

# Armoured Vehicles Testing Standards

Current approach

Piet-Jan Leerdam |



25 October 2023

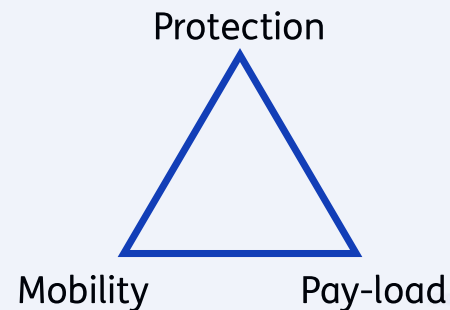
# Agenda

- The introduction
- Overview test standards
- Protection requirement specification
- The VPAM standard
  - VPAM Ballistic testing process and choices
  - VPAM Blast testing process and choices
- Injury assessment approach (ATD)
- Certification and reports
- Summary and Final remarks






# Introduction

- Armouring a vehicle is an expertise, testing the armoured vehicle is another one
- But also: Procuring vehicles is an expertise, specifying the (protection) requirements is another one
- The need for Civilian Armoured Vehicles is still there, the need for certified armoured vehicles is growing
  - Test standards provides the procedures for proper testing and certifying
- The focus is to the occupant safety:
  - Crew & passenger should survive and preferably with no or limited injuries. What is acceptable?
  - Mobility helps the survivability, therefor protection of critical drive-line components could be involved as well
- Balanced approach between capabilities:
  - Weight / volume restrictions
  - Road worthiness restrictions



# Overview of (international) vehicle standards

Scope		Ballistic	Mine / IED
	Armoured Military Vehicles	STANAG 4569 AEP-55 Vol. 1	STANAG 4569 AEP-55 Vol. 2 + 3
	(UP)Armoured Civilian Vehicles	VPAM BRV PAS 300 STANAG 4569 AEP-55 Vol. 1	VPAM ERV PAS 300 STANAG 4569 AEP-55 Vol. 2 + 3
	Armoured VIP Vehicles	VPAM BRV PAS 300	VPAM ERV PAS 300

# Overview of (international) vehicle standards

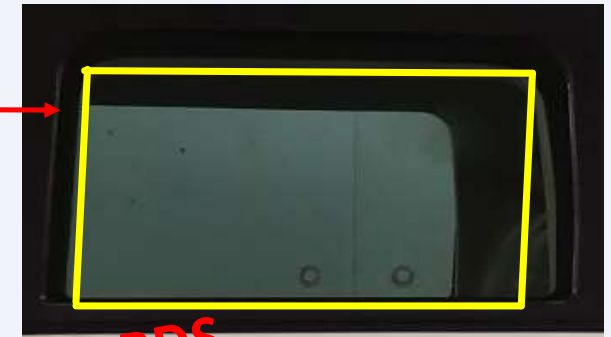
- STANAG 4569:
  - Well known and world-wide accepted in military domain
  - Officially for use by NATO-countries, but also used in other countries
  - Testing by any experienced test institute possible
- VPAM-BRV and VPAM-ERV:
  - Well known, originally a German standard
  - Certifying limited to VPAM members (GE Beschussamten, TNO)
- PAS 300 (CPNI):
  - Well known, originally an UK standard
  - Certifying by any experienced test institute possible



# Overview of (international) standards

- And what about other standards?

- EN 1063 (BRx)
- EN 1522/1523 (FBx)
- Nij (0101.06)



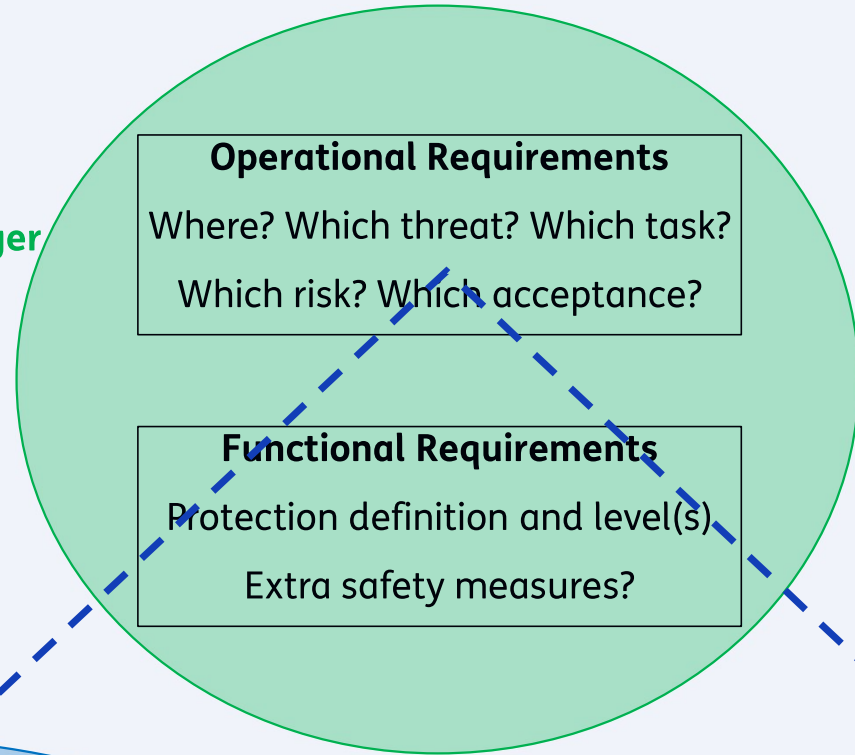
THESE ARE NO VEHICLE TEST STANDARDS

- These standards refer to material (plate) tests for both opaque and transparent material or door sections.
- A vehicle test standard is needed for testing the integrated armour solution in order to judge the occupant safety.

