically, electric heat tape to prevent freezing will be spiral wrapped about six turns per pipe foot around the drain and the fire main pipes.

Self-regulating heat tape is constructed with two parallel bus wires embedded in a carbon-filled semiconductor (matrix) material that allows current to flow between the bus wires. The current flow in the matrix generates heat. The matrix material conductivity changes (self-regulates) inversely with temperature. A flexible insulation covers the bus wires and carbon-filled matrix, and the tape is sold on a reel. The heat tape is cut from the reel, and the wire length determines the resistance: the longer the cable -- the lower the resistance—the more electrical current drawn.

In 1994, heat tape of this type was responsible for a fire on board a U.S. fish processing vessel, the ALL ALASKAN, while the vessel was underway near Unimak Island, Alaska. The fire caused between $24 and $31 million in damage to the vessel and cost the life of one crewman.

The U.S. Consumer Product Safety Commission (CPSC) has been concerned about the safety of electric heat tapes used to prevent residential water pipes from freezing. The CPSC reported that the national fire data for 1985 through 1987 show 3,300 residential fires, 20 deaths, 160 injuries, and $25.4 million in property losses annually in the United States from electric heat tapes. As a result of its concern, the CPSC contracted two safety studies in which consumer-available electrical heat tapes (resistive and self-regulating types) intended for residential installation were tested.

Both CPSC studies concluded that the self-regulating heat tapes present a potential fire hazard when connected without a fuse and a ground-fault current interrupter (GFCI). The 1994 study determined that a 30 ampere branch circuit breaker or fuse did not provide fire protection when the heat tape failed; however, a l0-ampere fuse did allow some protection but did not have 100-percent reliability as a safety measure. The GFCI was very effective at eliminating the fire hazard when the heat tape was covered with an electrically grounded metal braid.

As part of its investigation into the All ALASKAN fire, the U.S. National Transportation Safety Board tested new heat tape provided by the heat tape manufacturer and heat tape taken from the ALL ALASKAN at Underwriters Laboratories Incorporated in Chicago, Illinois. The testing was conducted to determine the relevance of the CPSC studies for the residential shoreside to the commercial heat tape used on vessels and to demonstrate the heat tape behavior when it fails. The tape, tested without end-seal terminations and in the horizontal position, was electrically powered as on vessels and had salt water dripping on its exposed terminal end until arcing and ignition of its jacket occurred. Various salt-water concentrations were used; however, to facilitate failure in a reasonable time period, salt concentrations higher than sea water were used to cause repeated failures of the heat tape. Arcing around the bus wire was first noted as the salt water wet the bus wires and the matrix material. Time to ignition of the heat tape was dependent on the salt-water concentration. Flaming took about 20 minutes when the concentration of salt water was about 200 grams/liter (sea water is about 35 grams/liter concentration), and the flames moved along the tape towards the power source and extinguished when electrical power was terminated.

A 30-ampere protection device was built into the testing circuit from which the test heat tape was powered. In no experiments in which the heat tape arced and ignited did the current exceed the circuit breaker rating to stop current flow to the tape, and power had to be manually secured. The test results were consistent with the CSPC findings: a fuse and/or circuit breaker was not a reliable protection against arcing and ignition of material wrapped around the heat tape when a tape failure occurs. No regulations or national marine safety standards exist in the United States for heat tape installation and use on vessels.

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Refrigeration Compressors

Refrigeration compressors often are cited as a fire cause. Compressors used on domestic refrigerators and freezers and commercial types of equipment are of either the hermetic or semi-hermetic type. These types of compressors are constructed so that the electric motor portion of the unit is completely enclosed within the refrigeration system. Hermetic compressors use a welded compressor shell, while semi-hermetic compressors are bolted together.

These types of compressors are constructed so that the temperature on the outside of the shell cannot exceed certain limits, usually around 300^o F (149^o C). Extensive tests have shown that these compressors will not ignite combustible materials, even if they are in direct contact with the shell. In tests, compressors have been completely covered with materials such as dust, wood shavings, or shredded newspaper and have operated for extended periods with no ignition occurring.

It is possible, however, for an electrical failure to occur with components and wiring outside of the compressor that might serve as an ignition source.

Smoking and Related Fires

The heat generated by burning cigarettes will vary from 550^o F (288^o C) measured on the outside of the glowing ash to 1,350^o F (732^o C) in the center of the glowing ash. Higher temperatures have been recorded in research experiments.

In order for a discarded cigarette to ignite an item of furniture or bedding, it must be insulated. If the cigarette is dropped on the surface of the item, the most probable result will be only local surface charring and it will most probably self-extinguish. The cigarette becomes insulated when it is located in cracks or crevices. This insulating effect allows the build-up of heat from the glowing ash, and increases the surface contact with the heat source. The greater the insulating effect, the greater the chance a fire will occur.

