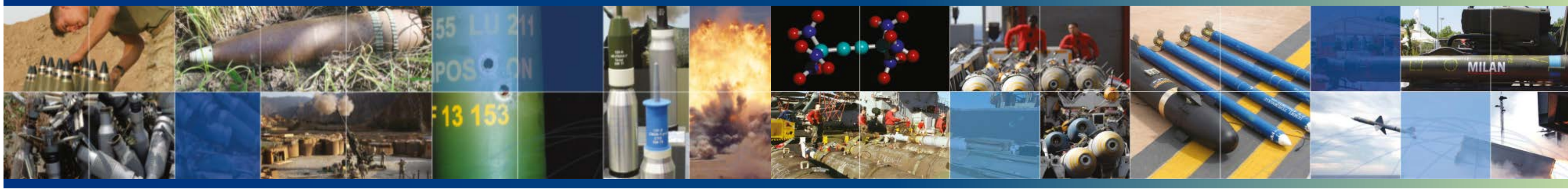
MSIAC

Munitions Safety Information Analysis Center

Supporting Member Nations in the Enhancement of their Munitions Life Cycle Safety



MITIGATION TECHNOLOGIES FOR PROPULSION APPLICATIONS

Christelle Collet, Maud Cheneau, Emmanuel Schultz

IMEMTS 2018
Portland, OR, USA

OVERVIEW

Introduction

1. Passive Venting Devices
2. Active Mitigation Systems
3. Intumescent Coatings
4. Casing Materials
5. Barrier – Packaging – Arrangement

Analysis & Conclusions

INTRODUCTION

General SRMs' IM Signatures agreed by experts during the MSIAC workshop on IM Technology Gaps* :

Rocket Motor Type	IM Signature					
	FCO	SCO	BI	FI	SR	SCJ
Reduced Smoke /Smokey	IV	I-IV	IV	IV	Pass	III
Min Smoke	IV	I-IV	I-IV	I	I-III	I

In 2016, in the frame of an MSIAC internship project, a review was done on mitigation technologies applied to SRMs

53 examples of mitigation techniques / examples / strategies were found during this study:

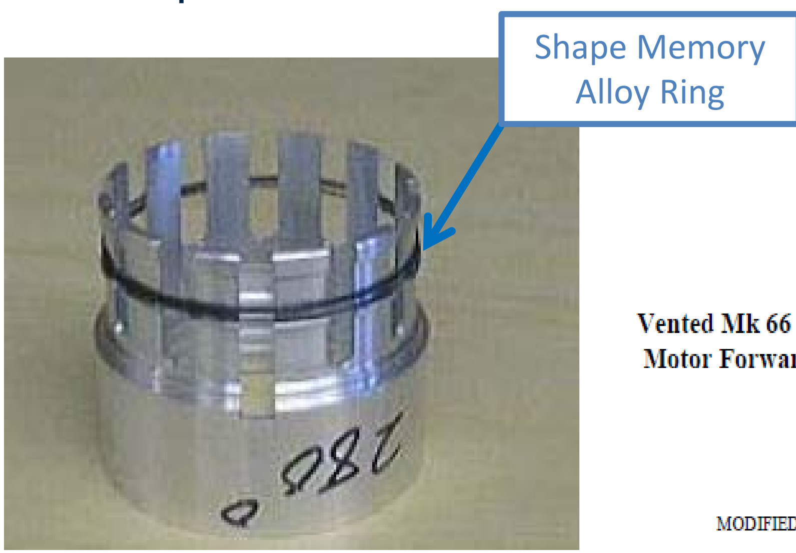
1. Passive venting devices: 8 examples
2. Active mitigation systems: 16 examples
3. Intumescent coatings: 15 examples
4. Casing materials: 8 examples
5. Packaging – Barrier – Arrangement: 6 examples

