Ballistic Protection
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Ground System Survivability
United States Army RDECOM-TARDEC

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<table>
<thead>
<tr>
<th>a. REPORT</th>
<th>b. ABSTRACT</th>
<th>c. THIS PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>unclassified</td>
<td>unclassified</td>
<td>unclassified</td>
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</tbody>
</table>

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SAR

18. NUMBER OF PAGES
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Standard Form 298 (Rev. 8-98)
Prepared by ANSI Std Z39-18
**Mission**

- Mature Armor Systems from Technical Readiness Level (TRL) 4 to TRL 6 to fulfill ground vehicle Program Management (PM) needs.

**Base Armor**

- Small Arms/Frag Opaque B-kits
- Medium Cal/Frag Opaque B-kits
- Transparent Armor

**Appliqué Armor (C-kit)**

- Passive Multi-Threat
- Reactive Multi-Threat
- Active Multi-Threat

**Integration / Design Enablers**

- Scalable, Modular & Common Armor System Integration Techniques
- Multifunctional Armors
- Modeling & Simulation
- Testing Capabilities
# TRL Definitions & Industry Involvement

## TRL Definitions

<table>
<thead>
<tr>
<th>TRL</th>
<th>General Definition</th>
<th>Armor Package Definition</th>
<th>Industry Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Component validation in a lab environment</td>
<td>Armor meets ballistic performance (threat, number of shots, multi-hit shot spacing, velocity) at the coupon level.</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Component validation in a relevant environment</td>
<td>Armor maintains ballistic performance at the coupon level after exposure to relevant environments or in packaged configurations.</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Subsystem / system demonstration in a relevant environment</td>
<td>Armor maintains ballistic performance after packaged/mounted on a vehicle-representative structure and after introducing relevant environments and relevant threat engagements.</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The following tests have been identified as potential tests that could be required for maturation of a new armor design. The tests required will be dependent on the materials and uniqueness of the armor design.

**MIL-STD 810**
- Heat Loading
- Cold Loading
- Thermal Cycling
- Contamination by Fluids
- Solar Radiation
- Rain
- Humidity
- Salt Fog
- Sand & Dust
- Acidic Atmosphere
- Vibration
- Shock
- Fire, Smoke & Toxicity

**ATPD 2352 (First Article)**
- Allowable Defects
- Transmittance
- Haze
- Optical
- Chemical
- De-icing
- Humidity
- Abrasion
- Sun Exposure
- Weathering
- Ballistic (@ ambient temp)
- Temp (Shock, Low & High)
- Rock Strike / Low Impact
Facilities

- Modeling & Simulation and Design (TRL 5 & 6)
- Fabrication (TRL 4, 5 & 6)
- Coupon Level Ballistic Testing / Validation (TRL 4, 5 & 6)
- System / Sub-System Integration and Testing (TRL 6)

- Reduce Ballistic Vulnerabilities
- Integration Burden Mitigation / Ballistic Performance Design
- Environmental / Durability Simulations

- Ceramics
- Composites
- Metallic
- State-of-the-Art Combinations

- Small and medium caliber ballistics / frag testing
- Transparent Armor Testing
- Opaque Armor Testing
- Sub-System Testing

- System Installation
- Integration of Enabling Technologies

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
# Program Roadmap

<table>
<thead>
<tr>
<th>Name</th>
<th>FY 11</th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14</th>
<th>FY 15</th>
<th>FY 16</th>
<th>Description</th>
</tr>
</thead>
</table>
| Advanced Combat Vehicle Armor Development (ACVAD) |       |       |       |       |       |       | Reduced cost, lighter weight, extended multi-threat 2nd generation B and C combat armor systems:  
  - B kit - encapsulated ceramics  
  - C kit - passive, reactive & electro-magnetic  
  - Health monitoring                                                                 |
| Armor Development                          |       |       |       |       |       |       | Research, development & testing of armor system maturation enablers:  
  - Emerging technologies  
  - System engineering process  
  - Standards (design, integration, test)  
  - Manufacturing capabilities  
  - Test & evaluation of A & B armor systems                                                                                             |
| Transparent Armor (TA)                    |       |       |       |       |       |       | Research, development & testing of transparent armor:  
  - Reduced interlayer de-bonding  
  - Rock strike abatement  
  - Lighter weight strike face & interlayer  
  - ATPD 2352 revisions  
  - First article & production quality control testing                                                                                     |
ACVAD Program Overview

Purpose:
- Further mature and develop weight / space trades to reduce cost of the threshold CVAD armor for GCV
- Develop GCV objective threat armor system while meeting platform weight, space and cost goals
- Advance electro-magnetic armor systems maturity
- Develop smart armor with embedded, real-time health monitoring capability.

