

# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> -Half-symmetric model is used in AutoDyn to simulate Depth of Penetration (DOP) experiments on SiC tile with and without a gap supported by solid Aluminum (Al5083) -Impacts by .30cal AP M2 projectile and are modeled using SPH elements in AutoDyn -Center strike model validation runs with SiC tiles are conducted based on the DOP experiments described in reference - ARL-TR-2219, 2000 -Tile gap is found to increase the DOP as compared to baseline center impact -Simulations were run on gap sizes 0.508 (20 mil) and 1.061 mm (40 mil) at the standard muzzle speed of 850 m/s -DOP is the main measurement used to determine which geometry and configuration yield the best results.					
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Nicole A. Cicchetti, Bazle Z. (Gama) Haque,  
Shridhar Yarlagadda

# MODELING AND SIMULATION OF CERAMIC ARRAYS TO IMPROVE BALLISTIC PERFORMANCE

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## **OBJECTIVE AND GOALS**

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- ❑ **The University of Delaware Center for Composite Materials (UD-CCM) is developing the next generation of lightweight hybrid ceramic/composite armor kits for Marine Corps tactical and combat vehicles**
- ❑ **The focus is on simulating and modeling the performance of ceramic/composite lightweight armor at seams and corners, and improving the armor's performance in these regions**

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## **OBJECTIVE AND GOALS**

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- The ceramic/composite armor is comprised of composite backings, adhesives, ceramics and covers**
- The tiles will be restricted to the sintered ceramics (SiC) due to the ability to fabricate SiC into complex geometries and cost analysis conducted in previous research**
- Model ballistic experiments will validate the modeling done in simulation**

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## **SUMMARY**

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- ❑ **Half-symmetric model is used in AutoDyn to simulate Depth of Penetration (DOP) experiment on SiC tile with and without a gap supported by solid Aluminum (Al5083)**
- ❑ **Impacts by .30cal AP M2 projectile and are modeled using SPH elements in AutoDyn**
- ❑ **Center strike model validation runs with SiC tiles are conducted based on the DOP experiments described in reference - ARL-TR-2219, 2000**

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## **SUMMARY**

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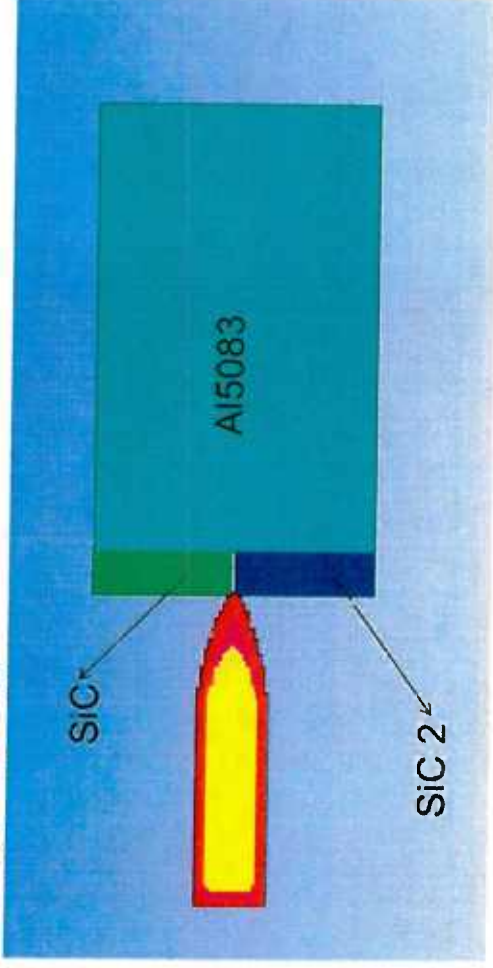


- ❑ **Tile gap is found to increase the DOP as compared to baseline center impact**
- ❑ **Simulations were run on gap sizes 0.508 (20 mil) and 1.061 mm (40 mil) at the standard muzzle speed of 850 m/s**
- ❑ **DOP is the main measurement used to determine which geometry and configuration yield the best results.**

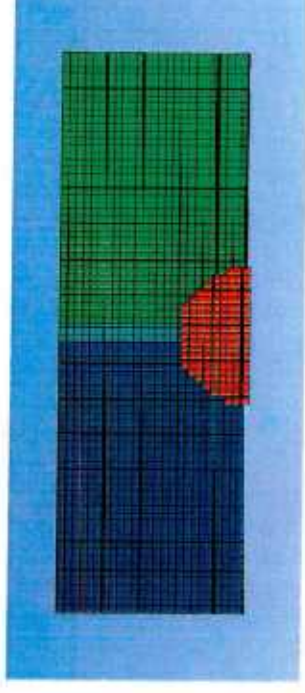
# HALF SYMMETRIC MODEL WITH GAP IN AUTODYN



Side View



Front View



- ❑ Smoothed-particle hydrodynamics (SPH) used for all parts
- ❑ SiC and SiC 2 are identical in properties and dimensions
  - ❑ Setup as different to differentiate damage in each tile
- ❑ SPH size = 0.40-mm
- ❑ Clamp boundary condition used

# MATERIAL MODELS

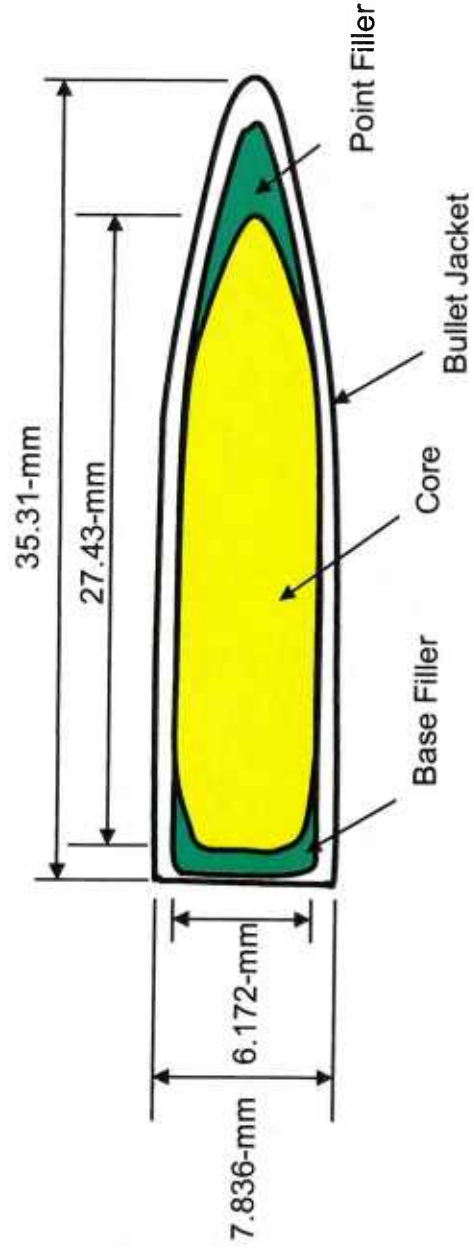


## Material Models

MATERIAL	EOS	STRENGTH MODEL	FAILURE MODEL
Steel Core	Polynomial	Johnson & Cook	Johnson & Cook
Lead Filler	Gruneisen	Piecewise Johnson & Cook	N/A
Copper Jacket	Linear	Piecewise Johnson & Cook	N/A
SiC Ceramic	Polynomial	JH-2	JH-2
Aluminum	Polynomial	Johnson & Cook	Johnson & Cook
S-Glass/Phenolic	Linear	LS-DYNA MAT162	LS-DYNA MAT162
Polymeric Foam	Linear	Non-linear Elastic	N/A
Adhesives & Interlayers	N/A	Cohesive Laws	Cohesive Laws