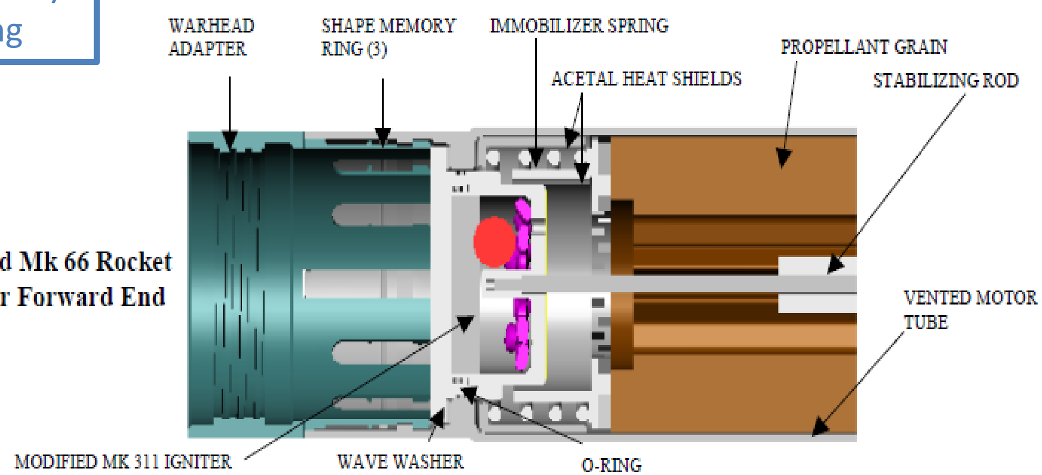
*Sharp, M.W., MSIAC IM Technology Gaps Workshop – Output from the Rocket Motor Technology Discussion Group, MSIAC Report L-183, January 2014

1. Passive Venting Devices

- Venting devices are designed to release the pressure in the casing created by an unexpected combustion before it transits into a more hazardous regime (in case of DDT for instance)
- Passive venting devices are mostly designed against FCO and SCO threats

- Example of a shape memory alloy ring for the MK66 motor: upon heating, the ring contracts, squeezing the tang fingers inward, and releasing the adapter





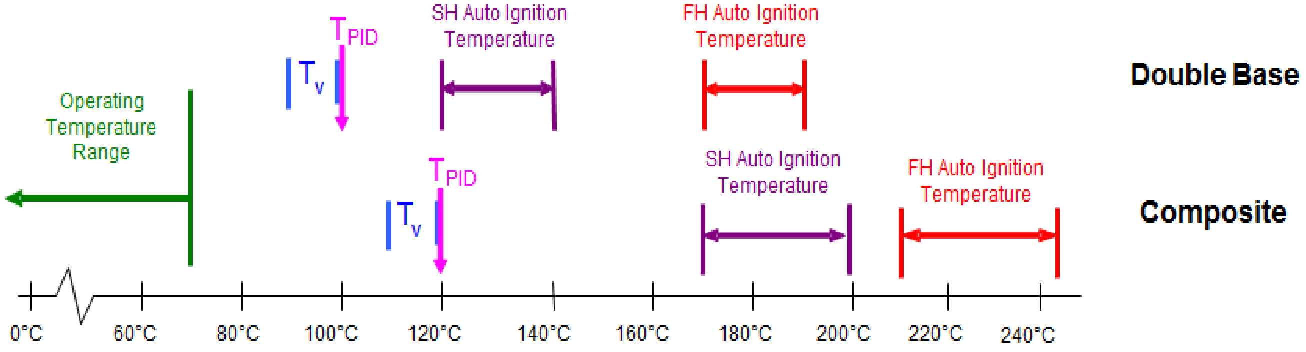
Vented Mk 66 Rocket Motor Forward End

Hawley, E., Johnson, J., Insensitive Munition Technologies developed for the 2.75-Inch Rocket System, IMDT, 2003

