Presentation Start

What is an Explosion?

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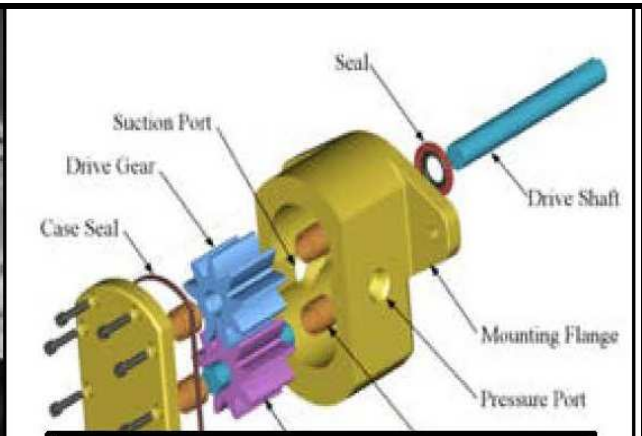
Problem Statement

- RCS community needs internally self-consistent language
  - Terminology not precisely defined leads to inappropriate and confusing code
    - Overly restrictive or worse not restrictive enough
    - Confusion over what is the hazard
    - What are the appropriate safety measures
    - Lead to exaggeration of a hazard causing damage to emerging technologies

