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Munitions Safety Information Analysis Center

Supporting Munitions Safety

Slow Heating Test Thermal Equilibrium and Maximum Reaction Temperature

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Dr. Ernie Baker
TSO Warheads Technology
e.baker@msiac.nato.int

Dr. David Hubble
Naval Surface Warfare Center Dahlgren Division
US Navy

Outline

- Background
- STANAG 4224, Edition 4
- Analytic Thermal Soak Calculations
- Finite Difference Thermal Soak Calculations
- AOP-4382 Heat Soak Update
- Maximum Reaction Temperature Review
- Summary

Background

- MSIAC was asked to examine STANAG 4224 ED. 4 and determine if the preconditioning table and formulas are appropriate for a preconditioning requirement in AOP-4382 (Slow Heating Test).
  - MSIAC (E. Baker) did analytic thermal calculations and NSWCDD (D. Hubble) did 1-D thermal finite difference calculations for 50ºC soaks in order to investigate the applicability.
  - A new preconditioning heat soak formulation developed as a result of these studies.
- MSIAC was subsequently requested to review maximum reaction temperatures.
  - Information valuable for SH oven designs.
- AOP-4382 has been updated and is currently being ratified.

STANAG-4224, Edition 4

Large Calibre Artillery And Naval Gun Ammunition Greater Than 40 Mm, Safety And Suitability For Service Evaluation (superseded)

- When conditioning ammunition, durations below shall be used as a minimum:

Calibre (mm)	40	57	76	90	100	105	120	155	165	203
Duration (h)	4	7	8	13	15	18	20	22	23	26

- For ammunition of calibres not specified in table:

  a. For calibre ≤ 105mm.

$$D = 0.1016 + 0.0516*S + .0009946*S^2$$

  b. For calibre > 105mm.

$$D = 16.8414 - 0.0013*S + .0002292*S^2$$

D = Duration of Conditioning (hr), S = Ammunition Calibre (mm)

Analytic Thermal Soak Calculations

One-term approximation solutions for the time required for a cylinder to reach 48ºC and 45ºC using a 50ºC heat soak. The computational procedure consists of solving for the Fourier number, τ from the following equation.

$$\frac{T_0 - T_\infty}{T_i - T_\infty} = A_1 e^{-\lambda_1^2 \tau}$$

The time can then be calculated from the Fourier number.