2. Active Mitigation Systems

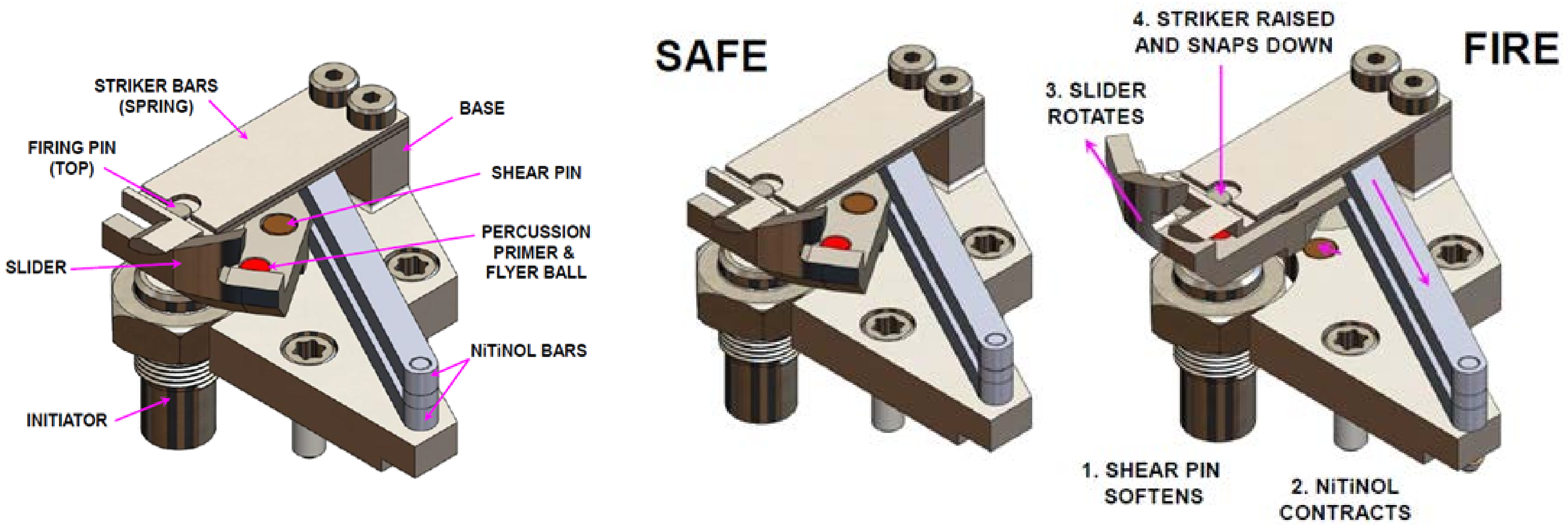
Functioning principle:

1) Temperature raises rapidly around the munition (FCO) or uniformly within the munition (SCO)
2) A venting device reacts, resulting in a rupture of the case
3) **<u>Before</u>** reaching its slow heating auto ignition temperature, **<u>but after</u>** the venting device has functioned, the propellant is ignited by a Pre-Ignition Device (PID)
4) The gases are evacuated through the vent, resulting in a controlled and low burning rate



Strickland, A., Nugeyre, J-C., A scientific review of the current state of IM mitigation devices for use with rocket motor systems and the future development outlook, IMEMTS, 2007

A relevant example in this family: the RITA system designed for the MK22 rocket motor

