Retrieval of Misfired Perforating Systems: Potential Thermal Cookoff Hazards from Shallow Well Operations

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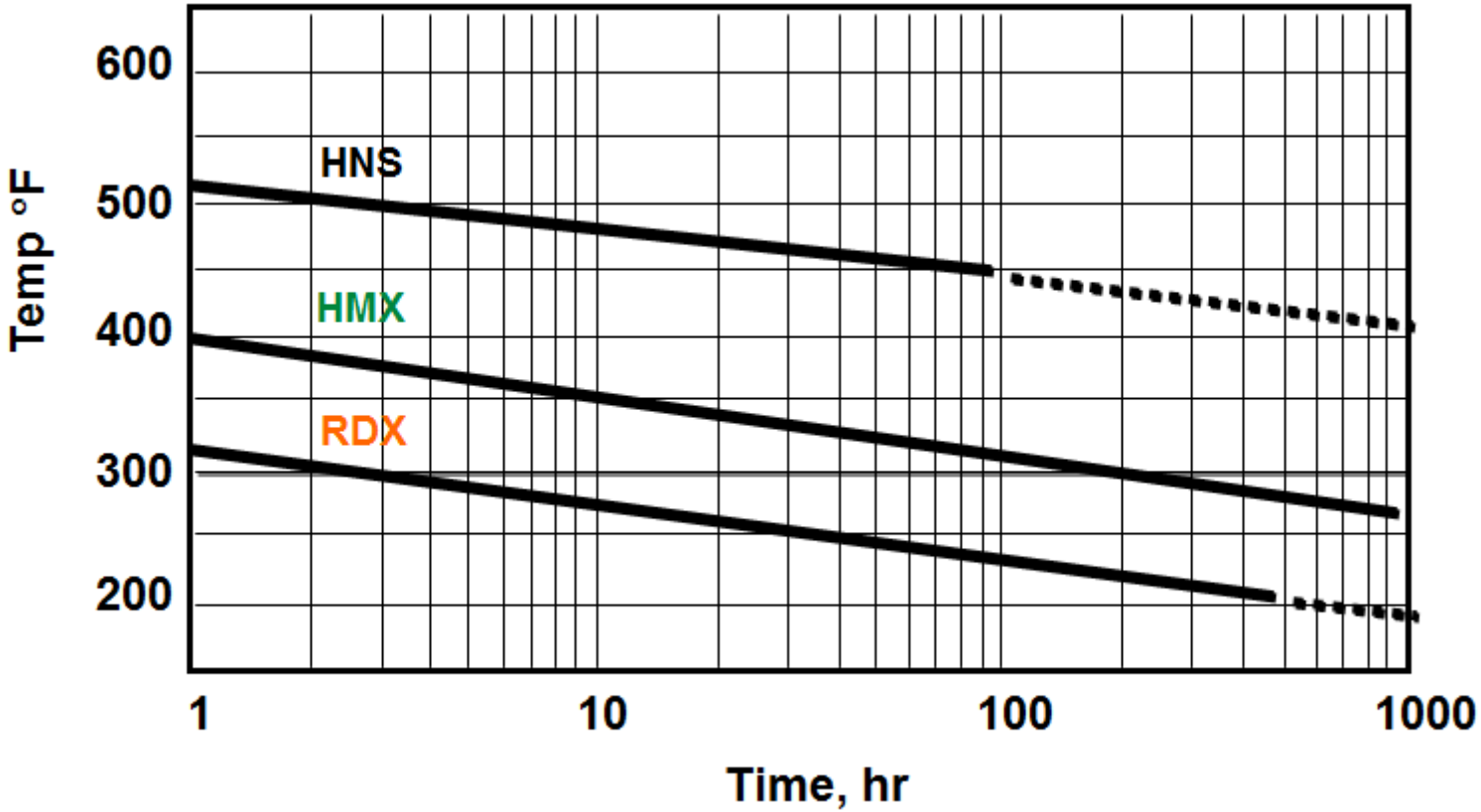
HALLIBURTON

Introduction

- The vast majority of perforating operations are accomplished without issue
- A special case of misfire occurs when guns partially fire, leaving an unknown state of the remaining ballistic train
- This type of misfire, especially in shallow wells, can be retrieved to surface quickly, which may require special planning to account for unknown factors.