# .30cal AP-M2 PROJECTILE MASS PROPERTIES



Component	Material	Weight (g)
Jacket	Gilding Metal	4.2
Core	Hardened Steel - RC 63	5.3
Point Filler	Lead	0.8
Base Filler	Lead	0.5
<b>Total Weight</b>		<b>10.8</b>

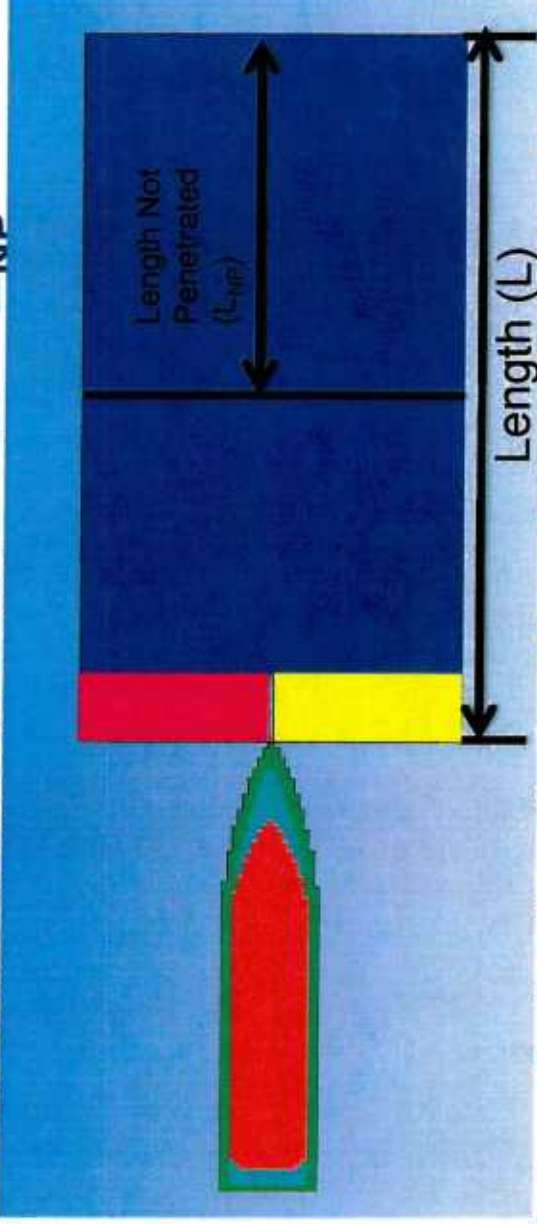


# DOP SIMULATION DETAILS

# CALCULATING DEPTH OF PENETRATION



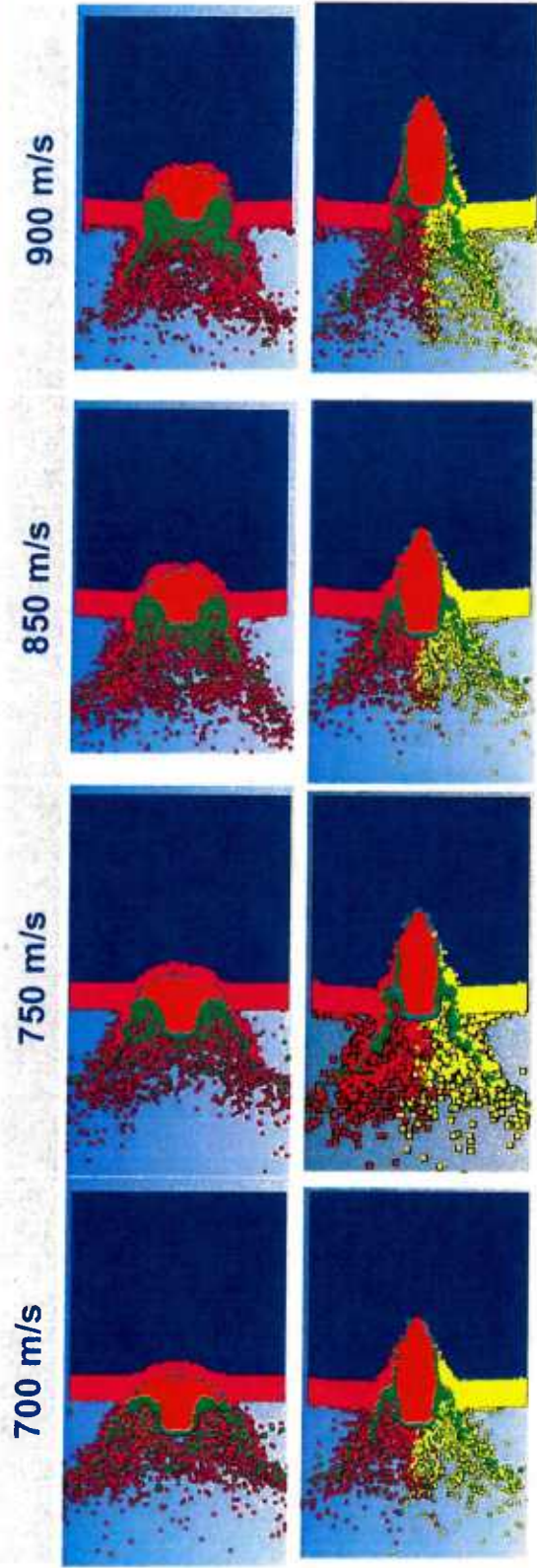
□ DOP is calculated:  $DOP = L - L_{NP}$



- Where  $L$  is the length of the entire target ceramic tiles and aluminum backing
- $L_{NP}$  is the length of the target left not penetrated when the velocity and kinetic energy of the projectile have reached zero