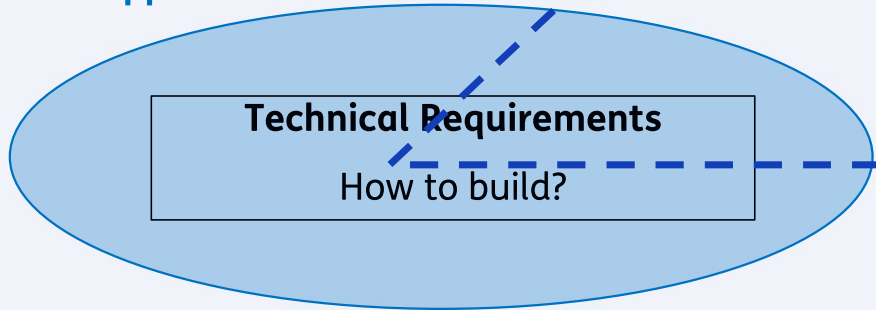


# Requirements

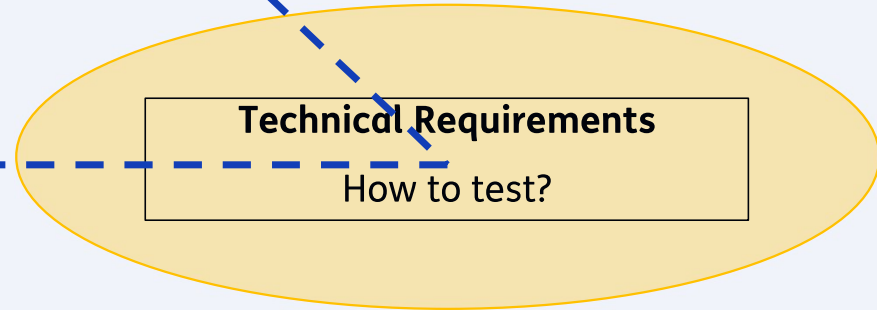
End-user  
Procurement Manager  
Fleet Manager