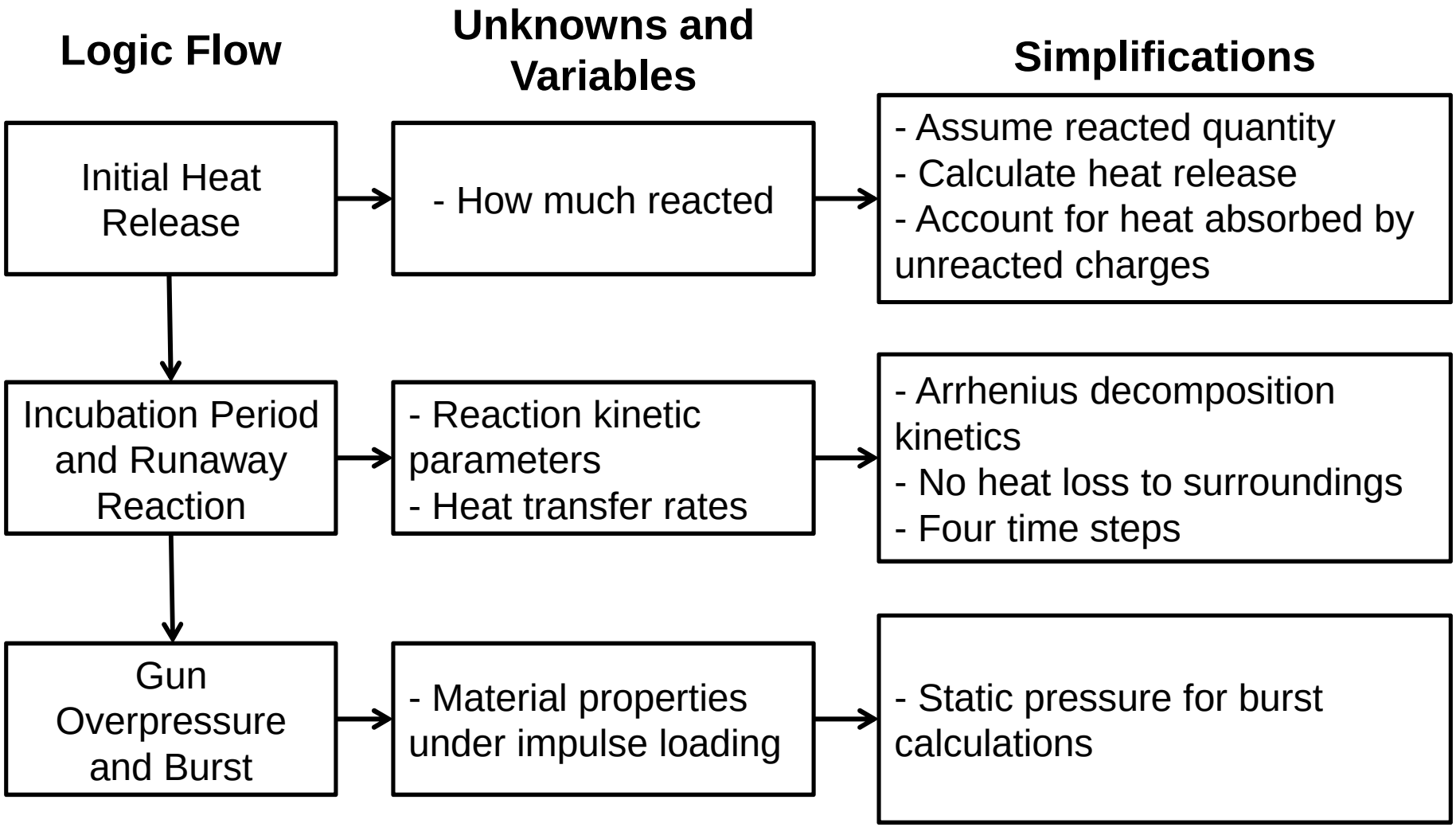
Background



Rate of temperature rise in explosive = Rate of heat generation due to decomposition - Rate of heat removal due to conduction

