HAP-Free Intumescent Coatings for Protection of Munition Containers

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The Army Research Laboratory

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

Background

- Collaborative Research with Army Research Lab (ARL)
- Purpose
  - Provide capability for new or existing coatings to improve munitions response to IM threats
    - Mainly focus on fast cook off with impact considerations
- Result
  - Coating formulation and technologies for IM design
  - Demonstration of integrated technologies for improved IM behavior of packaged munitions
- Payoff
  - Improved tactical and combat system survivability
  - Reduced transportation and storage burden

Technical Approach

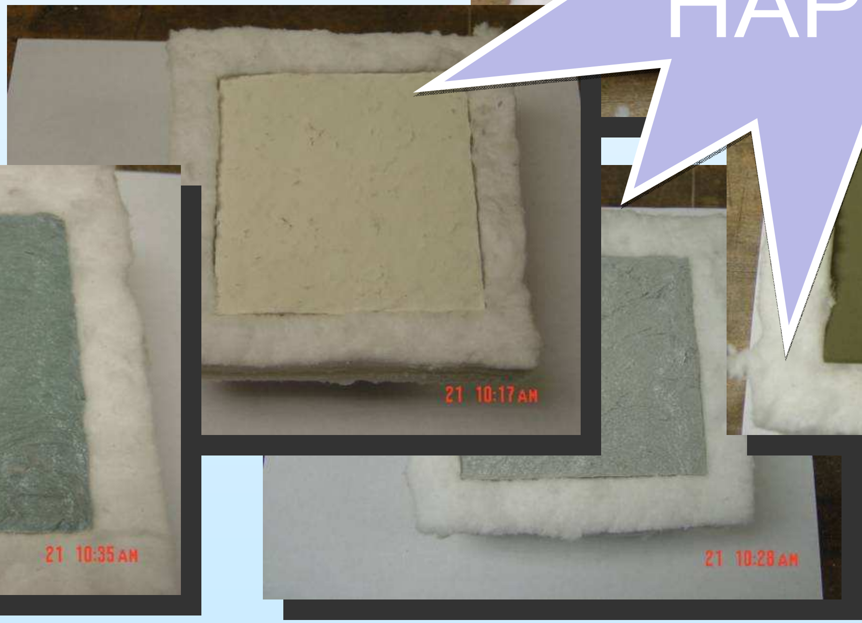
- Material research, technology survey, material testing and analysis
- Evaluation of coatings to determine if it meets IM criteria
  - Evaluated certain coatings with polyurea over-coating
- Down-selection and evaluation testing
  - 21 potential candidates
- Full scale testing
  - 4 potential candidates

Intumescent Coatings

- Material expands when exposed to heat
  - ↑ volume
  - ↓ density
  - Thermal insulation layer
  - Reduce heat transfer
  - Prevent/Delay escape of fuel
- Provides durable and attractive surface, similar to a paint finish
- Drawback
  - Char has degraded mechanical properties
  - Optimal when char is homogeneous
  - Added weight and cost

Coatings Evaluated

- Ballistic coatings
- ARL formulation
- Various commercial products



Coating Application Techniques

- Ballistic and ARL coating formulations applied by ARL

- Commercially available coatings trowel-applied per manufacturer specifications in laboratory environment

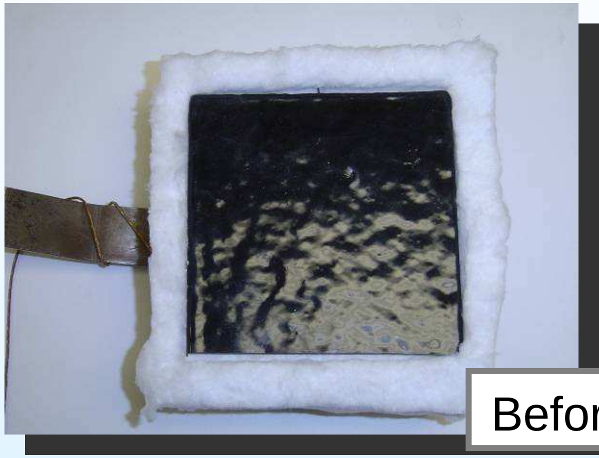
- Measured coating thicknesses ranged from 1.5 – 5.0mm (~ 40 - 200 mil)

