Mitigation Techniques for Reduced Rocket Motor Vulnerability against External Thermal Stimuli

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RHEINMETALL
DENEL MUNITION

Outline

Introduction

Rocket motor response rationale for external thermal threats

Rocket motor design options for cook-off mitigation

Thermally-initiated active mitigation

Conclusions

Introduction

Background

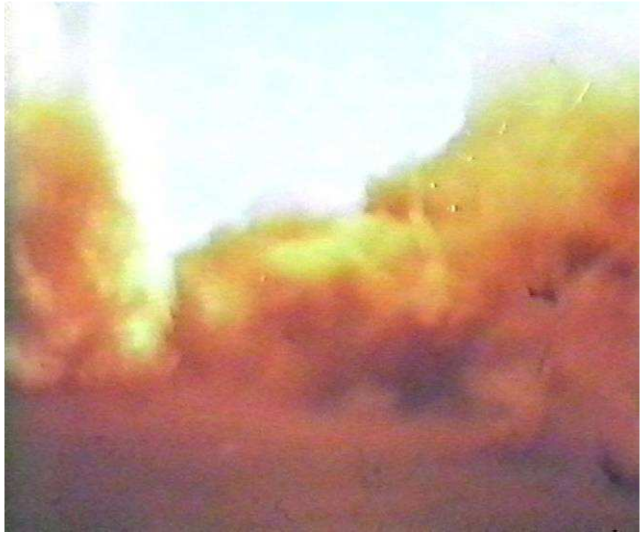
- Conventional tactical missiles particularly vulnerable to unplanned external stimuli.
- IM compliance of fragmentation warheads effectively achieved by ‘insensitive’ high explosive formulation.
- Reduced rocket motor vulnerability imperative for missile IM compliance.

Factors considering Tactical Rocket Motors

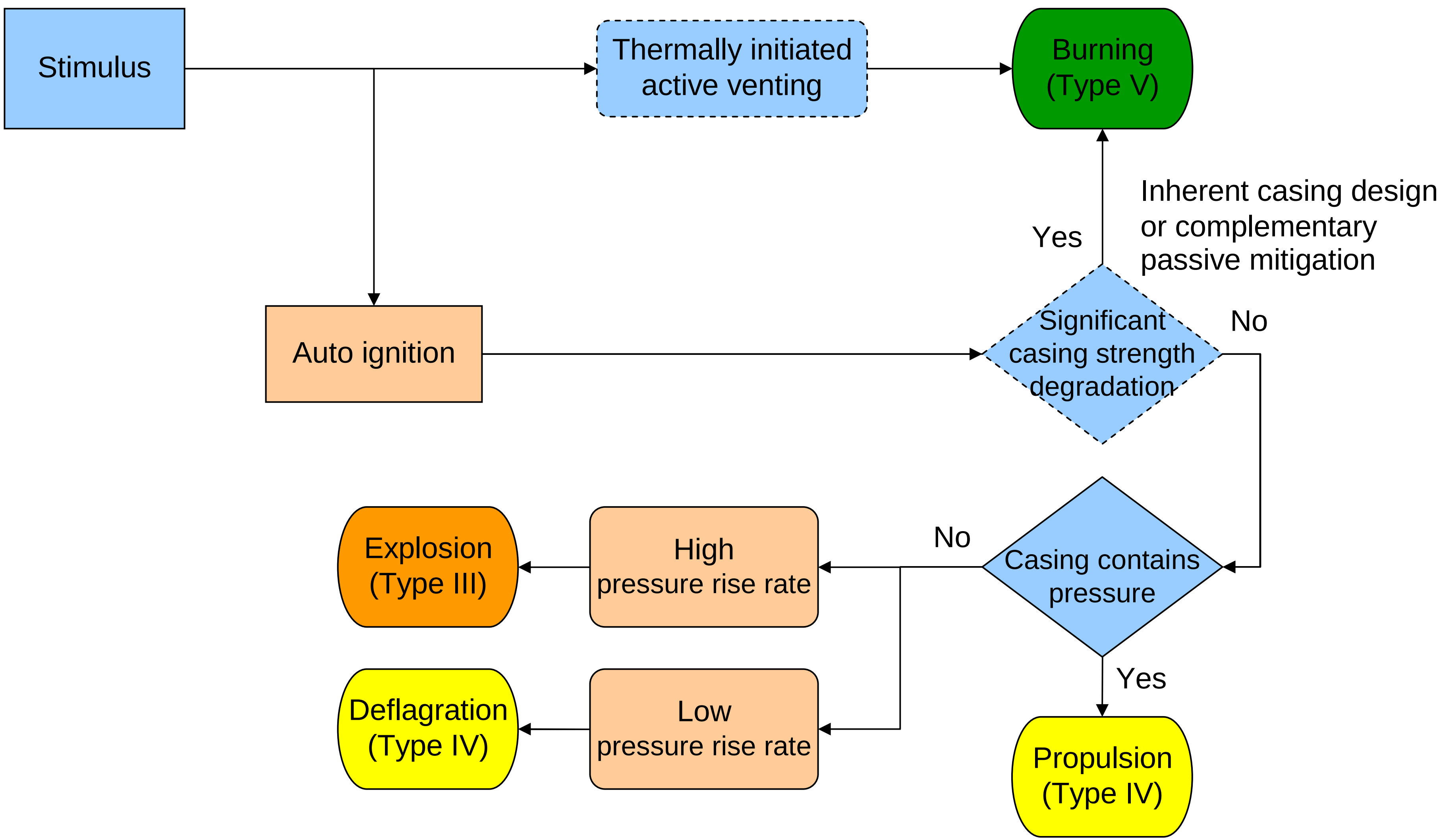
- Propellant generally constitutes up to 85% of the energetic material in missile.
- Rocket motors require confinement of casing for normal operation.
- Conventional composite propellants more sensitive than high explosives for some thermal stimuli.

