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**RDECOM**



U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

# Fire Resistant Energy Attenuating Materials for use in Military Vehicles

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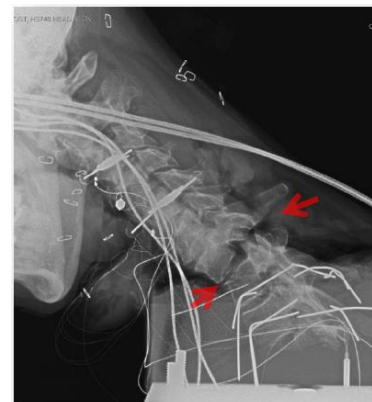
TARDEC Ground System Survivability

Interior Blast Mitigation Team

14 October 2015



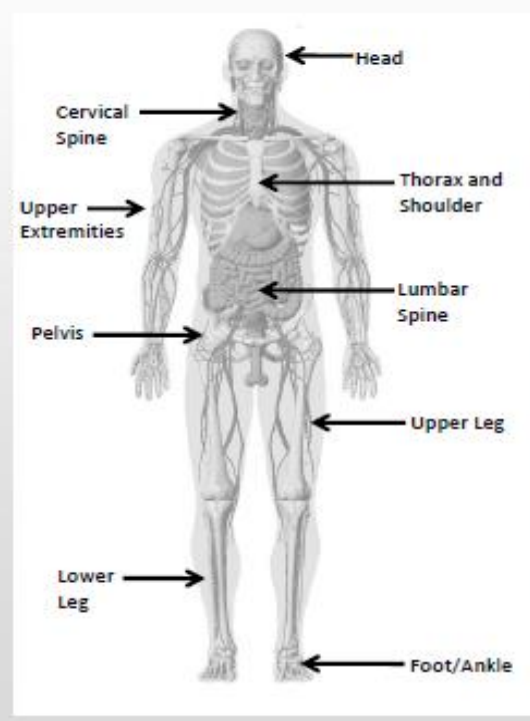
- Statement of the Need
  - Underbody blast, collision and roll-over events in current military vehicles result in high percentage of head and neck impact related wounded and killed in action mounted war-fighters incapable of completing their mission.
  - Military ground vehicle interiors need significant improvement in mounted war-fighter head & neck impact protection over current vehicle performance
  
- Solution to the Need
  - Find an integrated solution for effective mounted war-fighter impact injury protection




**Medical Research and Materiel Command**  
**U.S. Army Aeromedical Research Laboratory**  
**Fort Rucker, Alabama**


## Whole-Body Summary

KIA	Injuries (n=2180)	Indiv (m=116)
Head and Face	24%	84%
Cervical Spine and Neck	7%	52%
Upper Extremity	7%	49%
Torso (shoulder and abdomen)	35%	78%
Lumbar Spine	5%	30%
Pelvis (perineal and hip)	8%	51%
Lower Extremity	1%	9%
Upper Leg	4%	44%
Lower Leg (knee)	4%	43%
Foot/Ankle	7%	36%



WIA	Injuries (n=1664)	Indiv (m=439)
Head and Face	9%	16%
Cervical Spine and Neck	6%	19%
Upper Extremity	7%	16%
Torso (shoulder and abdomen)	20%	32%
Lumbar Spine	17%	35%
Pelvis (perineal and hip)	4%	8%
Lower Extremity	1%	2%
Upper Leg	2%	8%
Lower Leg (knee)	11%	28%
Foot/Ankle	23%	33%

n = total number of injuries for KIAs and WIAs, respectively  
 m = total number of Individuals for KIAs and WIAs, respectively