Vehicle Protection  
Supplier

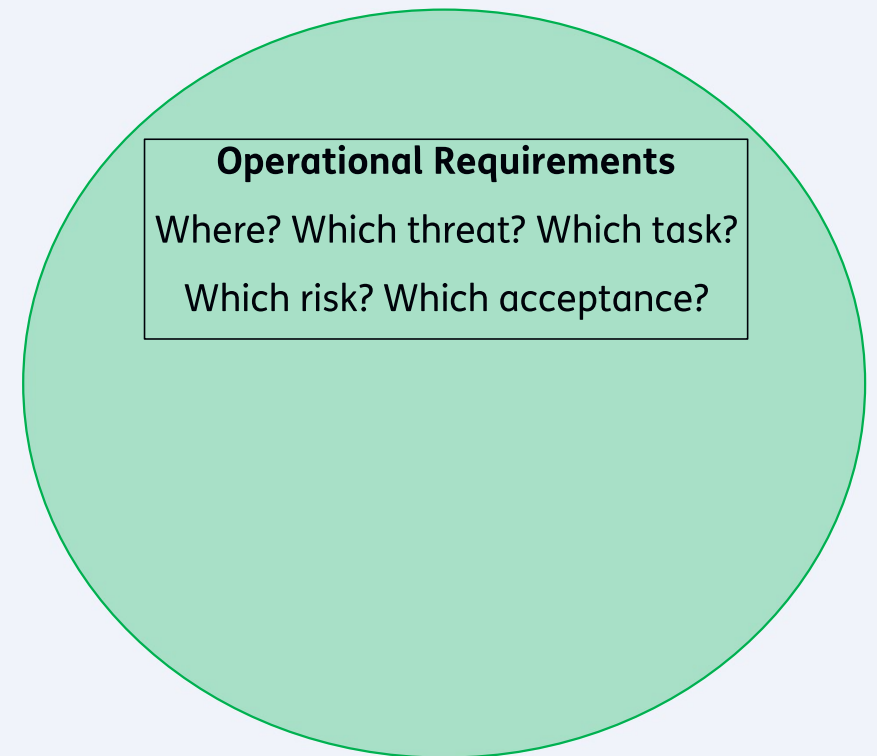


Test Institutes



# Operational requirements

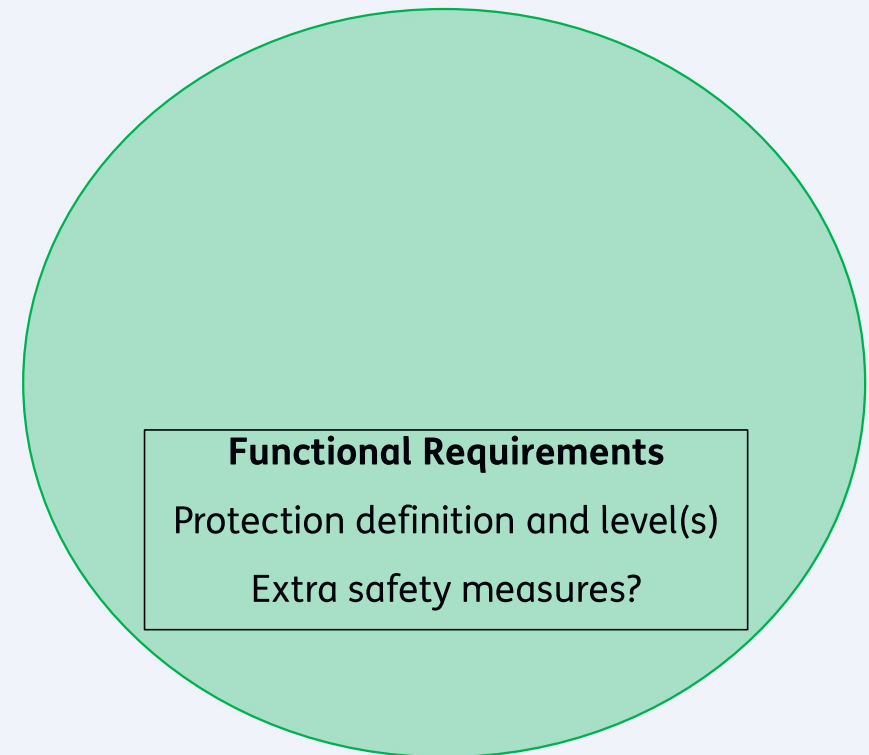
- Area of operation
  - Continent, countries, war-zone, peace-keeping
  - Terrain: country-side, urban
- Threat scenario's:
  - Ballistic threats: hand weapons, rifles, machine guns
  - Blast threats: hand grenades, AP/AT mines, IEDs
  - Others, like AT weapons?
- Occupant safety acceptance criteria:
  - Injury severity
  - Risk of getting injured
  - Fragment injuries, bio-mechanic injuries





# Functional requirements

- Primary protection requirements:
  - Protecting the occupants (crew/passenger) for protection level XX
  - Ballistic protection mandatory
  - Hand grenade / AP-mine / Side blast optional or mandatory?
- Secondary requirements:
  - Mobility related
    - Protection of critical (automotive) components
  - Safety
    - Security lock
    - Emergency exit
    - Close-in fire capability (gun-ports or roof hatch)



# Technical requirements

## Technical Requirements

How to build?

- Armouring sides/roof/floor of occupant compartment
- Armouring (selected) critical automotive components
- Material specification and selection
- Construction and Integration
- Design (CAD) drawings
- Production quality control

## Technical Requirements

How to test?

- Test specification and procedures
- Threats for testing
- Charge location, angles, distances
- Instrumentation
- Acceptance criteria
- Report and certification

# The VPAM standard

- VPAM
  - Association of test institutes for protective materials and constructions
  - Main goal is to define test procedures for standard testing and sharing experiences
- Two vehicle test procedures:
  - BRV: Ballistic Resistance Vehicle
  - ERV: Explosive Resistance Vehicle
- Latest editions of BRV and ERV:
  - VPAM-BRV Edition 3
  - VPAM ERV 2010 Edition 2 (01-08-2017)\*
  - VPAM-ERV Edition 3 (15-03-2021) on customer request\*

*\* Available on request after signing a non-disclosure agreement*

**It is not just testing,  
it is a process!  
It is about confidence in the  
protection concept!**



[www.vpam.eu](http://www.vpam.eu)



Chairmanship by TNO  
since August 2023

# VPAM Ballistic Process (Approach)

## 1. Test plan:

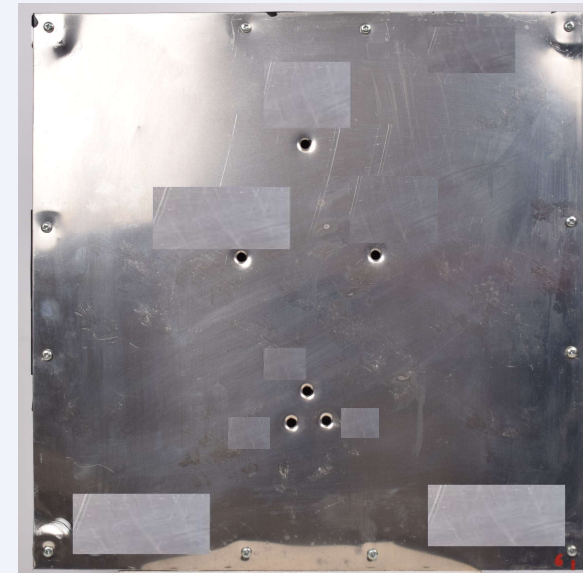
- Protection level
- Description of vehicle design and main armour concept (=Main Areas)

## 2. VPAM-PM testing:

- Main Area sample testing (3x, 3+3 shots large and small triangle)
- *Flat* and *curved* transparent armour (3x, 3 shots large triangle)