Performance Tests

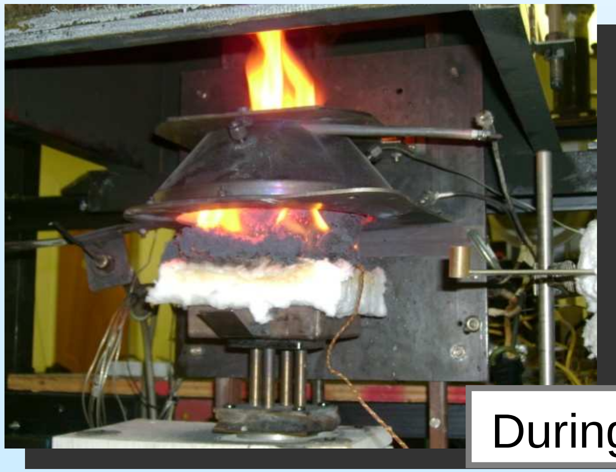
- Thermal Tests
  - Cone Calorimeter
  - Burn Through
  - Thermal Conditioning-Drop Test
  - UL 1709 Furnace Exposure
  - Slow Cook Off
- Ballistic
- Rough Handling Tests
  - Accelerated Corrosion Resistance Testing
  - Impact Resistance Testing
  - Humidity Testing
  - Water Immersion Resistance

Small-Scale Screening Tests

- Initial screening tests performed using cone calorimeter with 4in. x 4in. samples
- Small-scale test apparatus capable of providing consistent, uniform exposures via radiant heating element
- Incident heat flux of 100kW/m^2 used to simulate relatively severe, rapid heating exposure

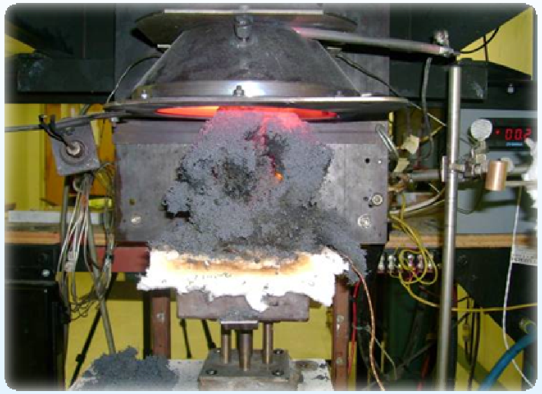
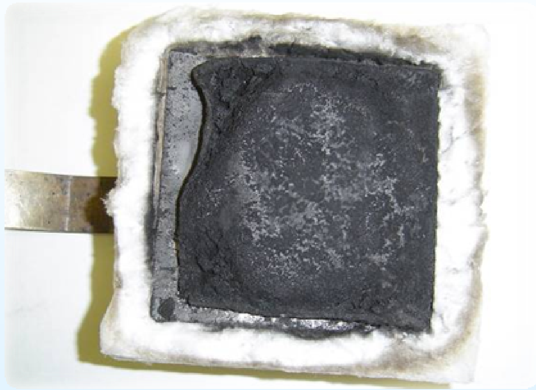