	Fragmentation Warhead				Rocket Motor			
	FCO	SCO	BI	FI	FCO	SCO	BI	FI
Conventional	II	V	I	I	III	II	IV/V	IV/V
IM Variant	V	V	NR	NR	V?	V?	IV/V	IV/V

Slow Heating Test
Baseline Rocket Motor Design (HTPB Propellant)

Rocket Motor Response to Fast Cook-off Stimuli (Fuel Fire)

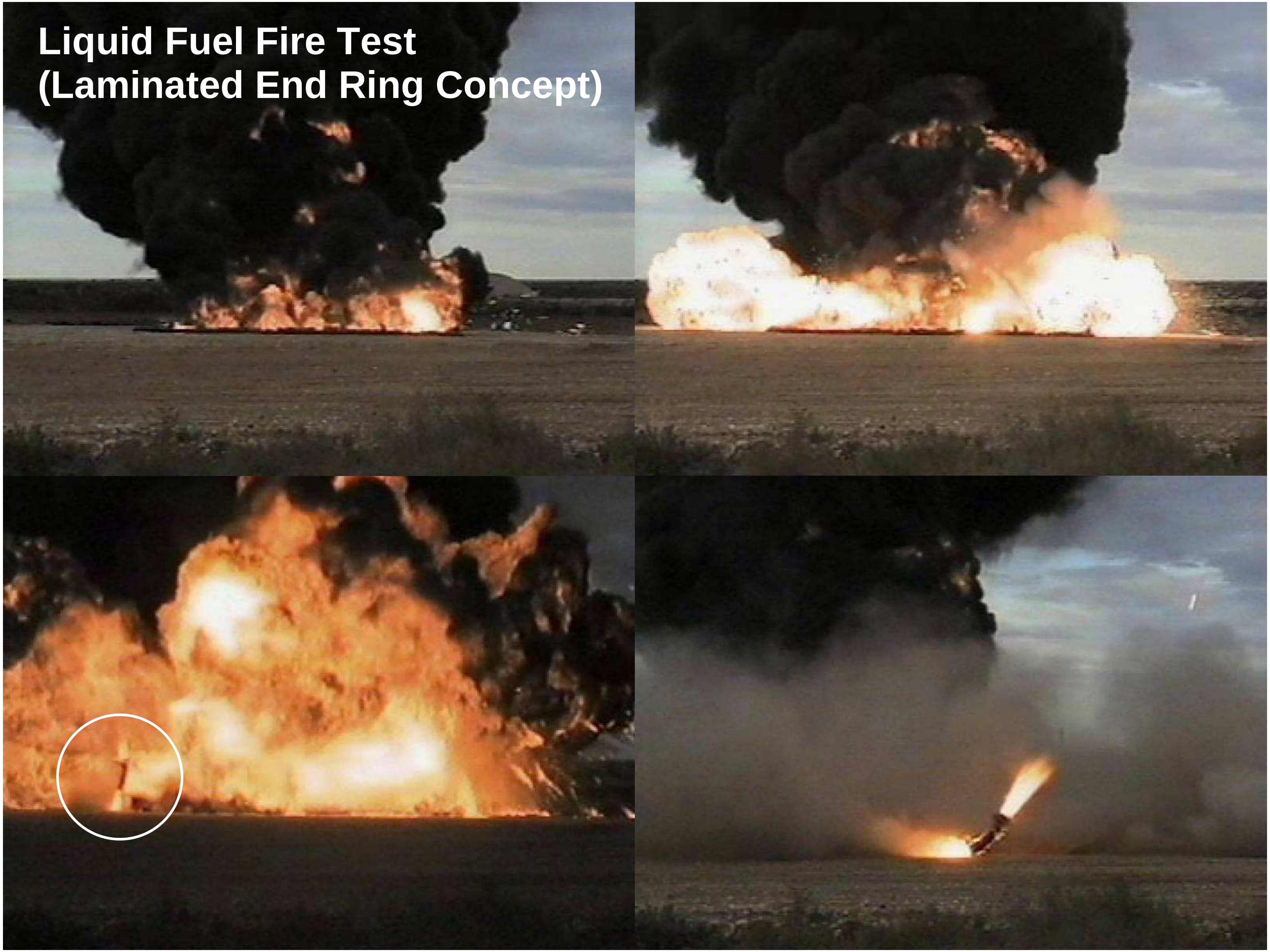


Composite Casing Technology

Laminated end rings with reduced structural integrity of bondline interface at elevated temperatures