What is an Explosion? Consider these -

Food Explosion

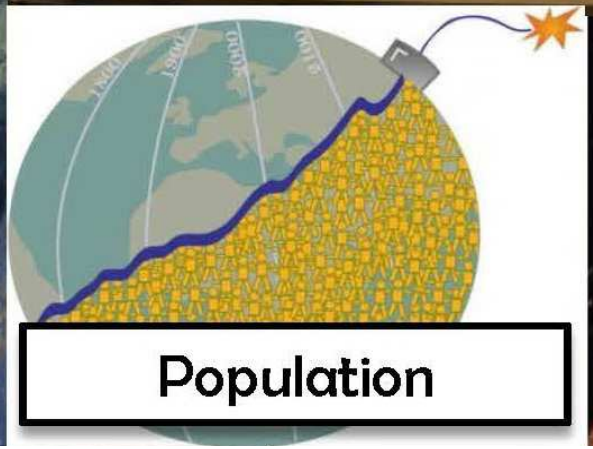
Blew my Mind



An "exploded" view

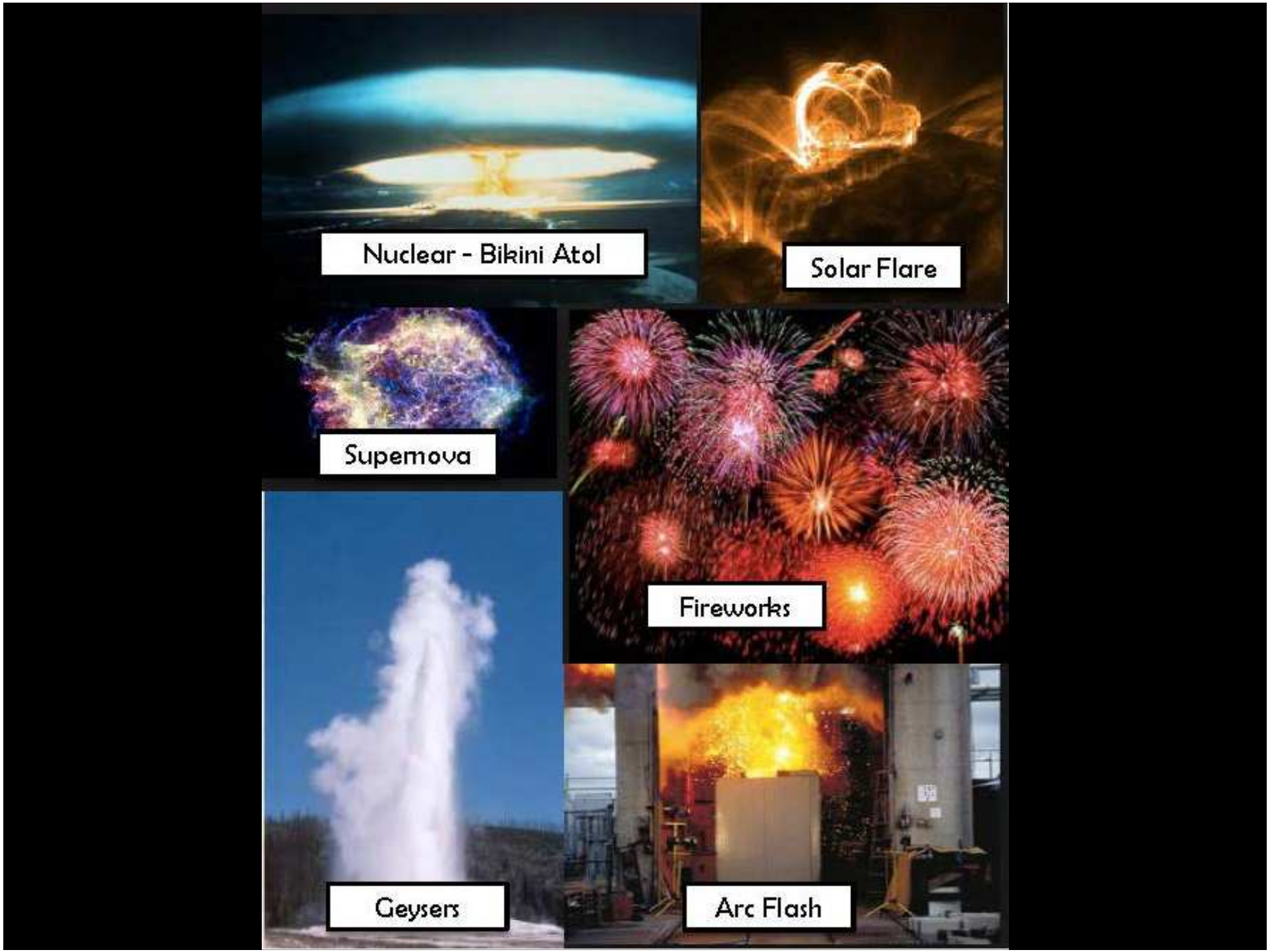
Tires

Please hold down the lid of
Salad Dressing while
"SHAKING".....
this prevents messy
"EXPLOSIONS".....



