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14. ABSTRACT
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.
Impacts of a .30cal AP M2 projectile over an impact velocity range 700 m/s to 1000 m/s are modeled using SPH elements.
Model validation runs with monolithic 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 monolithic tiles
The next step will be run simulations on narrower and wider gap sizes and different geometries of tile configurations.
Determinations need to be made on what the manufacturers tolerances on tile gaps are and possible filling materials for gaps.
DOP is the main measurement to determine which geometry and configuration yield the best results.

15. SUBJECT TERMS
.30cal AP M2 Projectile, 762x39 PS Projectile, SPH, Aluminum 5083, SiC, DoP Expeminets, AutoDyn Simulations, Tile Gap

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MONTHLY REPORT
OCTOBER 2013

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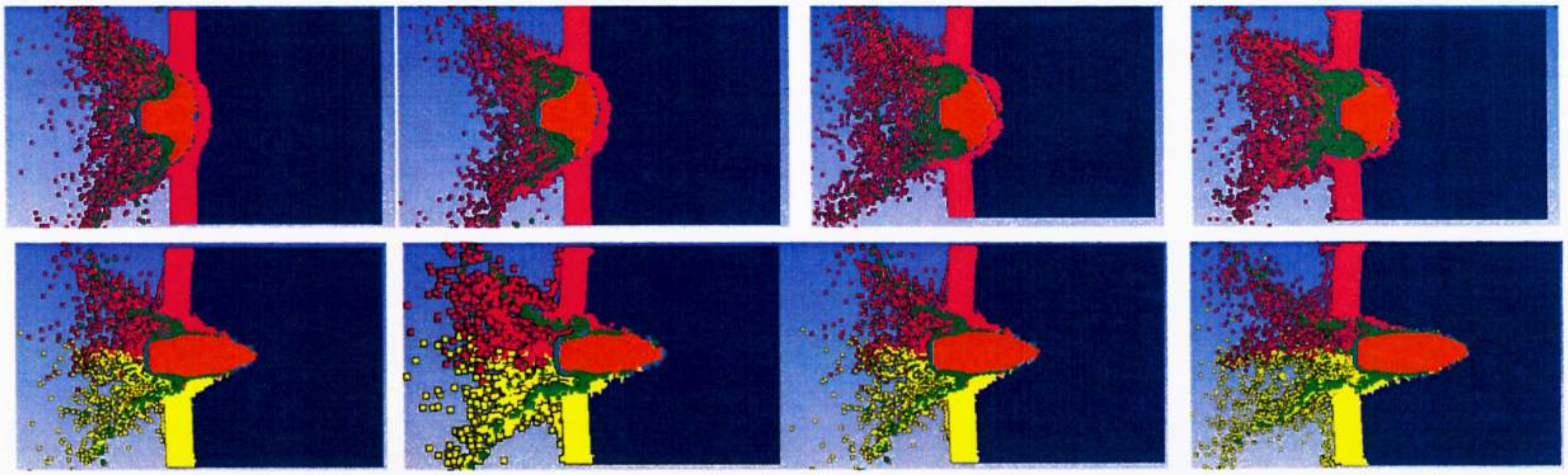
MODELING AND SIMULATION OF CERAMIC ARRAYS TO IMPROVE BALLAISTIC PERFORMANCE