$$t = \frac{\tau r_0^2}{\alpha}, \qquad \alpha = \frac{k}{\rho c_p}$$

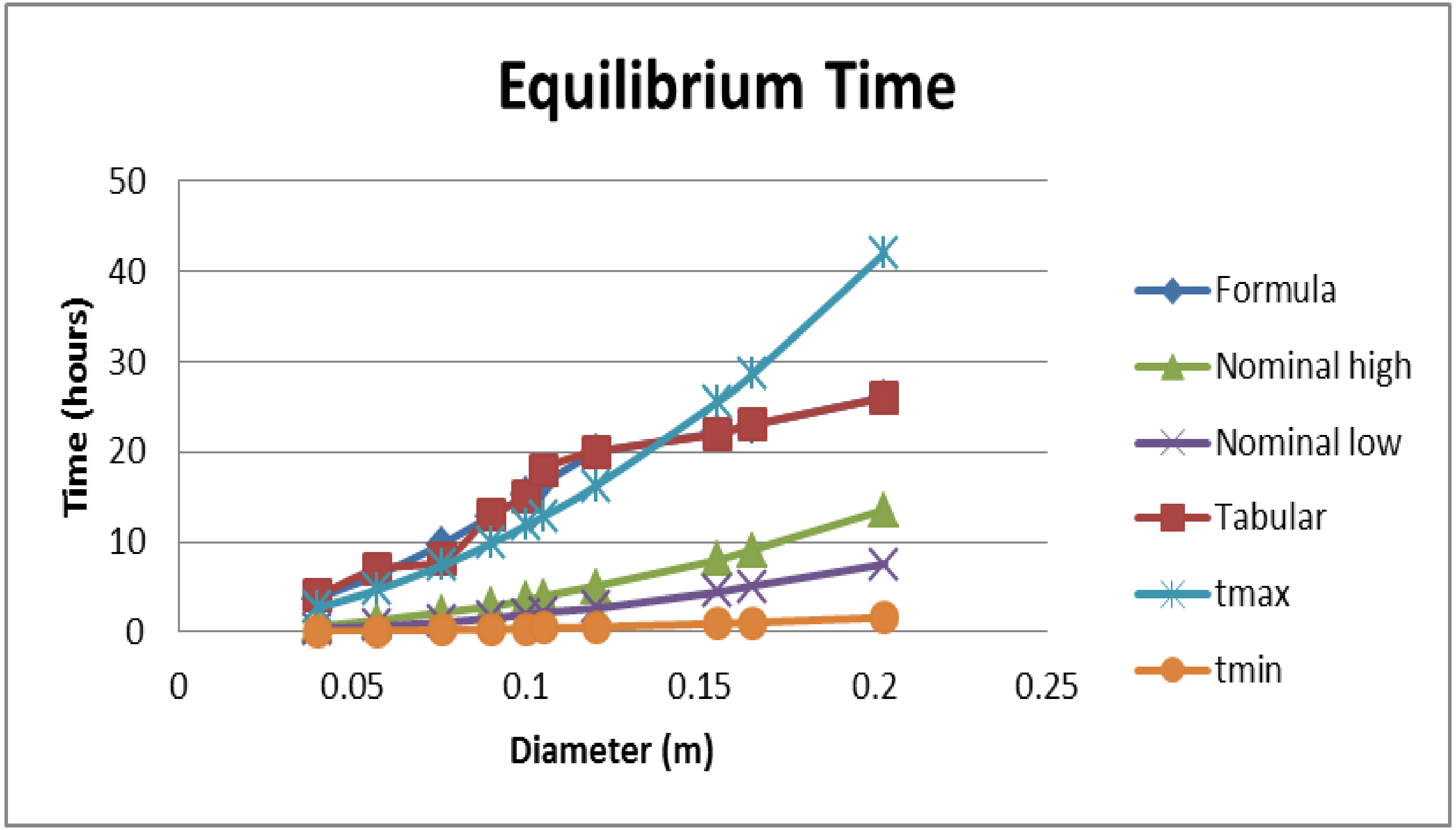
The values for A_1 and λ_1 depend on the Biot number, $\mathrm{Bi} = \frac{h r_0}{k}$. *h* is the heat transfer coefficient. *k* is the thermal conductivity. c_p is the specific heat and ρ is the density.

Bounding Calculations

- In all cases the Biot numbers were large (much greater than 0.1) and the Fourier numbers were large (much greater than 0.2). Therefore the one term solutions should be accurate within 2%.
- Completed bounding calculations of maximum time and minimum time based on a range of expected explosive and propellant properties.
- Subsequently completed the same calculations based on a more nominal maximum and minimum range.