Smoldering fires in furniture such as sofas, chairs, or beds usually require long periods of time to produce open flame. It is difficult to identify the minimum time period needed, but laboratory tests have shown open flame as early as 20 minutes and as late as 6 to 8 hours. The typical time is from 1 to 1-1/2 hours but this time can vary greatly in either direction.

A smoldering fire inside padded furniture eventually may produce temperatures of between 1,4000 and 1,600^o F (760^o and 871^o C) inside the furniture. This temperature is sufficient to cause the annealing and collapse of springs. The collapse of springs must be considered in conjunction with other indicators.

Smoldering fires also produce large quantities of heavy smoke. Heavy accumulations may be present on bulkheads, overheads, and glass windows or ports as well as other items or contents. Remember that if a fire vents through an open access to fresh air, a clean burn may occur.

Heavy deck damage may occur when an item of padded furniture burns, regardless of the ignition source. If the padding is foam, it will melt and produce patterns at the edge and under the furniture that can be misinterpreted as being the result of an accelerant. It is not unusual for burnthrough of wooden or fiberglass decks to occur as the result of the dropping down of this burning material.

A cigarette dropped into trash or other similar combustible materials also can become an ignition source. Again, it depends upon the type of materials available how long a delay might occur before open flame. It could range from a few minutes to several hours.

Flammable and Combustible Liquids

The improper storage and handling of flammable and combustible liquids is a major cause of accidental fires. These types of liquids can be commonly found in storage cabinets, storerooms, paint lockers, and workshops.

Improper selection and use of storage containers may be a contributing factor in fires involving flammable and combustible liquids. Plastic containers not specifically designed for such use, such as milk jugs and antifreeze containers, will become brittle with age and may develop cracks or leaks. They also are susceptible to being punctured by sharp objects, edges, or corners and may break upon impact if dropped. The liquid also may act as a solvent and actually dissolve the container.

Lightweight metal containers also can be dangerous, in that the lightweight construction may rust or deteriorate along the crimped seams. This will cause slow leaks to develop. Regardless of whether the can is plastic or metal, it should be listed and approved for the storage of a flammable or combustible liquid.

Another common cause of fires is the improper use of flammable liquids for cleaning. Because flammable and combustible liquid vapors are heavier than air, they settle at low points. These vapors may contact an ignition source a considerable distance away and flashback to the container or source. Some of the more commonly available ignition sources are sparking of electrical equipment, motors, static electricity, and smoking.

The indicators of a fire involving flammable liquid vapors are rapid flame spread, very heavy charring of wood structures, and low burning. Corroborating evidence would include the presence of cleaning equipment containing the residue of flammable liquids, the presence of containers, and witness statements.

It should be remembered that when a combustible liquid is heated to its flashpoint or above, it will behave like a flammable liquid.

Fuel Gases

Fuel gases such as natural gas and LP (propane, butane) can be involved in a fire. Leaks involving equipment and piping and malfunctioning equipment can lead to explosions and/or fires. These gases, which are naturally odorless, are required to be odorized but under certain circumstances odorization may fail, thus allowing the presence of the fuel gas to be undetected.

LP gases are heavier than air and will normally settle to the lower levels of the structure, Explosions involving LP gas usually will produce heavier damage at the lower levels. Natural gas, on the other hand, is lighter than air and will rise to the upper levels of the structure. Explosions involving this gas usually will produce heavier damage at upper levels.

The most common odorant is ethyl mercaptan -- this gives the gas the characteristic rotten egg smell. It is known that a certain small percentage of the population has a complete or partial loss of their sense of smell and that some people are insensitive to the odorant. Factors such as age, colds, allergies, and certain diseases affect the ability of the human nose to detect gas odorant. It is estimated that approximately 96 percent of the population has a "normal" sense of smell.

Because the boiling points of the odorant and LP are different, odor fade can occur when an LP tank has been out of service for some time. As gas is first drawn from the container, the level of odorant will be at its lowest level and may be undetectable. As more gas is drawn from the tank, the liquid and odorant will begin to boil and the odorant level in the vapor will increase.

Odorant fade also can occur with new LP containers. In these new containers, the odorant can be absorbed by the steel and/or may react with any rust inside the container. The precise mechanism of odor fade has not yet been determined and further research is underway.

Open Flames and Sparks

Cutting and welding operations often are conducted in areas where combustibles are stored. A fire may smolder for a long period of time after completion of the actual welding and cutting operation. The fire may result from the effects of heat conduction or convection from the welding, when welding or cutting objects are connected to or pass through combustible construction, or by direct flame contact.

The indicators of a fire caused by cutting or welding include slag in the area of origin, spot burning, welding or cutting equipment in the area, the presence of metal objects showing evidence of recent welding/cutting, and witness statements.