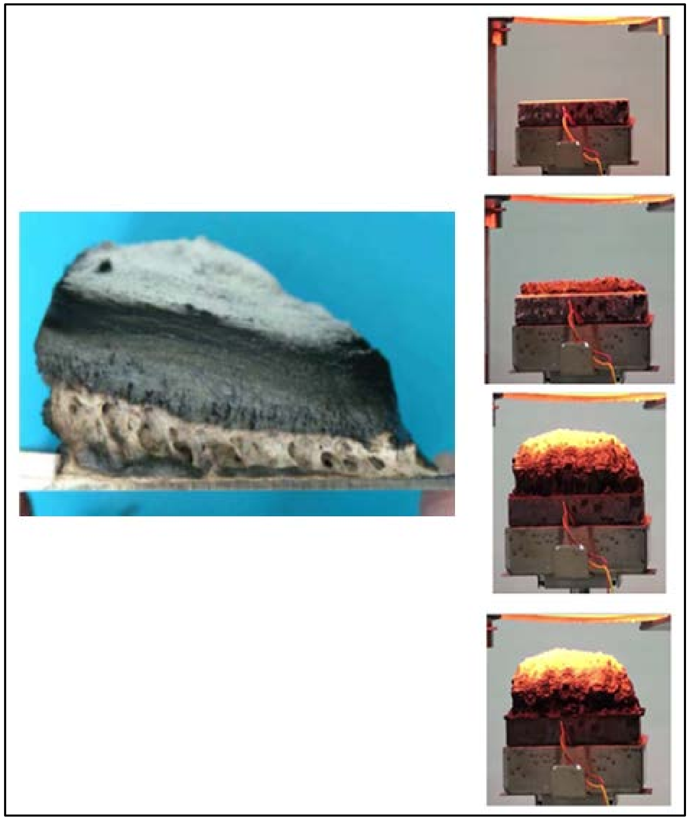


Sain, J., Sanford, M., Active Mitigation: Rocket Initiator Thermally Activated (RITA) Insensitive Munitions (IM) Device for the MK22 Mod 4 Rocket Motor, FUZE 2012

3. Intumescent Coatings

Supporting Munitions Safety

- Intumescent coatings are materials that swell (i.e. intumesce) when subjected to heat, such as from a fire
- They expand to several times their original thickness, forming a foam-like insulating barrier with reduced thermal conductivity thus reducing the heat transfer rate
- Intumescent coatings are designed against FCO threats



3. Intumescent Coatings

- Although intumescent coatings delay munitions' reaction, they generally do not make this reaction less violent!

→ used in association with other mitigation devices/strategies (e.g. apply intumescent coating everywhere except on one strip – bare strip - along the axis)

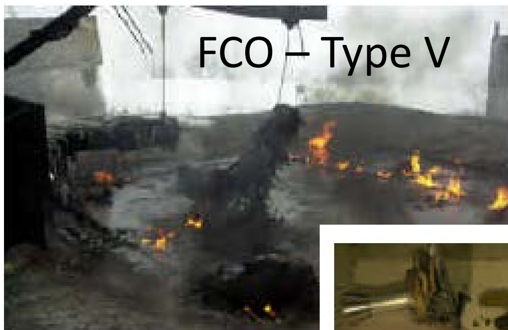
Results on MAGIC 1 for different coating configurations*

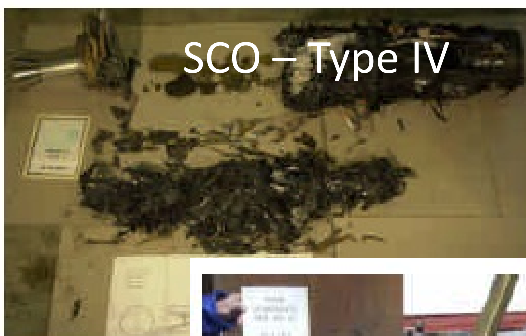
Outer thermal Insulation thickness (mm)	Outer thermal insulation weight (kg)	Bare strip width (mm)	Initial temperature (°C)	Reaction (Type)	Time before reaction (s)
0	0	0	15	III	100
0	0	0	40	IV - III	90
0	0	0	70	IV	60

