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13. SUPPLEMENTARY NOTES

14. ABSTRACT

-Half-symmetric model is used in AutoDyn to simulate Depth of Penetration (DoP) experiments on aluminum targets with ceramic facing with and without a gap between tiles.
-Impacts from a .30cal AP M2 projectile are modeled using SPH elements.
-Model validation runs were conducted based on the DoP experiments described in reference - ARL-TR-2219, 2000.
-Boundary conditions were modified in order to achieve better data agreement.
-Further analysis will be conducted to determine the effect of material properties and gap size on DoP.
-Nicole Cicchetti has joined the project as a graduate student.
-Will be studying the effect of gaps on DoP of projectiles on ceramic targets.
-In past reports simulations were on single tiles with no gaps.
-Will be analyzing DoP to determine what tile geometry will improve the penetration resistance at the gap between two tiles.

15. SUBJECT TERMS

.30cal AP M2 Projectile, 762x39 PS Projectile, SPH, Aluminum 5083, SiC, DoP Expeminets, AutoDyn Simulations

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MONTHLY REPORT
SEPTEMBER 2013

Nicole A. Cicchetti, Bazle Z. (Gama) Haque, & Shridhar Yarlagadda

MODELING AND SIMULATION OF CERAMIC ARRAYS TO IMPROVE BALLAISTIC PERFORMANCE

MONTHLY REPORT FOR SEPTEMBER 2013

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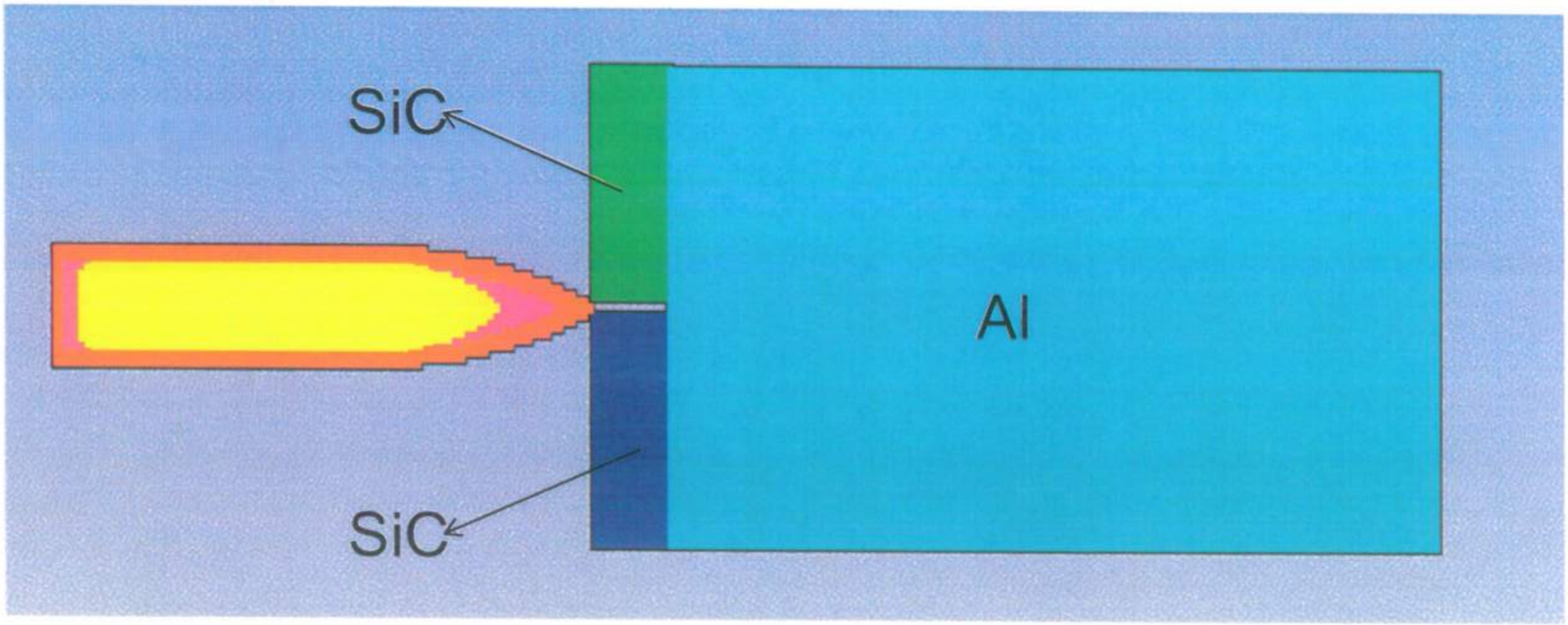
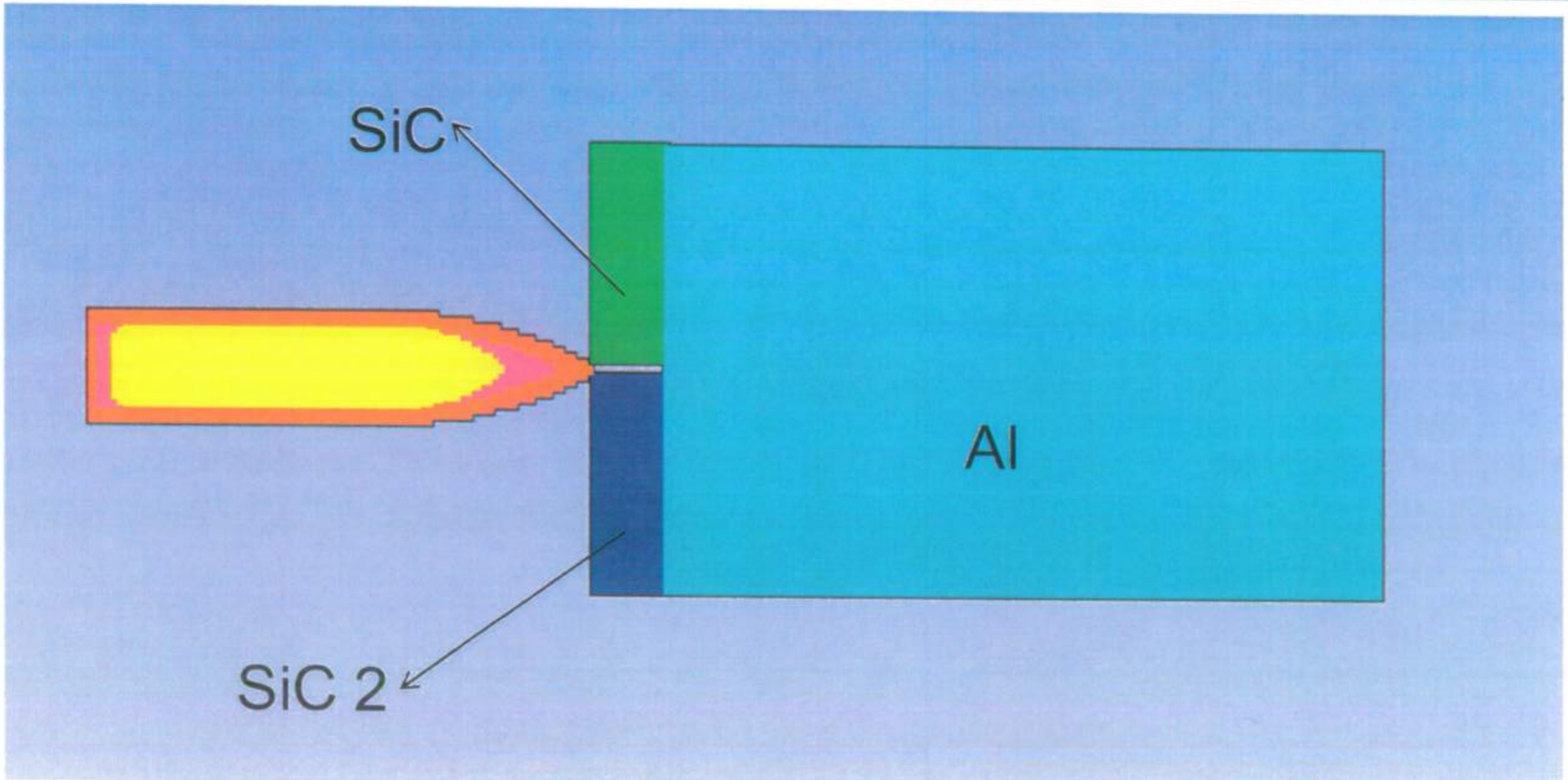
- ❑ Will be analyzing DoP to determine what tile geometry will improve the penetration resistance at the gap between two tiles.