Requirements:
- Reduce CVAD cost, weight and/or space performance parameters while maintaining threshold threat protection.
- Transition objective threat TRL 6 armor systems to GCV in FY16 for block upgrade

Products:
- Next generation combat armor systems demonstrated ballistic performance after packaged / mounted on a vehicle or representative structure and after introducing relevant environments
- Improved modeling & simulation tools for advanced threats and materials
- Efficient manufacturing processes for armor designs
- Embedded ultrasonic and optoelectronic sensors for health monitoring of ceramic and transparent armors
### Milestone / Activity

| Armor technology trade studies / continued threshold armor improvements and maturation activities (weight, space claim, performance vs cost). Determine armor sensor options per recipe and recognize defect identification. |
| Early performance evaluations on down selected armor samples (risk mitigation test data). Evaluate results for thermal exposure, automotive inputs and ballistic multi hit shots. **Validate sensor integration performance post vibration and environmental testing. Continue armor maturation activities and plan integration efforts.** |
| Armor development effort and TRL 4 recipe transitions. Level 1 & 2 B-kits and Level 0, 1 & 2 C-kits. |
| Finalize risk mitigation evaluations on C-kit designs. Mature armor and **conduct TRL 5 testing** of armor designs (environmental & structural), conduct effect of defects study to determine how manufacturing defects change armor performance. |
| TRL 6 armor panel design, attachments, integration, and system level test. Includes vibration, environmental & combined effects. |

<table>
<thead>
<tr>
<th>Milestone / Activity</th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armor technology trade studies / continued threshold armor improvements and maturation activities (weight, space claim, performance vs cost). Determine armor sensor options per recipe and recognize defect identification.</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
</tr>
<tr>
<td>Early performance evaluations on down selected armor samples (risk mitigation test data). Evaluate results for thermal exposure, automotive inputs and ballistic multi hit shots. <strong>Validate sensor integration performance post vibration and environmental testing. Continue armor maturation activities and plan integration efforts.</strong></td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
</tr>
<tr>
<td>Armor development effort and TRL 4 recipe transitions. Level 1 &amp; 2 B-kits and Level 0, 1 &amp; 2 C-kits.</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
</tr>
<tr>
<td>Finalize risk mitigation evaluations on C-kit designs. Mature armor and <strong>conduct TRL 5 testing</strong> of armor designs (environmental &amp; structural), conduct effect of defects study to determine how manufacturing defects change armor performance.</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
</tr>
<tr>
<td>TRL 6 armor panel design, attachments, integration, and system level test. Includes vibration, environmental &amp; combined effects.</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
<td>![Timeline]</td>
</tr>
</tbody>
</table>
## Armor TRL Requirements and Responsible Organization

<table>
<thead>
<tr>
<th>Armor Description</th>
<th>Vehicle Area</th>
<th>CVAD Weight</th>
<th>ACVAD Weight</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-kit Level 1 Threshold</td>
<td>Side</td>
<td>xx psf</td>
<td>0% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>B-kit Level 1 Objective</td>
<td>Side</td>
<td>N/A</td>
<td>0% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>B-kit Level 2 Objective</td>
<td>Side</td>
<td>N/A</td>
<td>0% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>C-kit Level 0 Passive</td>
<td>Side</td>
<td>xx psf</td>
<td>-21% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>C-kit Level 1 Passive</td>
<td>Side</td>
<td>xx psf</td>
<td>-21% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>C-kit Level 1 Active</td>
<td>Side</td>
<td>xx psf</td>
<td>-29% psf</td>
<td>-% Chg</td>
</tr>
<tr>
<td>C-kit Level 2 Objective</td>
<td>Side</td>
<td>N/A</td>
<td>0% psf</td>
<td>-% Chg</td>
</tr>
</tbody>
</table>

- ACVAD TRL 6 armor deliverables to GCV (with non integrated weight targets)
- TARDEC’s armors will include metallic, composites, glass, ceramics, 3D weave, MMC and metallic encapsulated ceramics. C-kit armor defeat technologies include passive, reactive and electro-magnetic

**ACVAD POC:** Douglas Bertoia
Purpose:
Mature, integrate and demonstrate high energy / high power compact power control / distribution devices for defense applications
   Electro-Magnetic Armor (EMA)
     • Integrate and test the Pulse Power Unit with hybrid armor modules for low risk EMA
       - Testing to include durability, environmental and limited live fire testing
     • Develop, integrate and test Power Brick based EMA with focus on operation, condition monitoring, and safety
   High Energy Laser Tech Demo (HEL-TD)
     • Develop, test and deliver Next Generation Laser Power Supply (reduced size, weight, increased power per kg)