# Background - Vehicle Baseline Testing



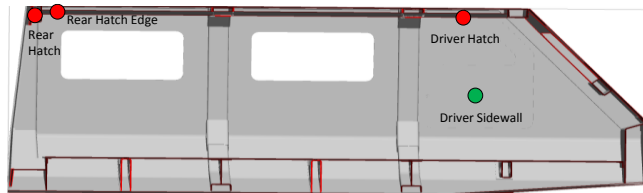
- Testing the original structure of the vehicle without the addition of interior impact protective solutions, IIPS.
  - head impact injury performance of the vehicle's current design state
  - determines whether adding energy attenuating materials would be beneficial in reducing potential head impact injuries.
- Impact locations were selected based upon the proximity to the occupant's head in the upward and lateral motion typical of an underbody blast.
- Testing conducted at Soldier System Interface Impactor (SSII) Laboratory
  - Selfridge Air National Guard Base
- Free Motion Headform (FMH) injury assessment values compared to Occupant Centric Protection (OCP)
  - Threshold:  $HIC(d) \leq 1000$
  - Objective:  $HIC(d) \leq 700$
- FMH Impact Speed Measurement
  - $24 \text{ kph} \pm 1.0 \text{ kph}$
- Advanced Combat Helmet (ACH)
  - FMVSS 201U test equipment had too much variation for repeatability
  - Testing as conducted without an ACH where applicable



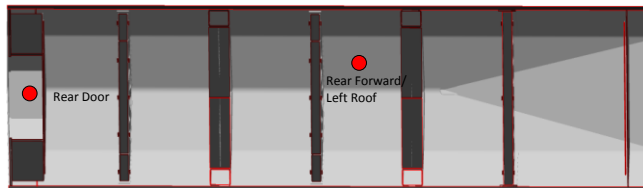
# Vehicle A Baseline Testing



- 87 head impact tests performed from June 2013 to July 2013
- Baseline testing without ACH was conducted on 6 locations

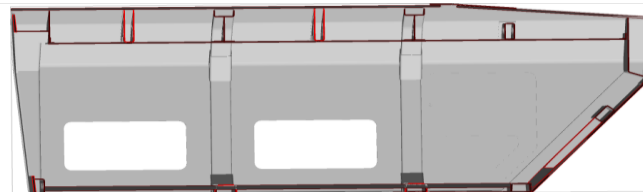


Side section view



Rear

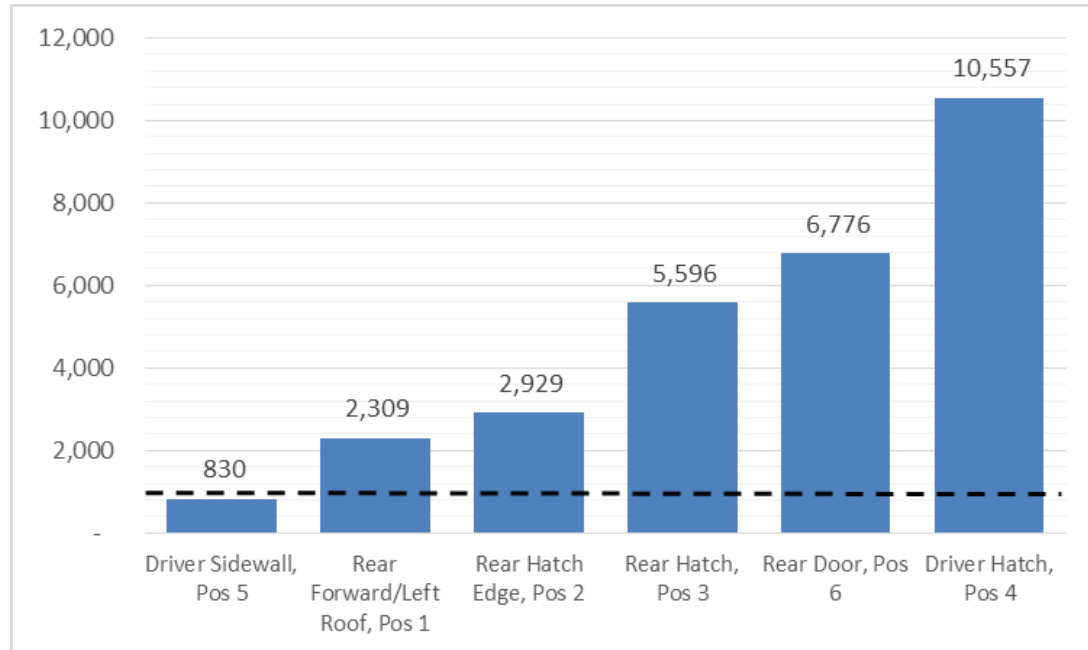
Hull plan view (ceiling)



