GUN & ELECTRIC WEAPON SYSTEMS DEPARTMENT (E)

Investigating a Proper Heating Rate for the Slow Heating Test Using Documented Incidents

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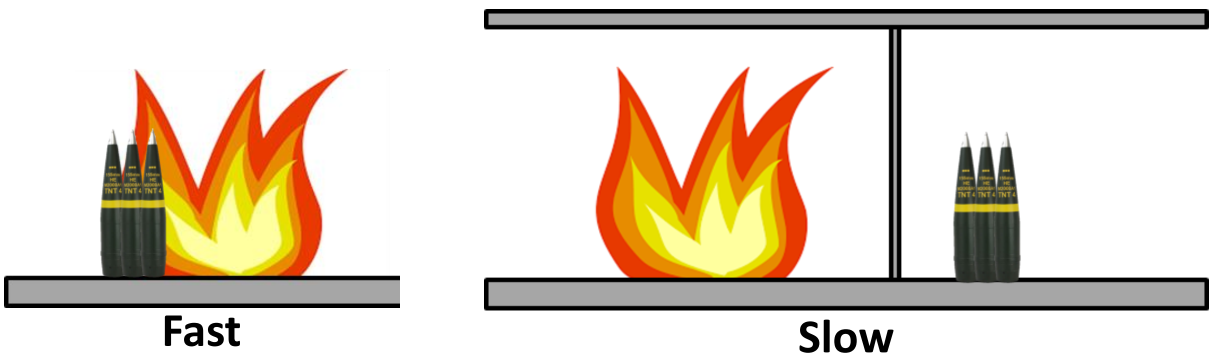
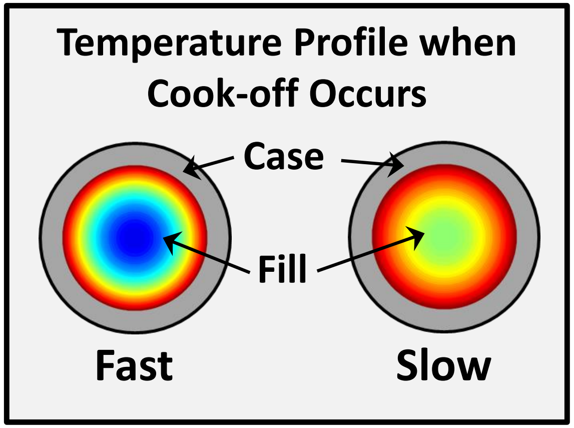
Background

- Hazard classification testing is performed to asses the potential reaction of Ammunition and Explosives (AE) to specified phenomenon
- One phenomenon studied is exposure to an external thermal stimulus
  - Heating an energetic item can cause it to react, or “cook-off”
  - The rate that the item is heated influences the violence of the reaction

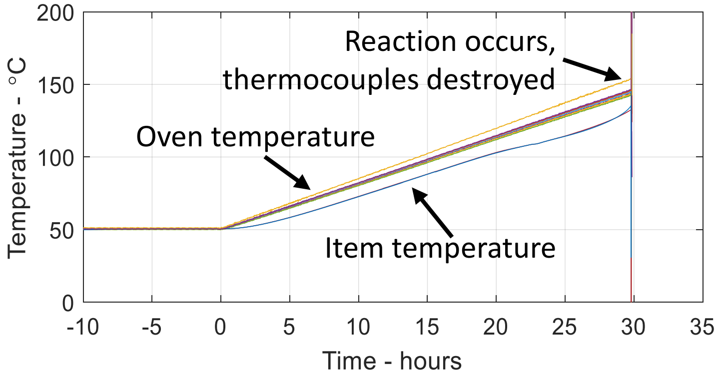




➢ **Slow heating often results in a severe reaction because the energetic fill is at a high average temperature when the cook-off occurs**

Background

- The Slow Heating Test is performed to simulate accident scenarios in which AE are slowly heated
- Typically, the test is performed by heating the AE in a disposable oven at a rate of 3.3°C/hr until it reacts



- Recently, the validity of the 3.3°C/hr rate has been questioned
  - Is it too slow to represent a realistic threat?
  - Concern that mitigations that are designed to work at 3.3°C/hr might not work at higher, more realistic rates