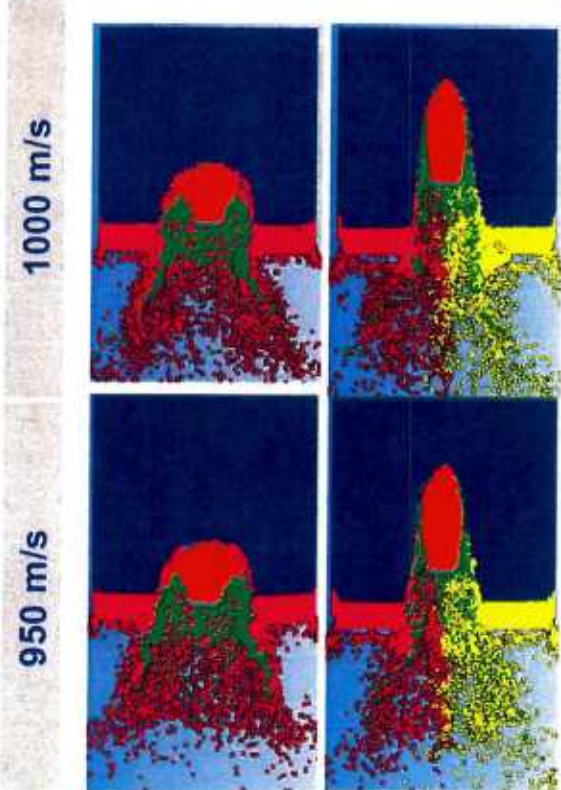
# EFFECT OF 1.2 mm TILE GAP ON DOP



Center Hit Tile

Tile with Gap

Velocity (m/s)	Center Hit Tile DOP (mm)	Tile w/ 1.2 mm Gap DOP (mm)
700	10.02	16.40
750	8.59	18.70
850	10.00	24.05
900	11.13	20.04
950	12.96	28
1000	14.31	30.28



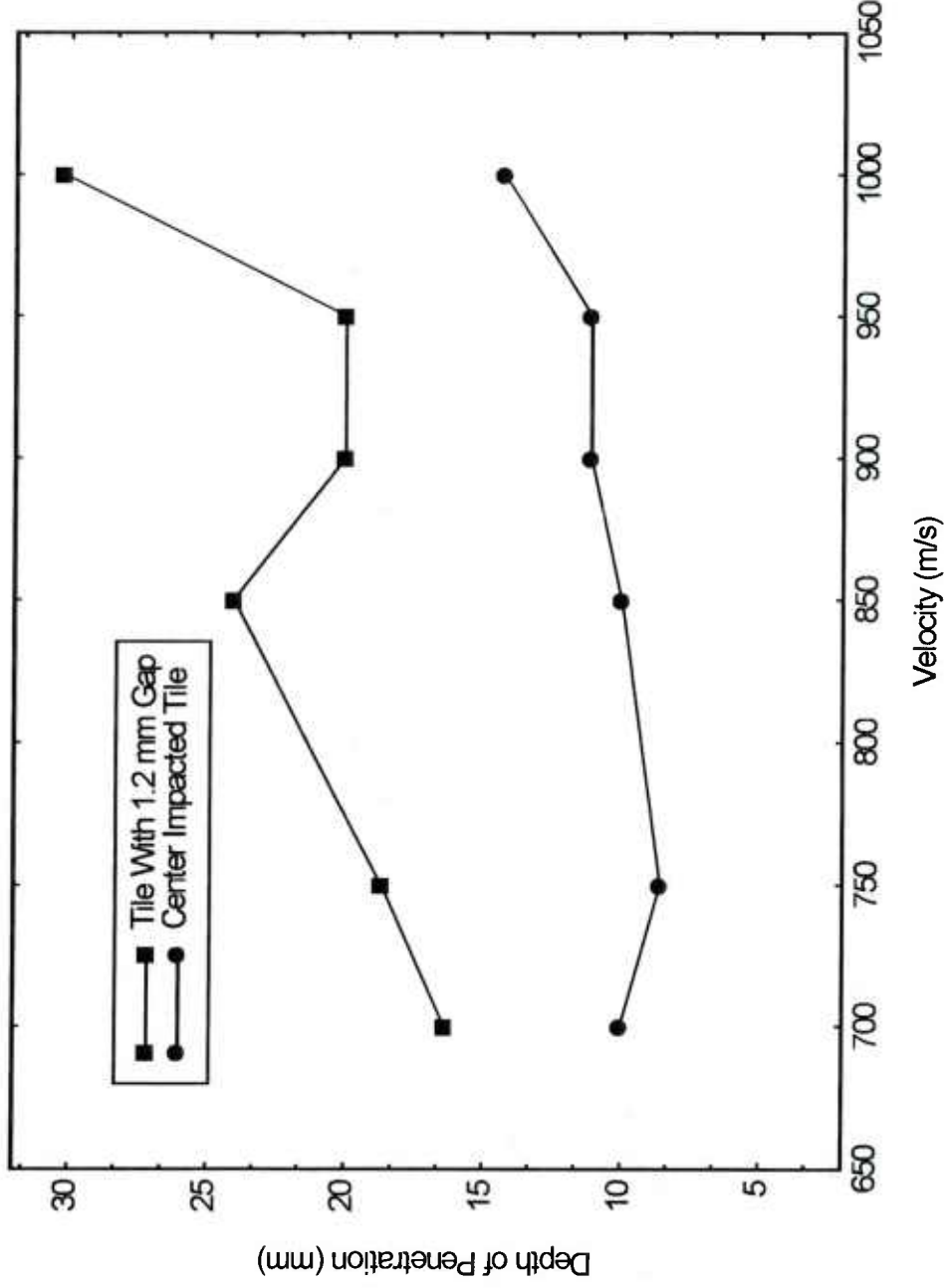
Center Hit Tile

Tile with Gap

# GRAPH OF EFFECT OF A 1.2 mm TILE GAP ON DEPTH OF PENETRATION FOR CENTER IMPACT AND SEAM IMPACTED TILES



Effect of 1.2 mm Tile Gap on Depth of Penetration for Center Impact and Seam Impact  
Depth of Penetration vs. Velocity