Side section view (right)

- KEY:**
- Impact Location Meet Threshold
  - Impact Location Exceed Threshold

Front



\*Testing conducted without ACH

## Data Takeaway:

- Very rigid interior design, significantly higher than the injury criteria requirements (HIC(d) < 1000)
- Threshold requirement met for 1 location
  - Driver Sidewall
- Driver sidewall location consists of an electrical door panel which may act as an energy attenuator providing enough energy dissipation to prevent impact related head injuries without needed additional protection.
- Next Steps:
  - Addition of EA materials to each baseline location.

# Background – Material Testing



- Soldier System Interface Impactor (SSII) Laboratory located at Selfridge Air National Guard Base to conduct head impact testing
- FMH injury assessment values compared to Occupant Centric Protection (OCP)
  - Threshold:  $HIC(d) \leq 1000$
  - Objective:  $HIC(d) \leq 700$
- Current FMH analysis includes:
  - $HIC(d) = 0.75446$  (Free Motion Headform HIC) + 166.4
  - $HIC = \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} (t_2 - t_1)$
- FMH Impact Speed Measurement
  - 24 kph  $\pm$  1.0 kph
- Advanced Combat Helmet (ACH)
  - FMVSS 201U test equipment had too much variation for repeatability
  - Testing as conducted without an ACH where applicable