Postulated Example

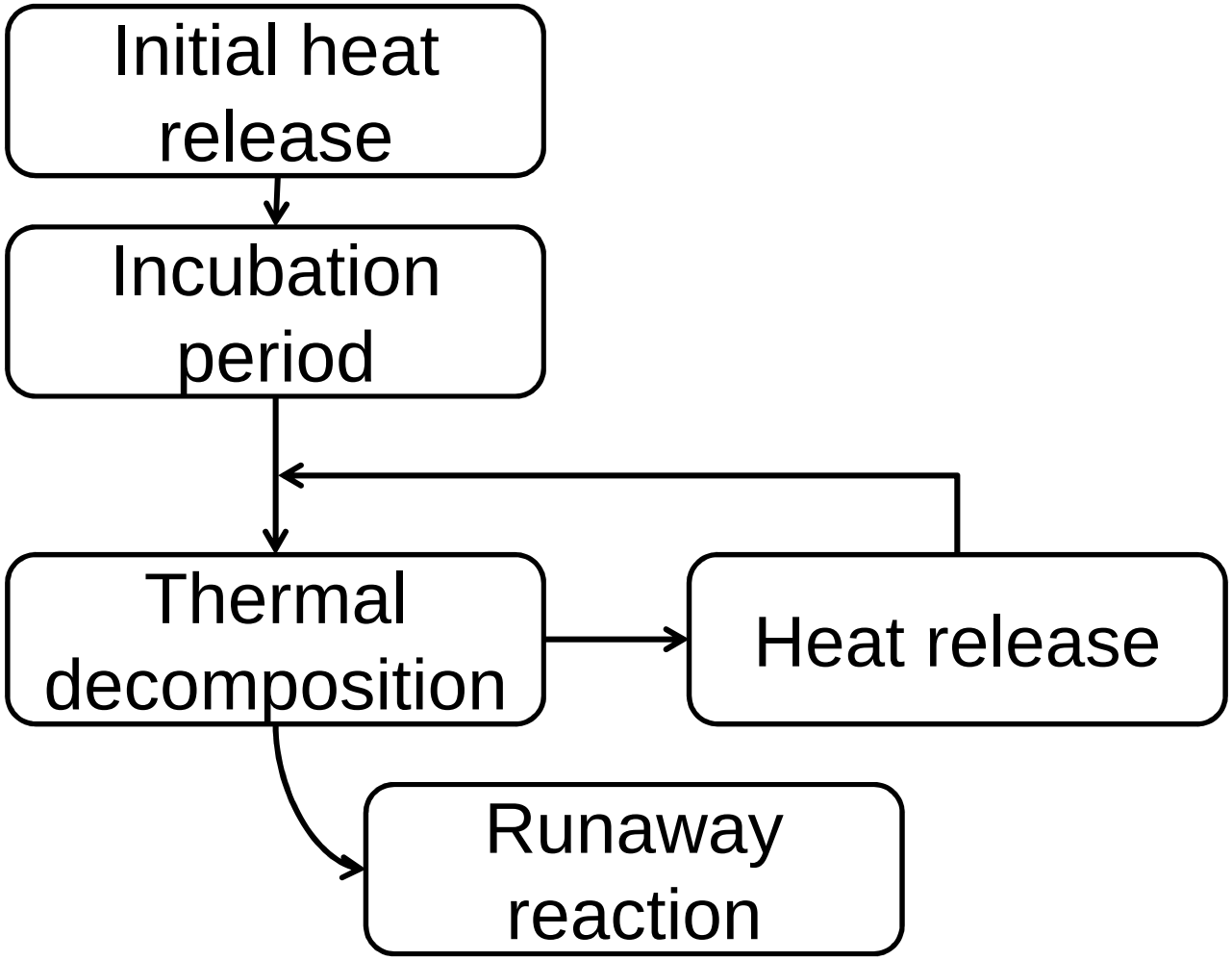
- Shallow well
- 10ft perforating gun by 5 spf
  - 50 charges
- HMX explosives
  - ~2000g total
  - ~100g initiation train
- Downhole misfire
- Retrieval time about 30 minutes