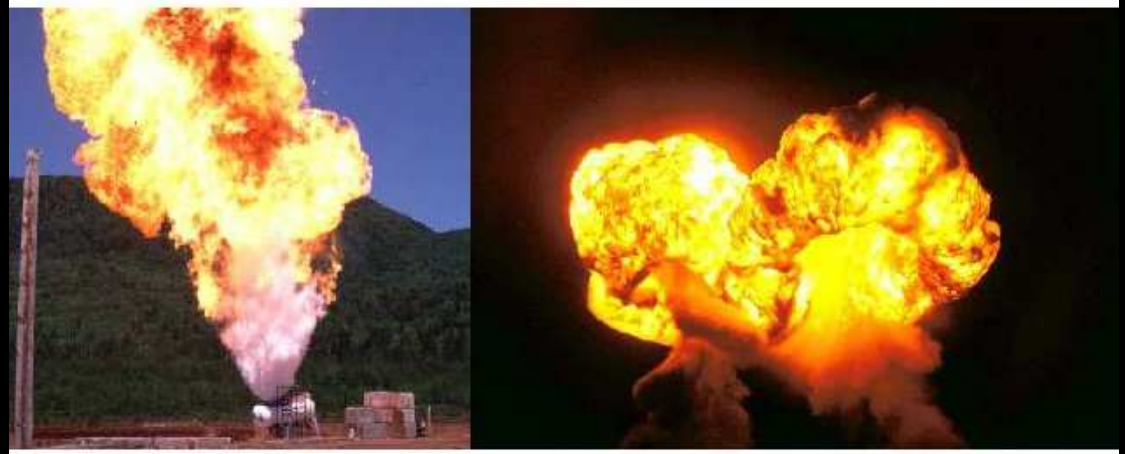
Population

Champagne

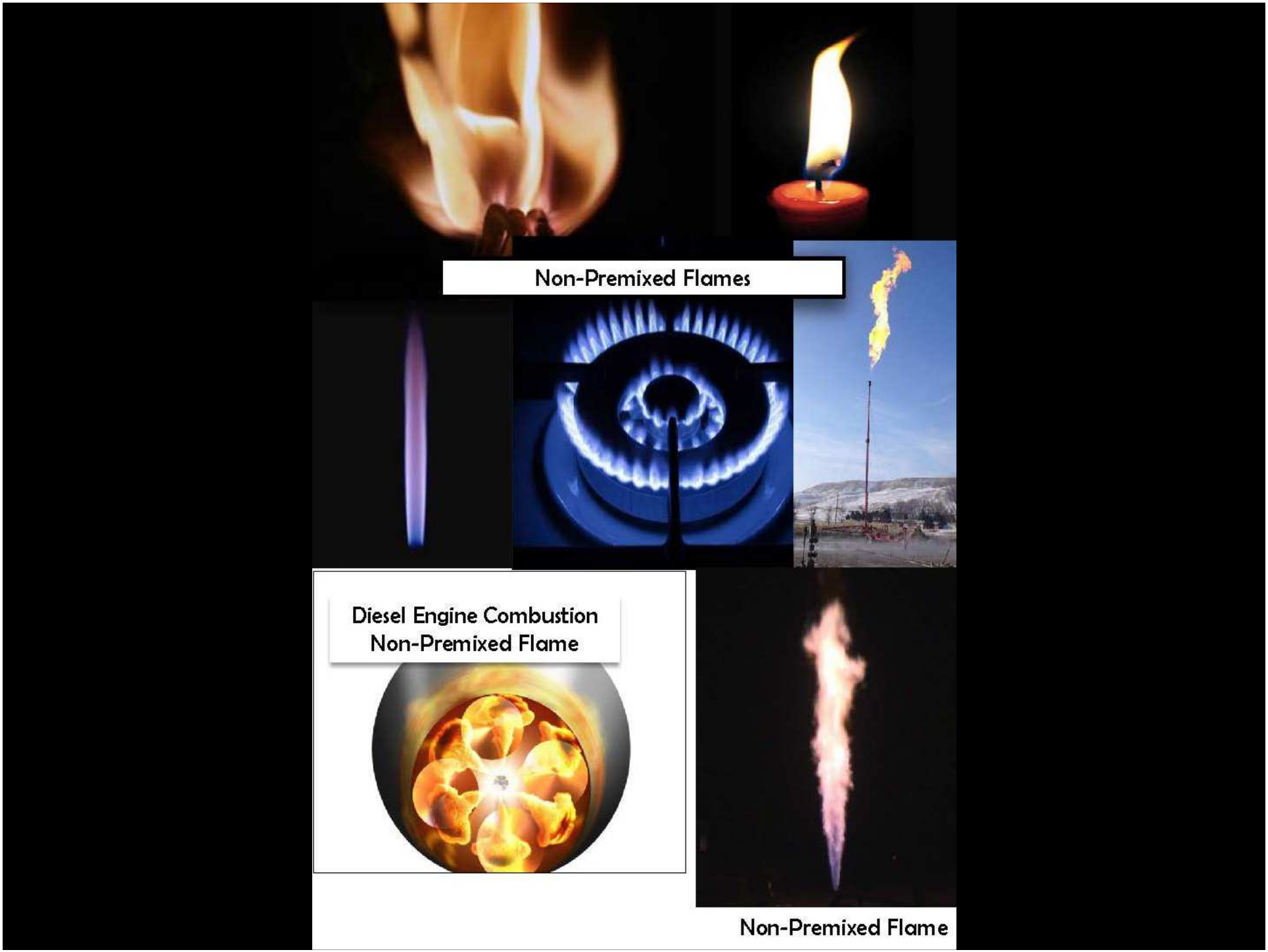

Nuclear - Bikini Atol
Solar Flare
Supernova
Fireworks
Geysers
Arc Flash

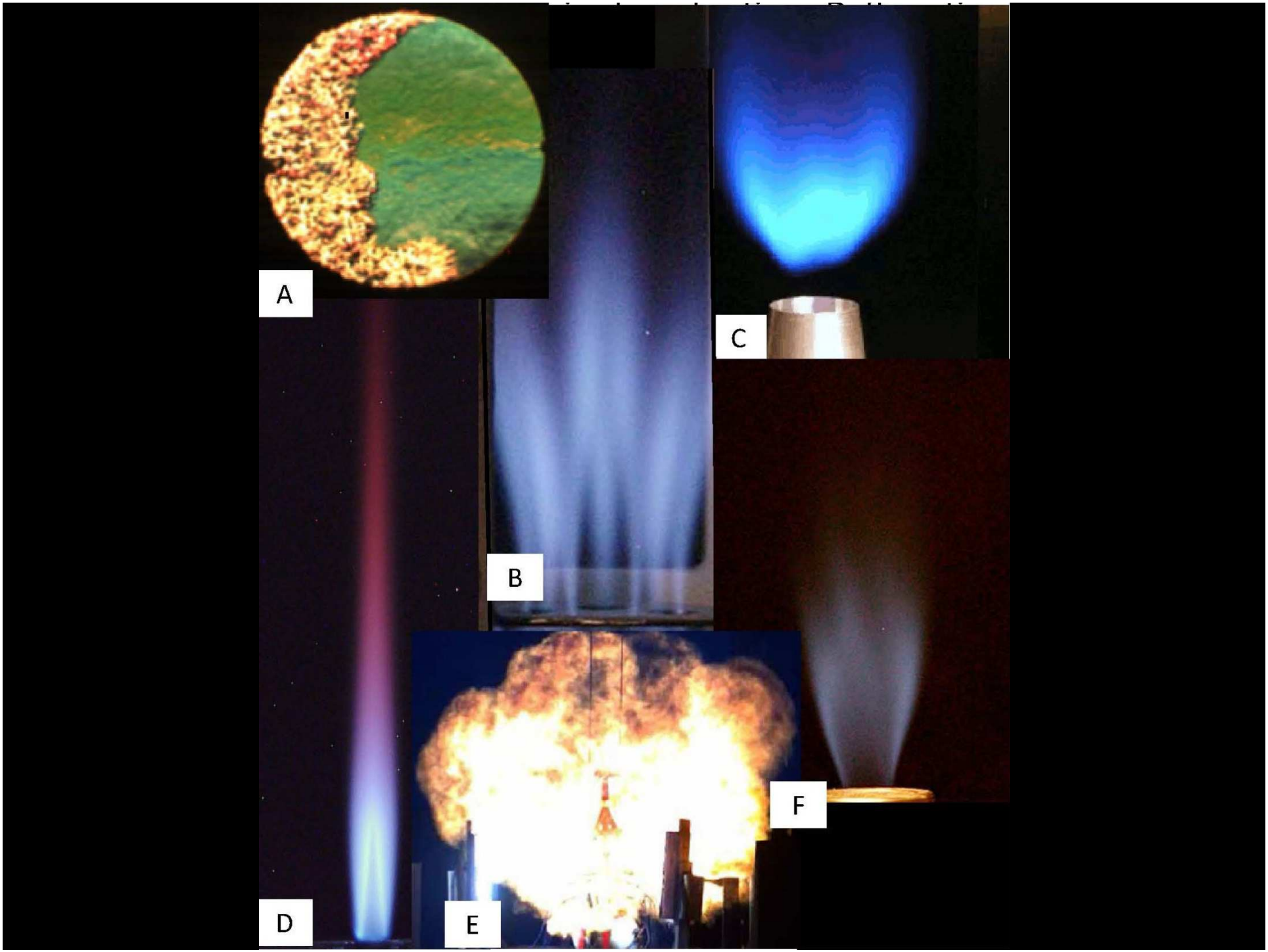
Boiler Tank catastrophic failure due to over pressure (no combustion)

Tank catastrophic failure due to over pressure (no combustion in side the tank)



Examples of BLEVE – Boiling Liquid Expanding Vapor Explosion. Top steam, bottom LPG