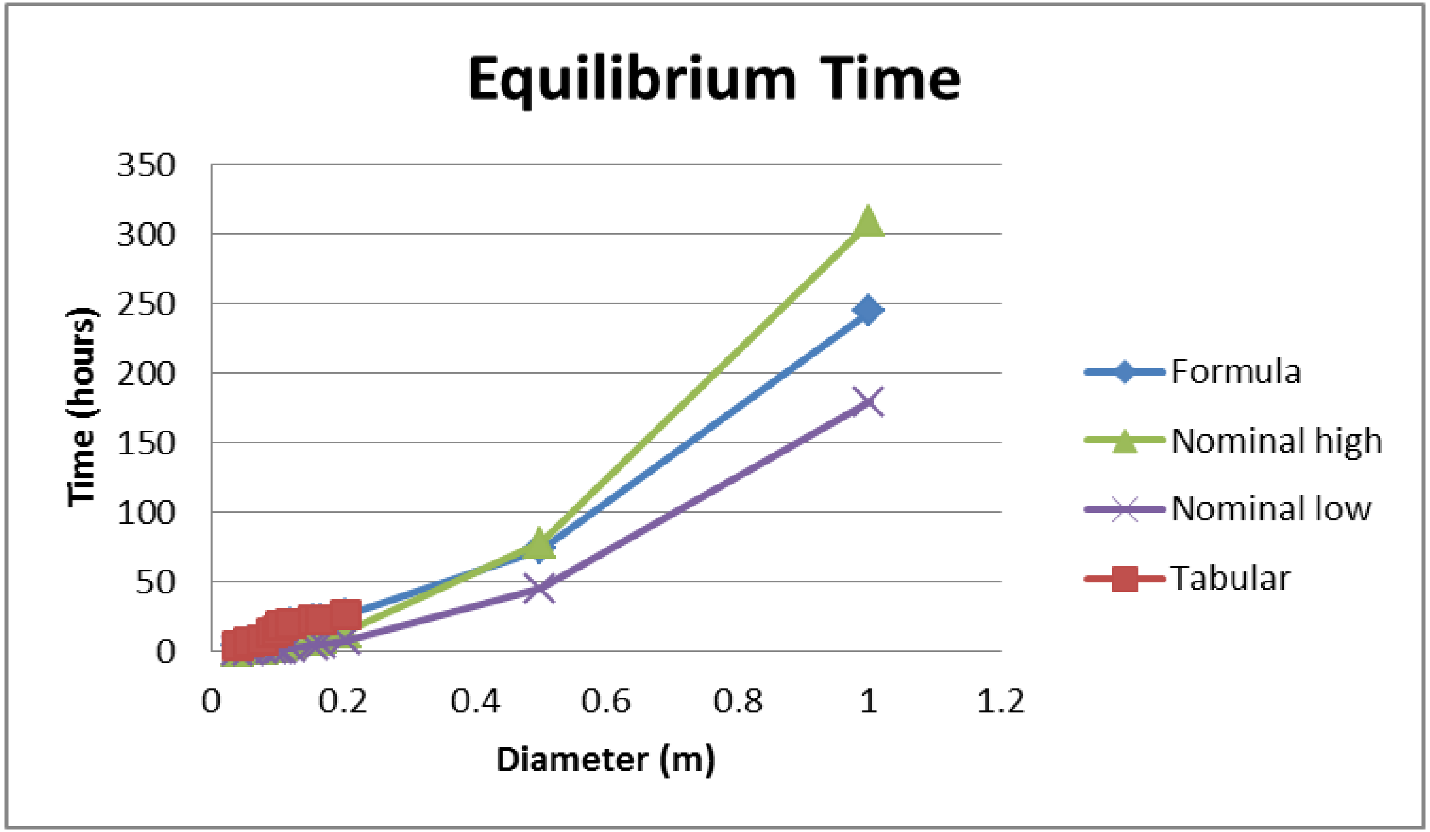
Value	Extreme range	Nominal range
ρ (g/cc)	1.5 – 2.2	1.7 – 1.8
k (W/m·ºC)	0.1 – 0.5	0.2 – 0.3
Cp (J/kg·ºC)	500 – 1500	1200 – 1300
h (W/m^2)	55 – 120	75 - 100

Bounding Soak Calculations



Calculated time for a cylinder center to reach 45ºC compared to the tabular and formula based guidance in STANAG 4224.

Bounding Soak Calculations



Calculated time for a cylinder center to reach 45ºC compared to the tabular and formula based guidance in STANAG 4224.

Comp B Calculations

- Completed calculations for a cylinder of Comp B to reach 45ºC using a 50ºC heat soak in order to make comparisons with a specific material
- The heat transfer coefficient is oven and item dependent.
- Dr. David Hubble provided heat transfer coefficients that he had obtained based on experiments that he had conducted using steel cylinders in the NSWCDD standard oven design.
- These heat transfer coefficients are somewhat lower than the values previously used in the calculations.