HALF SYMMETRIC MODEL WITH GAP IN AUTODYN



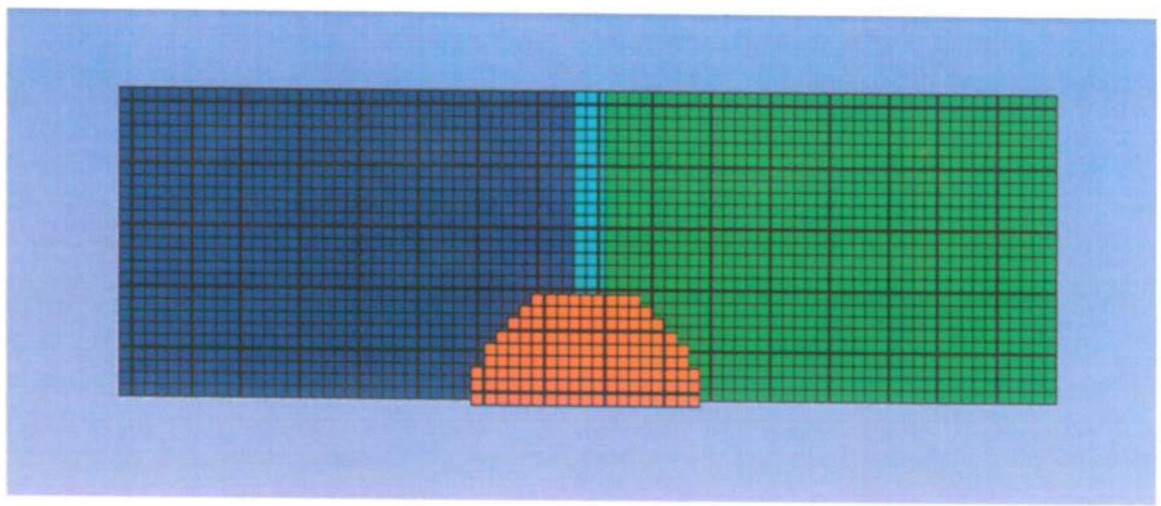
- ❑ Smoothed-particle hydrodynamics (SPH) used for all parts
- ❑ SPH size = 0.40-mm, totaling 278k elements
- ❑ Clamp boundary condition used

