CANNEY BROOK FORENSIC ENGINEERS

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# FIRE FORENSICS: METHODOLOGY AND HYPOTHESIS TESTING

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# FIRE INVESTIGATOR EXPERIENCE

- Registered Professional Engineer, PE  - Mech, H&V 1981
- BS Mechanical Engineering
  - Thermodynamics, Heat Transfer, Fluid Dynamics, Materials Science
- MS Architectural Engineering
  - Convection, Conduction, Radiation, Boiling and Condensation
  - Building Systems
- 30+ Years Combustion, Heat Transfer and Fluid Dynamics Professional Experience
- Certified Fire and Explosion Investigator & Instructor

# WHAT IS FORENSIC FIRE SCIENCE?

- Oxidation.
- Forms of energy.
- Role of heat energy in chemical reactions.
- Heat of combustion and ignition temperature.
- Exothermic v. endothermic chemical reaction.
- Oxidation of iron to rust.
- Requirements for initiating combustion.

- Detection and identification of hydrocarbons and fire residue.
- Collection of physical evidence.
- Collection of non-physical evidence (witnesses knowledge, materials science, fire dynamics data)
- Construction of reasonable hypotheses
- Testing of constructed hypotheses
- Formulate objective opinion based on science not conjecture

# TERMS TO KNOW

- **Energy:** the combined ability or potential of a system or material to do work.
  - dissipated = heat
  - stored = chemical, electrical, potential, and kinetic
- **Heat of combustion:** the heat evolved when a substance is rapidly oxidized [burned in oxygen].
- **Autoignition:** Combustion initiated by temperature without a flame

* **Exothermic reaction:** a chemical transformation in which heat energy is liberated.
* **Endothermic reaction:** a chemical transformation in which heat energy is absorbed from the surroundings.
* **Ignition temperature:** the minimum temperature at which a fuel will spontaneously ignite.
* **Flash point:** the minimum temperature at which a liquid fuel will produce enough vapor to burn.
* **Pyrolysis:** the decomposition of organic matter by heat into flammable gases.

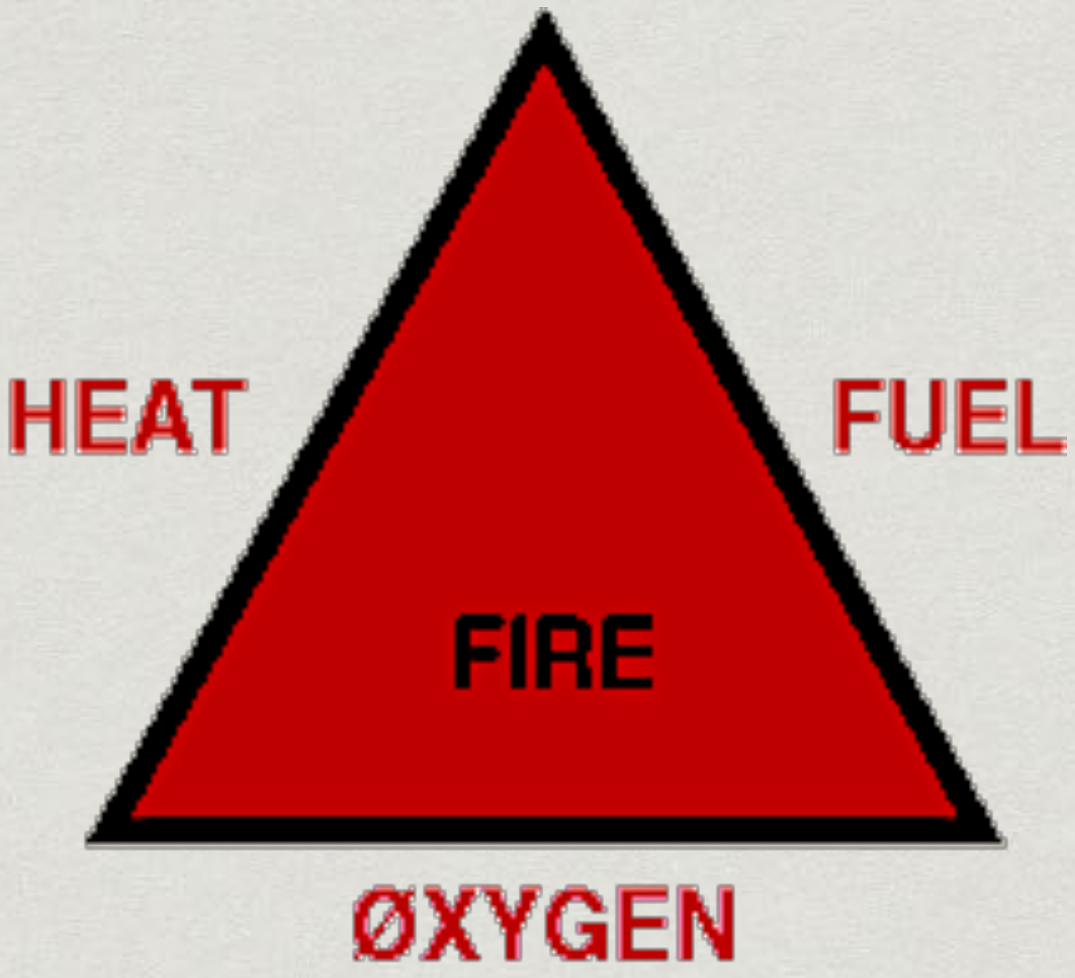
- **Flammable range:** the entire range of possible gas or vapor fuel concentrations in air that are capable of burning.
- **Glowing combustion:** burning at the fuel-air-interface. Examples are a red-hot charcoal or a burning cigarette.
- **Spontaneous combustion:** a fire caused by a natural heat-producing process in the presence of sufficient air and fuel.
- **Oxidizing agent:** a substance that supplies oxygen to a chemical reaction (air).
- **Accelerant:** any material used to start or sustain a fire. The most common accelerants are combustible liquids.