Value	Composition B
ρ (g/cc)	1.7
k (W/m·ºC)	0.226
Cp (J/kg·ºC)	1130
h (W/m^2·ºC)	11 – 25

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Comp B Analytic Thermal Calculations

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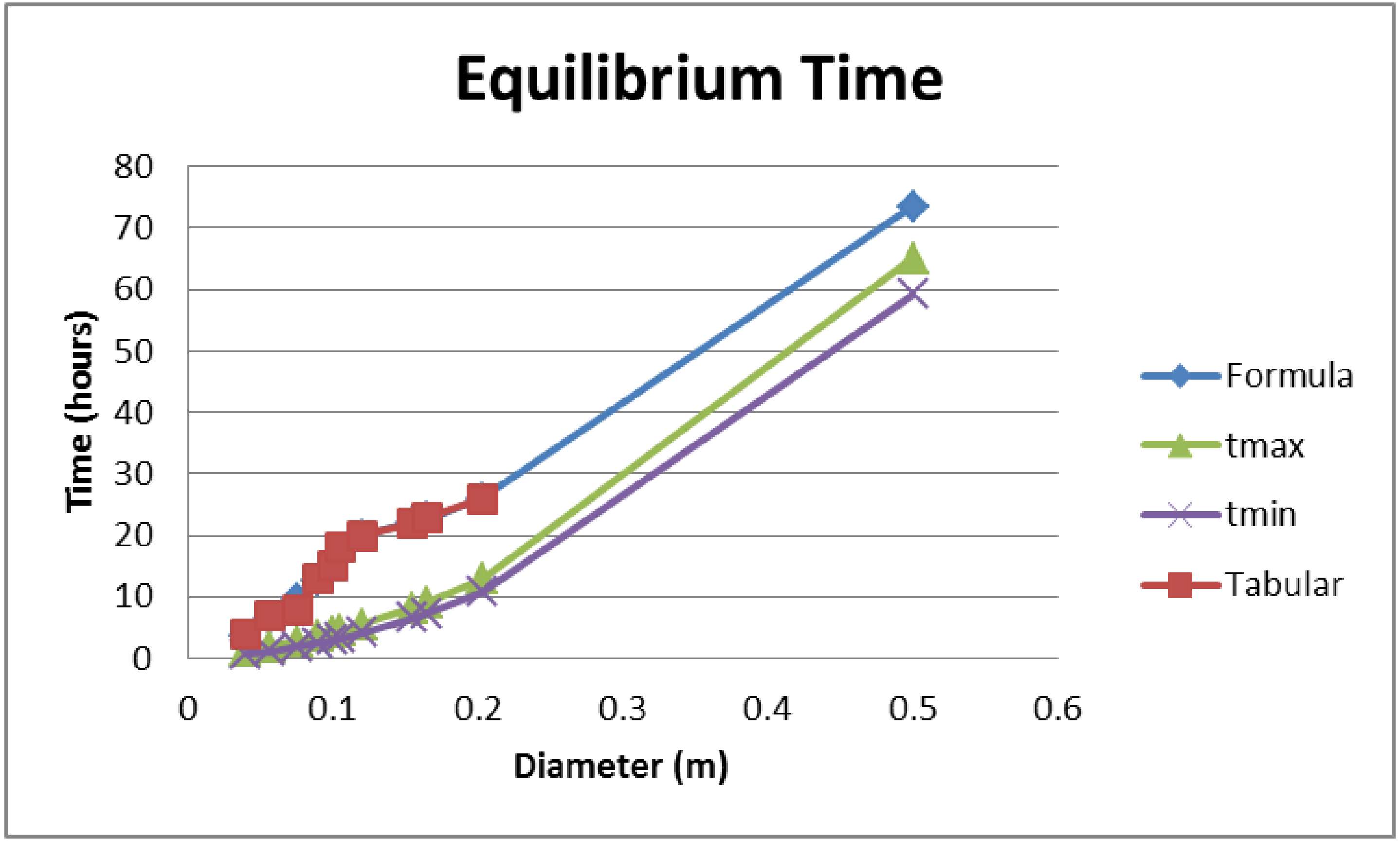
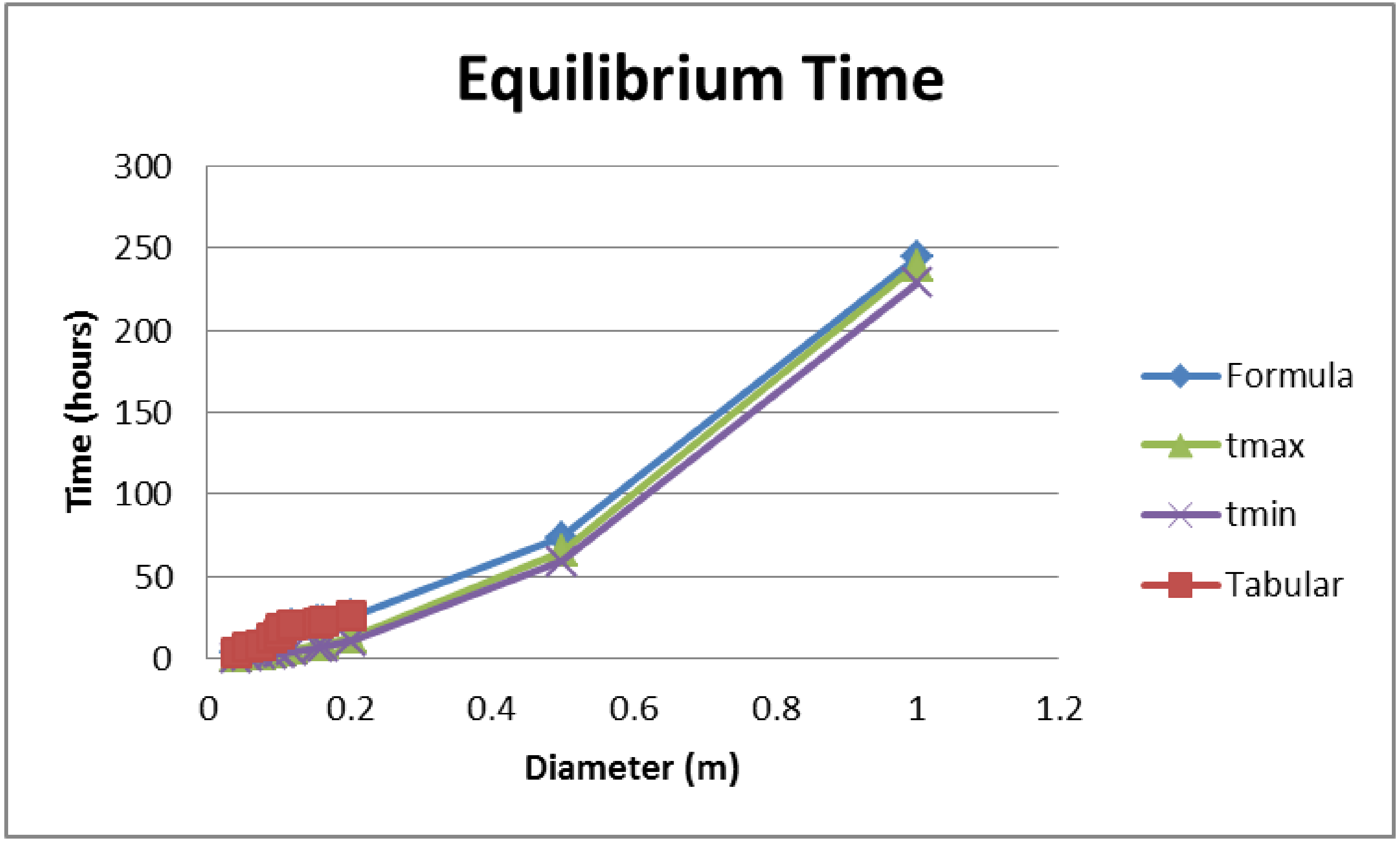