HALF-SYMMETRIC MODEL WITH GAP IN AUTODYN

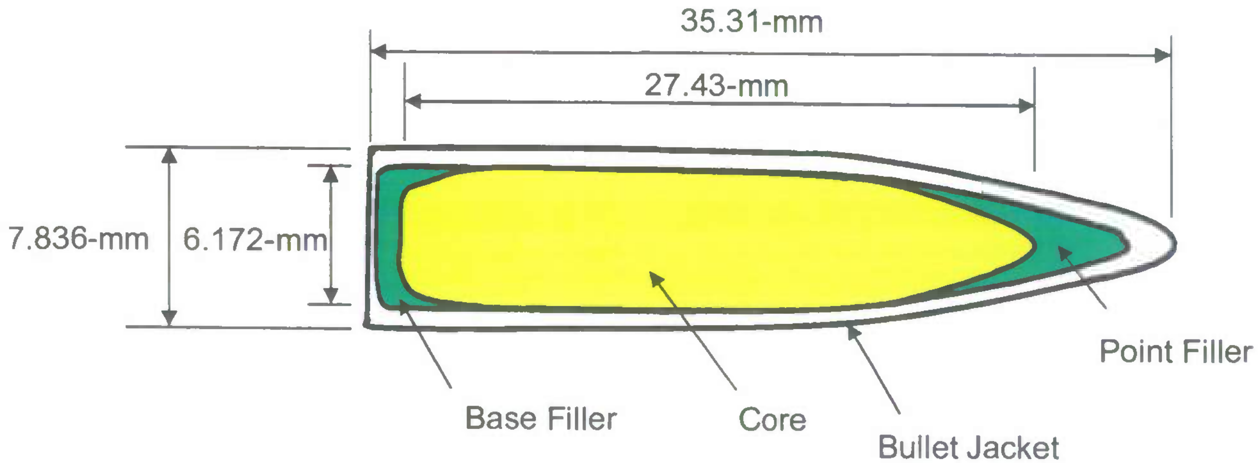


- SiC and SiC 2 have the same properties. They have been saved as separate materials to differentiate between the two ceramic tiles
- There is a gap size of 1.2 mm in-between the two ceramic tiles to simulate a impact on a seam