The SHCWG

- The Slow Heating Custodial Working Group (SHCWG) was formed to review the test standards that govern the slow cook-off test used for Insensitive Munitions testing
  - A key topic for the SHCWG – What should the heating rate be?
- At the first SHCWG meeting there was a general consensus that 3.3°C/hr was too slow but a new rate was not selected
  - This led the chairman of the group to request a thorough investigation be performed to guide the discussion towards realistic threat scenarios

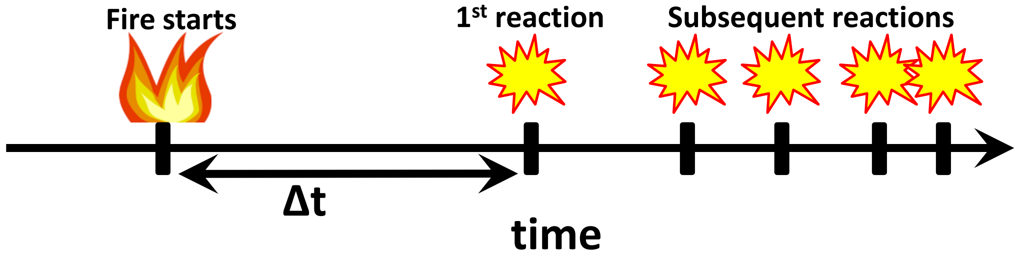
Investigation Overview

- The goal of the investigation was to determine the slowest heating rate that could occur that could lead to a cook-off
- The investigation consisted of both a thermal modelling effort and a review of historical incidents
  - The results of the modelling effort were presented at IMEMTS 2018 in Portland, Oregon[1]
- This presentation will focus on the portion of the investigation that attempted to determine realistic heating rates from actual incidents and accidents

[1] **D. O. Hubble, "An Investigation into a Proper Heating Rate for Slow Cook-off Testing," in *IMEMTS*, Portland, OR, 2018**

Heating Rate from Incident Data

- Can the heating rate that AE experienced be conservatively estimated from real-world incidents?
  - If the heating duration and the cook-off temperature are known, then the average heating rate can be estimated (ΔT/Δt)
  - Conservative means slowest possible, minimize ΔT and maximize Δt
- Unfortunately, in most incidents there are multiple items that react
  - In some cases there are hundreds of reactions over several days
- To simplify the analysis, only the **initial reaction** was investigated
  - All subsequent reactions were ignored
  - Eliminates the confusion of fire spreading from early reactions



Identifying Incidents

- A major focus of this investigation was to find as many incidents as possible in which heating durations could be estimated
  - Used MSIAC's MADx database of ~13,000 accidents
  - Analyzed each of the 173 incidents contained in the Boggs et al.[2] report
  - Additional independent incident review
- These sources rarely contained the information needed to estimate durations but were crucial in identifying cook-off incidents (when and where)
  - Heating details were then obtained from other sources
  - Relied heavily on old news reports to determine heating durations


The New York Times.

MUNITIONS BLAST DAMAGE AT LEAST $93,000,000; TEN KNOWN DEAD, 25 MISSING, HUNDREDS INJURED; MANY ARE HOMELESS; SHELLS STILL EXPLODING

STRIKE CRISIS TODAY: HEDLEY ASKS MEN TO RETURN BY NOON

REFUGEES JAM HIGHWAYS

Homeless, They Flee in Fear of a New and Worse Explosion.

FIRE RAGES, SHELLS SHRIEK

16 Navy Buildings Intact, but New Explosion Is Still Possible.

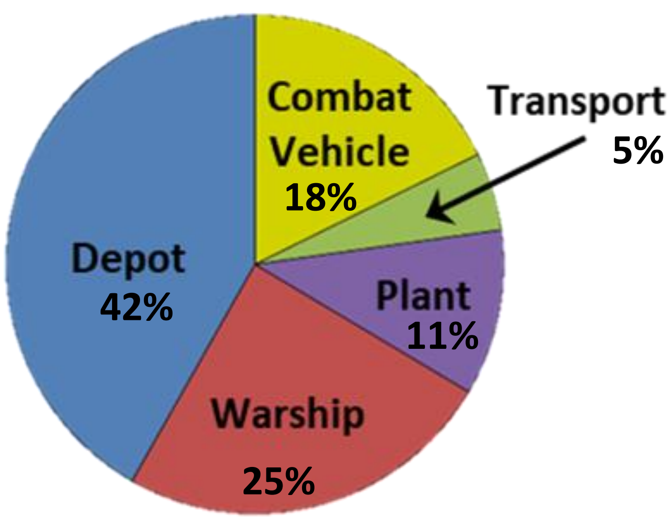
[2] T. L. Boggs, K. P. Ford and J. Covino, "Realistic Safe-Separation Distance Determination for Mass Fire Hazards," 2013.