# EFFECT OF DOP ON VARYING TILE THICKNESSES AT 850 m/s GAP SIZE 0.508 mm



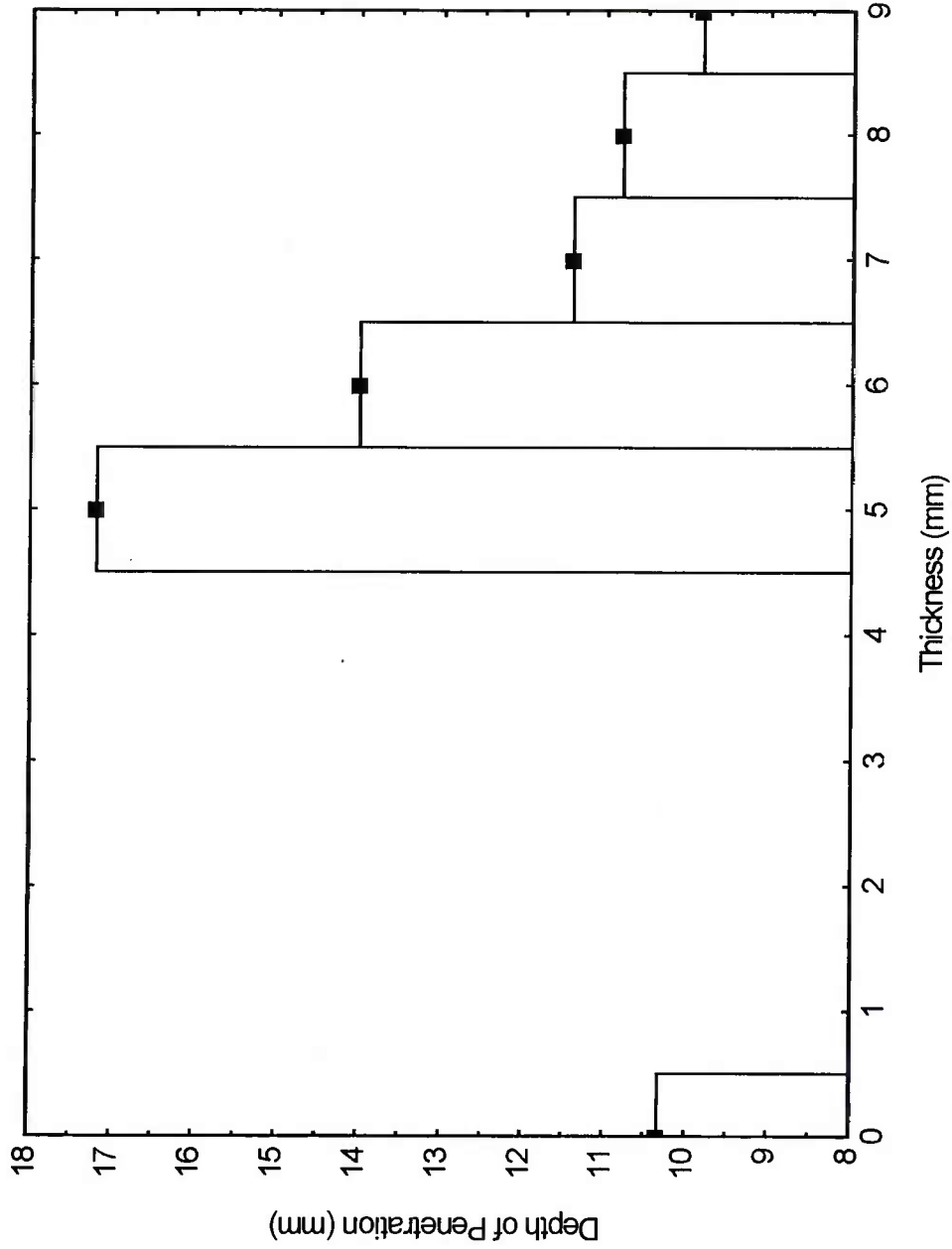
## Depth of Penetration on Baseline Tiles and Modified Tiles at 850 m/s, Gap Size 0.508 mm

Gap Size (mm)	Tile Modification	Depth of Penetration (mm)
None (0)	Baseline (5 mm)	10.33
0.508	Baseline (5 mm)	17.19
0.508	6 mm	14.00
0.508	7 mm	11.40
0.508	8 mm	10.80
0.508	9 mm	9.83

# THICKNESS VS. DEPTH OF PENETRATION ON TILES WITH A 0.508 GAP SIZE

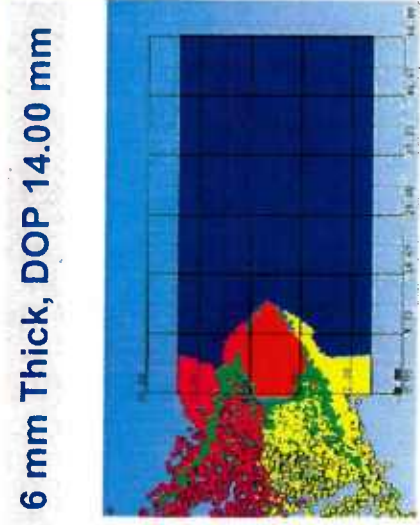
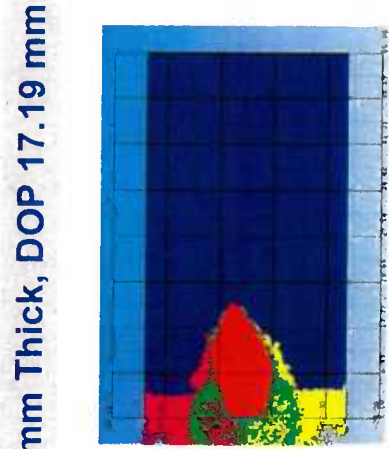
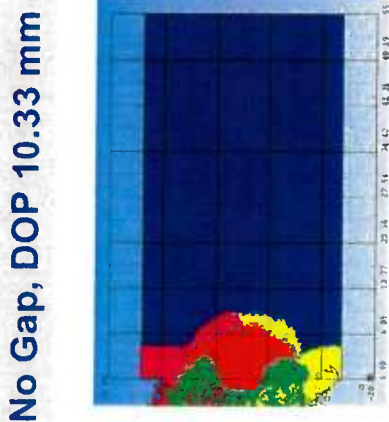


Thickness vs. Depth of Penetration on Tiles with a 0.508 mm Gap Size

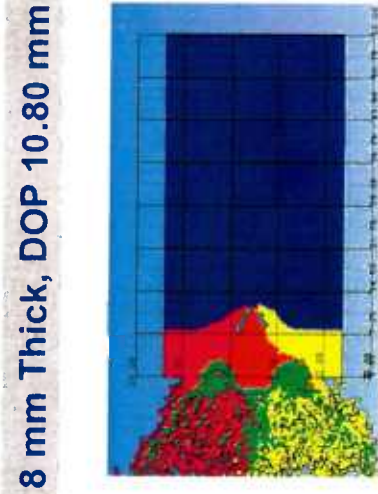
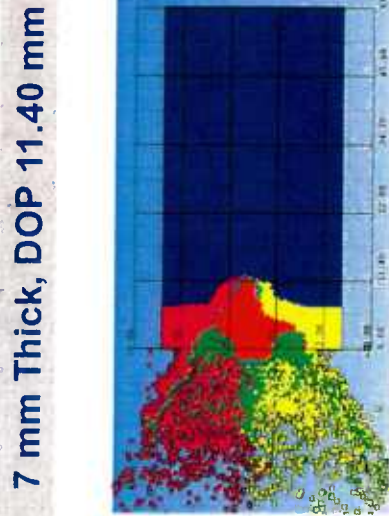