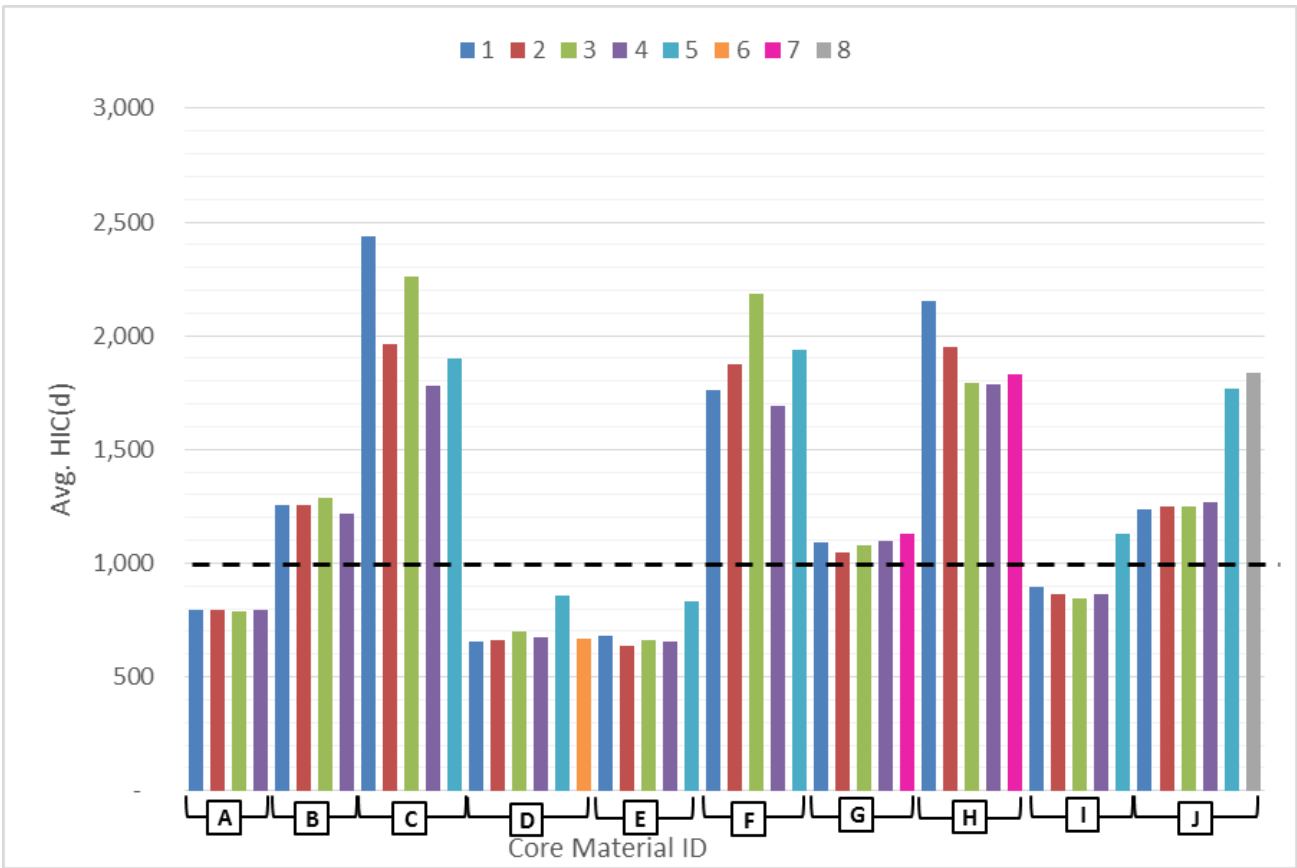


# Material Analysis of Alternatives (AoA)



Core Material ID	Facesheet Material ID	Facesheet Material	Material	Thickness
A	1	Fabric	Plastic	1.4 inch (35.5 mm)
A	2	Fabric		
A	3	Fabric		
A	4	Fabric		
B	1	Fabric	Plastic	0.8 inch (20.3 mm)
B	2	Fabric		
B	3	Fabric		
B	4	Fabric		
C	1	Fabric	Plastic	0.5 inch (12.7 mm)
C	2	Fabric		
C	3	Fabric		
C	4	Fabric		
C	5	Rigid		
D	1	Fabric	Plastic	1.5 inch (38.1 mm)
D	2	Fabric		
D	3	Fabric		
D	4	Fabric		
D	5	Rigid		
D	6	Fabric		
E	1	Fabric	Plastic	1.5 inch (38.1 mm)
E	2	Fabric		
E	3	Fabric		
E	4	Fabric		
E	5	Rigid		
F	1	Fabric	Plastic	0.5 inch (12.7 mm)
F	2	Fabric		
F	3	Fabric		
F	4	Fabric		
F	5	Rigid		
G	1	Fabric	Foam	1.0 inch (25.4 mm)
G	2	Fabric		
G	3	Fabric		
G	4	Fabric		
G	7	Fabric		
H	1	Fabric	Foam	0.5 inch (12.7 mm)
H	2	Fabric		
H	3	Fabric		
H	4	Fabric		
H	7	Fabric		
I	1	Fabric	Non-resilient	1.6 inch (40.6 mm)
I	2	Fabric		
I	3	Fabric		
I	4	Fabric		
I	5	Rigid		
J	1	Fabric	Non-resilient	0.78 inch (19.8 mm)
J	2	Fabric		
J	3	Fabric		
J	4	Fabric		
J	5	Rigid		
J	8	Rigid		

- 150 head impact tests performed from January 2013 to May 2014
- Each core material was tested with a different durable exposed surface sheet to understand the effects the exposed surface sheet had on the energy attenuation characterizes of the core materials.
- Core material target thickness range: 25.4 mm (1.0 inch) to 38.1 mm( 1.5 inch)
- Core material tested thickness range: 12.7 mm (0.5 inch) to 41 mm (1.6 inch)