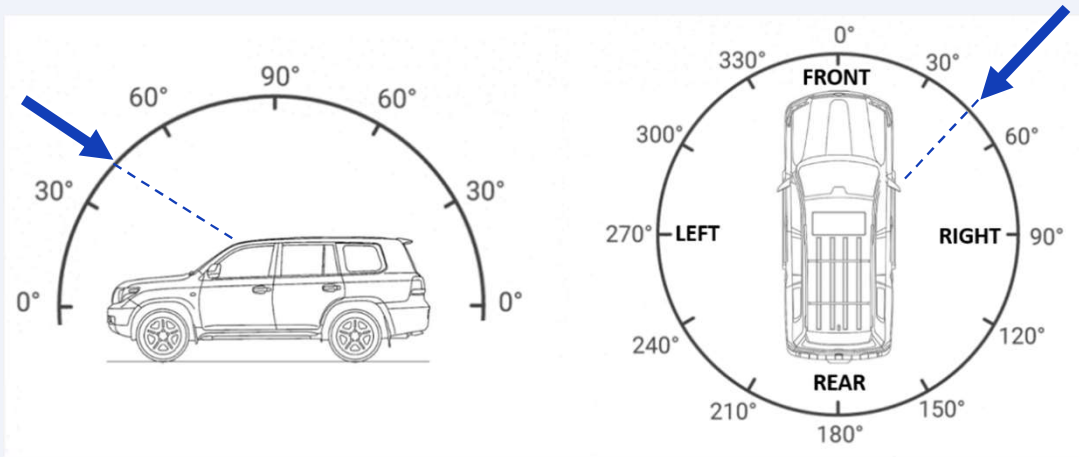
## 3. VPAM-BRV testing

- Vehicle Inspection
- Vehicle Testing
- *Re-test on mock-up*



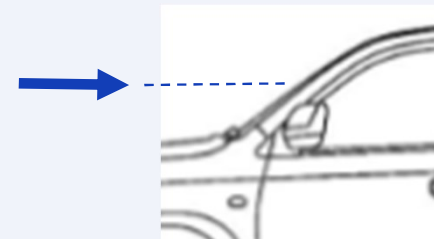
# VPAM Ballistic Process (Selections)

- Test level (VRx)
- Azimuth 360°
- Elevation angle
  - 90°, reduction to 45° or 30° over whole vehicle (not only roof)
  - Reduction to 0° for windscreen (VR8+)
  - Negative angles (if realistic for higher vehicles)



Test level	Ammunition and projectile				Test conditions	
	Caliber	Type	Nominal mass [g]	Manufacturer/type	Firing distance [m] <sup>12)</sup>	Impact velocity [m/s]
1	22 Long Rifle <sup>4)</sup>	L/RN	2.6	RUAG HV Field Line	10 ± 0.5	360 ± 10
2	9 mm Luger <sup>5)7)</sup>	FMJ/RN/SC	8.0	DAG, DM 41 <sup>11)</sup>	5 ± 0.5	360 ± 10
3	9 mm Luger <sup>5)7)</sup>	FMJ/RN/SC	8.0	DAG, DM 41 <sup>11)</sup>	5 ± 0.5	415 ± 10
4 <sup>1)</sup>	357 Magnum	FMJ/CB/SC	10.2	Geco	5 ± 0.5	430 ± 10
	44 Rem. Mag. <sup>6)</sup>	JSP/FN/SC	15.6	Speer No. 4454	5 ± 0.5	440 ± 10
5	357 Magnum	FMs/CB	7.1	Specification IAW VPAM <sup>13)</sup>	5 ± 0.5	580 ± 10
6	7.62 x 39	FMJ/PB/FeC	7.9	PS <sup>10)</sup>	10 ± 0.5	720 ± 10
	223 Rem. <sup>2)8)</sup>	FMJ/PB/SCP	4.0	MEN, SS 109	10 ± 0.5	950 ± 10
7 <sup>1)</sup>	308 Win. <sup>9)</sup>	FMJ/PB/SC	9.55	MEN, DM 111	10 ± 0.5	830 ± 10
	7.62 x 39	FMJ/PB/HCI	7.7	BZ <sup>10)</sup>	10 ± 0.5	740 ± 10
8	308 Win. <sup>3)9)</sup>	FMJ*/PB/HC	9.6	FNB, P 80	10 ± 0.5	820 ± 10
10	7.62 x 54 R	FMJ/PB/HCI	10.4	B32 <sup>10)</sup>	10 ± 0.5	860 ± 10

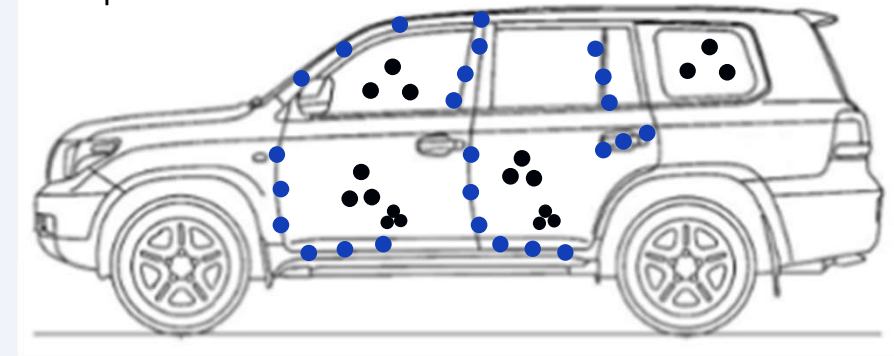
The twist rates can be gathered from the dimension sheets (TDCC) of the C.I.P.  
Deviating twist rates and dimensions are marked by exponents in the column "Caliber".