Non-Premixed Flames
Diesel Engine Combustion
Non-Premixed Flame
Non-Premixed Flame


A
B
C
D
E
F

Definitions from RCS Literature

- Explosion
  - A sudden increase of pressure and temperature, due to oxidation or other exothermic reaction (ISO/IEC CD 8079-38)
    - Includes – fast deflagration, detonation, audible noise
    - Excludes – slow deflagration, BLEVE, jet flames, non-combustion events
  - A rapid temperature and pressure rise resulting in an audible spherically propagating pressure wave (ISO/IEC CD 8079-38)
    - Includes – fast deflagration, detonation, audible noise, non-combustion events
    - Excludes – containment failure, BLEVE, slow deflagrations
  - The bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration (NFPA 69, Standard on Explosion Prevention Systems, 2008 Edition)
    - Includes only containment failure from a deflagration

Definitions from RCS Literature

- Explosion
  - Fast Combustion of a gas mixture releasing heat, hot combustion gases, and a shock wave. Explosions can be further subdivided into the two main cases of deflagration and detonation (ISO/PDTR 15916)
    - Includes – detonation, audible noise
    - Excludes – containment failure, BLEVE, deflagrations, non-combustion events
  - In contrast to burning in a fire, an explosion is essentially a self-sustained propagation of the reaction zone (flame) through the explosive atmosphere (EN 1127-1:2007)
    - Includes – detonations, deflagrations, audible noise
    - Excludes – containment failures, BLEVE, non-combustion events

Definitions from RCS Literature

- Explosive atmosphere
  - a mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour, mist or dust in which, after ignition, combustion spreads throughout the unconsumed mixture (ISO/IEC CD 80079-38)
- Explosion / Flammability limits
  - *(Explosion)* limits of explosion range (EN 1127-1:1997)
  - When the fuel vapor percentage is between the lower and upper flammable or explosive limits ignition will occur. And if the volume of fuel is significant (as in a house filled with natural gas) the ensuing ignition will have explosive consequences (Glenn Corbett Fire Engineering's Handbook with Firefighter I and II, Chapter 5 Fire Behavior, pg 79)
  - Lower (LFL) and upper (UFL) concentrations of fuel gas in a flammable mixture that will ignite and support a flame (ISO/PDTR 15916)
    - Note: no mention of explosion limits is provided in this reference.

Definitions from RCS Literature

- Deflagration
  - **Explosion** propagating at subsonic velocity (ISO/IEC CD 8079-38, EN 13237:2003, also references EN1127-1:1997)
    - Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium (NFPA 68)
  - **Explosion process** in which a flame or chemical reaction moves through a flammable mixture at a rate less than the speed of sound in the unburned mixture.
    - Note1: fast deflagrations are characterized by velocities in the hundreds of metres per second, where confinement causes elevated pressures, and their effects to not differ much from those of a detonation
    - Note 2: some deflagrations proceed so slowly that they do not produce any pressure wave: they should not be considered as explosions (ISO/PDTR 15916)

Definitions from RCS Literature

- Detonation
  - **Explosion** propagating at supersonic velocity and characterized by a shock wave (ISO/IEC CD 8079-38, also references ISO 8421-1:1987, 1.12, (EN13237:2003), also references EN1127-1:1997)
  - Propagation of a **combustion zone** at a velocity that is greater than the speed of sound in the unreacted medium (NFPA 68)
  - **Explosion** characterized by an exothermic chemical reaction coupled to a shock wave that propagates through a detonable mixture or medium.
    - Note1: The thermal energy of the reaction sustains the shock wave, and the shock wave compresses unreacted material, producing the high temperatures necessary to drive the reaction.
    - Note2: The detonation process is characterized by a propagation speed that is greater than the speed of sound in the unburned mixture (ISO/PDTR 15916)

Definitions from Combustion Literature

- Explosion
  - A runaway chemical reaction, one which the reaction rate increases with time. This can be caused by the chemical kinetic path way creating more radicals (chain branching) than it destroys (chain termination) or by a thermal process
- Explosive atmosphere
  - A mixture, temperature and pressure environment that supports a spontaneous explosion as defined here.