# Flame, Smoke, & Toxicity (FST) Methodology



- Current FST Standard: FMVSS 302
- TARDEC had very little data characterizing the thermal characteristics of the ignition sources typical to U.S. Army vehicles.
  - ignition time
  - heat generation
  - flame spread of the fire initiator
- Characterizing the fire initiator provides important information used to select appropriate fire assessment test methods.
- TARDEC developed fire resistance requirements based upon subject matter experts from NAVSEA and TARDEC's Fire Protection Team.
- NAVSEA conducted ASTM testing on selected material samples

Requirement	Objective	Test Method
Avg. Peak Heat Release Rate 50 kW /m <sup>2</sup>	< 85 kW /m <sup>2</sup>	ASTM E1354
Peak Heat Release Rate after Ignition 50 kW /m <sup>2</sup> @ 20 s, 180 s, & 300 s	< 60 kW /m <sup>3</sup>	
Flame Spread Index	< 30	ASTM E162
Smoke Density Flammability @ 240 s	Dm < 200	ASTM E662
Smoke Density Non-Flammability @ 240 s		



IAV Fire

# ASTM E1354 – Cone Calorimeter



- Heat Release Rate determined by measurement of oxygen consumption
  - determined by the oxygen concentration and the flow rate in the exhaust product stream
  - heat evolved from the specimen per unit of time

$$\dot{Q}(t) = \left(\frac{\Delta h_c}{r_o}\right) (1.10) C \sqrt{\frac{\Delta P}{T_e}} \frac{(X_{O_2}^o - X_{O_2}(t))}{1.105 - 1.5X_{O_2}(t)}$$

## Requirements

Avg. Peak Release Rate	< 85 kW/m <sup>2</sup>
Avg. Heat Release Rate @ 60 sec, 180 sec, & 300 sec	< 60 kW/m <sup>2</sup>

## ASTM E1354 @ 50 kW/m<sup>2</sup>

		Avg. Peak Release Rate	Avg. Heat Release Rate	Avg. Heat Release Rate	Avg. Heat Release Rate
		(kW/m <sup>2</sup> )	@ 60 s	@ 180 s	@ 300 s
Core Material ID	B	1,019	117	394	NC
	G	415	260	342	277
	J	442	83	260	191
	L	675	142	413	317
	M	558	137	324	308
	N	376	168	221	215
	O	296	173	208	194
	P	82	49	36	NC
Facesheet Material ID	1	430	215	137	NC
	2	542	239	114	79
	3	693	311	180	NC
	4	771	371	210	NC
	5	462	146	208	NC

\* NC = Not calculated; all flaming extinguished prior to this time point.



ASTM E1354 @ 300 seconds - Core Material G

# ASTM E162 – Surface Flammability of Materials



## Flame Spread Index (Radiant Panel Index)

- Product of the flame spread factor, F, and the heat evolution factor, Q
- If flame spreads from the pilot burner position to the first 3 inch mark or from any 3 inch mark to the next in three seconds or less, is denotes with flashing



Core Material B  
Flaming, Dripping, and  
Flashing at 60 sec

## TPE engineering polyurethane and polyethylene core materials

- quickly ignited
- exhibited rapid flame progression
- flamed, dripped, and/or flame running

### Requirements

Flame Spread Index < 30

ASTM E162 @ 50 kW/m<sup>2</sup>

Flaming,  
Dripping,  
or Flame  
Running  
(Y/N)

	Material ID	Flame Spread Index	Flaming, Dripping, or Flame Running (Y/N)
Core Material ID	B	20	Yes
	G	1800	No
	J	123	No
	L	90	Yes
	M	116	Yes
	N	492	Yes
	O	309	Yes
	P	22	No
Facesheet Material ID	1	412	No
	2	582	Yes
	3	957	No
	4	1318	Yes
	5	158	No

# ASTM E662 – Specific Optical Density of Smoke



## Requirements

Smoke Density Flaming @ 240 sec	$D_m < 200$
Smoke Density Non-Flaming @ 240 sec	$D_m < 200$