# VPAM Ballistic Process (Full-scale test)

- Areas:  
Pillars (A/B/C/D-pillars), Door & glass edges and gaps,  
Roof edges, Door sills, Cant rail, Fenders, Fire wall,  
Mirror fixing, Door locks
- Shot pattern:
  - 3-shot pattern
  - Small/large triangle ( $4\pm 1$  calibre / 120 mm)
  - Small lines ( $4\pm 1$  calibre)
  - Long lines (min. 120 mm)
- Reports:
  - Test report(s)
  - Certification document

Example MA/SWA shot locations



Shooting under 'worst-case' conditions.  
All shots have to be stopped!  
In case of a perforation, the protection  
concept has to be modified and re-tested!

# VPAM Blast Process (Approach)

## 1. Test plan:

- Threats (hand grenade, AP-mine, side-blast)
- Charge locations
- Measurement set-up

## 2. *Optional pre-testing on samples:*

- *Fragmentation effects hand grenades and/or AP-mine*

## 3. VPAM-ERV testing

- Vehicle Inspection (combined with BRV inspection)
- Vehicle Testing
- *Re-test on mock-up*



# VPAM Blast Process (Selection)

- Grenade protection :
  - Hand grenade (vehicle floor and roof):
    - DM51 or HG85
    - Single or double
  - AP-mine:
    - DM31 surrogate (vehicle floor only)
- Road-side blast protection:
  - VPAM specified bare explosive charge
  - Distance to B-pillar (2 or 4 m)

The blast charge specification in VPAM differs from the STANAG 4569 and differs from the PAS300!

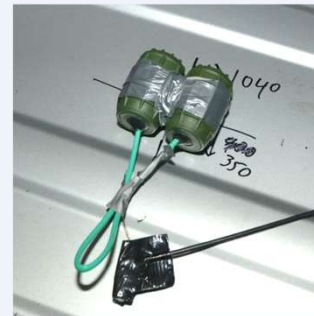
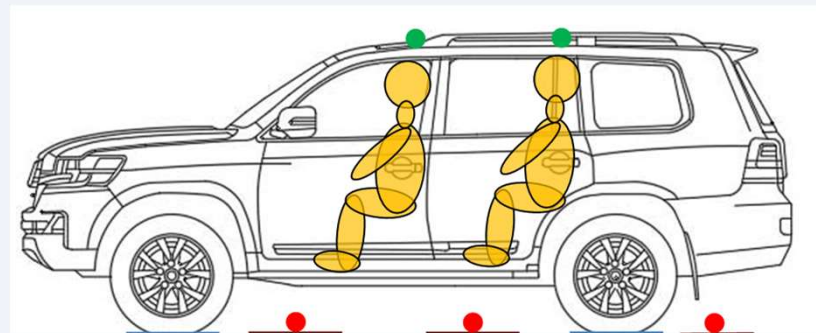
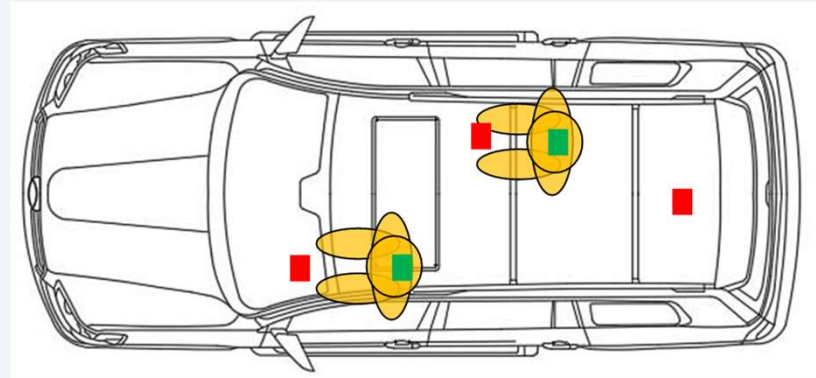
Threat level	Grenade	Single/double
n.a.	DM51	Single
n.a.	DM51	Double
n.a.	HG85	Single
n.a.	HG85	Double
n.a.	DM31	Single





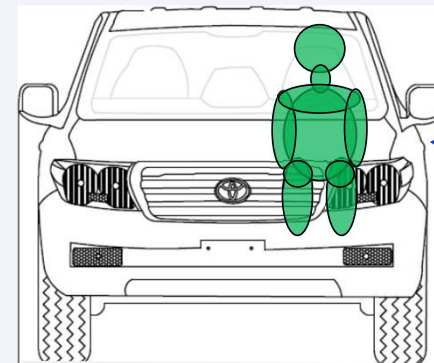
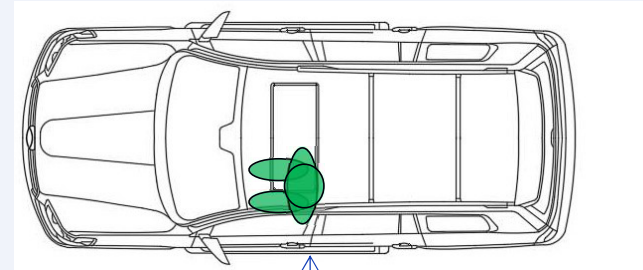
# VPAM Blast Process (Grenades)