FRONT VIEW OF MODEL AND PROJECTILE WITH GAP

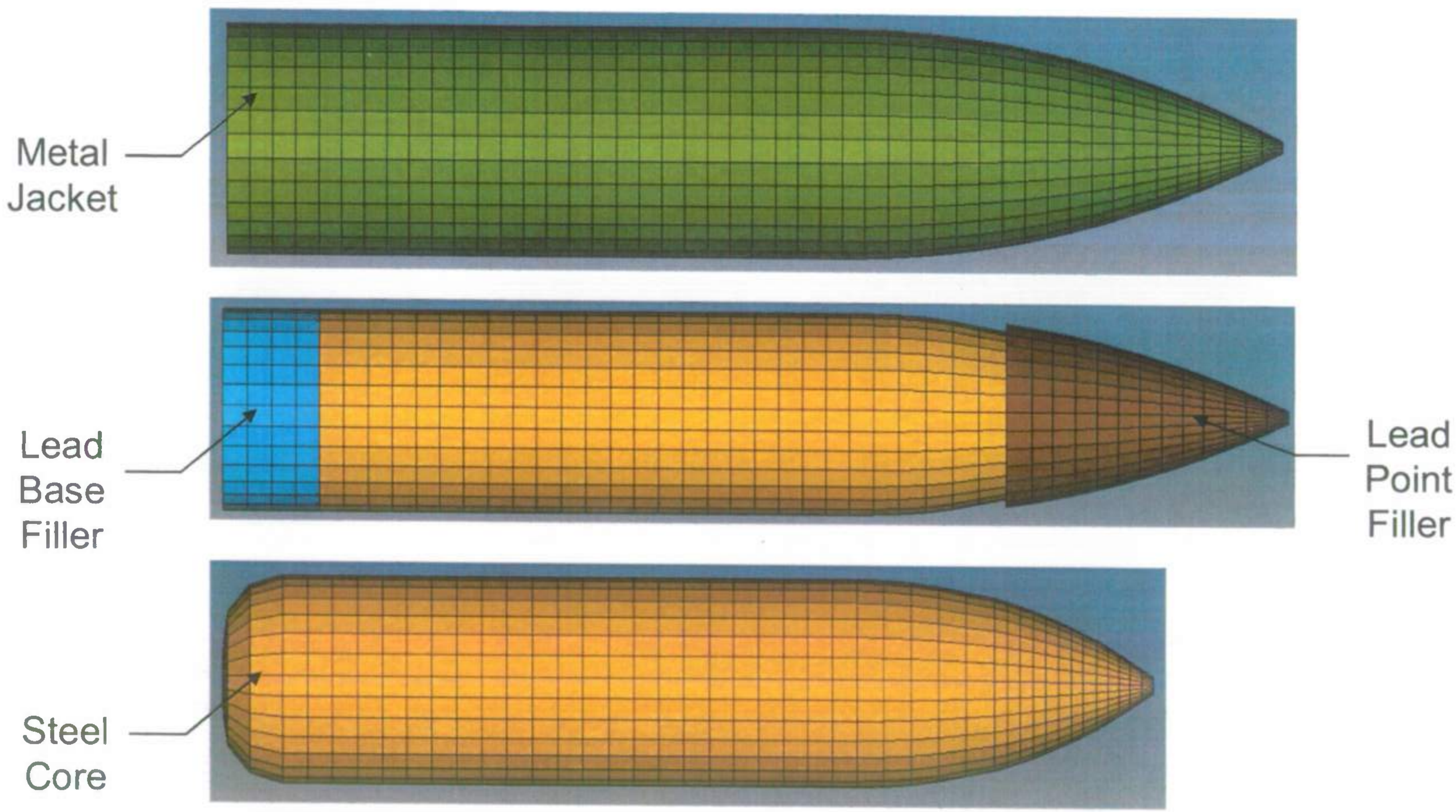


.30cal AP-M2 PROJECTILE MASS PROPERTIES



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
Total Weight		**10.8**

SOLID MODEL OF .30cal AP M2 PROJECTILE



MATERIAL PROPERTIES – Al 5083

Experimental Al 5083

	Al 5083
Density (g/cm³)	2.65
Tensile Strength (MPa)	377.1
Yield Strength (MPa)	318.5
Elongation (%)	9.3

Ref:
MTL TR-86-14, 1986.
ARL-TR-2219, 2000.

AutoDyn Al 5083

Equation of State	Linear
Reference density	2.70000E+00 (g/cm3)
Bulk Modulus	5.83300E+11 (ubar)
Reference Temperature	2.93000E+02 (K)
Specific Heat	9.10000E+06 (erg/gK)
Thermal Conductivity	0.00000E+00 ( )
Strength	**Johnson Cook**
Shear Modulus	2.69200E+11 (ubar)
Yield Stress	1.67000E+09 (ubar)
Hardening Constant	5.96000E+09 (ubar)
Hardening Exponent	5.51000E-01 (none)
Strain Rate Constant	1.00000E-03 (none)
Thermal Softening Exponent	8.59000E-01 (none)
Melting Temperature	8.93000E+02 (K)
Ref. Strain Rate (/s)	1.00000E+00 (none)
Strain Rate Correction	1st Order
Failure	**None**
Erosion	**None**
Material Cutoffs	-
Maximum Expansion	1.00000E-01 (none)
Minimum Density Factor	1.00000E-05 (none)
Minimum Density Factor (SPH)	2.00000E-01 (none)
Maximum Density Factor (SPH)	3.00000E+00 (none)
Minimum Soundspeed	1.00000E-04 (cm/s)
Maximum Soundspeed (SPH)	1.01000E+20 (cm/s)
Maximum Temperature	1.00000E+16 (K)

MATERIAL PROPERTIES - SiC

Experimental SiC

	SiC
Density (g/cm³)	3.20
Elastic Modulus (GPa)	455
Shear Modulus (GPa)	195
Longitudinal Wave Velocity (km/s)	12.3
Poisson's Ratio	0.14
Hardness (kg/mm²)	2700
Compressive Strength (MPa)	3410

Ref:
ARL-TR-2219, 2000.

AutoDyn SiC

Equation of State	**Polynomial**
Reference density	3.21500E+00 (g/cm3)
Bulk Modulus A1	2.20000E+12 (ubar)
Parameter A2	3.61000E+12 (ubar)
Parameter A3	0.00000E+00 (ubar)
Parameter B0	0.00000E+00 (none)
Parameter B1	0.00000E+00 (none)
Parameter T1	2.20000E+12 (ubar)
Parameter T2	0.00000E+00 (ubar)
Reference Temperature	2.93000E+02 (K)
Specific Heat	0.00000E+00 (erg/gK)
Thermal Conductivity	0.00000E+00 ( )
Strength	**Johnson-Holmquist**
Shear Modulus	1.93500E+12 (ubar)
Model Type	Segmented (JH1)
Hugoniot Elastic Limit, HEL	1.17000E+11 (ubar)
Intact Strength Constant, S1	7.10000E+10 (ubar)
Intact Strength Constant, P1	2.50000E+10 (ubar)
Intact Strength Constant, S2	1.22000E+11 (ubar)
Intact Strength Constant, P2	1.00000E+11 (ubar)
Strain Rate Constant, C	9.00000E-03 (none)
Max. Fracture Strength, SFMAX	1.30000E+10 (ubar)
Failed Strength Constant, ALPHA	4.00000E-01 (none)
Failure	**Johnson Holmquist**
Hydro Tensile Limit	-7.50000E+09 (ubar)
Model Type	Segmented (JH1)
Damage Constant, EFMAX	1.20000E+00 (none)
Damage Constant, P3	9.97500E+11 (ubar)
Bulking Constant, Beta	1.00000E+00 (none)
Damage Type	Instantaneous (JH1)
Tensile Failure	Hydro (Pmin)

CALCULATING DEPTH OF PENETRATION

- DoP is calculated:

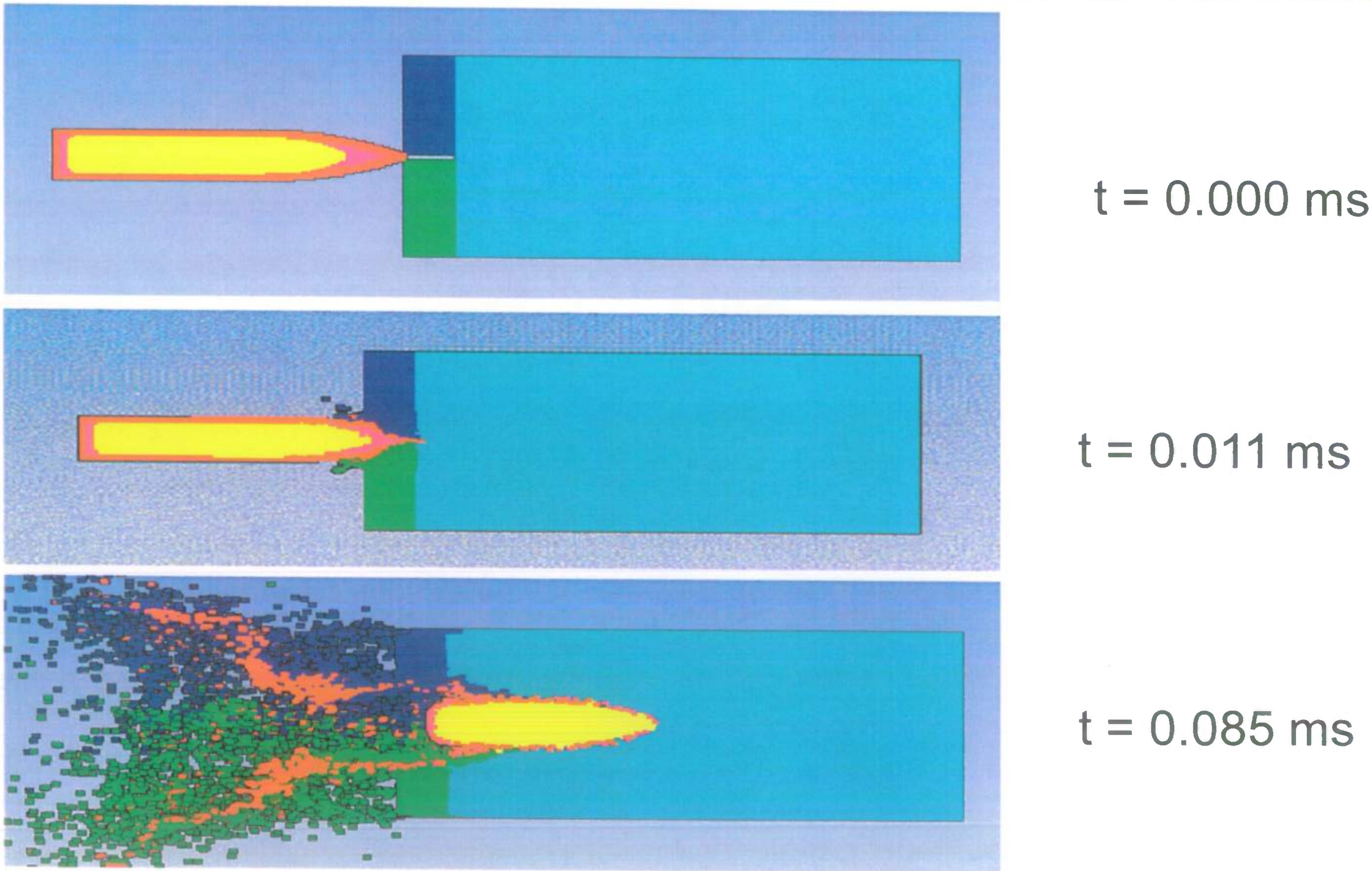
$$DOP = L - L_{NP}$$

- 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

Shot No. 3046 Vo = 842 m/s t_c = 5.08 mm particle size = 0.3, Gap = 1.2 mm

- ☐ Test model to find the correct dimensions for the SPH target
- ☐ Test to also find the correct boundary conditions on a model with a gap in-between two tiles.