The sparks produced by grinding operations also can provide an ignition source for both combustible materials and flammable and combustible vapors.

Friction and sparks from machinery are another cause of accidental fires. The friction from high-speed rotation of objects may result in extreme heat being generated if the machinery is improperly lubricated. This may result in the ignition of nearby combustible materials by conduction or convection. Indicators of a fire caused by friction may include a report of trouble or noise from the equipment involved or a point of origin near or inside the suspected equipment or machinery. Localized damage to the metal portions of the machinery may be present and, depending on the intensity of the heat, actual melting.

Sparks from machinery also may serve as an ignition source. These sparks may be from an electrical or mechanical source. Sparks from grinding will produce indicators that are similar to open-flame cutting.

Spontaneous Heating

Spontaneous heating leading to combustion sometimes ig used as a catchall by investigators. Spontaneous heating does occur but certain materials and conditions must be present. Spontaneous heating can be produced in three ways: chemical action, fermentation, or microbial thermogenesis *(oxidation)*. Since the most frequently encountered situation is fermentation, this section concentrates on this method. If a chemical reaction or oxidation is suspected, consult additional references such as NFPA 491M, *Manual of Hazardous Chemical Reactions.*

Moisture is a prime factor in the fermentation process. Storage of some materials while wet or green is an invitation to spontaneous heating. Spontaneous heating may be accelerated by outside heat sources such as sunshine, storage near steam pipes or heaters, or drying processes.

Another critical element of spontaneous heating is air movement. Too much air or air movement can dissipate the heat and keep the mass below ignition temperature. Too little air may accelerate the heating. For example, a rag soaked in linseed oil may produce spontaneous heating if wadded up at the bottom of a trash can but the same rag will only dry out if spread open on the floor or ground.

The mass of the material also is important. Material usually must be several inches deep to allow for spontaneous heating. The heating may occur in a matter of hours, or may take months to reach its ignition temperature. Bacteriological preheating may initiate the mass. The bacteria may die as the mass reaches temperatures in the 175^{o} F (79^{o} C) range, At that point, the heating may continue or halt, depending upon the other factors present.

Indicators of fires caused by spontaneous heating include charring inside the mass, or more than one area of such charring. It is also important that the suspected material be from some living source or base, although there are some exceptions. Some of the common materials that are susceptible to spontaneous heating are linseed oil, charcoal, fish meal, wool waste and foam rubber. A more complete listing is included in the *Fire Protection Handbook.*

Spontaneous heating is responsible for cloth fires after certain fabrics have been dried in a clothes dryer. It has been shown that fabrics that contained vegetable oils can produce spontaneous heating after being laundered. The spontaneous heating can occur if the items are left in the dryer or even if they are removed and placed into some type of container or basket. The contributing factors include the type of fabric, the amount and type of oil absorbed by the fabric, the type of detergent used, the manner in which the clothes were washed, and the temperature level to which the washed clothes were exposed.

Materials such as tennis shoes and foam padding also have been known to be susceptible to spontaneous heating after being dried in a dryer. Fires also can occur if the venting system of the dryer is incorrectly installed or blocked. Accumulations of lint block proper air flow.

Low-Temperature Ignition

Wooden vessels and vessels which use plywood extensively in their interior finishing may be susceptible to low-temperature ignition. When wood or similar materials are subjected to temperatures as low as 250^o F (121^o C) for an extended period of time, pyrophoric carbon is formed. In this process, the character of the material is changed. The exposed material becomes almost pure carbon and is subject to spontaneous heating. The time required for such ignition to occur depends upon the level of heat exposure, the duration of the exposure, the mass/density of the material, and ventilation. The timeframe may be several weeks or months although there have been cases that took several years.

Although it is generally believed that 250^o F (121^o C) is the minimum temperature at which spontaneous heating can occur, there is some research that indicates that a temperature as low as 212^o F (100^o C) could initiate such combustion.

Low-temperature ignition may develop in areas where combustibles are in contact with or very near light bulbs, steam pipes or other low-temperature, heat-producing appliances.

Low mass or low density (small or thin) materials are usually not affected by low-temperature heat. Low-temperature pyrolysis usually occurs only in solid timbers, but plywood constructions, such as uninsulated stack enclosures may also be susceptible when exposed to exhaust stack temperatures. This is due to the insulating effect of the larger mass/density.

Watch for the presence of a large charred section accompanied by a low-temperature heat source. Generally, even though a very large charred area can be expected, the charring will appear baked and will have very few, if any, deep cracks along the surface. A smooth surface with hairline dehydration cracks is the more common occurrence.

The following are examples of situations or equipment that can provide the necessary heat for low-temperature ignition. Saturated steam pipes (approximate temperatures on or near surface).