Before Testing



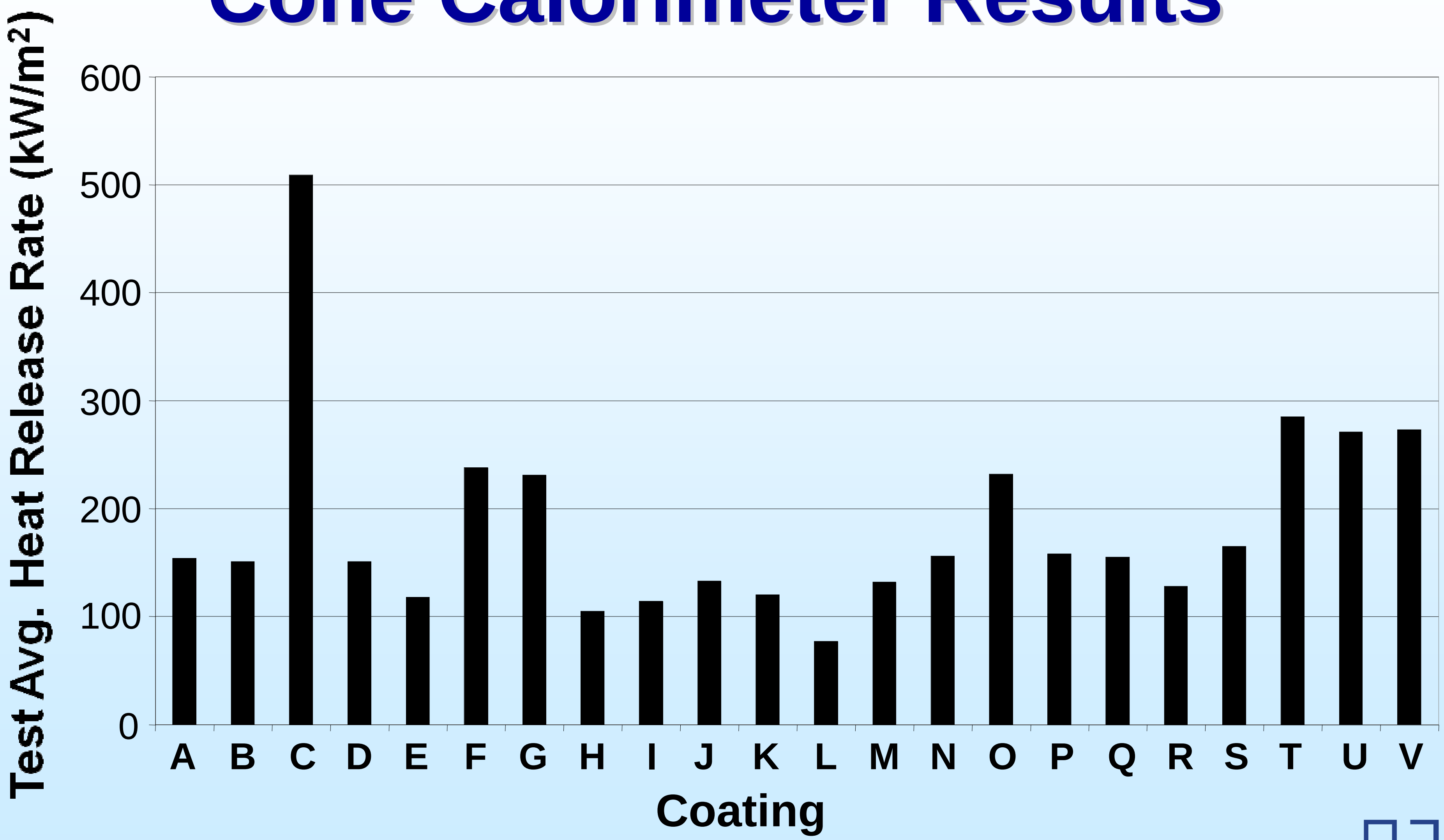
During Testing

Cone Calorimeter Results

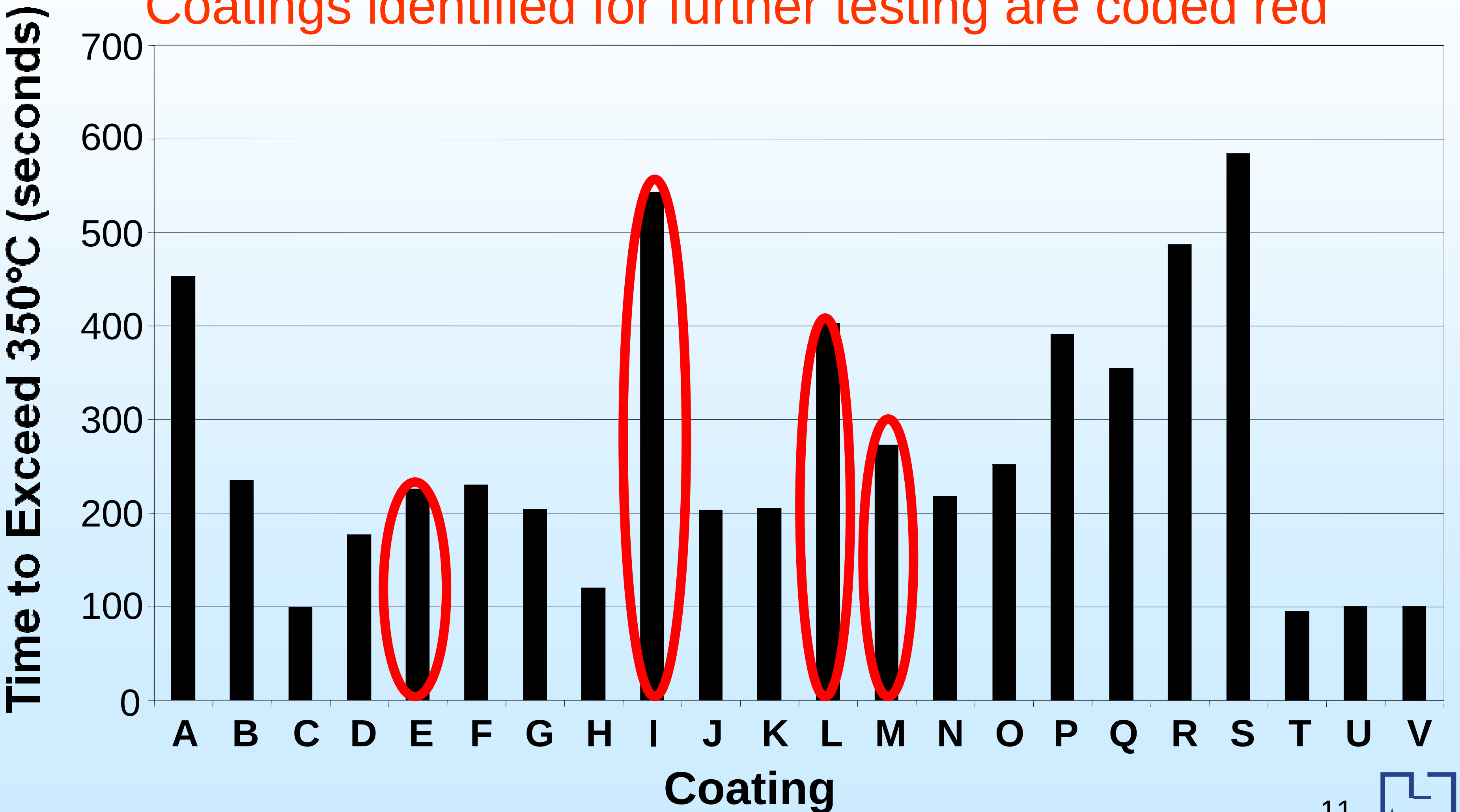


Cone Calorimeter Results



Cone Calorimeter Results

Coatings identified for further testing are coded red

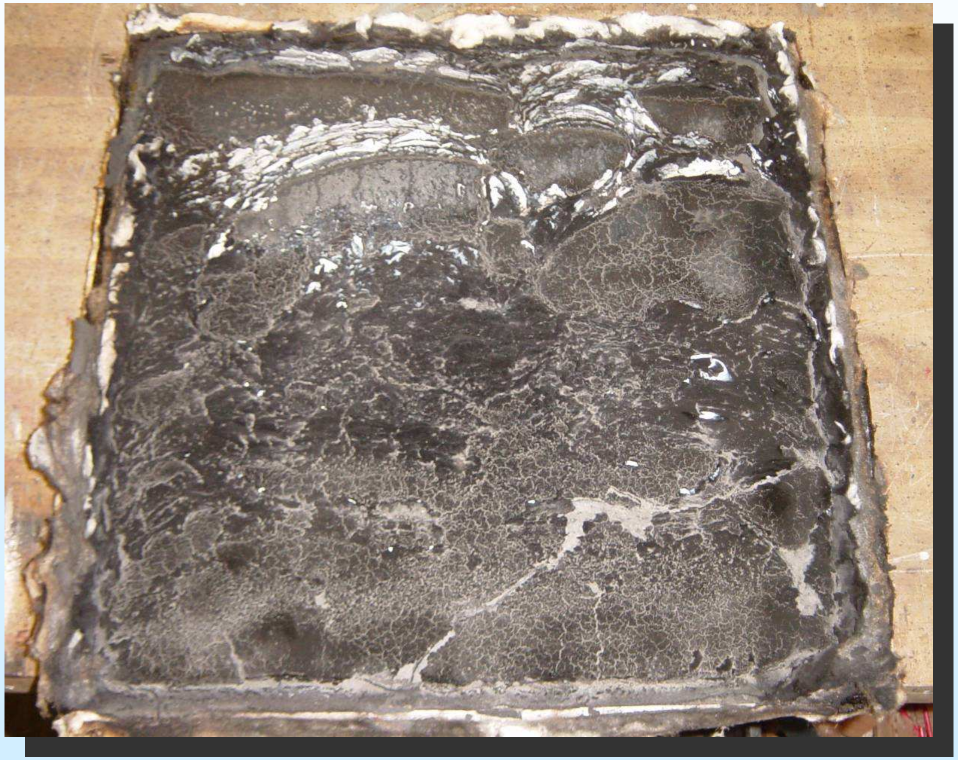


Intermediate-Scale Screening Tests

- Burn-through test apparatus used to evaluate down-selected coatings
- Tests conducted in accordance with MIL-STD-2031 App. B *David Taylor Research Center Burn-Through Fire Test* utilizing direct flame impingement