### ASTM E662 @ 50 kW/m<sup>2</sup>

Specific Optical Density (D <sub>m</sub> )	Flaming Mode		Non-Flaming Mode	
	Flaming, Dripping, or Flame Running (Y/N)	Specific Optical Density (D <sub>m</sub> )	Flaming, Dripping, or Flame Running (Y/N)	Specific Optical Density (D <sub>m</sub> )

Core Material ID	B	155	Y	6	N
	G	323	N	144	N
	J	16	N	1	N
	L	296	N	7	N
	M	300	Y	13	N
	N	582	N	320	N
	O	465	N	176	N
	P	23	N	6	N
Facesheet Material ID	1	106	N	154	N
	2	174	N	177	N
	3	187	N	185	N
	4	175	N	124	N
	5	196	N	28	N

- Optical Density: measurement characteristic of the concentration of smoke
- Specific optical density calculated at any given time:

$$D_s = G \left[ \log_{10} \left( \frac{100}{T} \right) + F \right]$$

- Flaming mode
  - 6 tube burner is used to apply a row of flame across the lower edge of exposed specimen
  - Application of 6-tube burner and specified irradiance level from heating element
- Non-flaming mode
  - Specified irradiance level from heating element



ASTM E662 @ 178 seconds - Core Material O

# Summary – Material FST Testing



		ASTM E1354 @ 50 kW/m <sup>2</sup>				ASTM E162 @ 50 kW/m <sup>2</sup>		ASTM E662 @ 50 kW/m <sup>2</sup>			
		Avg. Peak Release Rate (kW/m <sup>2</sup> )	Avg. Heat Release Rate @ 60 s	Avg. Heat Release Rate @ 180 s	Avg. Heat Release Rate @ 300 s	Flame Spread Index	Flaming, Dripping, or Flame Running (Y/N)	Flaming Mode	Specific Optical Density (D <sub>m</sub> )	Non-Flaming Mode	Specific Optical Density (D <sub>m</sub> )
Core Material ID	B	1,019	117	394	NC	20	Yes	155	Y	6	N
	G	415	260	342	277	1800	No	323	N	144	N
	J	442	83	260	191	123	No	16	N	1	N
	L	675	142	413	317	90	Yes	296	N	7	N
	M	558	137	324	308	116	Yes	300	Y	13	N
	N	376	168	221	215	492	Yes	582	N	320	N
	O	296	173	208	194	309	Yes	465	N	176	N
	P	82	49	36	NC	22	No	23	N	6	N
Facesheet Material ID	1	430	215	137	NC	412	No	106	N	154	N
	2	542	239	114	79	582	Yes	174	N	177	N
	3	693	311	180	NC	957	No	187	N	185	N
	4	771	371	210	NC	1318	Yes	175	N	124	N
	5	462	146	208	NC	158	No	196	N	28	N

\* NC = Not calculated; all flaming extinguished prior to this time point.

- TARDEC identified a limited number of core and facesheet materials which are capable of complying with the fire resistance requirements
- TARDEC acknowledges these test methods and criteria may be more severe than needed, however some materials were determined to be capable of complying with these requirements, making it a viable option. On-going research and development efforts continue.
- TARDEC is further characterizing fire ignition sources and fire resistance standards with the intent to refine these requirements as more knowledge is gained.
- MIL-PRF-32518 Performance Specification Interior Head Impact Protection for use in U.S. Army Military Vehicle Interiors



- TARDEC wishes to expand the number of materials known to provide sufficient energy attenuation, are capable of complying with the  $HIC(d) < 700$  requirement and also provide adequate fire resistance
  - Phase II SBIR Flame, Smoke, and Toxicity Resistant Recoverable Interior Trim Energy Absorption Material
- Collaboration with FAA in FY16 for further development of fire resistance requirements for version 2 of MIL-PRF-32518