Logic Flow
Unknowns and Variables
Simplifications
Initial Heat Release
- How much reacted
- Assume reacted quantity
- Calculate heat release
- Account for heat absorbed by unreacted charges
Incubation Period and Runaway Reaction
- Reaction kinetic parameters
- Heat transfer rates
- Arrhenius decomposition kinetics
- No heat loss to surroundings
- Four time steps
Gun Overpressure and Burst
- Material properties under impulse loading
- Static pressure for burst calculations

Decomposition Kinetic Principles

- Arrhenius Equation: $d\left(\frac{A'}{A}\right) = Ze^{-Ea/RT}dt$
  - Where
    - A'/A = ratio of initially reacted vs. unreacted material
    - t = time
    - k = reaction rate constant
    - Z = reaction rate frequency
    - E_a = activation energy
    - R = universal gas constant
    - T = absolute temperature

Thermal Decomposition Process



Initial Heat Released

- Downhole Temperature = 100 °C
- Assume detonating cord and first 5 charges deflagrate
  - 300g
  - 2000 kJ heat released
- Heat absorbed by unreacted charges
- Using $Q = mCp\Delta T$
  - **Incubation Temperature ≈ 245 °C**

Incubation Period – Time Step 1

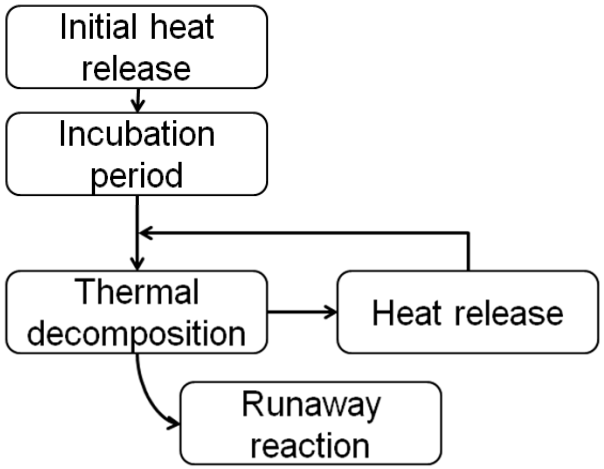
Symbol	Description	Units			
Z	Pre-exponential factor	s^{-1}	4.71E+13	4.71E+13	4.71E+13
Ea	Activation energy	$\frac{cal}{mole}$	43,400	43,400	43,400
R	Universal gas constant	$\frac{cal}{mole\ K}$	1.986	1.986	1.986
T	Temperature	K	518	518	518
K	Reaction rate constant	s^{-1}	2.26E-05	2.26E-05	2.26E-05
t	Time	min	**1**	**10**	**20**
	Percent Decomposition		**0.1%**	**1%**	**3%**