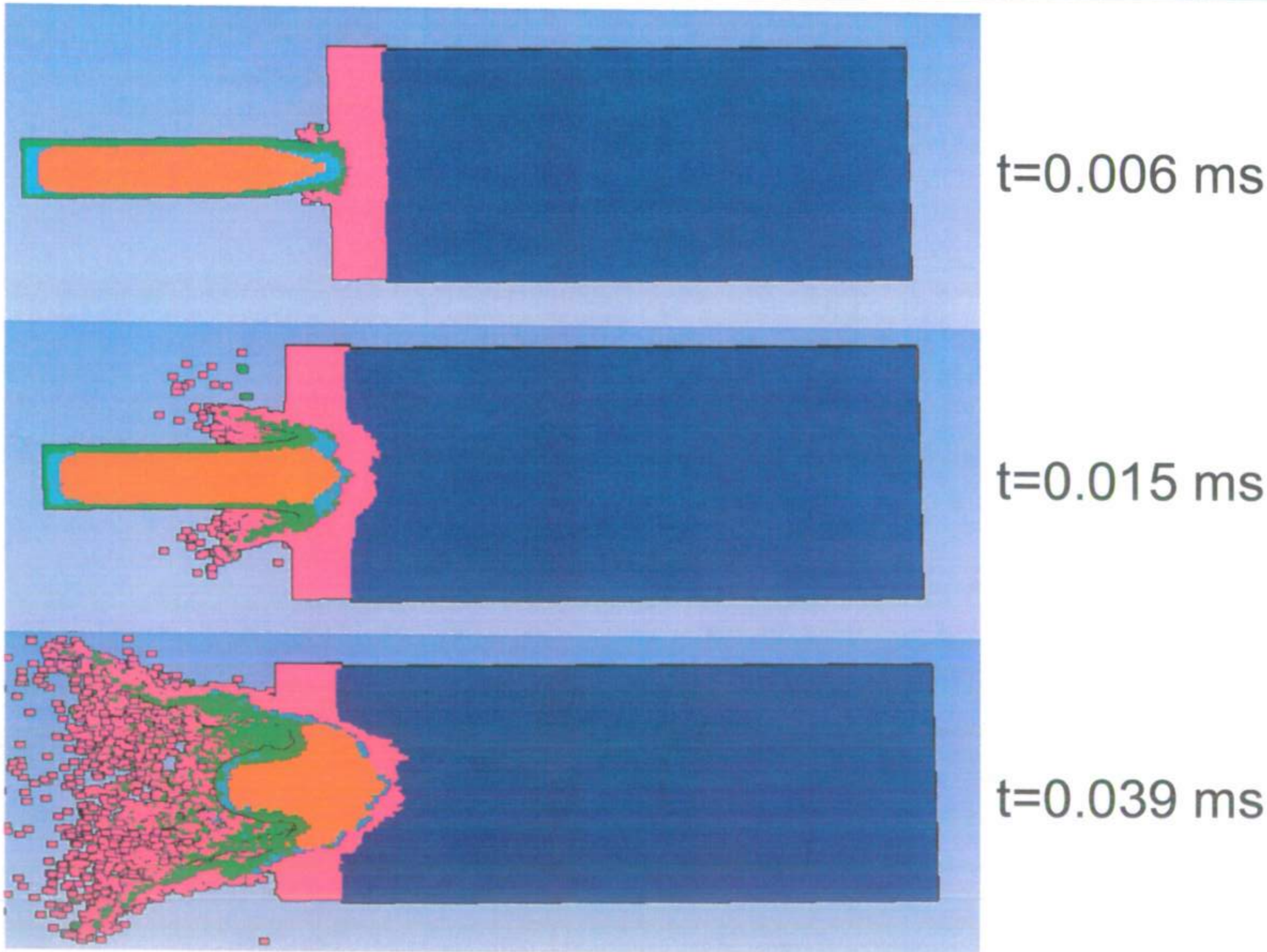
Shot No. 3046 Vo = 842 m/s t_c = 5.08 mm particle size = 0.3, Gap = 1.2 mm



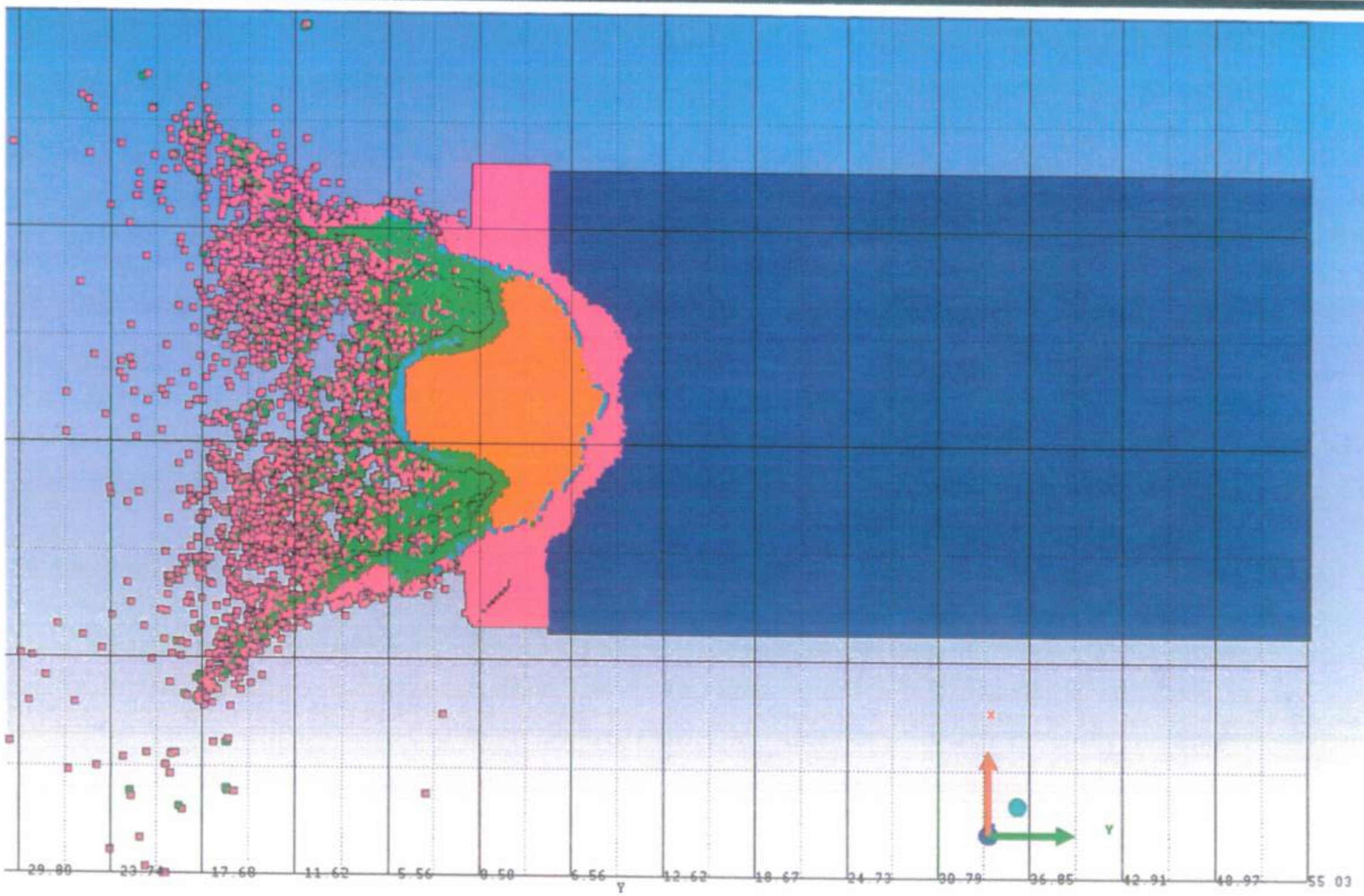
SHOT NO. 3044, V=851 m/s, t_c=5.08 mm, No Gap