\* 0 mm thickness represents Center Impacted Tile, No Gap

# EFFECT OF TILE THICKNESS ON DOP AT 850 m/s GAP SIZE 0.508 mm

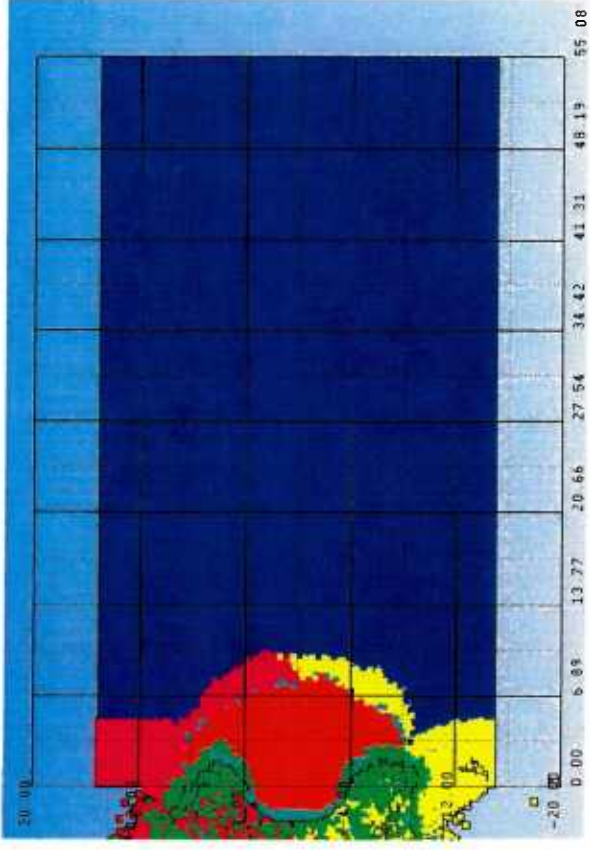
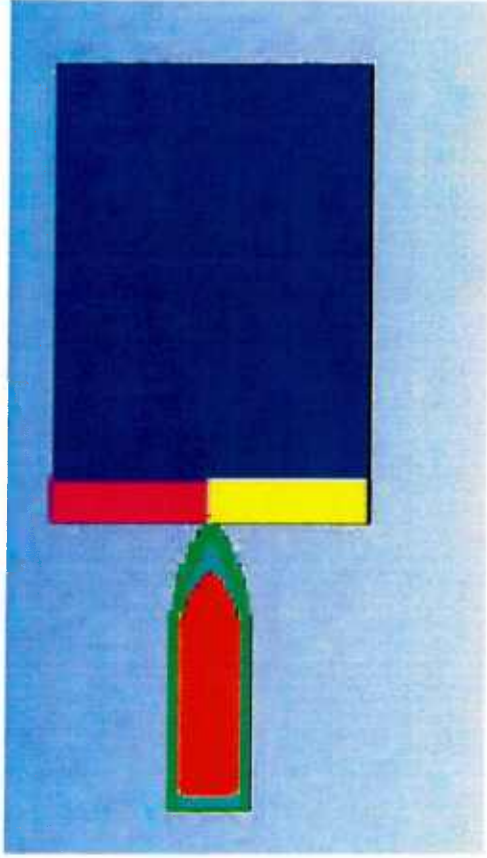


Depth of Penetration on Baseline Tiles and Modified Tiles at 850 m/s, Gap Size 0.508 mm		
Gap Size (mm)	Tile Modification	Depth of Penetration (mm)
None (0)	Baseline (5 mm)	10.33
0.508	Baseline (5 mm)	17.19
0.508	6 mm	14.00
0.508	7 mm	11.40
0.508	8 mm	10.80
0.508	9 mm	9.83



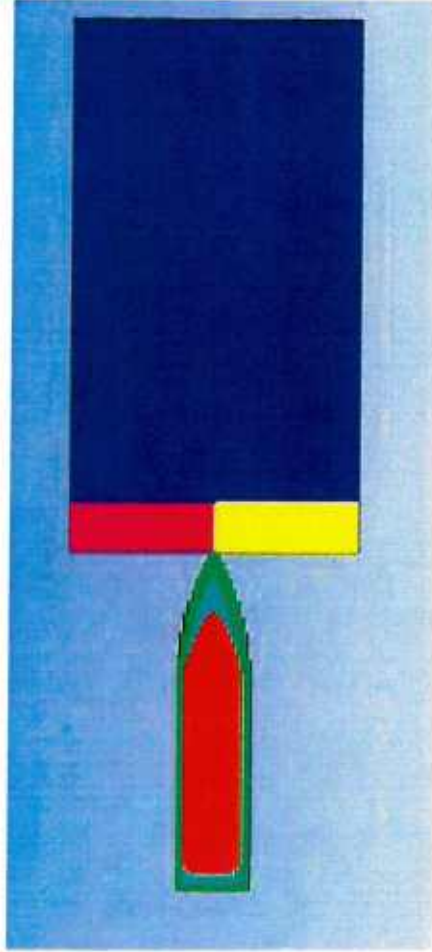
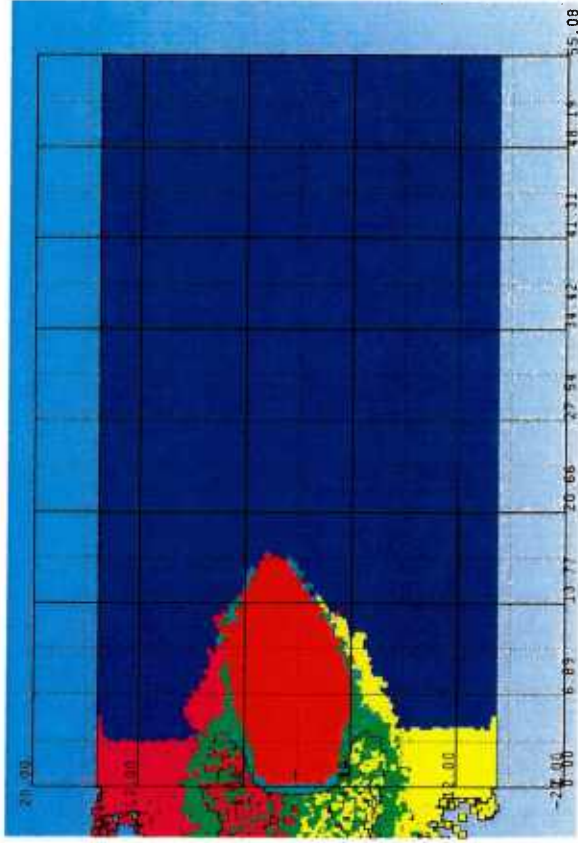