Customers:
• Electro-Magnetic Armor: PEO-GCS, GCV Increment 2

Products:
Electro-Magnetic Armor (EMA)
• Silicon carbide based devices and components for EMA
• High Energy Density Capacitors for EMA
• 2nd Gen EMA Control Interface

High Energy Laser Tech Demo (HEL-TD) coordinated with SMDC
• Next Gen Laser Power Supply High Energy Laser Tech Demo
• New Advanced Pulse Forming Network (APFN) cards
  - 40% smaller than previous generation
  - Increase run time with less thermal management burden

Payoff:
• Enable Electro-Magnetic Armors
• Enable future High Energy Laser (HEL) Demonstrations
## ACVAD Electro-Magnetic Armor / Pulse Power Schedule

<table>
<thead>
<tr>
<th>Milestones</th>
<th>FY</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACVAD Requirements</td>
<td></td>
<td></td>
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<tr>
<td>Supporting Programs:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Low Risk EMA Pulse Power Unit program Phase 4 – System Integration and Test.</td>
<td></td>
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</tr>
<tr>
<td>Integration, electrical bussing/ stand off, armor design, durability, reliability, lessons learned. Integrating efforts will allow common and streamlined development.</td>
<td></td>
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<tr>
<td>Power Brick Gen 1 + Mission Package Gen 1 TRL 5 (Large form factor)</td>
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<tr>
<td>Integration of Power Brick Gen 2 + Mission Package Gen 2 TRL 6 4QFY15 (Reduced form factor)</td>
<td></td>
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<tr>
<td>EMA System Control, Integration, Testing (Control System maturation, EMA integration and testing into vehicle architecture)</td>
<td></td>
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<tr>
<td>Programmable Pulse Power Supply (PPPS) for HEL</td>
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</tbody>
</table>

**Transfer EMA to ACVAD**

**Build/Test**
ACVAD Electro-Magnetic Armor / Pulse Power
Power Brick Key Technical Components

- Multi-hit system without recharging
- Provides support to meet emerging survivability threats
- Enables multi-threat armor systems

Power Brick

- DC to DC Charger
  28V to 600V
  Assembly starting in Summer 2011

- Battery
  (Prototype)

- Pulse Charger
  600v to 10kV
  (Initial Design)

- Capacitors
  High Energy Density
  (1.3J/cc)

- Solid State Switches
  Silicon, 2cm^2, 12kA
  SiC, .73cm^2, 5kA

Mission Package

EMA/Pulse Power POC: Joe White
### Milestone Schedule

<table>
<thead>
<tr>
<th>Phase</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 – Armor Module</td>
<td></td>
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<tr>
<td>Recipe Validation</td>
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<tr>
<td>Phase 2 – Component</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Integration and Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TARDEC design and build 1st</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gen LR EMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractor design and develop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse Power System</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Series I – Ballistic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Single Modules)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Phase 3 – Subsystem</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Integration and Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TARDEC design and build 2nd</td>
<td></td>
<td></td>
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<tr>
<td>gen LR EMA</td>
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<tr>
<td>Test Series II –</td>
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</tr>
<tr>
<td>Environmental/Durability/Ball</td>
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<tr>
<td>istic</td>
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<td></td>
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<tr>
<td>Phase 4 – System Integration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Series III –Ballistic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Multiple Modules)</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### TARDEC Armor System Modules

- **Pulse Power Unit**

### Project Goals

<table>
<thead>
<tr>
<th>Weight</th>
<th>xx psf</th>
<th>xx psf (integrated)</th>
<th>-10% psf (integrated w/ PPU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL</td>
<td>4</td>
<td>4+</td>
<td>5</td>
</tr>
</tbody>
</table>

**EMA/Pulse Power POC:** Joe White
Purpose:
- Development of opaque armors for the defeat of direct fire, IED, and Shape Charge Jet (SCJ) threats
- Manage ManTech efforts to reduce material and processing cost of advanced armor systems
- Fabricate sub-system and prototype system level armor packages
- Provide Subject Matter Expert (SME) support to PM offices and OGAs

Requirement:
- Need for lightweight armor solutions for an increasingly weight burdened force
- Development of processes and techniques to lower cost of advanced armor systems
  - Technology is there, but not affordable
- Maturation of new armor solutions to defeat an ever changing threat set