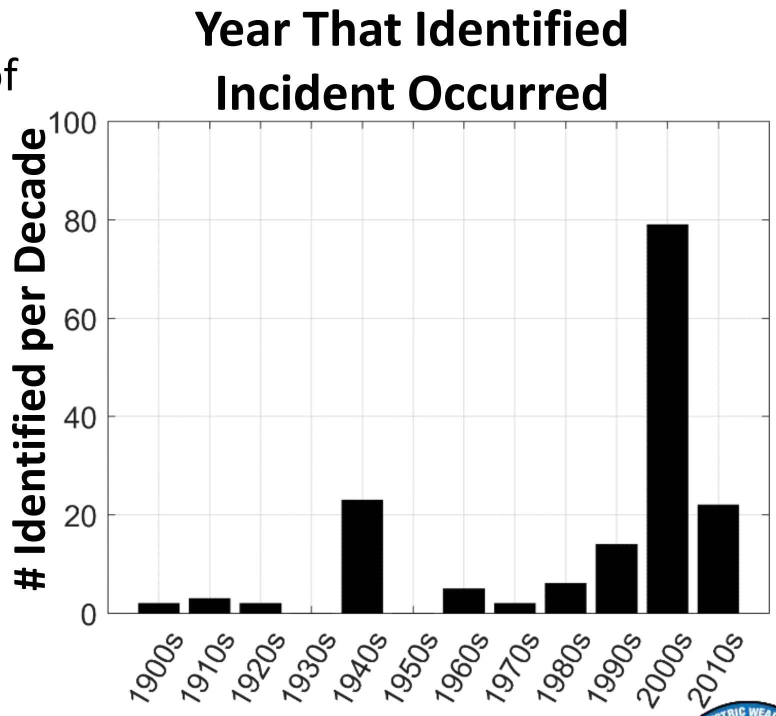
Maximum Time to 1st Reaction

- While the actual time to initial reaction is rarely documented, there is often enough information to **conservatively estimate** the amount of time that elapses prior to the first reaction
  - Example: "fire started at 0330, explosions heard during the morning"
  - Know when the fire started and that explosions started before noon so: 1200 - 0330 = 8.5 hrs max
- This estimate is the "**Maximum Time to First Reaction**" ($\boldsymbol{t_{max}}$)
  - This can then be used to conservatively estimate the average heating rate ($\Delta T/t_{max}$) experienced by the first item that reacted
  - Ensuring the duration estimation is high (t_{max}) is conservative because it ensures the **slowest possible calculated heating rates**