10 lb. gauge pressure 240^{o} F (121^{o}C)
15 lb. gauge pressure 250^{o} F (121^{o} C)
20 lb. gauge pressure 259^{o} F (126^{o} C)

Lightning

Lightning is a tremendous discharge of electrical energy. The discharge usually consists of several strokes back and forth, each lasting a few millionths of a second. The current flow during a lightning strike can reach as much as 200,000 amperes. Lightning strikes usually are accompanied by some physical destruction of any poor electrical conductor in its path.

The air in the path of the main stroke is heated to a temperature of 30,000^{o} C (54,000^{o} F) and expands at supersonic speed. The pressure wave can damage nearby structures with near explosive force. In the flash itself, the heat being generated by the current flow can be sufficient to cause ignition.

BASIC ELECTRICITY

Introduction

A fire investigator must possess a basic knowledge in various fields to successfully determine fire causes. Electricity is one of those fields. The intent of this section is to provide a basic understanding of electrical terminology, how electrical systems operate, and what indicators will be present to assist in determining a fire of electrical cause. When unexplainable circumstances occur, or when you have unanswered questions, seek the expertise of a professional marine electrician or an electrical engineer for assistance.

Some experts in the electrical field claim that electricity cannot cause fires. Although this statement is incorrect, many fires have been improperly determined by fire investigators to be electrical in nature. Electrical systems have become a "catch-all" cause when no other cause can be found and there is heavy fire damage to the system. Electricity can and does create fire situations. However, specific indicators must be present to substantiate such a determination. An electrical fire cause determination never should be based on one, single indicator.

Basic Terms

The following are basic electric terms with which every fire investigator should be familiar.

Electricity is the flow of electrons due to a difference in energy potential between two points on a conductor. All matter is composed of molecules that, in turn, are composed of atoms. An atom consists of a positive charged nucleus (protons and neutrons) surrounded by negative charged electrons which orbit around the nucleus. It is the electrons, and the ease with which they can move about, that determine the electrical properties of a material. Like charges (+ and + or - and -) repel each other, while unlike charges (+ and -) are attracted to each other.

Anytime a current of electricity is flowing, a magnetic field will be generated. This is the basic operating principle of an electric motor. Conversely, whenever a conductor is moved through a magnetic field, an electric current will be produced in the conductor. This is the basic operating principle of an electric generator.

Neither heat nor magnetism can be eliminated completely from an electric circuit. However, circuits can be designed to produce *mostly* heat (toaster) or to produce mostly magnetism (motor). Another byproduct of current flow is heat. The electrons passing through a conductor constantly collide with one another generating heat. The greater the current flow, the greater the amount of heat produced. *(Kirk's Fire Investigation,* 2nd Ed., pg. 173.)

A conductor is any material that allows free flow of electricity. Some examples of better known conductors are gold, silver, copper, aluminum, and carbon.

An insulator is a material that restricts or inhibits the flow of electricity. Rubber, plastic, glass, and porcelain are common examples of excellent insulating materials.

Units of Electricity

There are four basic units of electricity. Voltage is a unit of *force* or pressure that causes electrons to flow in a conductor (electromotive force) and is expressed in volts.

Current is the rate of electricity used. Current flow is determined by measuring the amount of electrons flowing past a single point in one second. This rate is expressed as amperes or amps. *(Kirk's Fire Investigation,* 2nd Ed., pg. 176.)

Resistance is the opposition of a conductor to the flow of current. Resistance is expressed in ohms. Current flowing through resistance creates heat and every circuit offers some resistance. An excess of resistance in a circuit can create temperatures high enough to eventually cause ignition of nearby combustibles. Resistance in circuits can be caused by pinched conductors, twisted or wound conductors, severely bent wires, or loose electrical connections. Each of these conditions poses the potential for a fire.

Wattage is a quantitative measurement of work done or power consumed. This measurement is usually expressed in watts per hour. *(Kirk's Fire Investigation*, 2nd Ed., pg. 177.) Every electrical appliance is rated as to the amount of power or energy it consumes. This rating is expressed in watts (per hour). Heat producing appliances, such as hair dryers, curling irons, coffee makers, toasters, electric blankets, etc., have a higher wattage rating than non-heat-producing appliances, such as radios, clocks, table lamps, etc. Larger appliances, such as refrigerators, microwave ovens, air conditioners, dish washers, clothes washers, etc., also have a higher wattage rating. (See the chart below for common appliances and approximate wattage ratings.)