- **Hydrocarbon:** a compound consisting of carbon and hydrogen.
- **Explosion:** a chemical or mechanical action resulting in the rapid expansion of gasses ($1^{st}$ and $2^{nd}$ Order).
- **Deflagration:** a very rapid oxidation reaction accompanied by the generation of a low-intensity pressure wave that can have a disruptive effect on the surroundings.
- **Detonation:** an extremely rapid oxidation reaction accompanied by a violent disruptive effect and an intense, high-speed shock wave.

# THE FIRE TRIANGLE

# FOR COMBUSTION TO BE INITIATED AND SUSTAINED:

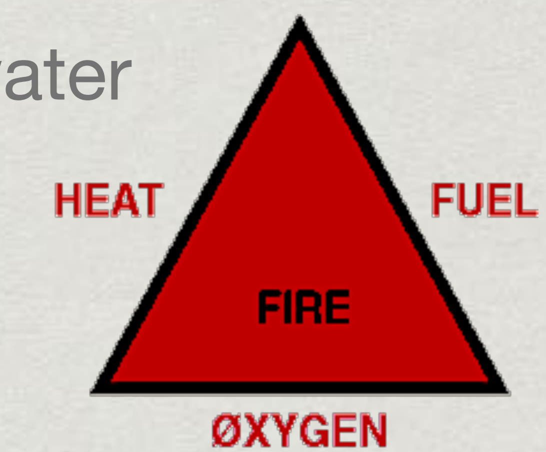
- Fuel must be present.
- Oxygen must be available in sufficient quantity.
- Heat must be available to initiate and generated in sufficient quantities to sustain the combustion



# FIRE IS OXIDATION

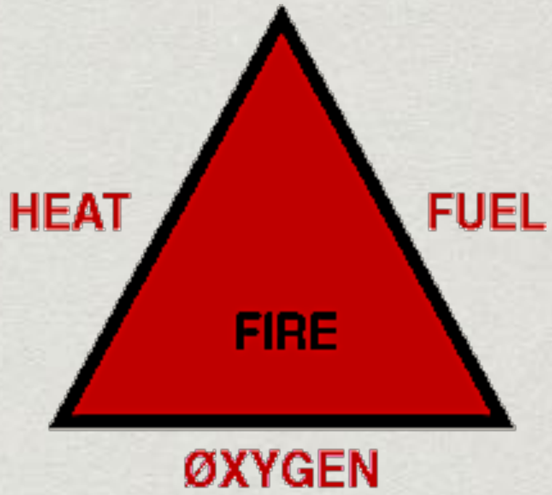
- A *transformation* process during which oxygen is united with some other substance to produce noticeable quantities of heat and light (a flame).
- Oxidation is a fundamental chemical reaction of fire:
  - the combination of oxygen with other substances to produce new substances.
- Example: burning of methane gas:

| | | | | | | |
|---|---|---|---|---|---|---|
| $CH_4$ | + | $2O_2$ | $\rightarrow$ | $CO_2$ | + | $2H_2O$ |
| Methane | | Oxygen | | Carbon dioxide | | water |