# DOP OF TWO TILES NO GAP AT 850 m/s

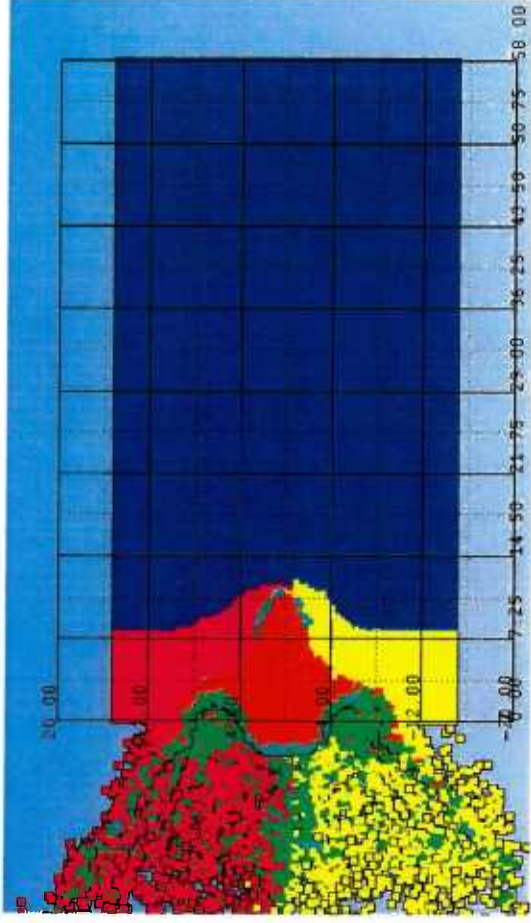
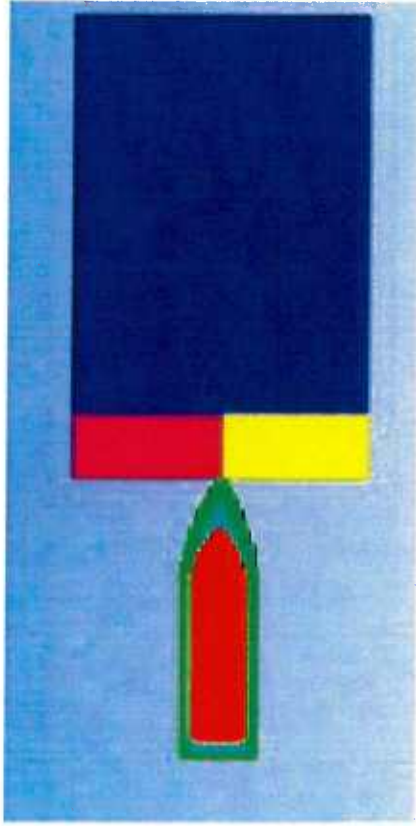


- ❑ Two tiles with no gap replicates the DOP of one solid tile

**DOP ON TWO TILES GAP SIZE 0.508  
5 mm THICK TILE AT 850 m/s**



# DOP ON TWO TILES GAP SIZE 0.508 8 mm THICK TILE AT 850 m/s



## **SUMMARY OF GAP SIZE 0.508 mm RESULTS**



- Achieving a DOP that was similar and even improved upon the DOP of a center impacted target was seen**
- To achieve that comparable DOP the tile thickness needed to be increased by 60%**
- At the gap size of 0.508 mm this is not an ideal solution, this will lower the weight and cost efficiency of the ceramic armor array**

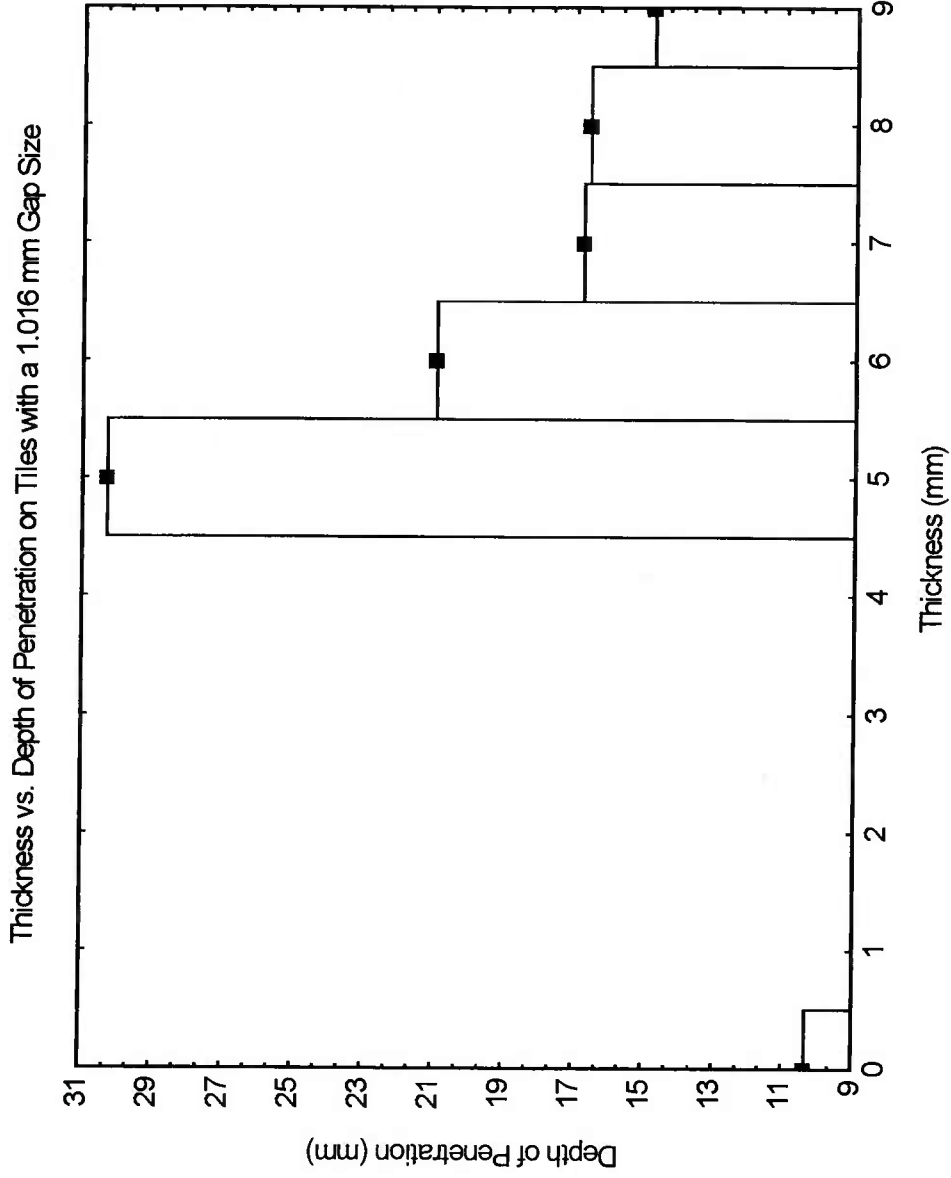
# EFFECT OF DOP ON VARYING TILE THICKNESSES AT 850 m/s GAP SIZE 1.016 mm