Appliance	Wattage
Lamps, incandescent	10 and upward
Lamps, fluorescent	15-69
Christmas lights	30·150
Clock	2-3
Radio	40-150
Television	200-350
Sunlamp (ultraviolet)	275-400
Heating pad	50-75
Blanket	150-200
Razor	8-12
Heater, portable	500·1,500
Heater, baseboard	1,000-2,500
Fan	50-200
Air conditioner, window	800-1500
Hair dryer	350-1,000
Projector, slide or movie	300-1,000
Sewing machine	60-90
Vacuum cleaner	500-1,500
Refrigerator	150-300
Freezer, household	300-500
Iron, hand (steam or dry)	660-1~00
Hotplate (per burner)	600-1,000
Stove (all burners and oven ON)	8,000-14,000
Stove (burners separate)	4,000-6,000
Oven (separate)	4,000-5,000
Toaster	500-1,200
Coffeepot (percolator)	500-1,000
Waffle iron	600-1,000
Roaster	1,000-1,650
Rotisserie (broiler)	1,200-1,650
Deep fat fryer	1,000-1,650
Frying pan	1,000-1,200

Blender	500-1,000
Knife	100
Mixer, food	120-250
Dishwasher	1,200-1,800
Garbage disposal	500-800
Clothes washing machine	*350-550*
Clothes dryer (electric)	4,000-5,000
Water heaters (electric)	2,000-5,000
Motors 1/4 hp	300-400
1/2 hp	450-600
over 1/2 hp (per hy)	950-1,000

Effects of Electricity

There are four effects of electricity; three of these effects can create heat that may be involved in the ignition of a fire. The first effect produced by electricity is a thermal action, which is heat. Examples of this action is evident in toasters, electric space heaters, or any other heat producing appliance. The second effect is magnetism. As current flows along a conductor, a magnetic field is produced and this field has the capability of creating heat. A chemical reaction, in the form of oxidation, is the third effect and can occur at loose or poorly made connections. This buildup of oxidation creates resistance, which, in turn produces heat. The last effect of electricity is illumination**,** the light that can be observed with a glowing conductor.

EXAMINING FIRES OF ELECTRICAL ORIGIN

This section is designed to assist the fire investigator in identifying indicators of fires of electrical origin. A single indicator is not sufficient to classify a fire as electrical. This indicator must be validated by displaying that other conditions existed that caused the situation. Caution must be exercised by the investigator to identify whether the physical electrical conditions found are a cause or a result of the fire.

Remember, safety is always the first consideration that should be taken into account by the fire investigator. Prior to beginning any type of examination of a fire scene, the investigator should first ascertain whether the electric service to the fire scene has been terminated. For your own safety, as well as the safety of overhaul crews, check to make sure that the incoming service has been cut before examining electrical systems and components.

If a fire is suspected of being electrical in cause, the investigator must properly identify the equipment that was involved in the ignition. Such identification must include the manufacturer's name, model number, serial number, voltage and current ratings, and if the equipment was laboratory certified.

There are several means of producing heat in electrical systems and equipment. These include arcs and sparks, heated connections, and overheated conductors. Careful determination of the precise form of electrical heating that initiated the fire should be made and then identification made of the material that was ignited.

The equipment involved, the form of heat, and the first material ignited are the three basic elements of an electrical fire cause, and would be considered direct evidence. It is the circumstantial evidence, however, which supports the case and ties the basic elements together.

Examine fuses for proper size, type and operation. Tripped circuit breakers should be removed from the bus bar and examined for evidence of pitting or arcing at the metal contacts. Also examine the breakers for evidence of arcing between breakers or across wire connections.

Inspect the connections inside fuse boxes. Look for evidence of tool marks that may indicate tampering or recent repairs. Check for loose wire terminal connections that could have created an overheating condition.

Examine switchboards and distribution panels for evidence of previous electrical system problems. Are there blown or discarded fuses in or on the distribution panels?

Examine the fuse boxes for indications of efforts to bypass the overcurrent protection devices. Some examples of tampering with these devices include placing a penny behind the fuse, cutting a strip off the metal screw threads and bending it down to the metal tip at the base of the fuse, wrapping the fuse in foil, replacing the fuse with screw base plug and placing a staple or brad into the receptacle openings. A cartridge type fuse can be bypassed by wrapping it in foil, running a nail through the length of the cartridge, or simply replacing the cartridge fuse with a metal bar or copper tubing.

Examine the interior of the panel. Conductors inside the distribution panel may display indications of arcing or other electrical activity that took place. Melted or molten beads of copper or aluminum adhered to the interior walls of the panel box usually indicates that arcing occurred. Finally, if necessary, safely remove the entire distribution panel box and be observant for indications of heating to the back of the panel box or area to which the panel box was mounted. This is a protected area and should display little or no damage.

Examine Undamaged Areas

The investigator should watch for any signs of unprofessional electrical work/repairs. Check for missing cover plates on junction boxes, bulkhead electrical outlets or switches. Look for loose connections or improper splices, which can create high resistance, and thus heat.