MONTHLY REPORT FOR OCTOBER 2013

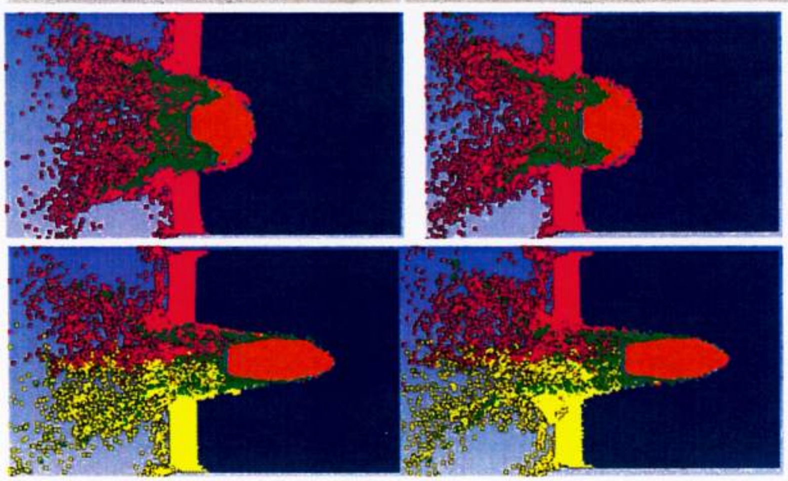
- Half-symmetric model is used in AutoDyn to simulate Depth of Penetration (DoP) experiments on SiC tile with and without a gap supported by solid aluminum.
- Impacts of a .30cal AP M2 projectile over an impact velocity range 700 m/s to 1000 m/s are modeled using SPH elements.
- Model validation runs with monolithic 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 monolithic tiles
- The next step will be run simulations on narrower and wider gap sizes and different geometries of tile configurations.
- Determinations need to be made on what the manufacturers tolerances on tile gaps are and possible filling materials for gaps.
- DOP is the main measurement to determine which geometry and configuration yield the best results.

EFFECT OF TILE GAP ON DOP

	700 m/s	750 m/s	850 m/s	900 m/s
Monolithic Tile				
Tile with Gap				



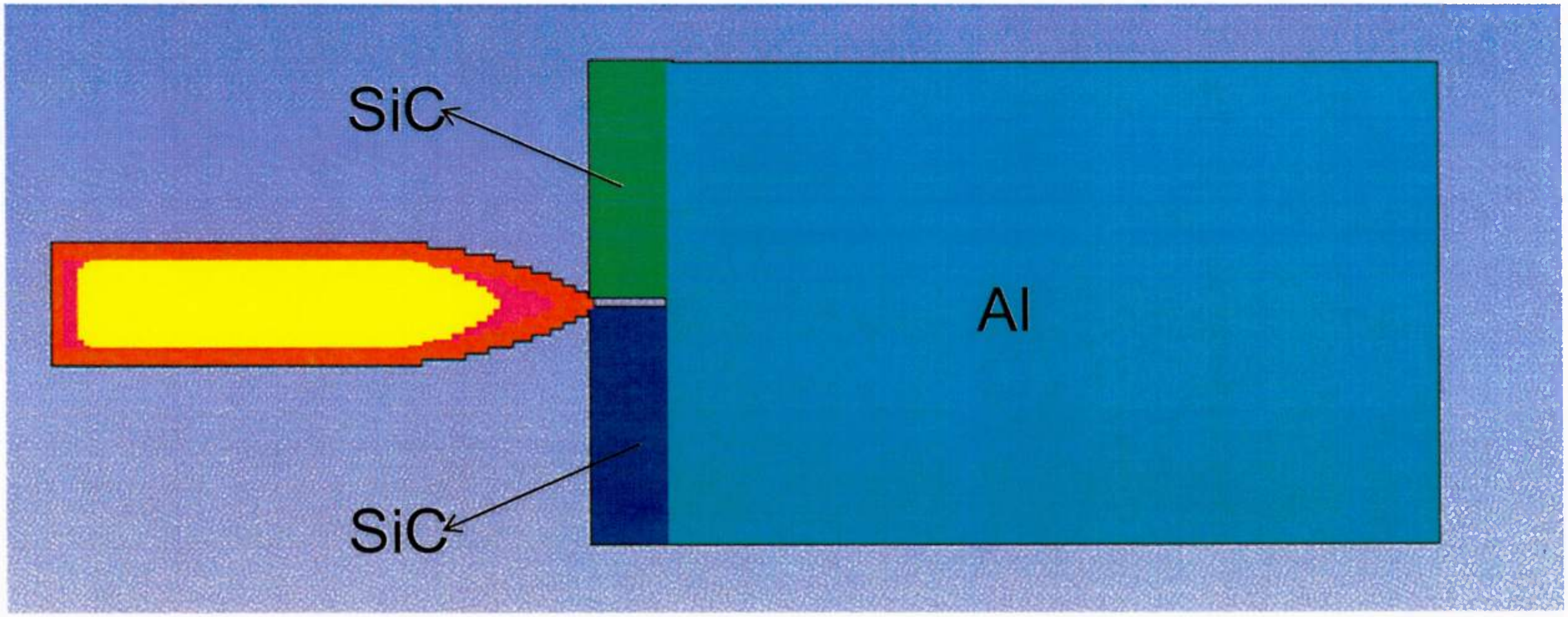
	950 m/s	1000 m/s
Monolithic Tile		
Tile with Gap		