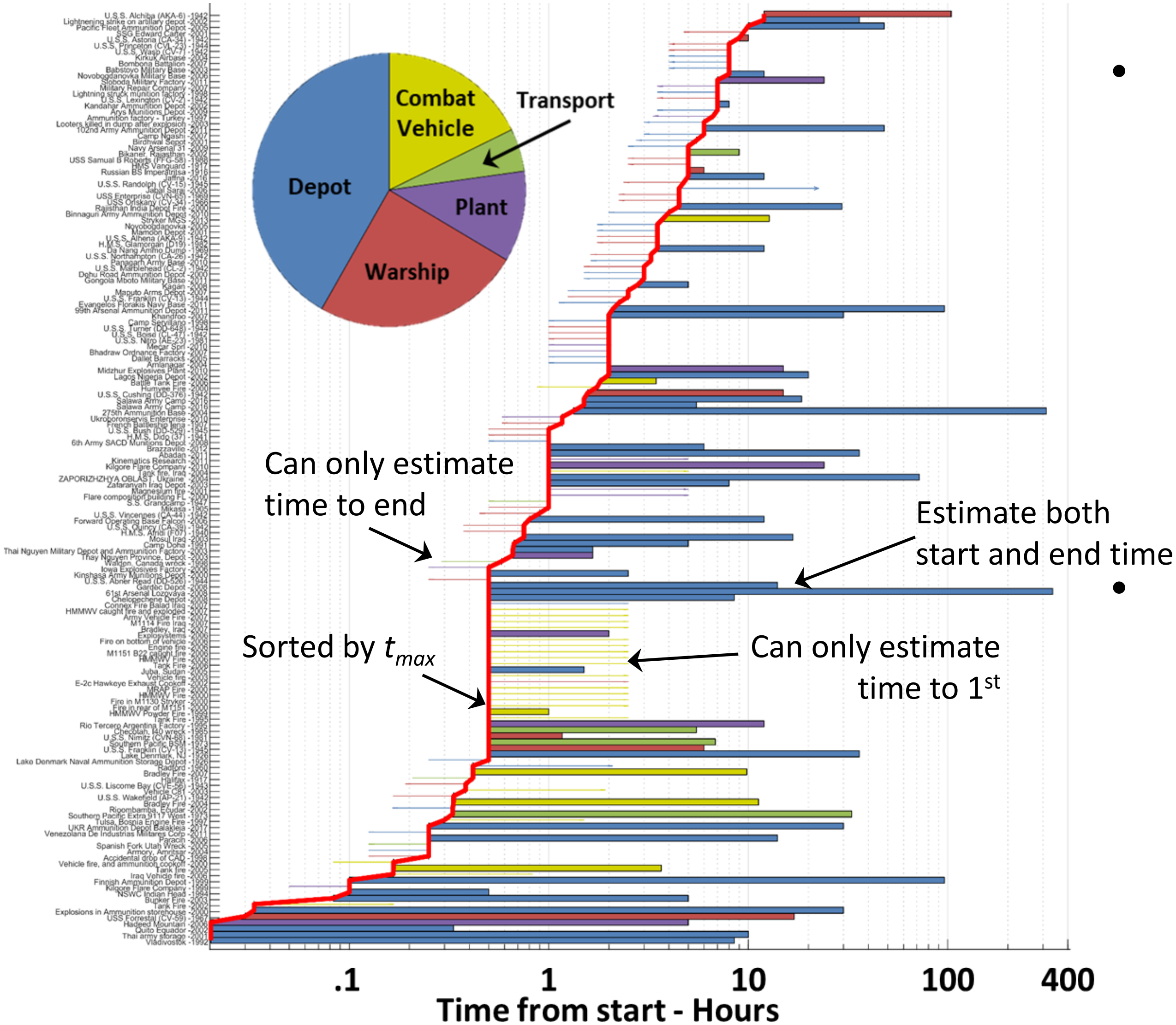
Incident Review

- In total, 158 incidents were found where a heat source existed, ordnance was present, and t_{max} could be obtained
- Incidents sorted into 5 categories
  - Depot, ship, plant, transport, and vehicle
- Incidents span over 100 years
  - Primarily after 1980 with the exception of documented WWII incidents





Incident Duration Data



- Durations shown on a log time scale on bar chart
  - Heating begins at *t=0*
  - Sorted by increasing t_{max}
    - Left arrow means only time to end is known
    - Right arrow means only t_{max} is known
    - Filled region means t_{max} and time to end are both known
- Data allows conservative estimation of heating duration prior to initial reaction for **158** incidents