Product:
- Lightweight B-Kit and C-Kit armor solutions that provide increased protection and are affordable
- Matured multi-threat armor solutions that are able to withstand extreme environments
- Advanced integration techniques to reduce integration burden (scalable, modular & common) and minimize vehicle vulnerabilities
### Armor Development Schedule

<table>
<thead>
<tr>
<th>Focused Efforts</th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14</th>
<th>FY 15</th>
<th>FY 16</th>
<th>FY 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive/Develop advanced B-Kit recipe from Industry</td>
<td></td>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Design/Integrate/Mature B-Kit recipe and perform APS residual testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receive/Develop advanced B-Kit and C-Kit recipes from Industry</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design/Integrate/Mature B-Kit and C-Kit recipes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Fastening and joining research under ballistic loading conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scalable, modular &amp; common integration &amp; best practices standards development</strong></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Enabling Capability**

**Technology Driven. Warfighter Focused.**
### Key Technology Components

- **New alloys**
  - Aluminum
  - Steel
  - Ti

- **Ceramics**
  - Silicon Carbide
  - Boron Carbide
  - Encapsulated

- **Manufacturing**
  - Build to print ceramics
  - Advanced joining

- **Modeling and Simulation**
  - Ballistic (sub-system level)
  - Material models
  - Further code development

### Needs

- Improved ballistic performance against both direct fire and fragmentation threats
- Significant cost reductions and improved manufacturing
- Improved integration techniques to minimize additional burden and increase damage resistance
- Automated assembly of custom ceramic parts
- Improved joining of thick section metallic (e.g. friction stir welding, laser beam welding)
- Improved M&S for ballistic events at sub-system level focusing on fasteners and joints
- High strain rate materials properties

---

**Armor Development POC:** Anthony Dolan
**Purpose:**
- Research and develop technologies and processes for improved performance and environmental stable transparent armor laminates
- Development of products and test procedures to improve rock-strike and delamination resistance
- Further refine ATPD 2352 to improve the overall quality of transparent armor purchased using the specification without additional cost to the Government

**Requirement:**
- Transparent armor provides two main functions for the Warfighter
  1. Ballistic protection from incoming threats
  2. Ability to maintain Situational Awareness
- Must be robust enough to withstand low velocity impacts (e.g. rock-strike) and extreme temperature environments with minimal loss of above capabilities

**Product:**
- Transparent armor laminates purchased by the Army will have improved rock-strike and environmental resistance
- Improved quality and consistency of transparent armor laminates
- Design guidance for transparent armor cross-sections and integration schemes
## Transparent Armor Schedule

<table>
<thead>
<tr>
<th>Focused Efforts</th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials and Processing</strong></td>
<td>Effects of autoclave processing temperature and pressure on ballistic performance</td>
<td>Investigation of novel polycarbonate materials and their effect on ballistic performance</td>
<td>Develop TA solution with improved rock-strike resistance and environmental performance</td>
</tr>
<tr>
<td></td>
<td>Investigation of various potting compounds and TA coupon edge wraps for improved weather-ability</td>
<td>Investigate novel integration techniques and develop a recommended maximum torque and bolt pattern for TA</td>
<td></td>
</tr>
<tr>
<td><strong>Integration Methods</strong></td>
<td>Effects of polycarbonate thickness and placement in TA cross-section on residual part stress. Obtain high strain rate materials properties for polyurethane.</td>
<td>Effects of size and shape of TA on residual stress. Effect of interlayer thickness of residual stress and ballistic performance</td>
<td></td>
</tr>
<tr>
<td><strong>Modeling and Simulation</strong></td>
<td></td>
<td></td>
<td>Utilize modeling and simulation for low velocity impacts (rock-strike) investigations</td>
</tr>
</tbody>
</table>
Key Technology Components

- **Glass**
  - Water white
  - Glass ceramic
  - Fused silica

- **Ceramics**
  - Spinel
  - AlON

- **Interlayer Materials**
  - Polyurethane
  - Other?

- **Backing Materials**
  - Polycarbonate
  - Thin section Glass
  - Other?

**Needs**

- Improved impact and damage resistance
- Damage localization of low velocity impacts.

- Significant cost reductions without performance loss
- Decrease in haze; improved luminous transmission

- Improved adhesion and “compliance”
- “Better” material for wide temperature range

- Improved abrasion and chemical resistance
- Improved ballistic performance at low temps

Transparent Armor POC: Anthony Dolan
Conclusion

• Who we are.
• What our mission is.
• How we plan.
• What we are investing in.
• When we plan to work these efforts.
• Ideas on how you can help us help the Warfighter.

This is the first of an annual event.....It may not be perfect, so we want the feedback to help us help you.

susan.l.rose-vincent.ctr@mail.mil