Velocity (m/s)	One Tile DOP (mm)	Tile w/ 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

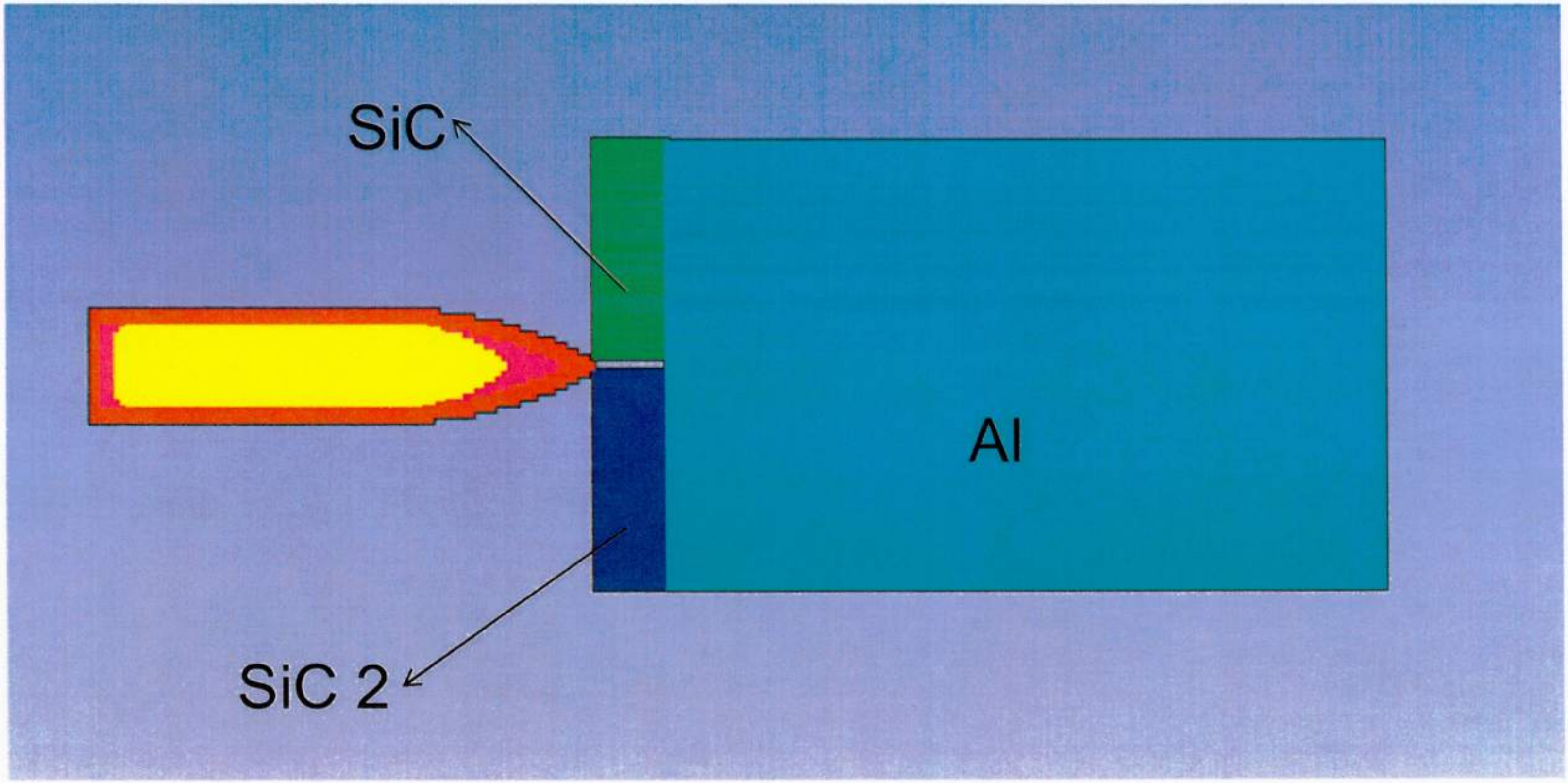
DOP SIMULATION DETAILS

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

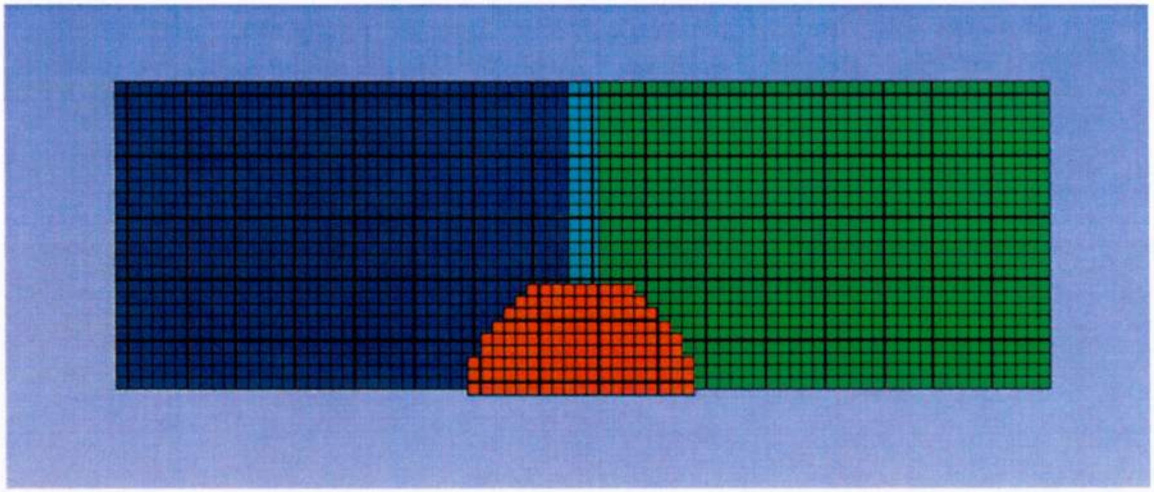


- SiC and SiC 2 have the same properties. They have been saved as separate materials to differentiate between the two ceramic tiles