# FUEL

- Organic Fuels (most common)
    - wood & paper
    - petroleum products & fossil fuels
- Most important attribute of any fuel:
    - energy stored in the bonds of the molecule
    - with proper "encouragement" bonds are broken releasing this energy
    - exothermic combustion reaction
- ***Combustion:***
    - the **rapid** combination of oxygen with another substance accompanied by the production of noticeable heat and light.
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
    - releases 51.6 kJ/gram fuel



# ACTIVATION ENERGY-OXIDATION

- All reactions require an initial input of energy to start them.
- Activation Energy: the energy barrier that must be surmounted before any bonds can be broken.
  - applied in the form of **heat** (flame, temperature, electrical discharge, spark
- Low energy reactions:
  - iron to rust: the energy in the environment is sufficient.
- High energy reactions:
  - Wood to carbon dioxide & water.
  - Temperature must exceed ignition temperature *(minimum temperature at which a fuel will ignite).*

# FORMS

# IGNITION ENERGY

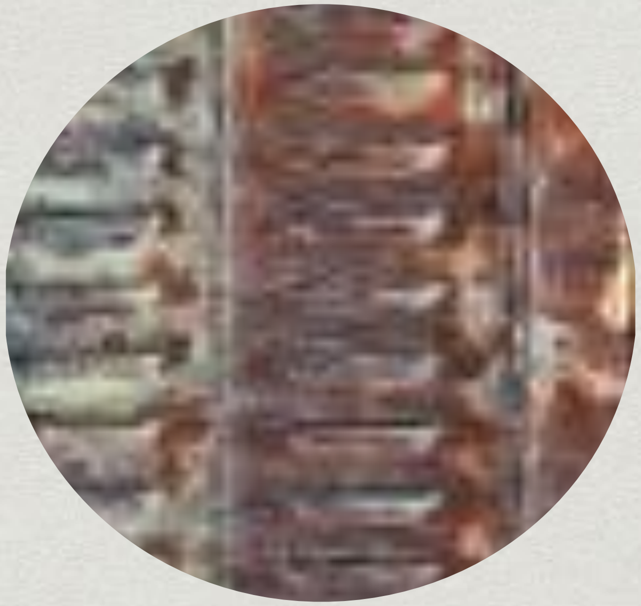
- ***Spontaneous combustion*** is rare:
  - For a material to spontaneously burst into flames, it must be continually generating heat in a poorly-ventilated area
  - Barn filled with wet hay - bacteria produces heat as a metabolism by-product which is not dissipated from center of stack
  - Auto-ignition temperature reached
  - May smolder for days even weeks prior to erruption

# SLOW VS RAPID OXIDATION

- Slow oxidation reactions result in structural failures not fire
  - Rusting
  - Rotting
  - Metabolism
- Medium to high rates of oxidation generate sufficient heat for combustion and fire
  - deflagrate=to burn rapidly with intense heat and sparks being given off

# RATE OF REACTION

- The conversion of iron to rust is an example of an extremely slow oxidation process, a situation that exists because of the inability of the iron atoms to achieve a gaseous state.
- Therefore, the combination of oxygen with iron to produce rust is restricted to the surface area of the metal exposed to the air, which severely reduces the rate of reaction.
- The reaction of methane and oxygen is one where all the reactants are in the gaseous state → rapid reaction.



# RATE OF REACTION

- The rate of reaction increases when the temp is raised.  For most reactions, a $10^0$C ($18^0$F) rise in temp doubles or triples the reaction rate.
- Burning is so rapid because as the fire spreads, it raises the temp of the fuel-air mixture, increasing the rate of reaction.  This in turn generates more heat, again increasing the rate of reaction.
- When either fuel or oxygen becomes depleted the cycle stops.

# HOW ARE FLAMES PRODUCED?

- Molecules of fuel must be in the **gaseous** state to produce a flame.
  - iron atoms are unable to achieve a gaseous state → rust
- Molecules of fuel must be mixed with a sufficient quantity of air for the reaction to sustain itself.
- Liquid fuels must be vaporized before they can burn.
  - the higher the temp the more molecules are converted to the gaseous state

# FLASH POINT

- ***Flash Point:***
  - The minimum temperature at which a flammable liquid gives off sufficient vapor to support a flame.
- The presence of vapor is necessary but not sufficient for ignition.
  - Fuel vapor must combine in proper proportions with oxygen-containing air (the *flammable range* for gasoline is 1.3 to 6.0 percent).
- Volatile liquids require a low temp to vaporize some molecules.