## Depth of Penetration on Baseline Tiles and Modified Tiles at 850 m/s, Gap Size 1.061 mm

Gap Size (mm)	Tile Modification	Depth of Penetration (mm)
None (0)	Baseline (5 mm)	10.33
1.016	Baseline (5 mm)	30.29
1.016	6 mm	20.95
1.016	7 mm	16.76
1.016	8 mm	16.59
1.016	9 mm	14.77

# THICKNESS VS. DEPTH OF PENETRATION ON TILES WITH A 1.016 mm GAP SIZE



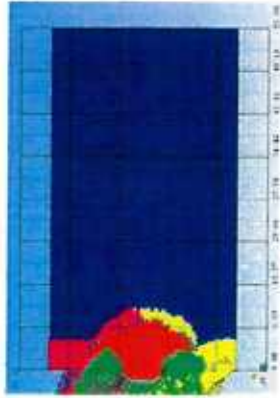
\* 0 mm thickness represents Center Impacted Tile, No Gap

# EFFECT OF TILE THICKNESS ON DOP AT 850 m/s GAP SIZE 1.016 mm

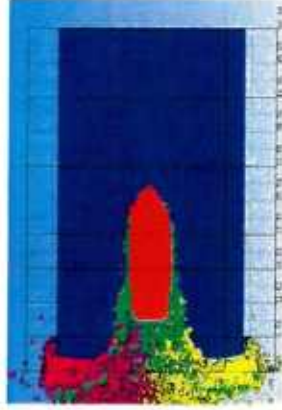


Depth of Penetration on Baseline Tiles and Modified Tiles at 850 m/s, Gap Size 1.061 mm			
Gap Size (mm)	Tile Modification	Depth of Penetration (mm)	Tile Modification
None (0)	Baseline (5 mm)	10.33	Baseline (5 mm)
1.016	Baseline (5 mm)	30.29	Baseline (5 mm)
1.016	6 mm	20.95	6 mm
1.016	7 mm	16.76	7 mm
1.016	8 mm	16.59	8 mm
1.016	9 mm	14.77	9 mm

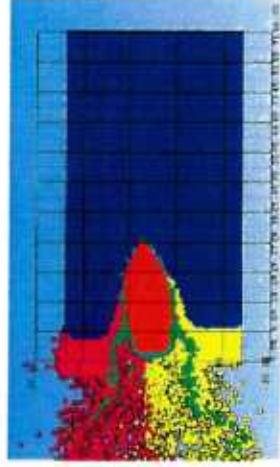
No Gap, DOP 10.33 mm



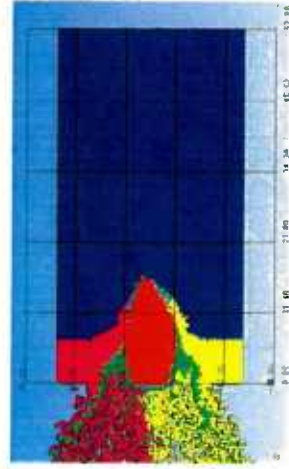
5 mm Thick, DOP 30.29 mm



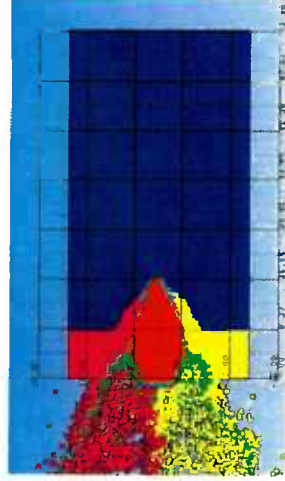
6 mm Thick, DOP 20.95 mm



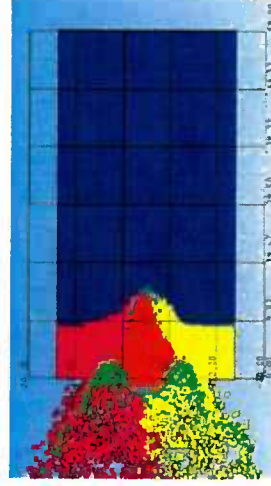
7 mm Thick, DOP 16.76 mm



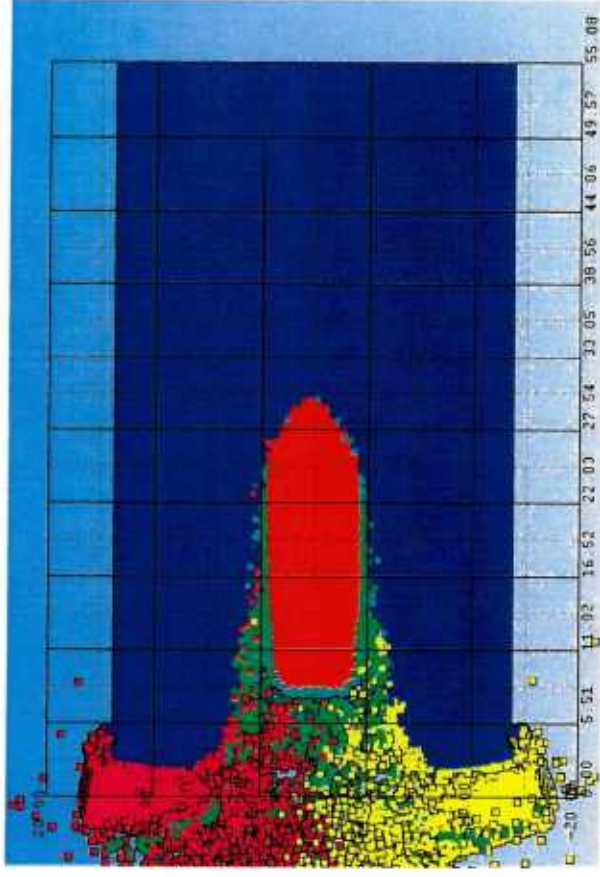
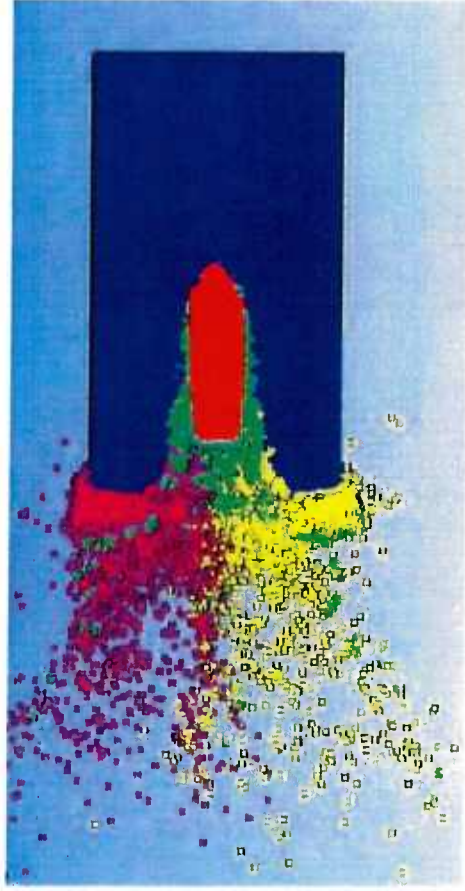
8 mm Thick, DOP 16.59 mm