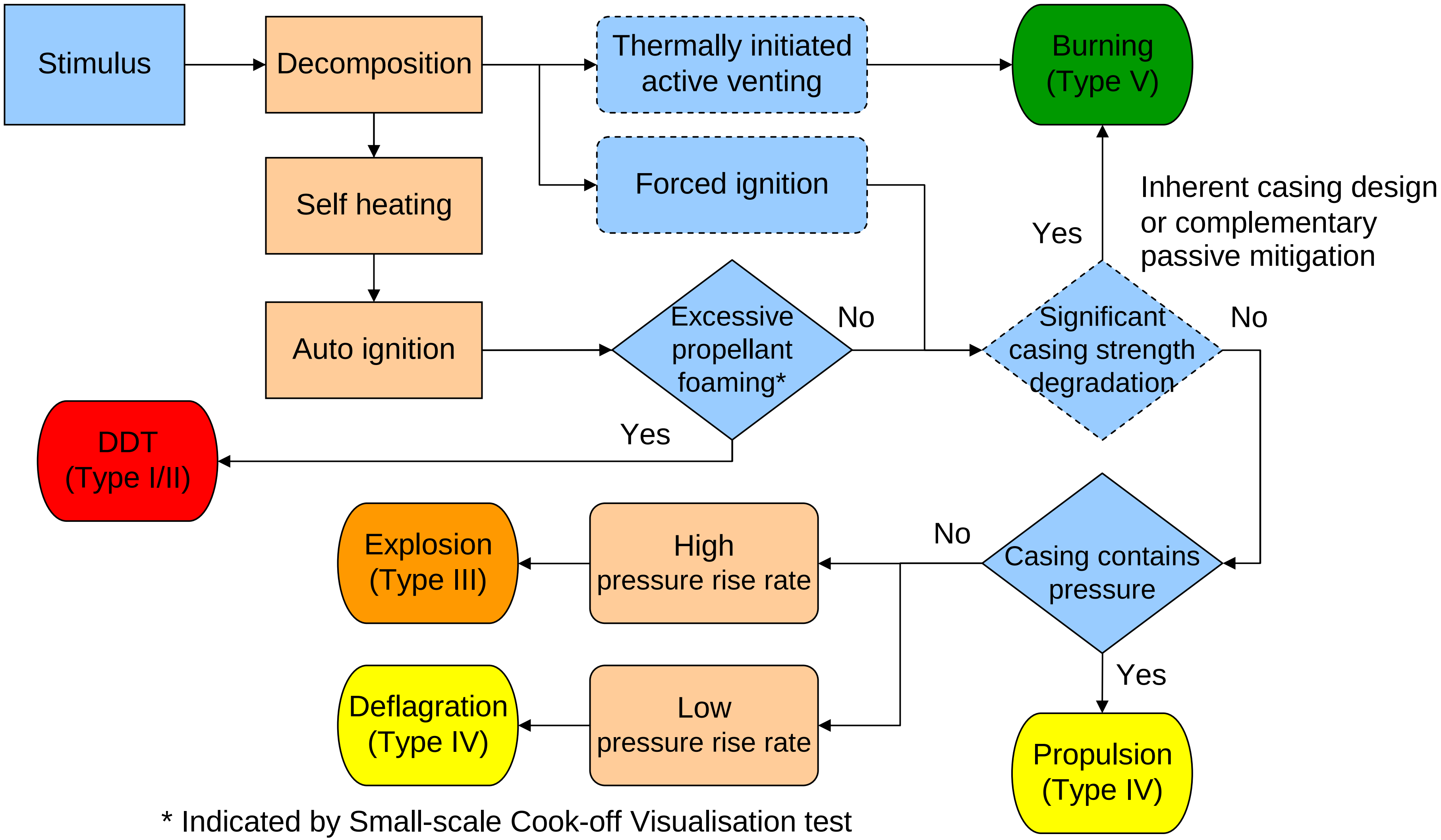
Hybrid laminate to reduce confinement of slender motors at elevated temperatures

Liquid Fuel Fire Test
(Laminated End Ring Concept)



Liquid Fuel Fire Test (Laminated End Ring Concept)

Rocket Motor Response to Slow Heating Stimuli



* Indicated by Small-scale Cook-off Visualisation test

Passive Venting of Casing - Considerations

Aero heating

- Determine as a function of mission time for various scenarios:
  - Interface temperature
  - Required strength and stiffness of motor casing (to overcome motor pressure and bending)
- Maximum strength not necessarily required at maximum temperature

Pressurisation rate influences:

- Casing burst pressure
- Casing failure mode

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Rocket Motor Design Options and Associated Vulnerability

Configuration		Vulnerability	
Propellant	**Mitigation**	**Fuel Fire**	**Slow Heating**
Conventional	None	Explosion (Type III)	Detonation (Type II)
Conventional	Passive venting	Burning (Type V)	Detonation (Type II)
'Insensitive'	None	Explosion (Type III)	Explosion (Type III)
Conventional	Forced ignition	Propulsion (Type IV)	Propulsion (Type IV)
'Insensitive'	Passive venting (NB: To be effective for slow heating)	Burning (Type V)	Burning (Type V)
Conventional	Forced ignition + Passive venting	Burning (Type V)	Burning (Type V)
Conventional	Active venting	Burning (Type V)	Burning (Type V)

Technologies for Cook-off Mitigation

Technology	Major Considerations
'Insensitive' propellant	■ Passive case venting required to avoid explosive or propulsive reactions
Forced ignition	■ Passive case venting required for non-propulsive burning
Laminated end rings/closures	■ Some propulsion for typical slender boost-sustain configuration ■ Not effective for slow cook-off
Shape memory alloy dislocating closures	■ Complex interfaces, mass penalty ■ Sectional venting of slender motors result some propulsion ■ Only effective for slow cook-off in combination with reduced sensitivity propellant or forced ignition
Active mitigation	■ Additional explosive elements ■ Aero heating for missile integrated devices