# IGNITION TEMPERATURE

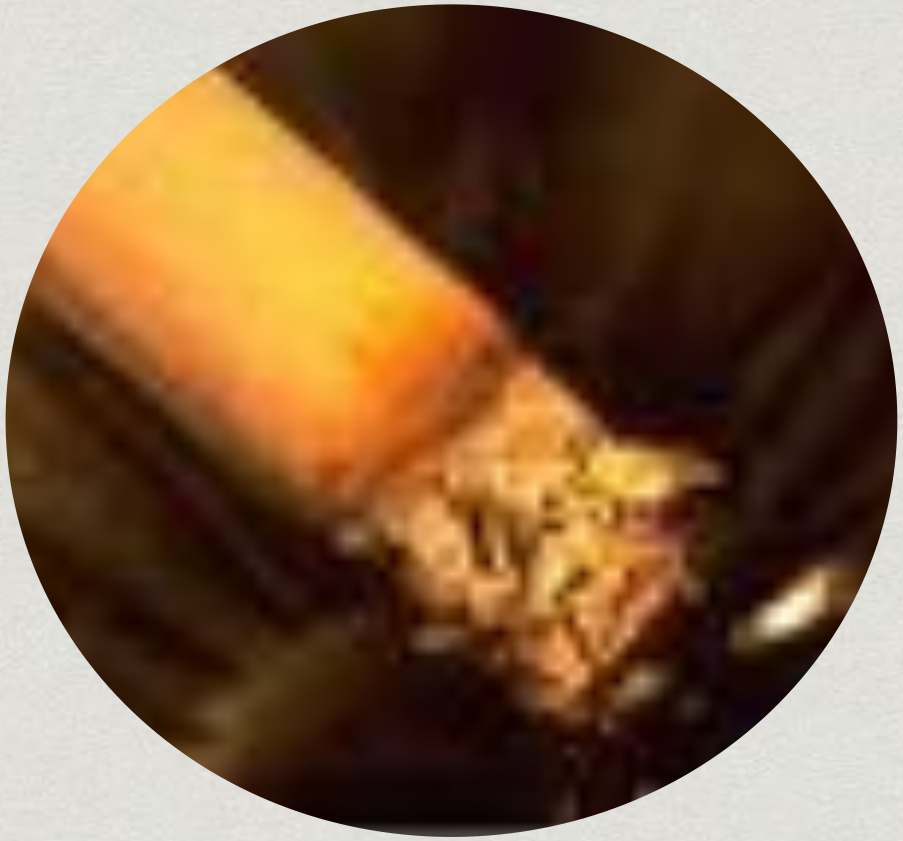
- The temperature which inputs sufficient energy to surmount the activation energy
- Ignition temp is always considerably higher than the flash point
- Example: gasoline
  - flash point: -50$^{o}$F
    - defines the temp which the bulk of the liquid must reach to produce vapor
  - ignition temp: 495$^{o}$F
    - temp required to start gasoline burning

# PYROLYSIS

- To produce a flame from a burning solid, molecules at the surface of the solid must be transformed directly to a gas.
- Heat can decompose complex molecules (wood) into smaller, more volatile molecules: ***pyrolysis.***
- Decomposition products react with oxygen.

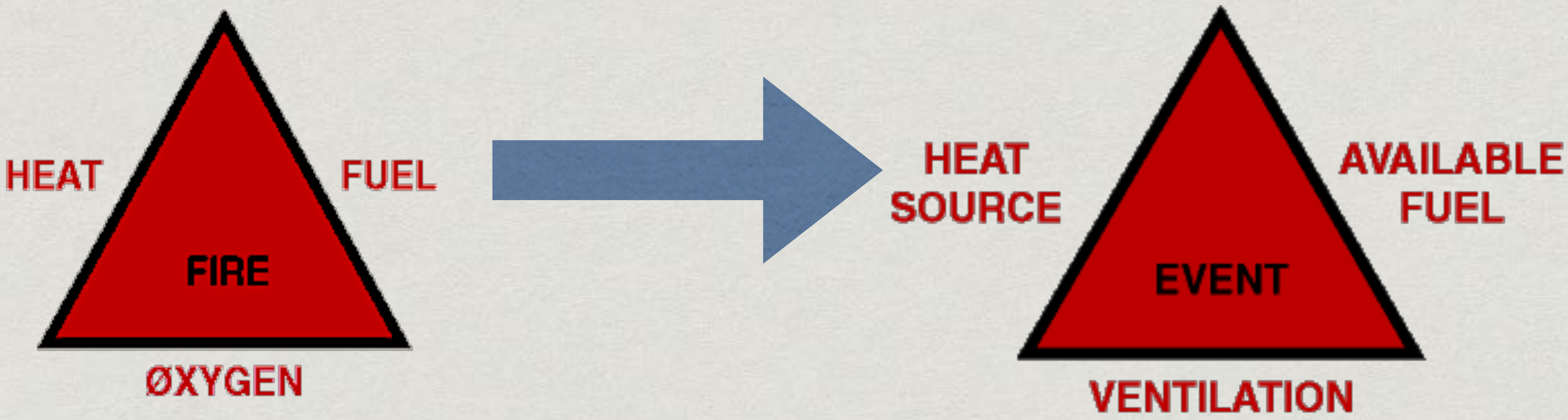
# SMOLDERING
## (OR GLOWING COMBUSTION)