- ❑ Impact on single SiC tile with Al backing
- ❑ Goal to measure DoP to compare with the same impact on a gap in-between two tiles

SHOT NO. 3044, V=851 m/s, t_c=5.08 mm, No Gap



DEPTH OF PENETRATION

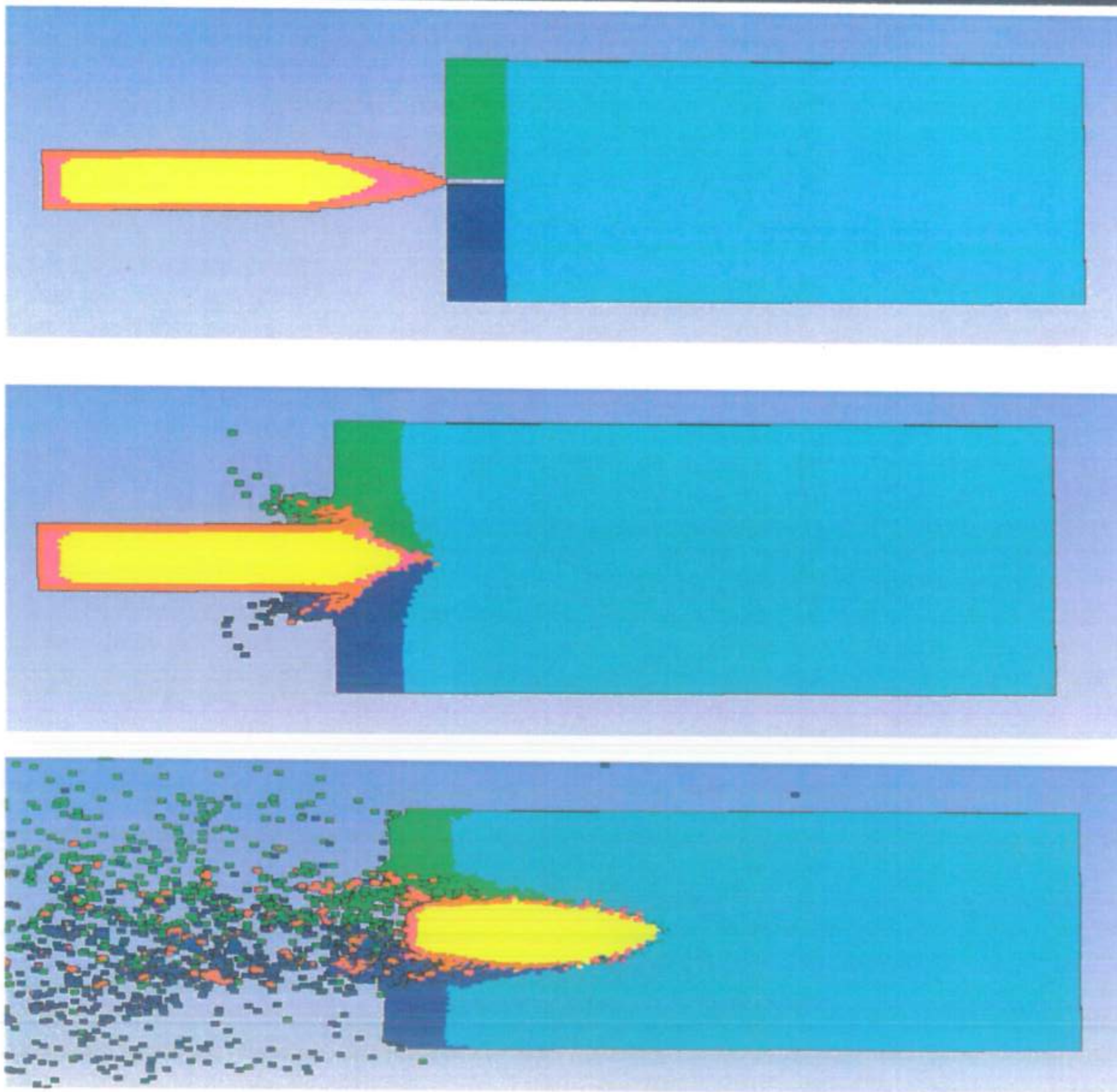


$$DOP = L - L_{np} = 55.08 - 46.52 = 8.56 \text{ mm}$$

Shot No. 3044 Vo = 851 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

- ❑ Impact on gap in-between two identical SiC tiles