Evaluate the Electrical System

Evaluate the entire electrical system and determine if any jury-rigged repairs or additions to the system were performed. Questions that should be answered through the investigator's observations include:

- Is there an adequate number and proper placement of receptacles?
- Is there excessive or unsafe use of extension or drop cords?
- Are there cube or octopus adapters used in receptacles? And if so, are they overloaded?

Show calculations (Ohm's Law) that indicate the misuse or overloading of electrical circuits. This will assist in verifying your findings.

Although the misuse of an electrical system does not prove the fire was of electrical cause, such indications do help to reinforce the investigative efforts.

Dismantle and examine all wiring and receptacles at or near the point of origin of the fire. Look for evidence of arcing or overheating. Examine all of the involved branch circuits, including junction boxes, switches, outlets, power cords, and appliances along the entire circuit from the service panel to the termination of the branch circuit. This examination can assist with either validating the investigator's claims or eliminating electrical causes.

ELECTRIC WIRING MALFUNCTIONS

Clues and Causes

A single indicator of an electrical malfunction is not sufficient to classify a fire as electrical in cause. An indicator must be validated by proving the necessary physical cause and conditions were present. If indicators cannot be validated, the fire cause should not be determined as electrical.

The physical conditions in a fire scene which serve as clues may be created by a hostile fire of other than electrical origin. Although not absolutely necessary, there should be some circumstantial evidence to indicate that the fire occurred as a result of age or deterioration of the electrical system. Some examples of the circumstantial evidence needed are: the system or component parts were misused or misapplied; the system *or* its components were installed improperly; an accident occurred; or a defective product was involved.

Arcs and Sparks

There are several ways that arcs and sparks are produced. Some arcs are an unavoidable result of operating electrical equipment and switches. That small spark that is observed when a wall switch is turned on is actually an arc. Breakdowns, malfunctions, or damage in electrical systems or equipment also can cause arcs.

Static electricity, such as when a person scuffs their feet across a carpet and then touches another conducting object and causes a spark, is another example of arcing. Lightning is yet another form of a natural arc.

Temperatures that can be developed by arcs typically range from 2,000 ^{o} to 7,000^o F (1,093^o C to 3,871^o C). Arcing temperatures can cause metal objects, such as copper conductors, to melt and splatter hot particles over a wide area. When the hot particles come in contact with combustible materials, the potential for a fire exists.

Normal arcing occurs when a fire attacks energized electrical conductors and equipment. The presence of arc damage alone is not sufficient to determine that the fire caused by the arcing action. A competent fire investigator must have the ability to differentiate between fire-caused arcing and fire-originating arcing.

The following conditions are necessary to determine that normal arcing caused ignition:

- It can be proved that ignitable mixtures of air and flammable gases, vapors, or dust were in an electrical system, or that equipment was not designed for this type of atmosphere.
- The electrical equipment was energized and operating at the time of ignition.
- The fire scene has signs of a flash fire or explosion typical of the material ignited.
- All other sources of ignition have been ruled out.

Abnormal operations, failure, or damage to the electrical systems or equipment can produce abnormal arcs. Indicators of a fire caused by abnormal arcing are:

- Holes melted in metal enclosures for electrical equipment or wiring.
- Holes melted into the metal conduit or armor shielding of a BX cable, usually at the point of the arcing.
- Portions of electrical insulators in equipment destroyed or damaged in areas adjacent to normally energized parts, while other insulators are not damaged in the same manner.

- Electrical equipment dislodged or deformed in a manner not consistent with damage caused by the fire. This may be an indication of heavy current flow.

- Electrical cabinets bulged or distorted from internal pressure.

- Melted or beaded wiring not consistent with temperatures developed by the fire.

Conditions necessary for abnormal arcing and ignition to occur are:

- Some outside influence must be present to initiate arcing process, such as physical damage, water on live parts, or conductive objects coming in contact with live parts. The voltages present on normal residential small commercial electrical systems will not spontaneously begin arcing.

- The suspected circuit or equipment must be energized and there must be current flow. The current flow can be the result of normally operating equipment or appliances, or it may be the result of "leakage" or an unintended path to ground (ground fault) through a high-resistance medium (moisture, dirt, etc.).

- Low level or intermittent faults may not cause a fuse or circuit breaker to open. Under these conditions, sufficient heat generated can cause ignition.

- The arcing must occur in the area of origin of the fire with suitable combustibles present.

  Example: The hot particles scattered by an arc could ignite newspapers but are less likely to ignite framing lumber or wood flooring.

- Arcing must be of sufficient duration to ignite the suspected combustibles.

- All other sources of ignition have been eliminated.