- Thermal exposure equivalent to approximately 200 kW/m^2
- 18in. square samples used
- Insulation performance evaluated via backside temperature measurements

Burn Through Test Results

- All coatings performed well, except coating I
- Poor adhesion to steel after thermal exposure
- Friable char identified as possible flaw due to tendency of char to slough off thus minimizing insulation performance of coating
- Turbulent conditions of full-scale, real-world fire scenario may exacerbate this problem



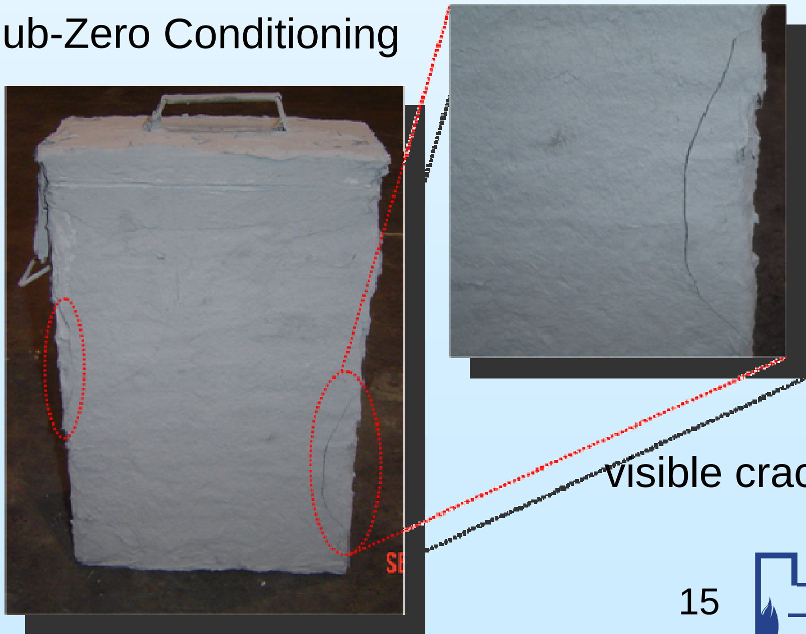
Full-Scale Test Method

- Three down-selected commercial coatings were then applied to 9 PA-124 munitions containers (3 each)
- Loaded with eight, inert mortars
- Containers were then subjected to thermal conditioning per MIL-STD-1904A *Design and Test Requirements for Level A Ammunition Packaging*
  - Elevated Temperature: 160ºF
  - Ambient Temperature: 72ºF
  - Sub-Zero Temperature: -65ºF
- Following thermal conditioning, all containers were immediately drop tested and evaluated using the UL1709 *Standard for Rapid Rise Fire Tests* furnace exposure