- In some instances, a fuel can burn without the presence of a flame.
  - burning cigarette
  - smoldering embers
- Combustion is taking place on the surface of a solid fuel in the absence of heat high enough to pyrolize the fuel.
- Fresh source of oxygen will re-ignite the flaming reaction if pyrolizable fuel is present.



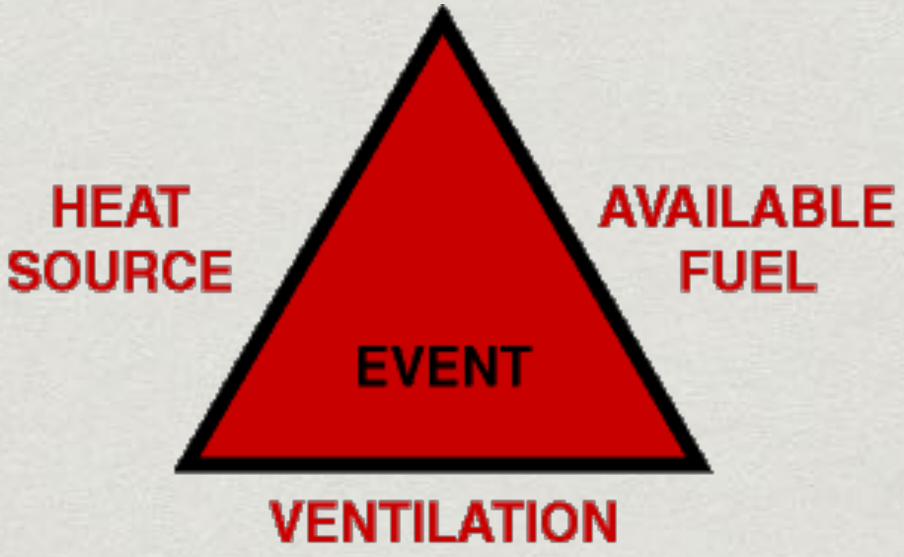
# THE FIRE INVESTIGATION

Fire Dynamics



# QUESTIONS TO BE ASKED:

- What was the heat source?
- What was the fuel?
- What provided the oxygen supply?
- What was the fire's point of origin ?
    - Provide evidence of first ignition and flame, spark, heat source.
    - Accidental, intentional, negligence, reckless act.



# FIRE PATTERNS

- **V-pattern:** indicates spreading from ignited fuel, may provide evidence of origin as fire travels upward
- **Ribbon pattern:** fire follows the path of ignitable fluid
- **Hot spots:** location of highly flammable materials

# FIRE INVESTIGATION

- What's the Legal Question?
  - "Did someone purposefully set the fire, and if so, who?"
  - Did someone (other than insured) accidentally cause or contribute to the fire's ignition, or contribute to the fire's spread.
  - What were the abnormal events