Cook-off Temperature

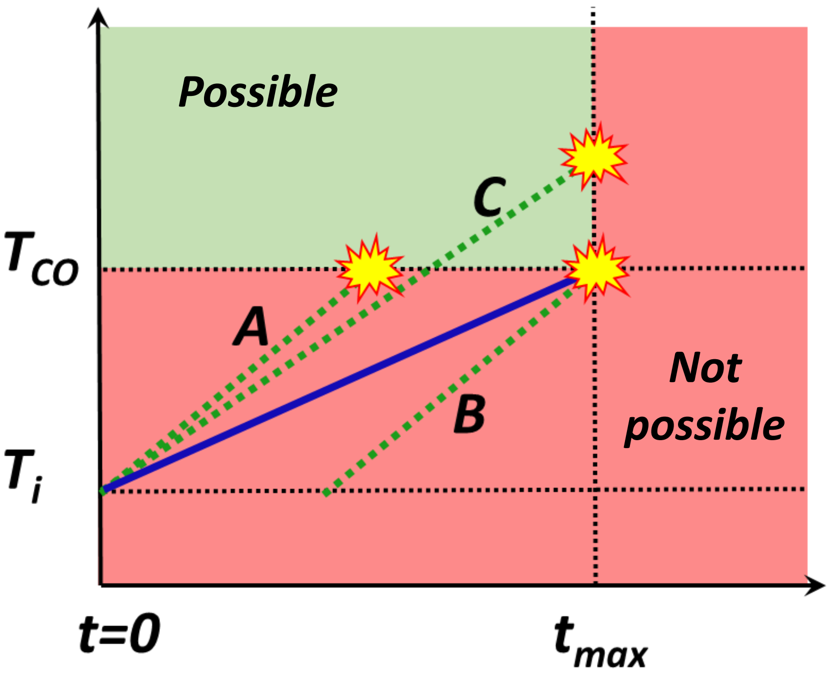
- In most cases the type of energetic item is not reported
- Since the cook-off temperature is unknown, it must be assumed
- To ensure a conservatively low heating rate estimation, the cook-off temperature should be as low as possible
  - $\Delta T/\Delta t$, already maximized Δt, now minimize ΔT
- For this investigation, a cook-off temperature of 130°C was used with an initial temperature of 30°C
  - 130°C is lower than any cook-off temperature ever measured during testing at Dahlgren