Definitions from Combustion Literature

- Explosion limits
  - Those values of temperature and pressure for a given **mixture** of reactants that bound the region where a spontaneous explosion can occur.
- Flammability limits
  - Those mixture limits for a given **pressure and temperature** which bound the region where a flame (deflagration and/or detonation) can occur (Combustion – Fourth Edition, Irvin Glassman, Richard A. Yetter, Copyright © 2008, Elsevier Inc., Chapter 3, Pp 96.)

*Given these definitions explosion limits are **not** flammability limits. Explosion limits are the pressure-temperature boundaries for a specific fuel-oxidizer mixture ratio that separate the regions of slow and fast reaction. For a given temperature and pressure, flammability limits specify the lean and rich fuel oxidizer mixture ratio beyond which no flame will propagate.*

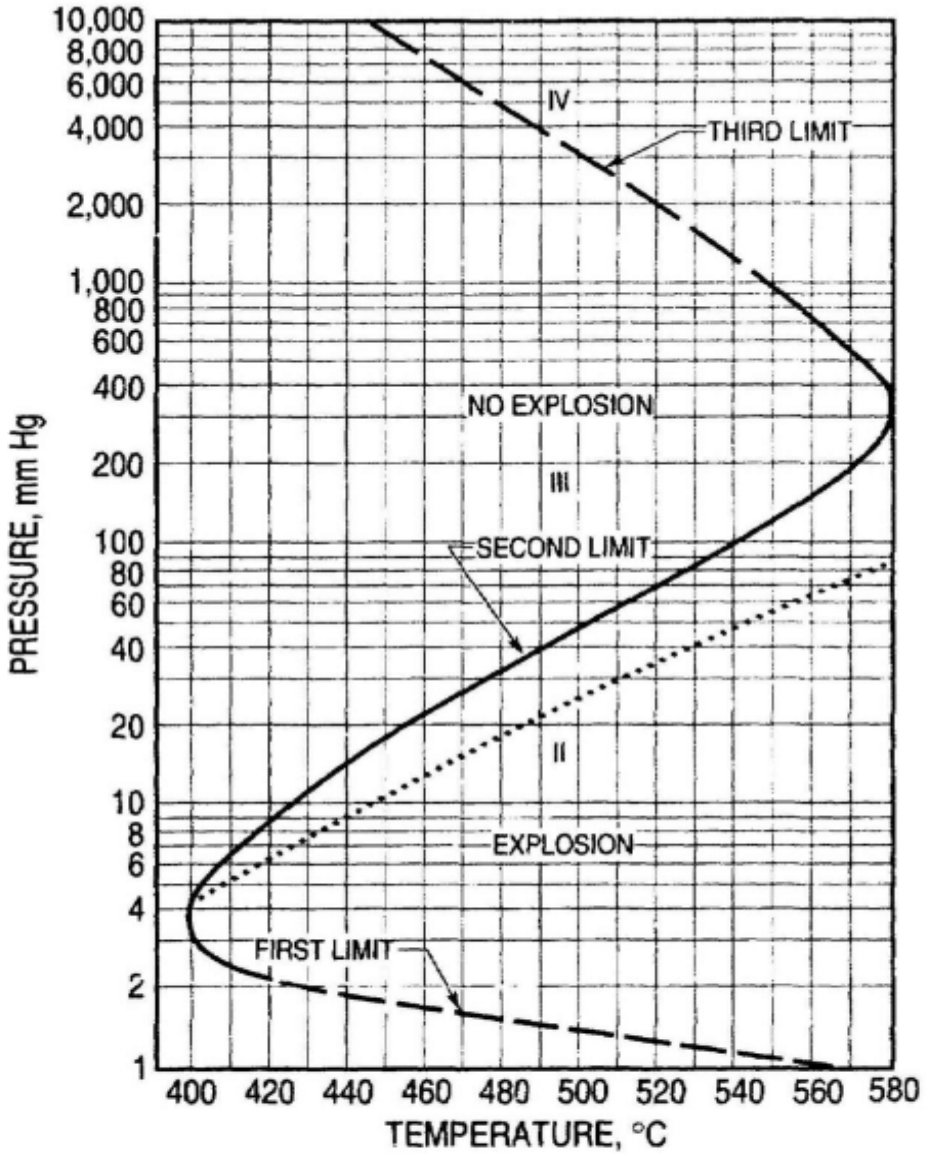


Figure 1. Explosion limits of stoichiometric H_2-O_2 mixture in a spherical KCl-coated vessel of 7.4 cm diameter. First and third limits are partly extrapolated. Dotted line defines condition where $2k_2 = k_{10}[M]$ in stoichiometric H_2-O_2. (From Ref. 3.)