Thermally-Initiated Active Mitigation Challenges

Functionality

- Effective for full spectrum of cook-off threats
  - Liquid fuel fire
  - Slow heating
- No external energy supply

Safety

- No stored energy
- Primary explosives out-of-line
- Only one environment for arming
- Only thermal stimuli associated with bulk cook-off threats to activate system
- Not to be initiated by aero heating*

Physical*

- Minimum mass (especially for wingtip-mounted missiles)
- Minimum protrusion from airframe

* Only for devices integrated for captive carriage and missile free flight

Thermally-Initiated Active Mitigation System (TIAMS)

Generic, modular design for various applications

- Integrated with missile
- Detachable from missile
- Integrated with packaging
- Integrated with launcher

Advantages

- Reduced production cost (design one-for-many)
- Serviceability (replacement unit)
- Retrofitable
- Reusable

Physical Characteristics

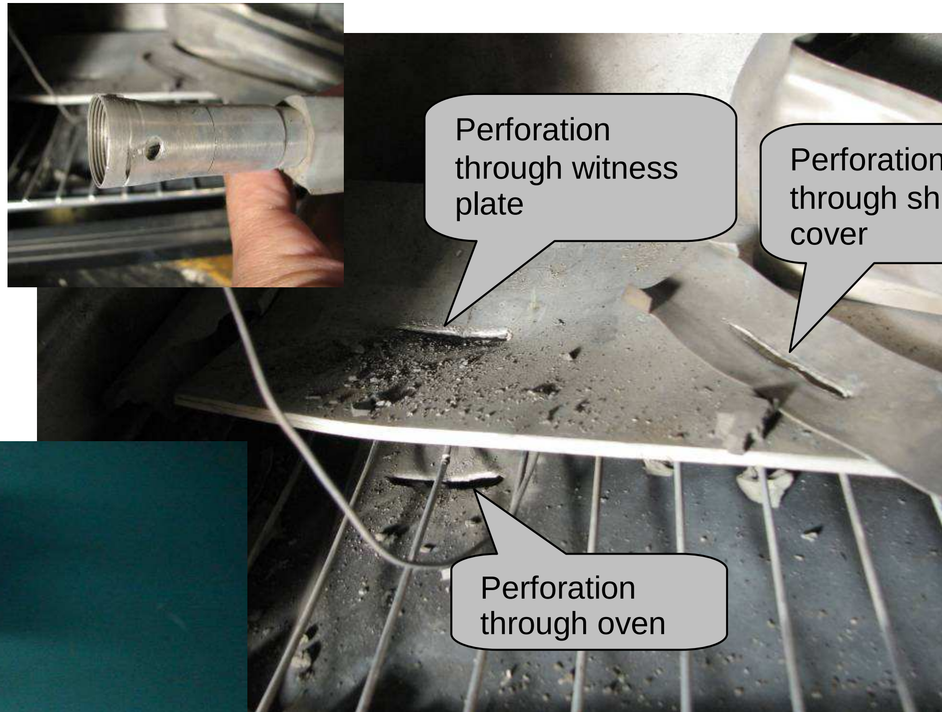
- Total mass < 500 grams
- NEC < 2 grams
- Overall dimensions: 25 × 25 × 380 mm

Functional Characteristics

- Venting
  - Perforate 1,5 mm maraging steel and thermal insulation
  - ‘Soft’ ignition of propellant
- Activation
  - Slow Heating reaction temperature ~140 ºC at 3,3 ºC/h
  - Fuel Fire reaction time 90 - 120 s