# EVIDENCE:

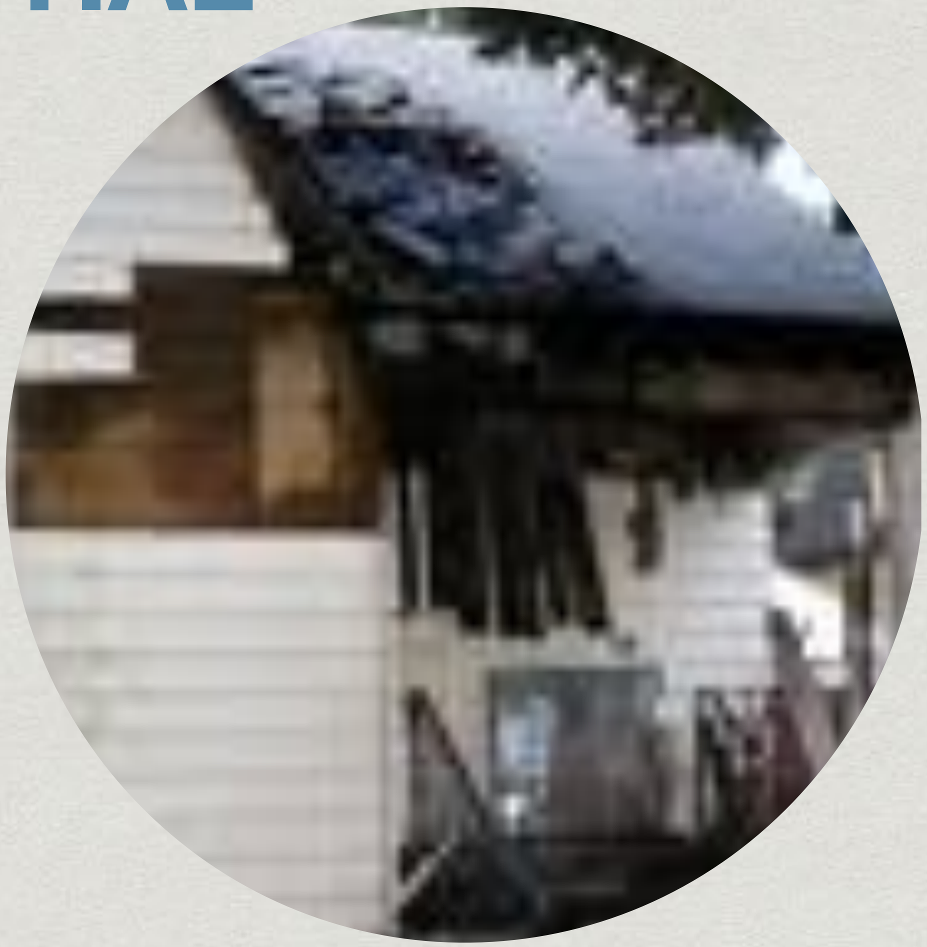
- Oxygen is abundant within the atmosphere – may become limited within confined spaces progression of fire may follow oxygen supply

- Fuel is usually fairly obvious, however so building materials may not support combustion while similar looking materials may be highly flammable.
- Ignition source often not obvious.

# ORIGIN AND RESPONSIBILITY?

- Evidence of an ignition:
    - Device - match, cigarette, firearms, ammunition, mechanical and heating equipment, electrical wiring & equipment, plumbers torch.
    - External – lighting strike, utility power surge

# MANAGING EVIDENCE- INITIAL INVESTIGATION



- Evidence must indicate a area of origin and cause which may be attributed to the actions of one or more individuals.
- Insured actions must be considered to determine possible culpability.
- Third party actions must be considered to determine possible culpability

# MANAGING EVIDENCE - JOINT INVESTIGATION

- Detailed fire investigation
- Spoliation – Exclusion of critical evidence
- Notice all identified possible responsible parties.
- Collection of evidence – minimal destruction
- Develop protocols for destructive testing after evidence collection

# COLLECTING EVIDENCE

- Evidence containing volatiles should be collected in airtight, solvent-resistant metal containers.
- Small evidence should be bagged and tagged
- Larger evidence tagged and preserved

# NFPA 921 GUIDE FOR FIRE AND EXPLOSION INVESTIGATIONS

- Published by National Fire Protection Association
- Approved as an American National Standard
- Serves as the ‘legal standard”
- NFPA 1033 – Standard for Competency

# BASIC METHODOLOGY

- Fire Investigations are complex endeavors involving skill, technology, knowledge, and science.
- Compilation of factual data and analysis of that data should be accomplished objectively and truthfully.
- Systematic approach and attention to relevant details