Calculated time for a Composition B cylinder center to reach 45ºC compared to the tabular and formula based guidance in STANAG 4224.

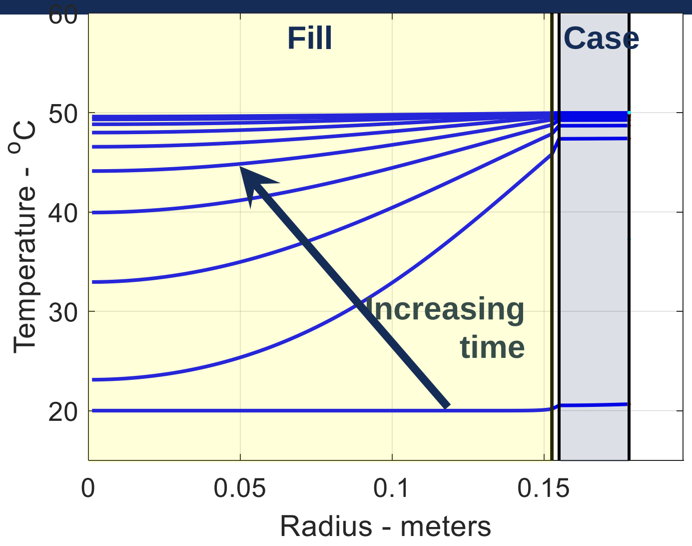
Comp B Analytic Thermal Calculations

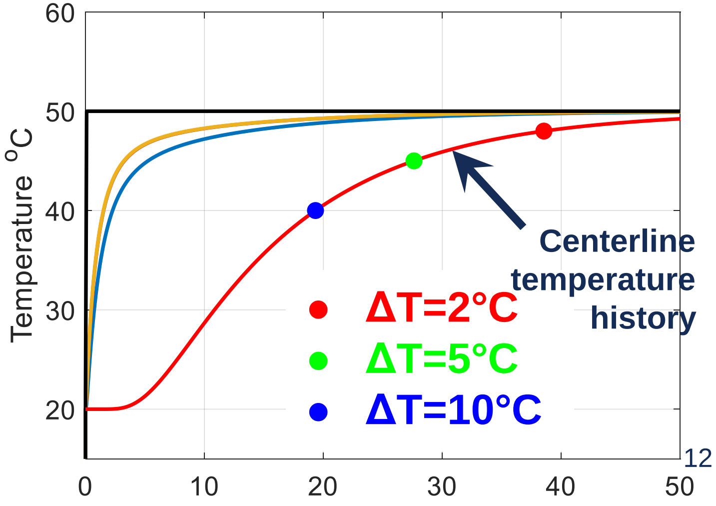


Calculated time for a Composition B cylinder center to reach 45ºC compared to the tabular and formula based guidance in STANAG 4224.