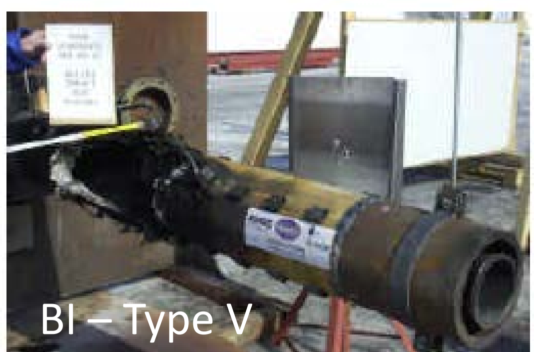
Bouchez, J., Fuel Fire Tests on Rocket Motors With and Without Insulation, Proceedings of the NIMIC Workshop on Cookoff, 1993

4. Casing Materials

- Composite and hybrid (composite & metal) casings have been progressively replacing metal casings to save weight in the munition system
- Their good ability in mitigating mechanical and thermal threats make them good candidates for IM







IM Tests on the ESSM Motor featuring a carbon fiber reinforced composite material*

Steel Strip Laminate: an association of steel strips and adhesive resin

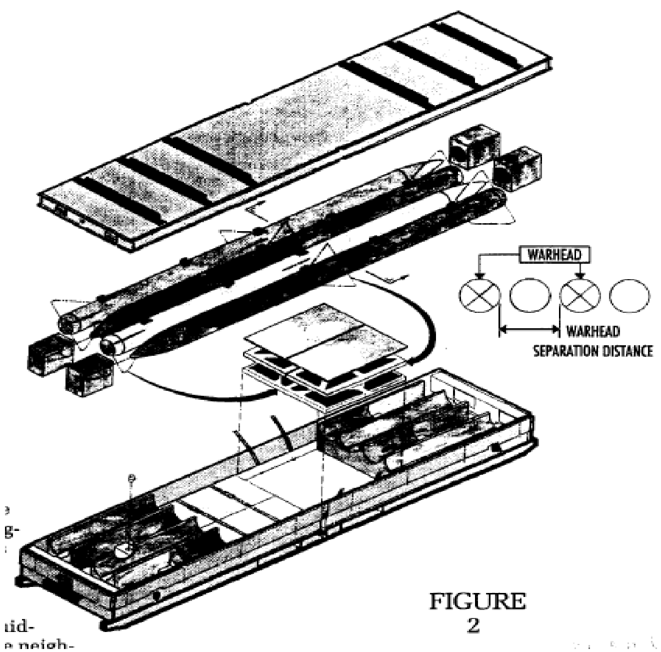
*Tenden, S., Fossumstuen, K., IM Improvement of Rocket Motor by Composite Case, Nammo Raufoss. Presented at the NATO RTO Applied Vehicle Technology (AVT) Panel Meeting in Aalborg, Denmark, September 2002

5. Packaging – Barrier – Arrangement

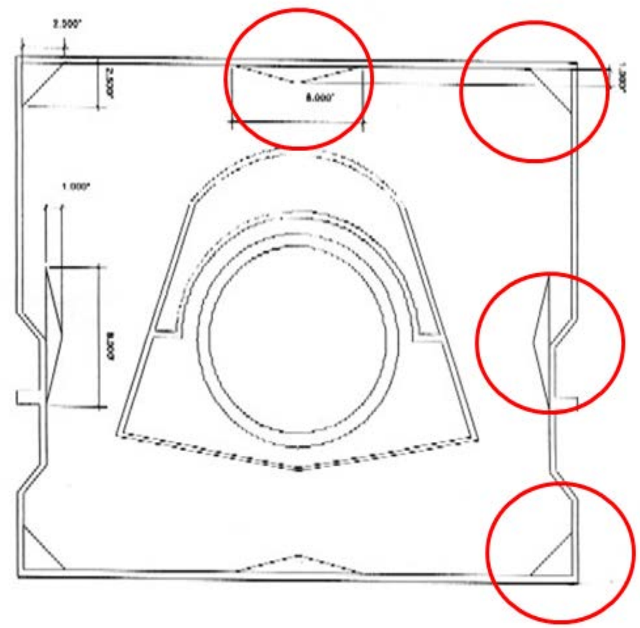
Supporting Munitions Safety

- These mitigation technologies are especially designed against mechanical threats that may occur during storage or transportation