Thermal Conditioning and Drop Testing

- After being conditioned for 24 hrs, each container was dropped from an elevation of 7 ft on the largest face of the container
- Sub-zero conditioning proved to be the most detrimental to durability of coatings

Sub-Zero Conditioning



Visible cracks

Chipping

Intermediate- Scale Furnace

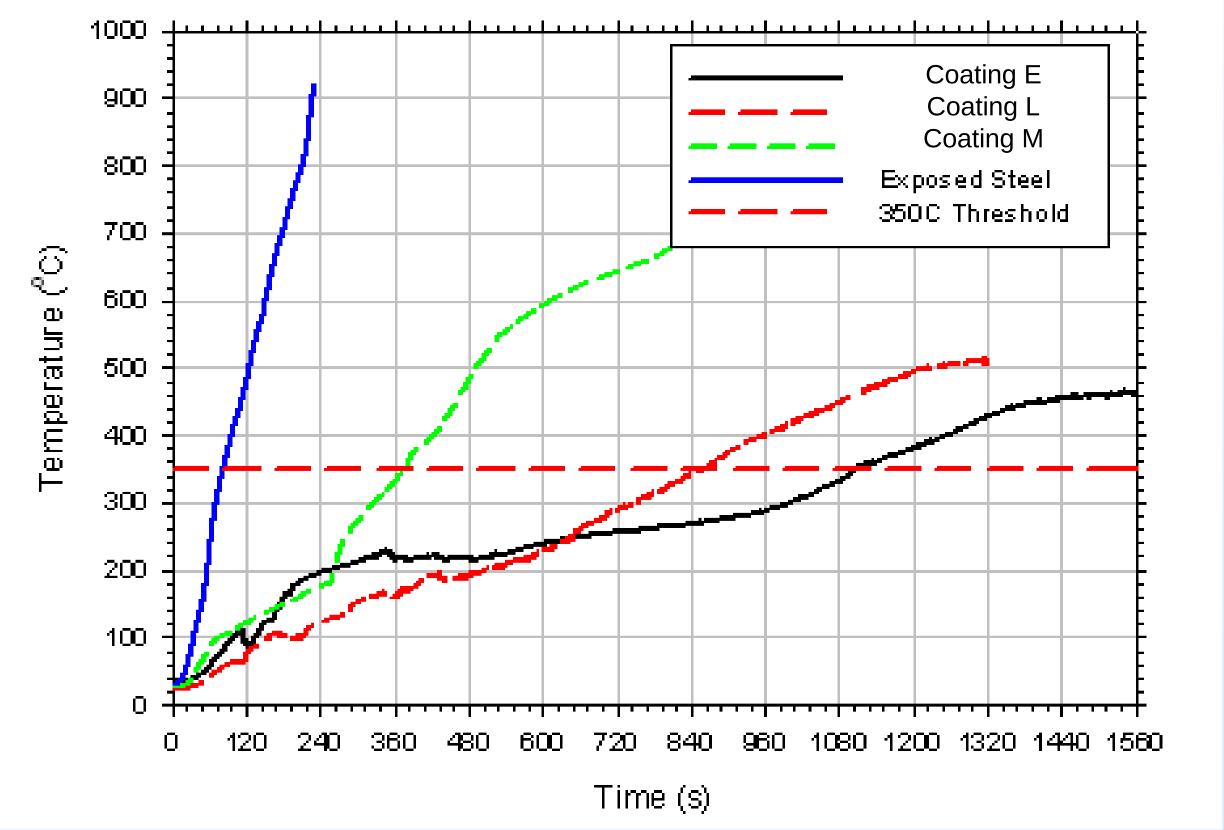
- After drop test, each container was exposed to UL1709 furnace fire
- Test method designed to simulate hydrocarbon pool fire
- T measurements collected at:
  - Container Wall
  - Mortar Tail
- Internal T: 350°C
  - Ensures fast cook-off point was passed