Overheated Connections

Any time one conductor is connected to another conductor, or to the terminal on a piece of equipment, the potential has been created for excessive heat. When a connection is properly made, the materials involved must be compatible, clean, and held in firm contact with sufficient area of contact to provide a low resistance to the flow of electricity. The amount of heat generated in a proper contact will be very small. In a poorly made or deteriorated connection, normally safe and acceptable current flow over a long period of time in the circuit can cause the connection to become hot enough to ignite common combustibles, including the plastic wire insulation or twist-on connector.

NFPA 70, *National Electrical Code*, requires that all connections be enclosed in an approved junction box, cabinet, or terminal box, with covers in place, and unused openings effectively closed. The enclosure requirement serves several purposes: physical protection for the connections, separation of the connections from combustibles, limitation of oxygen and containment of overheated materials should a breakdown occur, and protection of live parts from accidental contact with other conductive materials.

An overheated connection may continue to deteriorate and become an arcing fault, or may ignite adjacent combustibles such as the plastic wire insulation, before it is noticed.

Contacting surfaces in a switch or fuse holder, when they are loose, is a potential source of heating in the same manner as an overheated connection.

Indicators of a fire caused by an overheated electrical connection are:

- The suspected electrical parts display indications of localized heating.

- Surfaces of the wires, terminals, or connectors are discolored, pitted, or eroded. In a good installation, these surfaces are protected from fire damage by the enclosure.

- Charring is deeper where the electrical enclosure was in contact with combustible supporting surfaces. Normally, an electrical box or piece of equipment will provide a degree of protection (protected area) from an external fire to the surface on which it is mounted.

- Portions or all of a connection are deteriorated while other connections in the same enclosure are intact or display exposure damage only.

- Localized pitting, erosion, or deterioration is observed at the point of origin in normally non-energized metal parts of the electrical system.

There are two conditions necessary for ignition from overheated electrical connections. First, current must be flowing at or through the suspected connection. This is not always obvious, as an unused receptacle may serve as a connecting point for a downstream load. The connection can be energized, but will not heat until current flows to operate an appliance/fixture, or a current flow is caused by a fault at or downstream from the suspected connector. Second, susceptible combustibles must be exposed to the suspected connections or enclosures.

Overheated Wires

Whenever electric current is flowing on a conductor heat is generated. The allowable current capacity of a wire is based on several factors: the temperature rating and type of wiring; the type of metal, the diameter of the wire; the number of conductors; and whether they are enclosed or in open air.

If the overcurrent protective devices are improperly sized for the circuit, malfunctioning, or defective in some manner, the potential for excessive current exists within the branch circuit.

Indicators of a fire caused by overheated wires are:

- Damage to the insulation from internal heating throughout the length of the circuit from the point of overload, or fault, all the way back to the overcurrent protective device. This will occur if the fault draws a significant amount of current (amps) above the rated capacity of the conductor prior to operation of the overcurrent protective device.

- Indications of internal heating are loose (sleeving), sagging, swollen, or charred insulation along the entire length of the branch circuit. The legitimacy of a fault in this branch circuitry initiating the fire is greatly enhanced if other branch circuits in the immediate vicinity do not exhibit similar damage.

- Defective, tampered-with, modified, or improper fuses or circuit breakers serving the suspected circuit may contribute to the overheating and subsequent failure of the insulation.

- Multiple points of origin which occur along the suspected circuit.

- Charring inside holes where the suspected circuit passes through or comes in contact with wood structural members.

In order to have overheated wire ignition, the following conditions are necessary:

- a flow of current in the suspected conductor;
- an overload or fault condition which allowed excessive current flow; and
- a suitable combustible present at the point of origin.

Effects on Wires from Electrical Malfunctions

Whenever arcing occurs on wires, there will be characteristic marks left at the point of arcing. Arc marks can be distinguished from mechanical marks and fire melting. An arc mark is a distinct spot, but there may be multiple arc marks close together. The mark is an area where the metal has been melted. It may be a smooth cavity or a cavity with a projection. Sometimes, the small cavity will be rough with numerous small projections. Next to the arc mark, the surface of the wire will not be melted. However, there may be some splatter of melted metal onto the nearby surface if the wire was bare at the time of the arc. Arcs can leave cavities in wires or they can sever wires. The ends of severed wires may be smoothly melted or beaded.

Arcs are generally similar, whether in copper or aluminum wires. However, arcing in aluminum wire may leave only melted globs of aluminum rather than the characteristics found in copper wire.

Arcing in twisted, copper strand wire, commonly found in lamp cord or extension cords, will usually cause beading at the point of separation, rather than cavities.

Arcing that occurs within a junction box or other metal enclosure will frequently leave small droplets of metal around the interior of the box.