9 mm Thick, DOP 14.77 mm

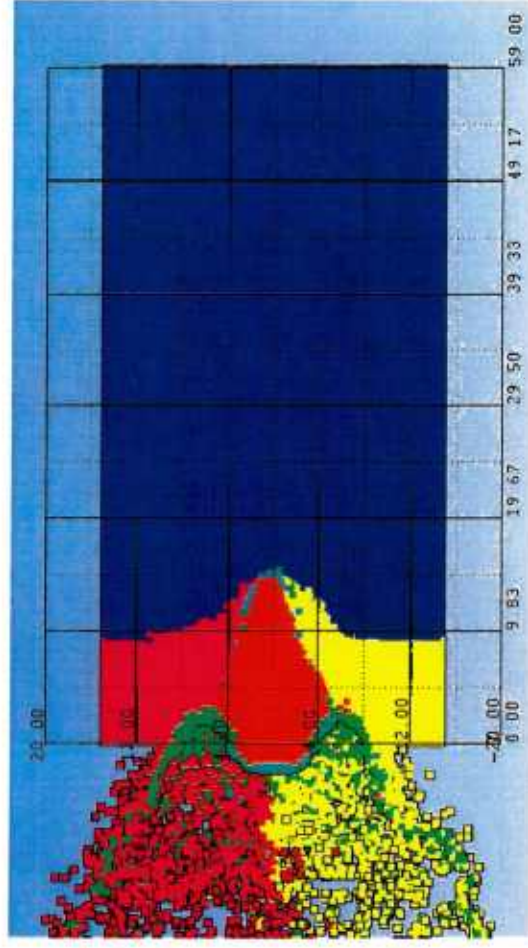


# DOP ON TWO TILES GAP SIZE 1.016 5 mm THICK TILE AT 850 m/s





# DOP ON TWO TILE GAP SIZE 1.016 9 mm THICK TILE AT 850 m/s

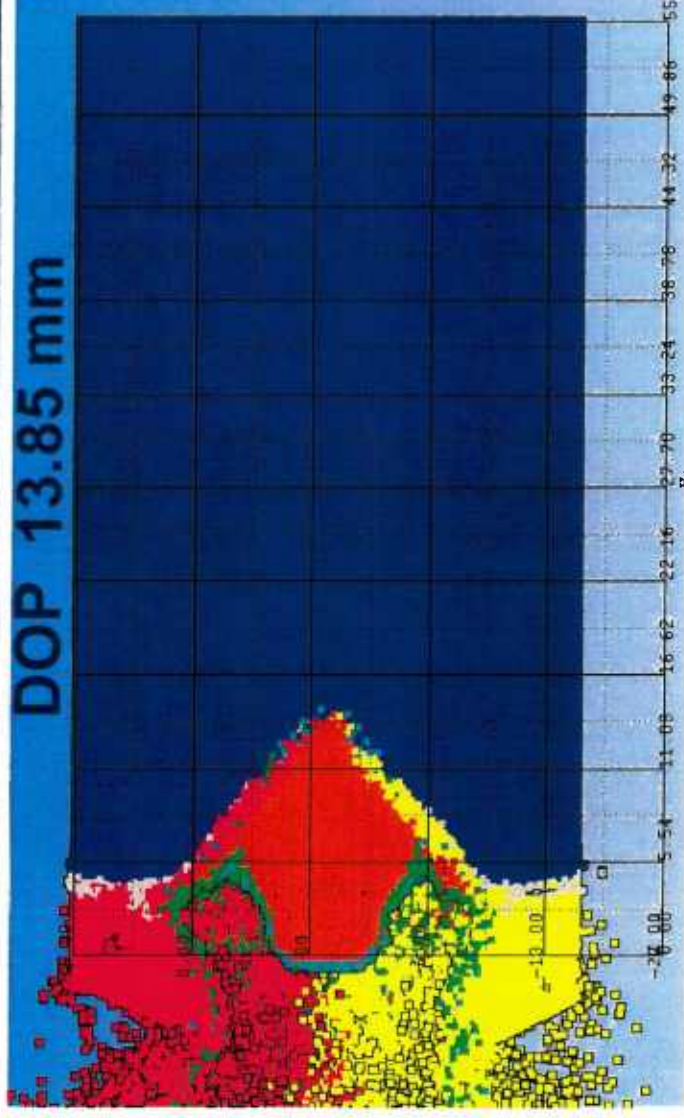


## **SUMMARY OF GAP SIZE 1.016 mm RESULTS**



- ❑ To achieve a DOP similar to the DOP of a center impacted tile the thickness of the tile would need to be more than doubled**
- ❑ At a gap size of 1.016 mm this is not a viable option as this would give rise to cost and weight inefficient armor**

# ADHESIVE LAYER GAP SIZE 0.508 mm 5 mm THICK TILE



Adhesive Layer DOP  
Compared to No Adhesive  
Layer DOP

Adhesive Layer DOP (mm)	No Adhesive Layer DOP (mm)
13.85	17.19

- An adhesive layer of Epoxy Resin was added in between the SiC tile and the Al backing
- The tile remained 5 mm thick and the gap size at 0.508 mm to compare to the baseline results when no adhesive was added

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## **DISCUSSION**

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- ❑ **Increased tile thickness at seams is one solution for increasing seam performance during projectile impacts**
- ❑ **Other proposed seam solutions are step ladder seams, angled seams, reducing gap size, and cover plates**
- ❑ **Continued modeling and experimental tests will down select for the best solution and improvement to seam design**