Head to tail arrangement
Example below with the AMRAAM container[1]



Diverters
Example below with the JASSM shipping container[2]



[1]Raevis, J., Insensitive Munitions Protection for the AMRAAM Missile Container, 1993

[2]Lobdell S.K., SMERF code analysis to examine the effect of diverters to prevent Sympathetic Reaction into JASSM shipping containers, IMEMTS, 1998

5. Packaging – Barrier – Arrangement

Even if no SRM featuring a bore mitigant has been yet qualified for in-service systems, this is considered as a promising technology against BI or FI threats. Indeed, this technology may prevent Burn to Violent Reaction transitions in SRMs.

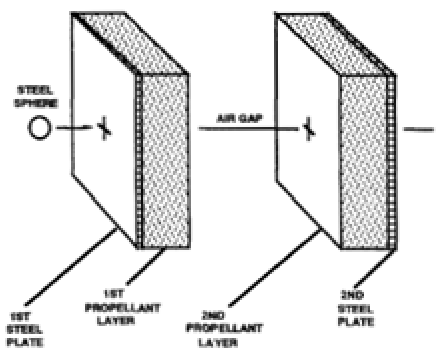
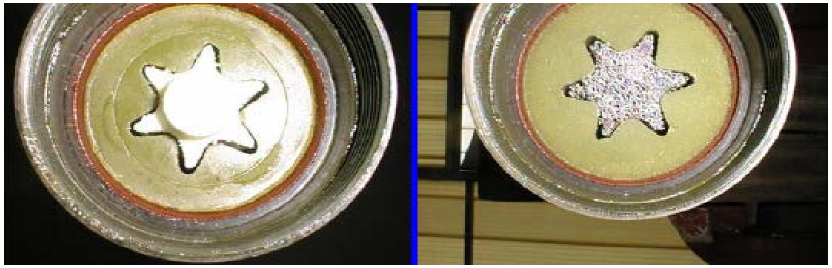


FIG. 1. Planar Rocket Motor Test Model.

TABLE II. Planar Model Test Results.

Test No.	Propellant	Air Gap Width, in	Air Gap Material	Impact Vel., ft/s	Reaction
1	HEP-2	1.5	Air	3,970	detonation upon debris bubble impact
2	HEP-2	0.75	Foam	4,301	no reaction
3	HEP-2	1.5	Foam	4,121	no reaction
4	HEP-2	2.25	Foam	4,173	no reaction
5	HEP-2	1.5	Foam	3,084	no reaction
6	XLDB	1.5	Air	3,780	detonation upon debris bubble impact
7	XLDB	1.5	Foam	3,980	no reaction

Finnegan, S, DeMay, S., Pringle, J., Heimdahl, O., Dimaranan, L., Smith, A., Use of Polymeric Foam Inserts for Mitigation of Impact-Induced Reactions in Solid Rocket Motors with A Center-Perforated Grain Design, 1994



LSRM Response to Bullet impact (STANAG 4241 ; 12.7mm P, 850m/s)

Test label	Metal fragments	Blast overpressure at 10 m (hPa)	Blast overpressure at 15 m (hPa)	Response Type
Reference	3 fragments up to 50 m	28		IV
Reference with igniter	5 fragments up to 45 m	33	19	IV
Hybride case	6 fragments up to 10 m		13	IV
Weakened case	10 fragments up to 65 m	26		IV
Reference & Aluminium foam	6 fragments up to 12 m	27	20	IV
Refrence & PEI Foam	5 fragments up to 7 m	23	12	V
	2 fragments on place	22	11	V