# BASIC METHODOLOGY

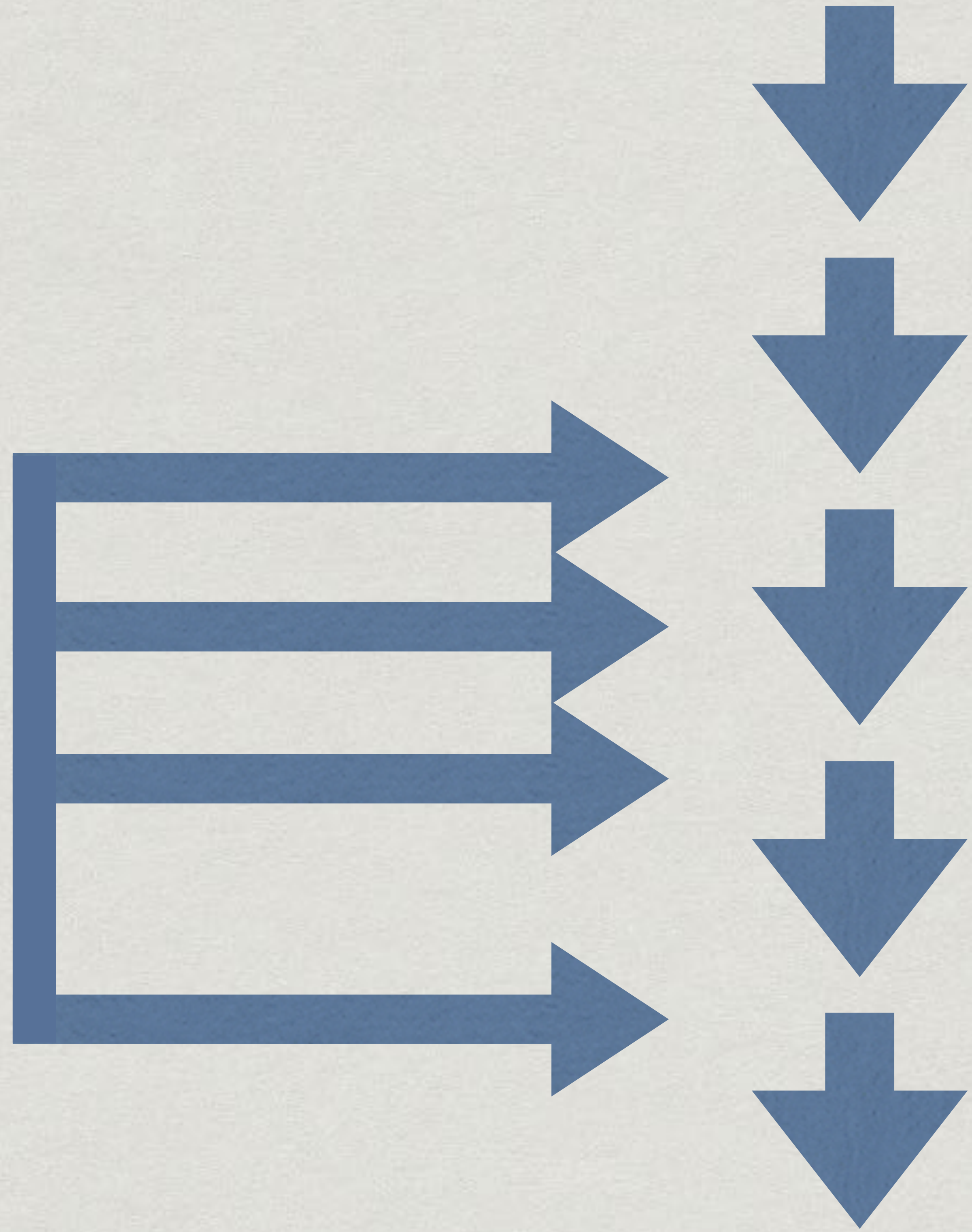
- With few exception, proper methodology is first to determine and establish the origin(s), then investigate the cause: circumstances, conditions, or agencies which brought together ignition, fuel, and oxidizers.

# SYSTEMATIC APPROACH

- The systematic approach recommended is that of the scientific method, which is used in the physical sciences.
- The “Scientific Method” provides the organizational and analytical process desirable and necessary for a successful fire investigation

# SCIENTIFIC METHOD

Recognize the need
Identify the problem
Define the problem
Collect data
Analyze the data
Develop a hypothesis
(inductive reasoning)
Test the hypothesis
Select final hypothesis



# RECOGNIZE THE NEED

- A fire or explosion has occurred a cause should be determined so that:
  - Future similar events may be avoided
  - Responsible party may be held responsibility for loss or injury

# PROBLEM – FIRE OCCURRED

* Conduct proper “Origin and Cause” investigation
  * Examination of Scene
  * Review prior scene investigations
  * Interview witnesses and other knowledgeable persons
  * Results of scientific testing

# EMPIRICAL DATA COLLECTION

- Facts based on observation or experience capable of being verified
- Facts about fire scene collected by:
  - Observation
  - Experiment