UL 1709 Exposure Results

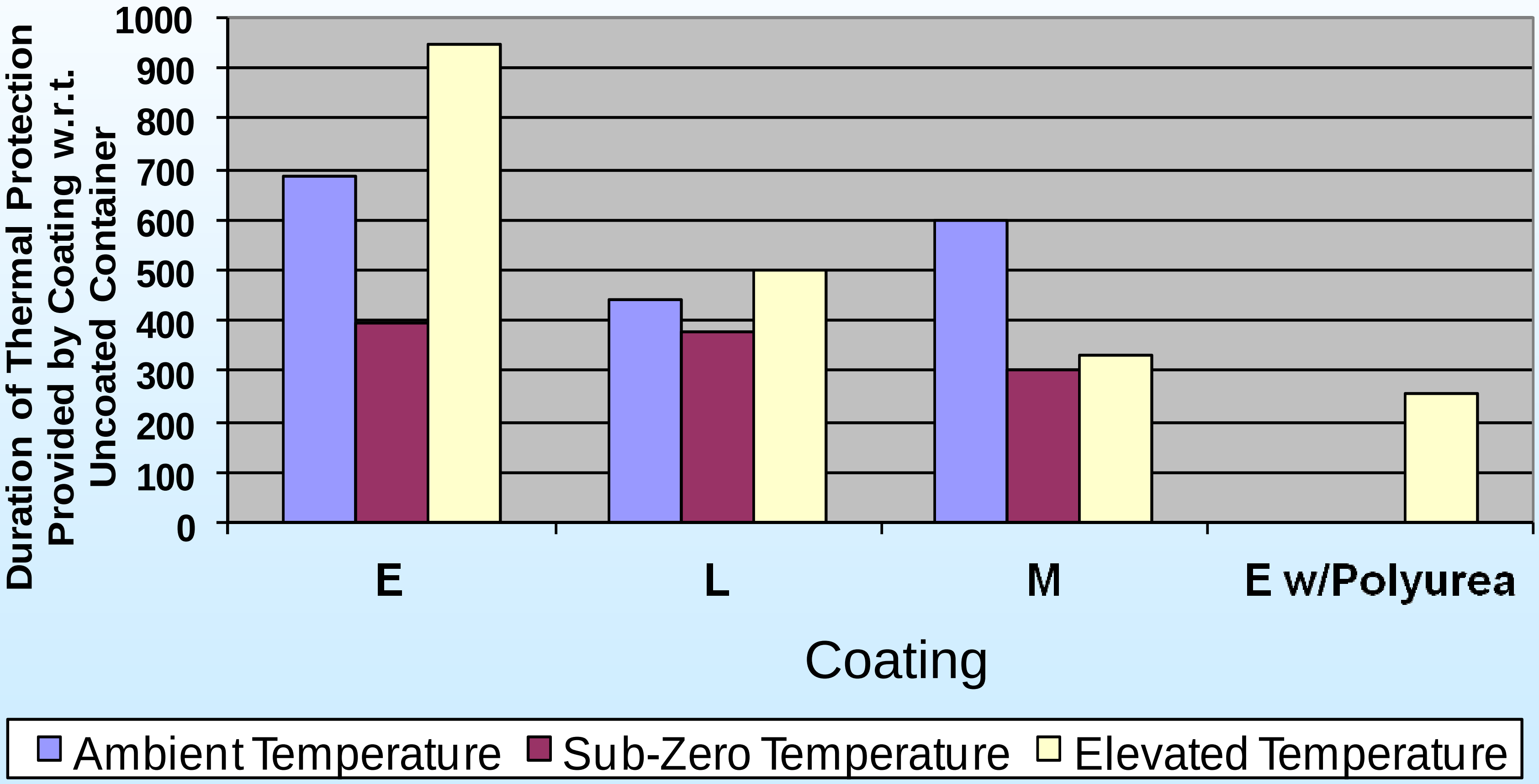
- On average, intumescent coatings evaluated provided 7-14 minutes of thermal protection
- More time before reaction in munitions