➢ **In each case, ΔT is assumed to equal 100°C**

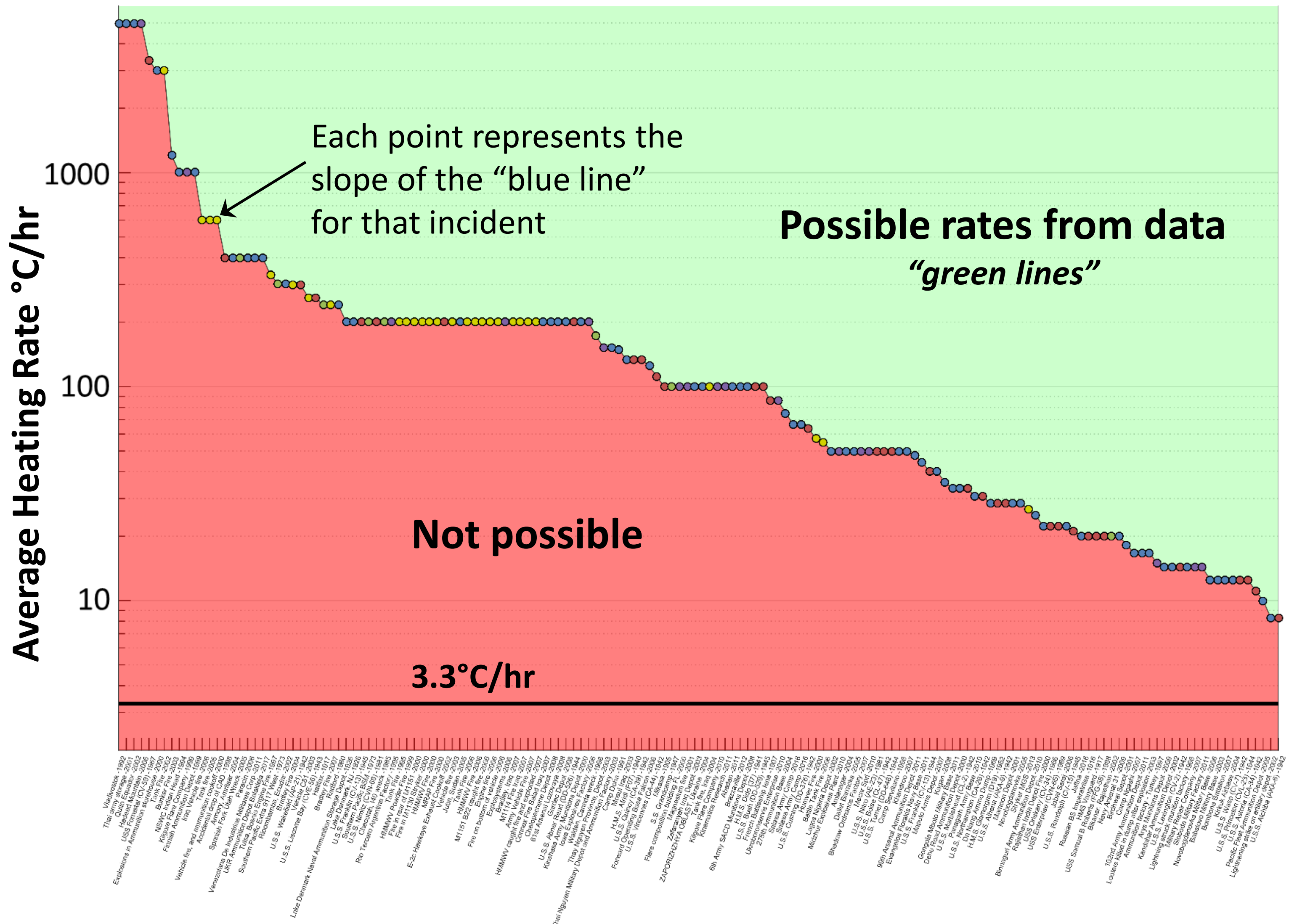
Estimating Heating Rates

- Use t_{max} and ΔT to estimate average heating rates
- Implied assumptions (blue line)
  - Heating begins when fire starts
  - Cook-off after 100°C rise
  - Cook-off occurs at t_{max}
- Most conservative estimate
  - For each case, actual heating rate could be faster **but not slower**
    - A. Reaction before t_{max}
    - B. Delayed initial heating
    - C. Higher cook-off temperature

➢ ***Any possible green line will be steeper than the blue line***

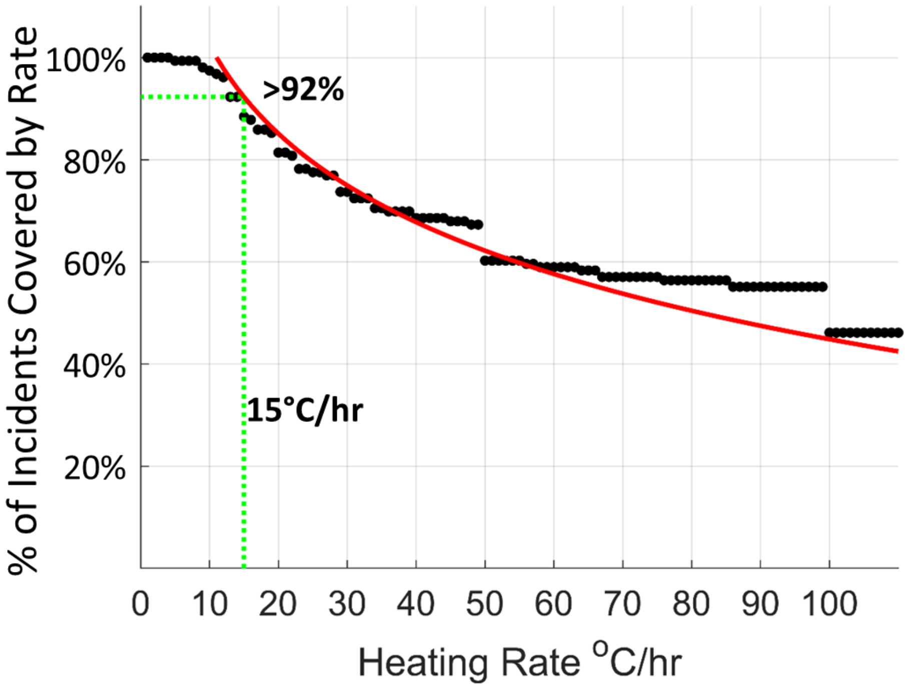


Estimated Heating Rates



Heating Rate Probabilities

- Determine, for any given heating rate, the minimum percentage of incidents that are faster than that rate
  - From curve fit to data, **at least** 92% of the initial reactions were heated faster than 15°C/hr
  - ➢ A test performed at 15°C/hr would subject **a minimum of 92%** of these items to a **slower heating rate** than they actual experienced



Incident Review Conclusions

- A review of historical incidents was performed and 158 cases were identified in which the time to 1st reaction could be conservatively estimated
- These durations were used to calculate average heating rates based upon a conservative temperature rise of 100°C
- The results show that in over 92% of these cases the initial reaction occurred after the ordnance item was heated faster than 15°C/hr
- The current rate of 3.3°C/hr is far slower than any of the heating rates indicated by the incident investigation
- Based partially on these results, the test standard that defines the Slow Cook-off Test is currently being revised to specify a heating rate of 15°C/hr

Acknowledgments

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