# ANALYZE THE DATA

- Collected data must be analyzed & challenged
- Collecting, gathering, cataloging of data is not equate to data analysis
- Analysis is based on individual's
  - Knowledge
  - Training
  - Experience
  - Expertise

# HYPOTHESES DEVELOPMENT INDUCTIVE REASONING

- Based on data analysis hypothesis are developed to explain the phenomena, origin location, fire patterns, fire spread, ignition sequence, fire cause, damage, responsibility for event.
- Hypothesis based solely on empirical data collected through observation and then developed into explanations for the event (based on investigator's knowledge, training, experience, and expertise)

# TESTING HYPOTHESES - DEDUCTIVE REASONING

- Provable hypothesis only if it can withstand the test of careful and serious challenge
- Deductive Reasoning requires the investigator to compare his hypothesis to all known facts as well as the body of scientific knowledge associated with the phenomenon relevant to the specific event.
- A hypothesis may be tested physically by conducting experiments or analytically by applying scientific principles in "though experiments."

# TESTING HYPOTHESES - DEDUCTIVE REASONING

- When relying on experiments or research of other, must insure the conditions and circumstances are sufficiently similar. Reliance of prior research should be disclosed.
- If the hypothesis cannot be supported it should be discarded and an alternate hypothesis developed. May include new data or re-analyzed existing data.
- Testing process continues until all feasible hypothesis have been tested and one is determined as uniquely consistent with the facts and principles of science.
- If no hypothesis can withstand an examination by deductive reasoning, the event should be considered undetermined.

# AVOID PRESUMPTION

- Until data has been collected, no specific hypothesis can be reasonable formed or tested.
- All fire and explosion events should be approached without presumption as to origin, ignition sequence, cause, fire spread, or responsibility until the scientific method has produced testable hypotheses

# EXPECTATION BIAS

- Well established phenomenon that occurs in scientific analysis when an investigator reaches a premature conclusion to early in the investigation and without considering all relevant data.
- Rather than collecting and examining data in a logical and unbiased manner to reach a scientifically reliable conclusion, a premature determination dictates the investigative process, analysis, to an unsound scientifically invalid conclusion.
- Bias relies on data that supports the previously formed conclusion and disregards data which does not support the conclusion.

# FIRE INVESTIGATION LEGAL CONSIDERATIONS

- Constitutional Considerations
- Authority to Conduct the Investigation
- Right of Entry
  - Consent
  - Exigent Circumstance – First Responders
  - Administrative Warrant – Allow those with a duty to investigate
  - Criminal Search Warrant – Government Agents

# EXPECTATION BIAS

- “There is an overwhelming sufficiency of the available information and evidence to support the conclusion that the fire was caused by failures, carelessness, and negligence of those two entities which allowed that potential ignition source (the unprotected chimney) to come into contact with a combustible material (the insulation).
- “There is overwhelming evidence to assess responsibility. All of the analysis and testing conducted of the hypothesis to support these conclusions, and other testing by other parties, validates the conclusion…

# TEST HYPOTHESIS

- Post-fire evidence – cellulose insulation did not ignite or burn
- Cellulose smothered only in contact with burning framing.
- Cellulose insulation contains boric acid to make the material a fire retardant and non-combustible
- MSDS – reports material is non-flammable, not combustible. Will decompose upon contact with extreme heat
- No reported auto-ignition temperature

# CELLULOSE PROTECTING FRAMING

# CELLULOSE – NO COMBUSTION

# HOUSE FIRE

# FIRE PLACE DEFECT

# WITNESS STATEMENT LIMITS

- Miranda Warnings – not generally applicable to non-governmental independent fire investigators unless evidence suggests criminal activity.
- Once a witness is represented by council, interviews may require approval of that council
- Some fire investigators advise other investigators not to speak with their client
- Early statements are desirable prior to statements and answers being rehearsed

# SPOILATION OF EVIDENCE

- Loss, destruction, or material alteration of an object or document that is evidence or potential evidence in a legal proceeding by one who has the responsibility for its preservation
- Occurs when the movement, change, or destruction of evidence or its alteration significantly impairs the opportunity of other interested parties to obtain the same evidentiary value as the prior investigator

# REMEDIES TO SPOLIATION

- May include discovery sanctions and monetary sanctions, application of evidence inferences, limitations under rules of evidence, exclusion of expert, and dismissal of claim

# NOTICE TO PARTIES

- Spoliation claims are minimized when notice is provided to all known interested parties, they be provided the opportunity to retain experts, and joint investigations are conducted.

**THANK YOU**

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