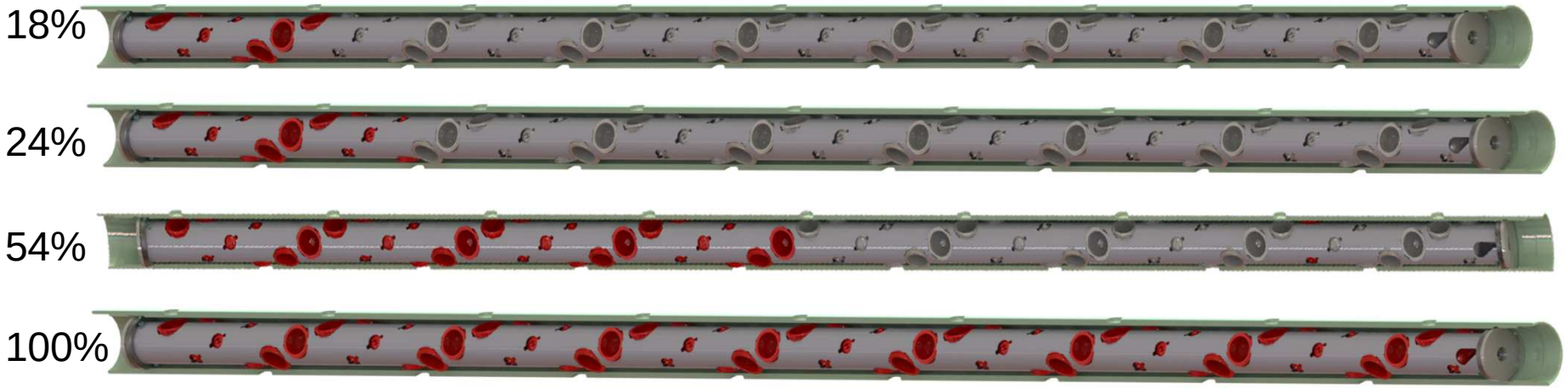
Arrhenius Equation: $\frac{d(\frac{A'}{A})}{dt} = Ze^{-Ea/RT}$