- Worst-case charge locations (w.r.t. the occupants):
  - Under feet
  - Above head
- Extra test (fragmenting effects):
  - In case of protection concept differences or expected weaknesses
- Measurements:
  - Fragments: witness foil
  - Roof-head impact sensor
  - Floor deformation
  - Bio-mechanic loads with a manikin



# VPAM Blast Process (Road-side blast)

- Worst-case locations (w.r.t. the occupants):
  - Aligned with B-pillar
  - Front row seat (driver or co-driver)
- Measurements:
  - Fragments: witness foil, normal/high-speed video
  - Pressure
  - Bio-mechanic loads with manikin(s)



2 or 4 m

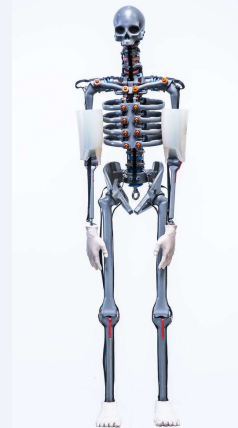
Top charge aligned with lower edge side window

# VPAM-ERV Edition 2 versus Edition 3

## Edition 2 (01-08-2017):

- Analysis of:
  - Fragmenting effects
  - Floor deformation
  - Roof-head impact
  - Pressure
- *Option for occupant response:*
  - Anthropomorphic Test Device (ATD)
  - Based on customer specification (i.e. STANAG 4569 AEP-55 Vol. 2 + 3)
  - Pass/fail approach

Re-use of ATD as long as certification/calibration is valid



## Edition 3 (01-03-2021):

- Analysis of:
  - Fragmenting effects
  - Roof-head impact
  - Pressure
- Occupant response with:
  - Biofidel (Primus) analysis (autopsy)
  - Star ranking approach

For each test a new dummy needed

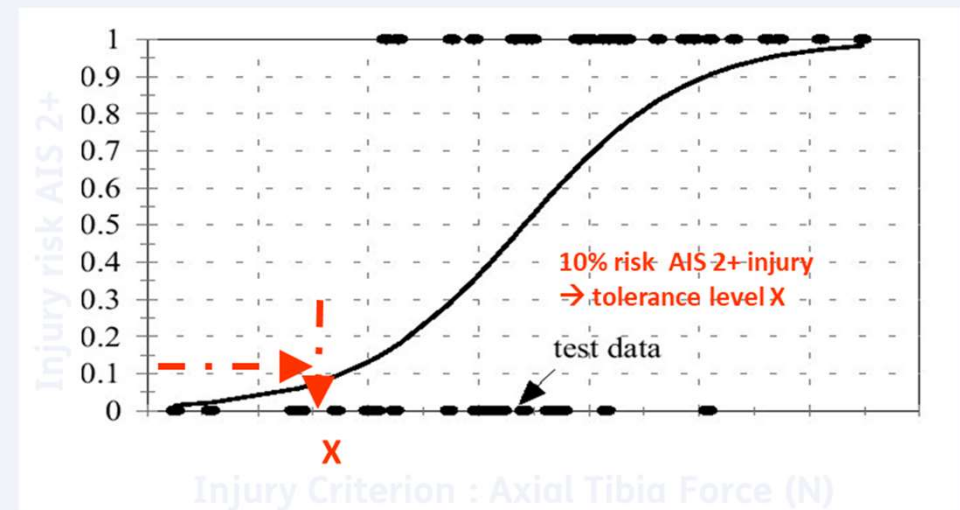
# Injury assessment with ATDs

- Anthropomorphic Test Device (crash test dummy):
  - A mechanical model to measure:
    - Acceleration
    - Forces, moments
    - Deflections
  - *Three Rs: Repeatable, reproducible, robust*
- Link to real injury:
  - Injury risk curves:
    - Injury severity (AIS)
    - Injury probability (10%)
  - *Match-pair testing:*
    - *PMHS versus ATD*



The Abbreviated Injury Score (AIS)

AIS	Severity code
0	no injury
1	minor
2	moderate
3	serious
4	severe
5	critical
6	maximum injury (virtually unsurvivable)