External Heat Impingement

When external heat impingement on the wire has occurred, fire melting can usually be distinguished from are marks because the fire affects a wider area. Fire melting of copper wire gives a graduation from light oxidation to distortion of the surface, to blistering, to flow of metal. Under some conditions, the flow of melted copper leaves a smooth surface with thin necks, beads, and a pointed end. This is sometimes referred to as "icicling".

It is characteristic of copper wire to melt on the surface and have an un-melted core. Fire melting of copper wire will be a function of the duration of the fire, the location of the wire, and the protection of the wire.

Caution must be exercised by the investigator, as fire can cause arcing of electrical wiring. This arcing in the fire can continue to destroy electric wire from the original point of the fire-induced arc back toward the power supply. This arcing may not activate circuit protecting devices. Again, caution must be exercised as this arcing or melting can mistakenly be taken to be the cause of the fire rather than a consequence of the fire.

Aluminum wiring will behave differently from copper wire during fire melting. Aluminum will sometimes drop off sharply because it melts throughout the entire conductor, instead of having an un-melted core.

Fire can obliterate arc marks, or any other characteristic effects that were present at the start of the fire. Failure to find characteristic marks in fire melted wires does not necessarily mean that no arcing occurred. This is especially a problem with aluminum wiring because it melts at such a relatively low temperature.

Overheating or Overcurrent Conditions

When greatly excessive current (overcurrent) melts a wire, it tends to melt all through and along the wire at the same time. When the wire finally separates, current stops and the wire cools. Often, there will be offsets where the wire began to fall apart when the current stopped. This effect can be found in copper, aluminum, or any other kind of wire.

When evidence of overcurrent is found (offsets, sleeving, or heated insulation on non-fire areas), fuses or circuit breakers need to be examined. Arc marks may indicate that the circuit was energized prior to and during the fire. Small isolated arcs are not likely to start fires unless a very easily ignitable fuel is present. Massive arcs, such as occur in service equipment, can easily ignite fires.

Mechanical marks or gouges in wires can usually be distinguished by shape or by lines of scraping. A wire that is gouged by a nail, saw, or some other means, but is not severed, will not create enough heat to cause a fire at allowable amperage, assuming that a short or ground fault is not created.

Recent Development -- Harmonic Imbalance

The most recent development in electrical fire cause is the discovery of an overheating situation created by an electronic phenomenon known as harmonic imbalance.

This situation has been observed in office buildings ashore where electronic office equipment such as computers, facsimile machines, copiers, etc., are used, or where electronic ballasts are used in fluorescent lighting. Another location for fires resulting from harmonic imbalance can be manufacturing plants that use variable-speed, three-phase motors. Since modern ships use much of the same electronic office equipment found in offices ashore, investigators should be aware of this phenomenon.

Electrical fires seldom start in undamaged, uninterrupted runs of wire. Fires often do start in damaged wires.

What is harmonic imbalance? Most electricity that feeds power to office equipment or small motors is 120-volt service, operating at 60 cycles per second, and is alternating current (AC). Once this current enters the equipment, it passes through a converter that changes the current to direct current (DC). This is done so that the electronic components, such as capacitors, diodes, resistors, etc., within the electronic equipment can operate properly. As we learned earlier, in an AC circuit, current enters the circuit on the "hot" wire and returns on the "neutral" wire. With DC there is no neutral wire and when the direct current is converted back to alternating current, the excess current causes overheating.

Electric circuits in North America operate on 60 cycles (or megahertz) per second. These cycles form a sine wave that can be observed on a an oscilloscope. If this 60·eycle sine wave remains constant, the harmonics are in balance. The excess current that occurs from the use of modern office equipment gives an erratic sine wave, thus causing a harmonic imbalance.

This harmonic imbalance can cause transformers and/or neutral phase conductors to overheat and create a fire situation if the overcurrent protection devices do not activate. When a harmonic imbalance occurs with the operation of three- phase, variable-speed electric motors, it can cause the motors to burn out.

Harmonic Imbalance

If a fire resulting from harmonic imbalance is suspected, ask the following questions:

1. Have there been previous problems with unexplained tripping of circuit breakers?
2. Have there been complaints of "burning or overheating odors"?
3. Have there been recent problems with the equipment itself?

Obtain the assistance of a qualified marine electrician or electrical engineer to verify your determination. Tools and formulas can verify the fact that a harmonic imbalance has occurred, but it is best to seek the help of a professional to corroborate your findings**.**

SUMMARY

Major causes of accidental fire include heating equipment, cooking equipment, smoking, flammable/ combustible liquids, fuel gases, open flames/sparks, spontaneous heating, low-temperature ignition, lightning, and electrical failure.

Fire cause determination requires identification of the device or equipment involved, the presence of a competent ignition source, the type and form of material first ignited, and the circumstances or actions that brought all factors together.

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