245 °C

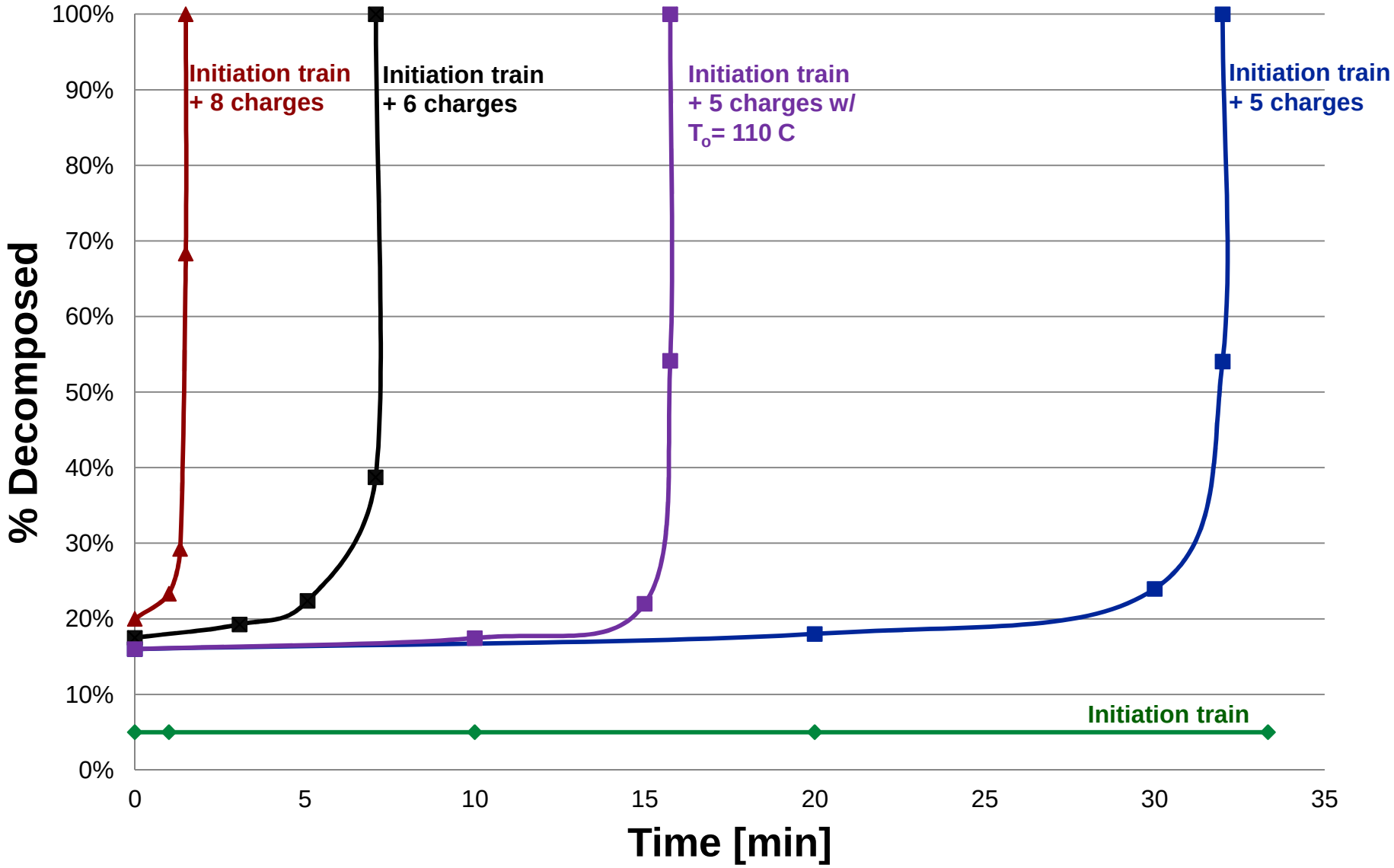
Thermal Runaway Process Steps 3-4

Step	Time Elapsed [min]	Reacted Amount [g]	Percent Reacted	Internal Temperature [°C]
1	**20**	**300**	**15%+ 3%**	**245**
2	30	360	24%	265
3	33	480	54%	325
4	33+	2000	100%	1155





% Thermal Decomposition Vs. Time



Pressure Rise

- Simplified Noble-Able EOS:
  - $P(V - 0.025n) = 0.0821nT$
    - P = Pressure
    - V = Volume of gas (free air volume)
    - n = Number of moles of gas
    - T = Absolute temperature of the gas

Step	Time Elapsed [min]	Reacted Amount [g]	Percent Reacted	Internal Temperature [°C]	Internal Pressure [psi]
1	20	300	15%+3%	245	15
2	30	360	24%	265	3,700
3	33	480	54%	325	4,200
4	**33+**	**2000**	**100%**	**1200**	**23,000**

Material Failure

- Calculated stresses based on internal pressure
- Bursts at ~22,000 psi

So what should we do?