# Injury assessment with ATDs

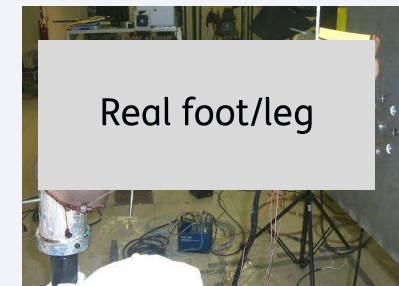
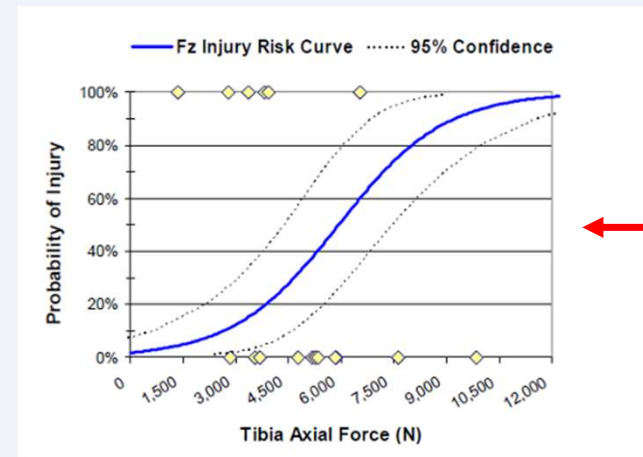
- STANAG 4569 acceptance decision:
  - Moderate injuries (AIS2)
  - <10% probability of injury
- HFM working groups defined list of injury criteria and (pass/fail) tolerance levels for several body regions:
  - For Hybrid III ATD (vertical impact)
  - For EuroSid-2re ATD (side impact)
- Main advantage of the use of ATDs:
  - Clear measurement data (direct after test available)
  - Clear information about the performance of the protection concept
  - International acceptance in automotive/military domain



Body region	Criterion	Unit	Criteria	Measured	Time [ms]	Filter cfc	
Head	Head Injury Criterion, HIC_15ms		250	4	31.4	1000	
Neck	Axial compr. force, Fz- (max.)	kN	4.0	0.6	39.8	1000	
	Axial compr. force, Fz- (time)			* see graph			
	Axial tension force, Fz+ (max)	kN	3.3	0.3	115.1	1000	
	Axial tension force, Fz+ (time)			* see graph			
	Axial shear force, Fx +/- (max)	kN	3.1	-0.2	60.2	1000	
	Axial shear force, Fx - (time)			* see graph			
	Axial shear force, Fy +/- (max)	kN	3.1	-0.09	48.2	1000	
	Axial shear force, Fy - (time)			* see graph			
	Bending mom. (flexion), Mocy+	Nm	190	26.1	73.2	600	
	Bending mom. (extension), Mocy-	Nm	96	11.5	138.4	600	
Thorax	Thoracic Com. Crit., TCC frontal	mm	30	2.0	526.1	600	
	Viscous Criterion, VC frontal	m/s	0.7	0.0	519.8	180	
Spine	Dynamic Response Index, DRlz		17.7	8.8	54.4	1000	
Femur	Axial compr. force, Left Fz -	kN	6.9	1.3	9.5	600	
	Axial compr. force, Right Fz -	kN	6.9	0.7	7.4	600	
Lower leg	Axial compr. force, Left Fz-, Lx	kN	2.6	4.1	8.5	600	
	Axial compr. force, Right Fz-, Lx	kN	2.6	2.2	8.3	600	
Pressure	Chest Wall Velocity	m/s	3.6	0.3	31.5		

# Injury assessment with ATDs

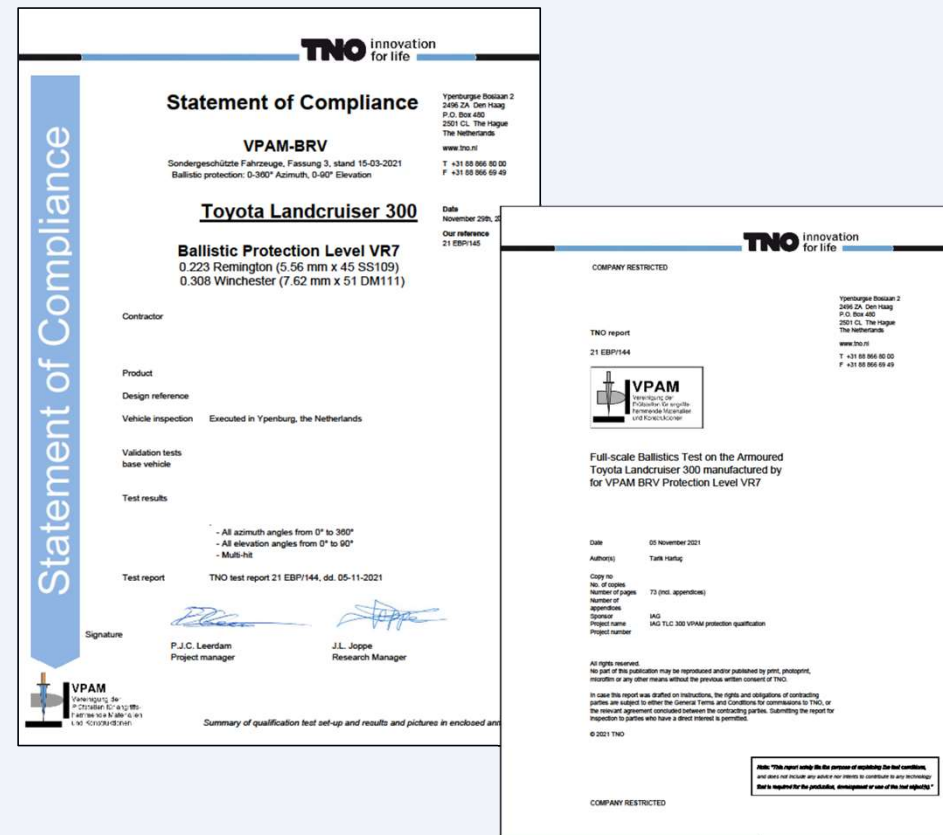
- ATDs developed for *kinematic response* (motion) and *resulting impact* (in car crashes)
- ATDs being used for *impact loads* from *high-rate acceleration* with **specific selected and developed criteria**
- Hybrid III for vertical impacts:
  - Lower leg load
  - Lumbar spine load (DRI)
  - Neck loads and/or head impact
- EuroSid-2re for side impact:
  - Pelvis impact
  - Thorax/ribs impact
  - Shoulder impact
  - Neck loads and/or head impact



The HFM working group supported the development of the Mil-Lx lower leg model with a new injury criterion as well as the shoulder impact criterion.