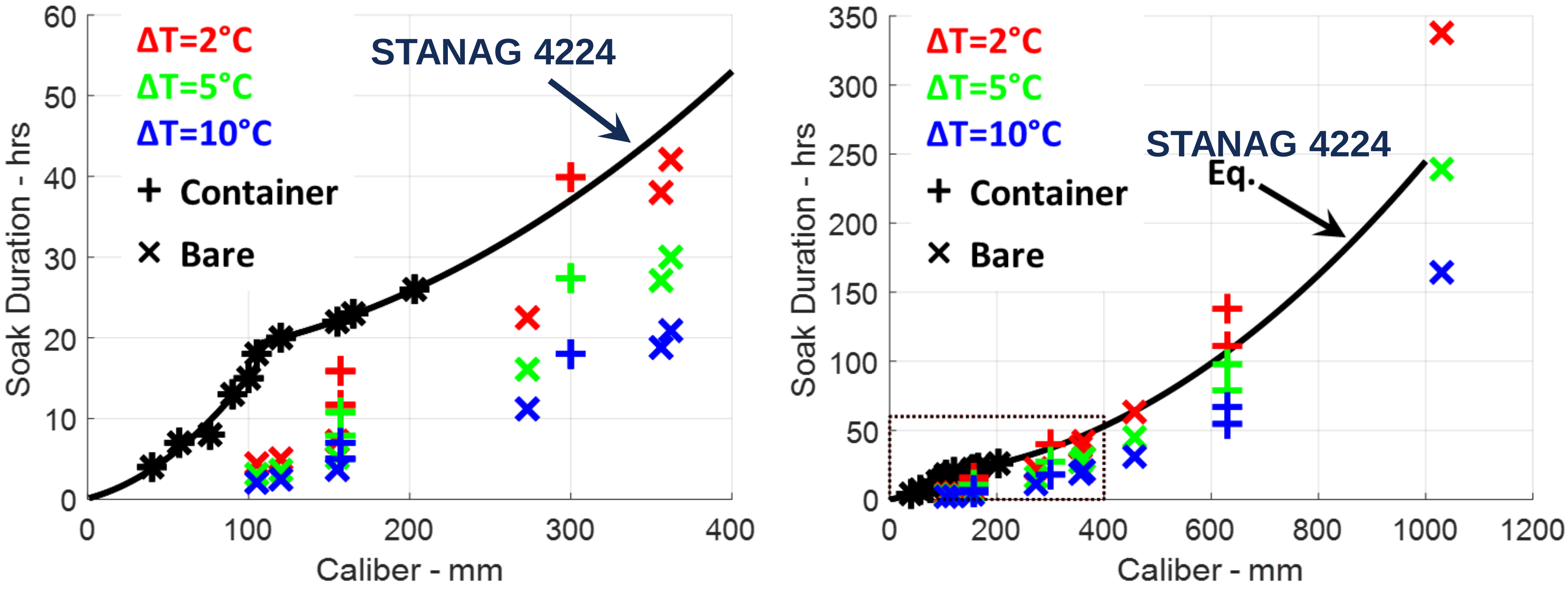
Finite Difference Thermal Modeling

- Analyzed a variety of munitions using a 1-D code
- Model used to calculate fill temperature vs time
- Temperature is asymptotic with time
  - How close to equilibrium is close enough?
    - Tightening equilibrium requirements increases soak time
  - Example: 1,000 lb bomb starting at 20°C
  - Center of fill reaches 40°C in 19hrs (ΔT=10°C) but takes twice as long (38hrs) to reach 48°C (ΔT=2°C)