Intermediate Scale Furnace Results

Comparison of wall temperature at the right face of containers conditioned at ambient conditions



Intermediate Scale Furnace Results



Slow Cook Off

- Tested coated PA-70 steel ammunition containers
  - One live munition
- Simulate munition response when energetic material cook-off in adjacent room
  - Type I (Detonation)
  - Type II (Partial Detonation)
  - Type III (Explosion)
  - Type IV (Deflagration Reaction)
  - Type V (Burning)
  - Type VI (No Reaction)

Slow Cook Off Results

Results

- Containers ruptured
- Some coatings caught fire

Coating	Temperature (°C[°F])			Container burn time (sec)	60 mm RXN
	Air	Mortar	Container		
E	360[182.2]	295[146.1]	332[166.7]	504	Type V, Burn
H	348[175.6]	286[141.1]	326[163.3]	165	Type V, Burn
I	338[170]	288[142.2]	325[162.8]	260	Type V, Burn
M	340[171.1]	NA	345[173.9]	902	Type V, Burn
L	354[178.9]	308[153.3]	347[175]	30	Type V, Burn

Ballistic V50 Test

- MIL-STD-662 *V50 Ballistic Test for Armor*
- 11.75” x 4.00” x 0.030” piece of steel
- 0.22 caliber bullet weighing 1.1 grams
- 2024 T-3 Al witness sheet behind sample

<u>Results</u>

- Slight improvements in ballistic protection
- Some coatings adhere to steel better

Ballistic V50 Test Results

Construction	Thickness (mm[in])	% Increase	Weight (lbs)	Area (ft^2)	Areal Density (lb/ft^2)	% Increase	V50 (ft/sec)	% Increase	Spread (ft/sec)
Polyurea	3.68[0.145]	383	0.609	0.326	1.87	52	890	59	33
E w/ topcoat 1	2.8[0.11]	267	0.563	0.326	1.73	41	833	49	28
E w/ topcoat 2	3.10[0.122]	307	0.571	0.323	1.78	45	765	37	28
E	4.88[0.192]	540	0.699	0.326	2.14	74	850	52	36
B	3.45[0.136]	353	0.582	0.326	1.79	46	791	41	42
A	5.21[0.205]	583	0.693	0.326	2.13	73	927	66	17
I	5.08[0.2]	567	0.695	0.326	2.13	73	973	74	29
E /Polyurea	1.09[0.043]	43	0.43	0.326	1.32	7	660	18	4
E	2.49[0.098]	227	0.556	0.326	1.71	39	835	49	7
Bare steel	0.76[0.03]	0	0.401	0.326	1.23	0	560	0	29

Rough Handling Tests

- Performed on coatings E, E w/polyurea, I, L, M

- **ASTM B117/GM 9540P**: Accelerated Corrosion Test
  - Polyurea performed best
- **ASTM D2794**: Impact Resistance Test
  - E did not perform as well as others
- **70±3°C (158±5.4°F) @ 95±5% RH**: Humidity Test
  - 10 days- all coatings passed
  - 21 days- E was terminated, blistering and moisture retention
  - 10 weeks- E w/Polyurea, L, M terminated, loss of gloss
- **ASTM D1308-02**: Water Immersion Resistance Test
  - E w/Polyurea showed most color change

Technical Challenges

- Coating delamination
  - Cracking and chipping
  - Rough Handling – esp. at extreme temp
- Impact resistance
- Flexibility
- Moisture resistance
- Material compatibility
- Cost

Next Step

- Need to continue research on potential coatings/ system
- Need a full protection system
  - Ballistic
  - Fire/Thermal
  - Weathering/Rough Handling

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Questions?

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