# Report and certification

- It is all about proof and traceability!
- Certificate is a 'Statement of Compliance' to a certain standard:
  - Reference to standard, edition number
  - Threat specification
  - Test target specification
  - Design reference(s), drawing number(s)
  - VPAM Test institute
  - Test results
  - Test report reference
- A test report gives all the details:
  - Also the failures and improvements!



Strongly advised:

- Ask for both the certificate and the test report(s).
- Check the vehicle being delivered compared to the vehicle being tested (production quality control)

# Report and certification (example BRV)

VPAM Qualification Authority	TNO Defence, Safety and Security Ypenburgse Boslaan 2 2496 ZA Den Haag The Netherlands
Test institute	TNO Weapon Effects & Protection Center Ypenburgse Boslaan 2 2496 ZA Den Haag The Netherlands
Customer	
Manufacturer base vehicle	
Manufacturer armoured vehicle	
Manufacturer armour steel	
Manufacturer transparent armour	

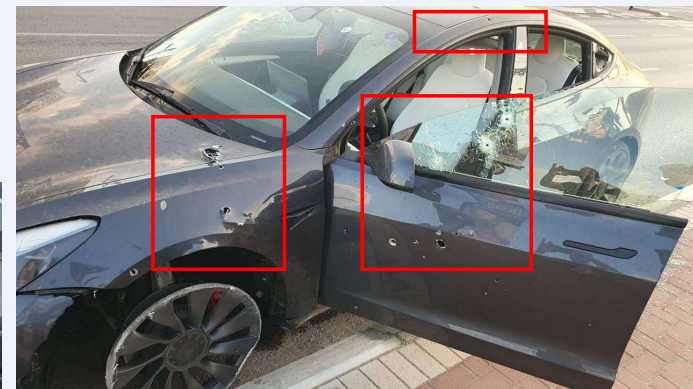
Vehicle type (base vehicle)	Toyota Land Cruiser 300
Design reference of base vehicle	xxx-xxx-xxx
Vehicle identification number (VIN)	JTMxxxxxxxxxxxxxx
Left/right hand drive	Left
Vehicle weight	xxx kg
Protection Side panels	Ballistic Steel Xxxxx xxxx BHN – x.x mm
Protection Fire wall	Ballistic Steel Xxxxx xxxx BHN – x.x mm
Protection Roof Hatch	Ballistic Steel Xxxxx xxxx BHN – x.x mm
Protection Roof	Ballistic Steel Xxxxx xxxx BHN – x.x mm
Protection Floor	Ballistic Steel Xxxxx xxxx BHN – x.x mm
Protection Side Windows	Xxx xx.x mm
Protection Front Windshield	Xxx xx.x mm
VPAM-PM ballistic test report transparent armour	TNO Test report xxxxx
VPAM-PM ballistic test report opaque armour	TNO Test report xxxx TNO Test report xxxx TNO Test report xxxx

Test regulation	VPAM-BRV, Fassung 3, 15-03-2021
Classification	VRx
Ammunition	• xxx
Angle of testing around vehicle	360° azimuth
Angle of elevation	Elevation up to xx°
Angle of testing for the windows	0° NATO for worst case.
Proving ground / firing range	TNO Weapon Effects & Protection Center, Target Bunker, The Hague, the Netherlands
Distance launcher to target	10 meter (for roof tests at ~2m)
Distance velocity measurement to target	0.2 to 1.0 meter ahead of the target
Witness plate material	Polycarbonate plate as specified in VPAM-BRV
Witness plate thickness	0.5 mm
Witness plate stand-off distance	Behind the back face surface of the armour at about 5 - 10 cm.
Witness plate position	Inside vehicle parallel to the back face
Temperature tests	17.5 to 20.5° C
Place and dates of testing	TNO The Hague Ypenburg, The Netherlands Month xx <sup>th</sup> – Month xx <sup>th</sup> , 202x



# Summary and Final Remarks

- Procurement of an Armoured Vehicle starts with clear requirements on both operational/functional/technical level
  - To guarantee the occupant safety a vehicle standard needs to be applied for testing and certification
  - There are differences between vehicle standards, but they all give a certain confidence in the safety
  - Focus is the 'occupant safety', which should also be for testing by including occupant response assessment
  - The use of an Anthropomorphic Test Device and a transparent international accepted standard with well-defined pass/fail acceptance criteria gives clear information about the performance of a protection concept
- 
- What about the future with electric vehicles?
    - What are the risks, what is accepted?
    - How to protect?
    - How to test?



Tesla Model 3 attack in October 2023

# THANK YOU



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