"Flammability and Explosion Limits of H2 and H2/CO: A literature Review", N. Cohen, Aerospace Report No TR-92(2534)-1, 10 September 1992. Ref. 3 in Cohen is B. Lewis and G. von Elbe, Combustion, Flames, and Explosions of Gases, 3rd edn. (New York Academic Press, 1987), Ch. 2.

Definitions from Combustion Literature

- Deflagration
  - A subsonic propagating flame (thin reaction zone)
    - Negligible pressure difference across the reaction zone
    - Speed of propagation limited to the speed of sound in the unburnt reactants
- Detonation
  - A supersonic propagating flame (thin reaction zone)
    - Large pressure difference across the shock (10 to 20 times)

Note: Under the right conditions a deflagration can accelerate to a detonation. This is referred to as a deflagration to detonation transition (DDT)

What are we interested in?

- Consistent terminology
  - Place explosion in the context of hazards mitigation
  - "Explosion" is an event that once initiated grows rapidly and initially unbounded
    - This event lacks mechanisms to control its rate of growth and will grow unbounded until some external influence is applied – like consuming all the fuel
  - This presents a hazard as it can result in thermal (burns), shrapnel, and/or mechanical (overpressure) exposure to people and structures

What are we interested in?

- Consistent terminology
  - "Explosion" is an event that once initiated grows rapidly and initially unbounded
  - This now works for all examples in the societal sense
    - Population explosion, explosion of emotion, explosion of data …
  - This now works for large energy release
    - Cosmic stars, nuclear bombs, point source of stored chemical energy
  - This now works for combustion phenomenon (run away chemical kinetics)
    - Deflagrations, detonations, jet flames.

We propose the following definitions

- Explosion
  - A event that once initiated grows rapidly and initially unbounded
    - A combustion event that once initiated grows rapidly and initially unbounded until either fuel or oxidizer are fully consumed or nearly so (Cohen 1992)
- Explosive limits
  - those temperatures and pressures for a **given flammable mixture** that separate regions of slow and fast reactions. They bound the conditions where chemical kinetics are self-regulated from those conditions where kinetics accelerates unbounded.
- Flammability limits
  - the values of the concentration of a fuel and oxidizer for a **given pressure and temperature** that bound conditions for a flame to exist (both deflagrations and detonations).
  -

Hazards Mitigation

- Hazardous condition
  - a set of circumstances which may result in harm to people or damage to structures.
- Hazardous flammability limits
  - the value of the mean concentration for a given pressure and temperature that bound conditions which may grow into a hazardous condition, for example: a deflagration can transition to a detonation or the over pressurization a vessel, or a deflagration becomes rapid enough that will result in a significant overpressure, …
- Consider Hydrogen Air Combustion
  - Mixture fractions (X) < 4% are not flammable,
  - 4% < X < 8% will not grow into a hazardous condition
  - 8% < X will potentially propagate into a hazardous condition

Summary

- Shown ambiguity with the definitions
  - Inconsistent with society view
  - Used in the RCS community
  - Used in the RCS vs combustion communities
- Suggested an internally self-consistent set of definitions
- Defined hazards
  - Applied these notions to Hydrogen / Air flames

Path Forward

- Publish paper in peer reviewed journal
- Engage NFPA Technical Committees – Initial focus:
  - NFPA 2, Hydrogen Technologies Code
  - NFPA 68, Standard on Explosion Protection by Deflagration Venting
- Engage ISO Committees
- Engage International Fire Code – After NFPA documents

Presentation End