- Misfired guns are filled with uncertainty…

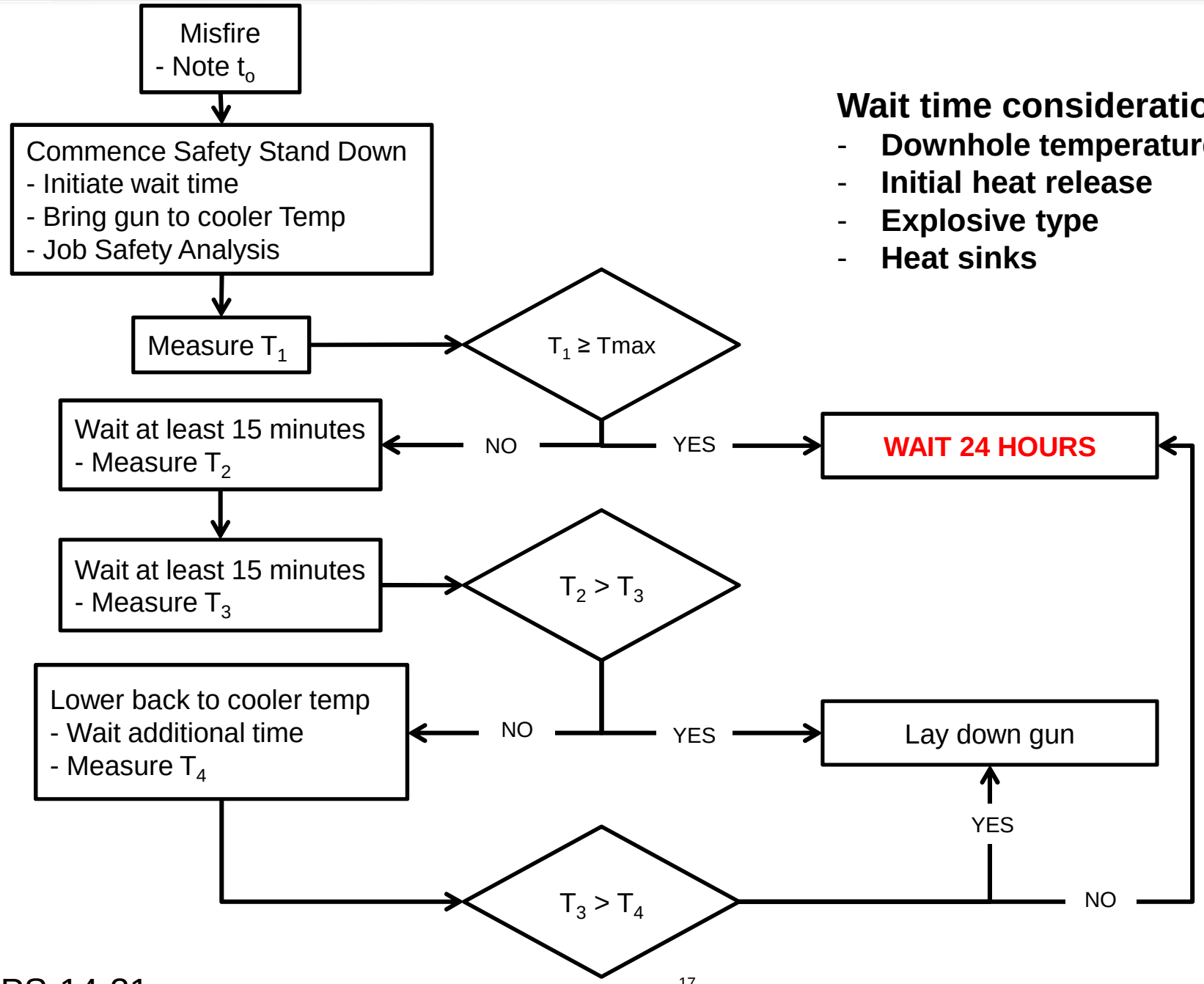
1. Utilize Process Safety Management principles
    1. Management of Change
    2. Standard Operating Procedure
    3. Process Hazard Analysis
    4. Employee training
2. Use time and cooler temperatures to your advantage
3. Take measurements where possible to reduce uncertainty

Recommendations for Retrieving Misfired Guns

- Record last firing attempt = t_o
- Raise gun system to cooler temperatures and initiate a wait time
- Commence safety stand down
  - Potential deflagration
  - Potential trapped pressure
  - Prepare laydown area
  - Secure pressure bleed tool
  - Clear non-essential personnel
  - Secure infrared thermometer

Determine a Safe Measurement Technique

- Use an accurate and calibrated measuring instrument
- Minimize personnel exposure to the carrier
- Train personnel on efficient measurement techniques
  - Avoid scallops (reflections)
  - Most representative readings on are the gun body itself



Wait time considerations:

- **Downhole temperature**
- **Initial heat release**
- **Explosive type**
- **Heat sinks**

Summary

- Misfires do occur in the field which leads to uncertainty
- All explosives decompose with temperature
- Temperature drives this reaction exponentially
- Incubation periods can create a false sense of security
- Utilize Process Safety Management principles to formulate a plan for retrieving misfired perforating guns
  - Include MOC, SOP, PHA, etc.
  - Take measurements to reduce uncertainty
  - Utilize time and temperature to reduce the hazards

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Thank you