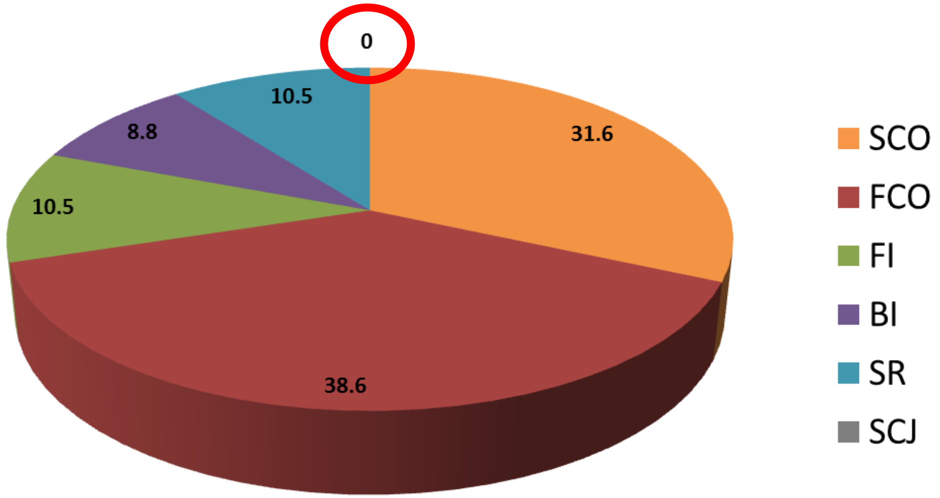
Le Roy, M., Zanelli, D., Roziere, J-M., A Concept to Mitigate the Rocket Motor Response at Impact, IMEMTS, 2001

ANALYSIS OF THIS WORK

The advantages and drawbacks for the 5 mitigation families found during this review are gathered here below

IM Family	Threats	Advantages	Drawbacks
Passive Venting Devices	FCO, SCO, BI, FI	Possibility to set the operating temperature	Useless against SCO if used alone Reliability level could be increased
Active Mitigation	FCO, SCO	Possibility to set the operating temperature	Use of EM adds safety issues Generally requires a combination of mitigation technologies
Intumescent coating	FCO	Ease of implementation Low cost	Requires surface pre-treatment Poor robustness Increased weight and diameter
Casing materials	FCO, BI, FI, (SR)	No additional part	Specific design of the case Relative high cost Not applicable for all types of missiles Not likely to respond under SCO
Packaging Barrier Arrangement	BI, FI, SR	Retrofittable for an existing munition	Requires a combination of IM technologies Increased weight and volume of packaged munitions

ANALYSIS OF THIS WORK



→ About 70 % of the existing mitigation technologies for SRMs are designed against thermal threats (FCO and/or SCO) although the impact threats (BI, FI, SR and SCJ) are considered as a critical issue for rocket motors, especially in the case of minimum smoke ones:

Rocket Motor Type	IM Signature					
	FCO	SCO	BI	FI	SR	SCJ
Reduced Smoke /Smokey	IV	I-IV	IV	IV	Pass	III
Min Smoke	IV	I-IV	I-IV	I	I-III	I

→ No existing mitigation technique against SCJ threats for SRMs

CONCLUSIONS

- Promising ways are existing to reduce or prevent high reaction levels from Solid Rocket Motors
- The review recently done by MSIAC on this topic revealed a total of 53 mitigation technologies, sorted into 5 families:
  - Passive Venting Devices
  - Active Mitigation Systems
  - Intumescent Coatings
  - Casing Materials
  - Packaging - Barrier - Arrangement
- These mitigation technologies are mostly designed against thermal threats (SCO, FCO) although mechanical threats remain a critical issue for SRMs, especially minimum smoke SRMs
- As a perspective, a summer project will be conducted in 2018 on mitigation technologies for warhead. The outputs from these summer projects will eventually result in an exhaustive and up-to-date online database of mitigation technologies available for the overall munition system. Coming soon in MTM…

QUESTIONS?