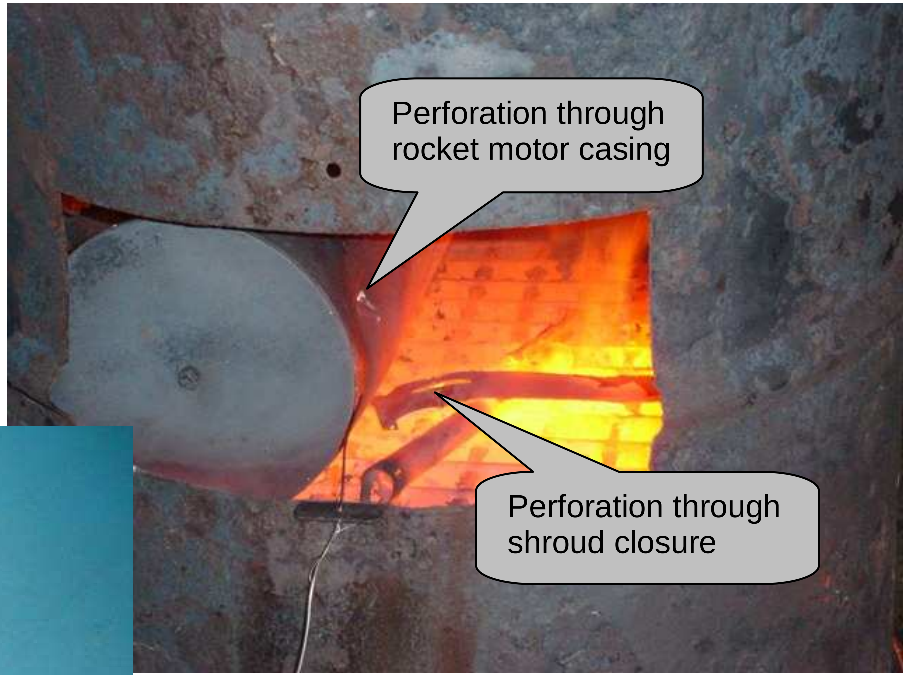
Slow Heating Test

- STANAG 4382
- Heating rate 3,3 ºC/h
- Reaction temperature 143 ºC/h



Liquid Fuel Fire Test

- Reaction time 150 seconds (from fuel ignition)
- Average fuel temperature 913 ºC (7 - 150 s)



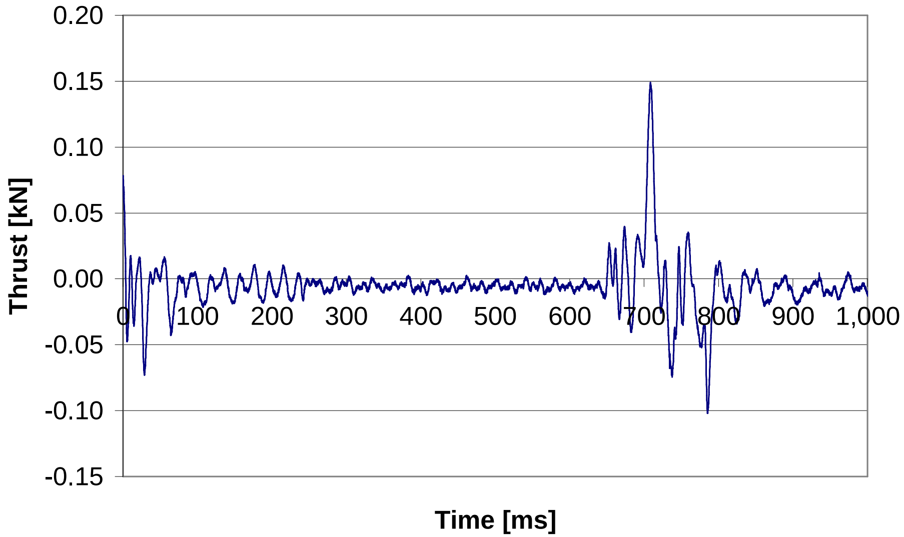
Slow Heating Evaluation

Reaction

- TIAMS reaction at 140 ºC
- Casing vented
- No significant thrust
- No debris beyond 15 m*

Classification

- Type V (burning)



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Conclusions

Passive venting concepts present limited alleviation of violent cook-off reactions.

Passive venting required to render rocket motors containing reduced sensitivity propellants IM compliant.

Active mitigation considered most effective IM solution for tactical rocket motors against thermal threats, considering retrofitability and demonstrated functionality.