- ❑ Tiles shown as two separate materials for clarity properties are identical
- ❑ Goal to measure DoP to compare with the same impact on a single tile with no gap

Shot No. 3044 Vo = 851 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

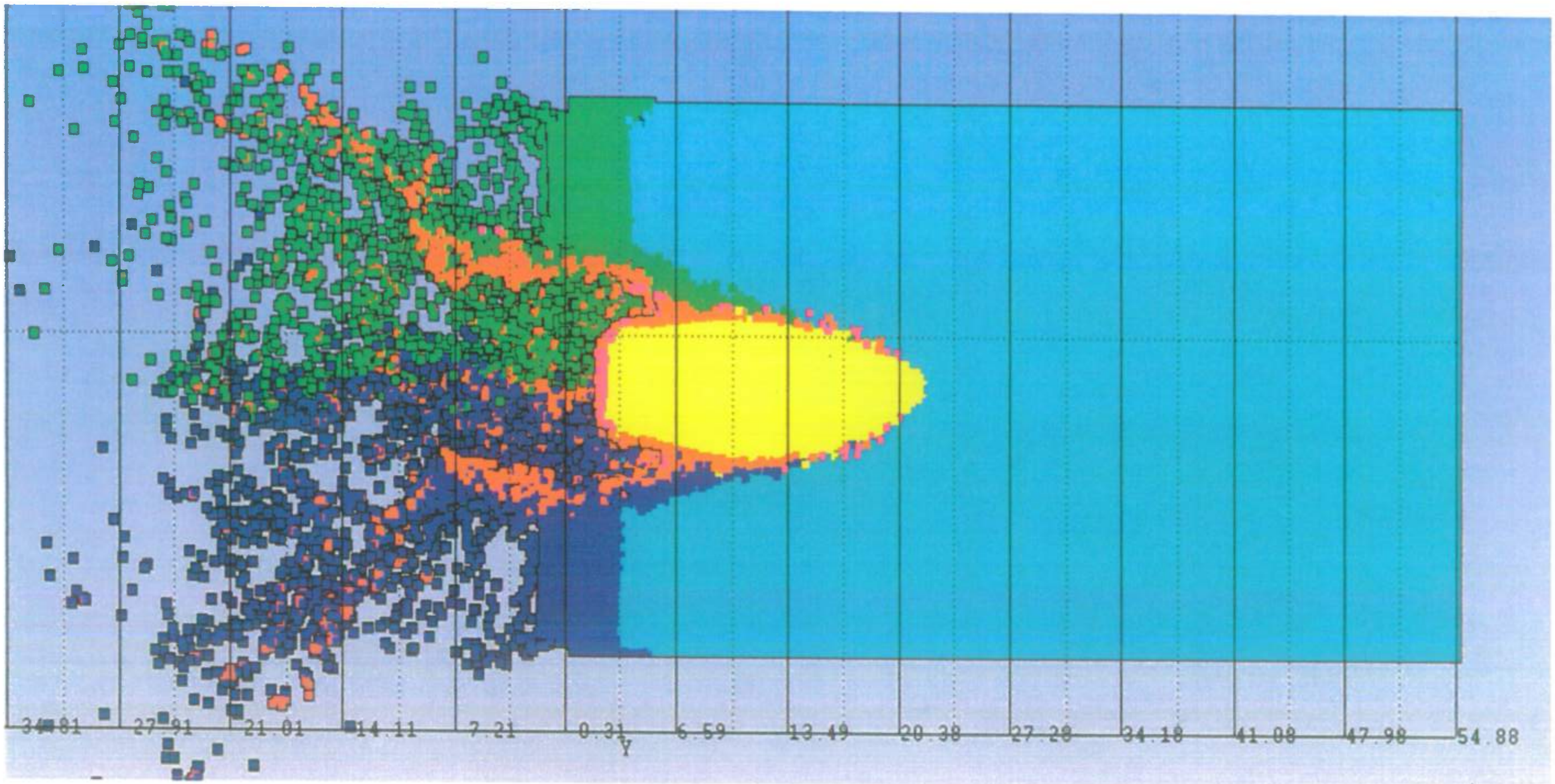


t=0.000 ms

t=0.014 ms

t=0.272 ms

DEPTH OF PENETRATION



$$DOP = L - L_{np} = 55.08 - 32.05 = 23.03mm$$

DoP COMPARISIONS, V_o = 851 m/s

Gap	DoP (mm)
1.2 mm, Two tiles	23.03
No Gap, One Tile	8.56