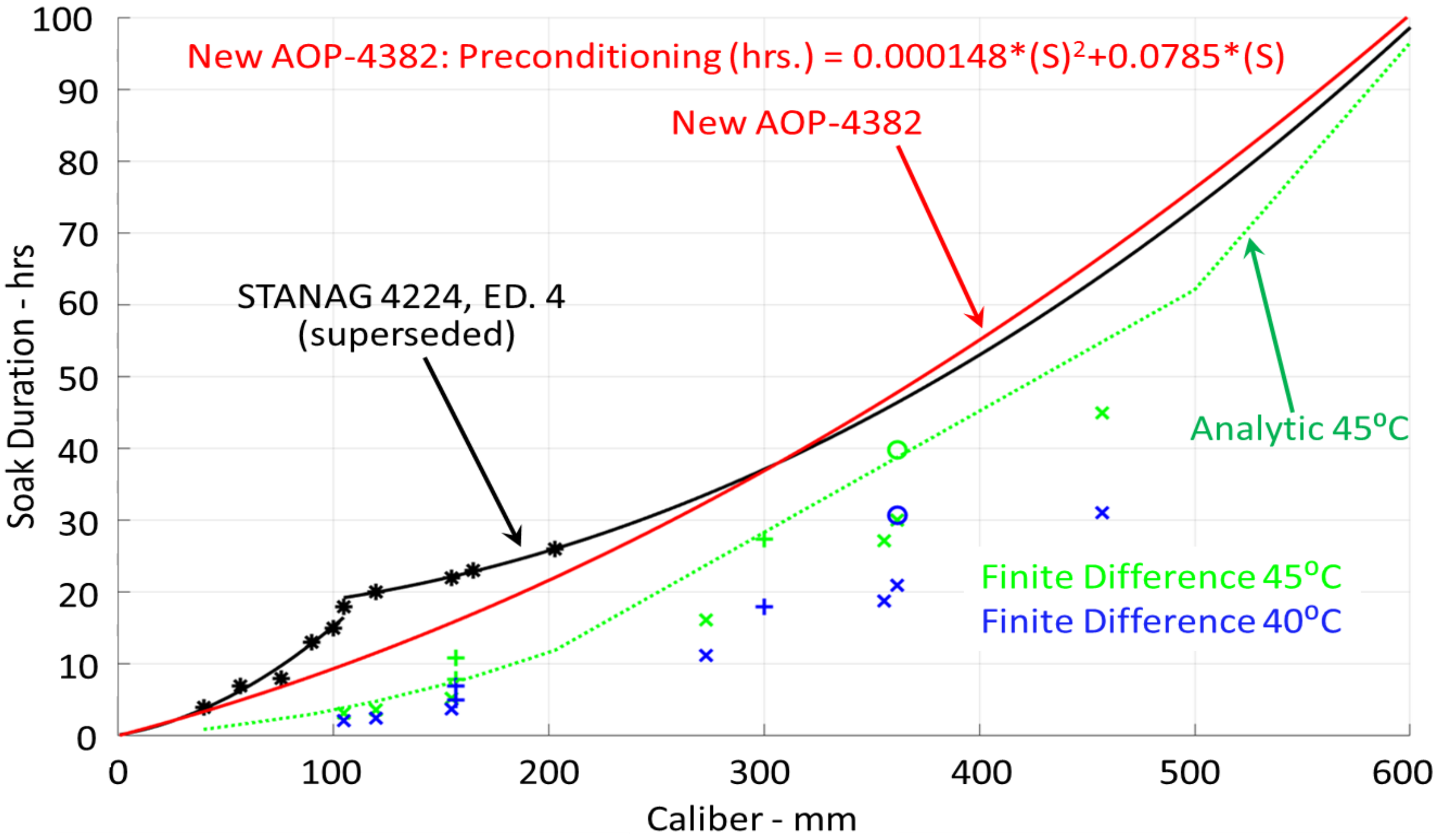




Finite Difference Thermal Modeling



AOP-4382 Heat Soak Update



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Max Reaction Temperature Review

- A review of maximum SH reaction temperature was conducted using the MSIAC Advanced IM Search (AIMS) database.
- 29 reaction temperatures found
- Highest found reaction temperature: 260ºC
- Majority of munitions react below 200ºC

Munition	Item	Main Energetic Material	Ext. Dim. (mm)	Config.	Heating Rate (°C/hr)	Reaction Temp. (°C)
PAC-3 Missile - Analog Rocket Motor	Rocket Motor	HTPB/Al Propellant	280	Pack.	27.8	260
2.75 " Rocket - Mk146 Mod 0 Warhead	Warhead	PBXN-110	70	Pack.	22.2	223
105 mm PGU 44/B HE Shell	Warhead	PBXN-109	105	Pack.		218
105 mm M915 DPICM Shell	Warhead	PAX-2A	105	Pack.	27.8	215
Apache Missile	Rocket Motor	HTPB/Al Propellant		Bare	3.3	196
5" HE Shell	Warhead	ARX-4024	127	Bare	3.3	195
ASRAAM Missile	Warhead	PBXP-31		Bare	3.3	195
MU90 Torpedo	Warhead	V-350	324	Bare	3.3	195
105 mm M915 DPICM Shell	Warhead	Comp A-5	105	Pack.	27.8	194

Summary

- Aim to develop a standard assessment protocols for:
  - Acceptability of explosive for gun launch
  - Acceptable defect types, sizes, distributions
  - Acceptable defect identification methods
- Review and generation of gun launch data
  - Acceleration and spin
  - Acceleration perturbations
  - Fill stress histories
  - Incidents
- Review of explosive mechanical response modeling under gun launch and in setback actuators
  - Current state of the art
  - Energetic mechanical response material models
  - Defects modeling
- Standards development: best practices document (STANREC)
  - Setback actuators
  - Statistical analysis and quantitative risk protocols
  - Defect identification methods
  - Explosive acceptability process
  - Acceptable defect types, sizes and distributions process