- There is a gap size of 1.2 mm in-between the two ceramic tiles to simulate a impact on a seam

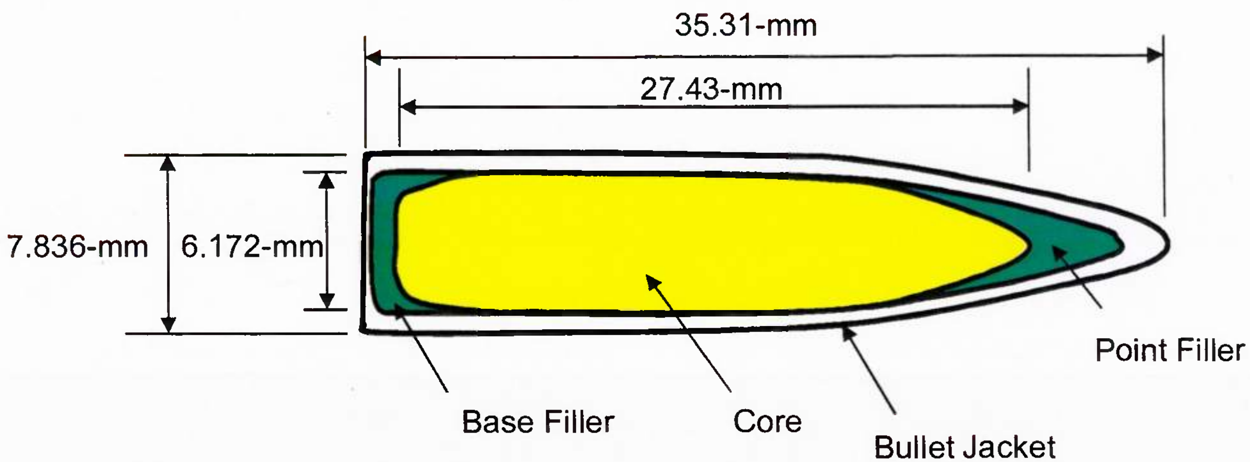
Target Dimensions

- Aluminum Backing
  - Length = 35.08 mm
- Ceramic Plate(s)
  - Length (t_c) = 5.08 mm
  - Gap size = 1.2 mm
- Total Length = 40.08 mm

FRONT VIEW OF MODEL AND PROJECTILE WITH GAP

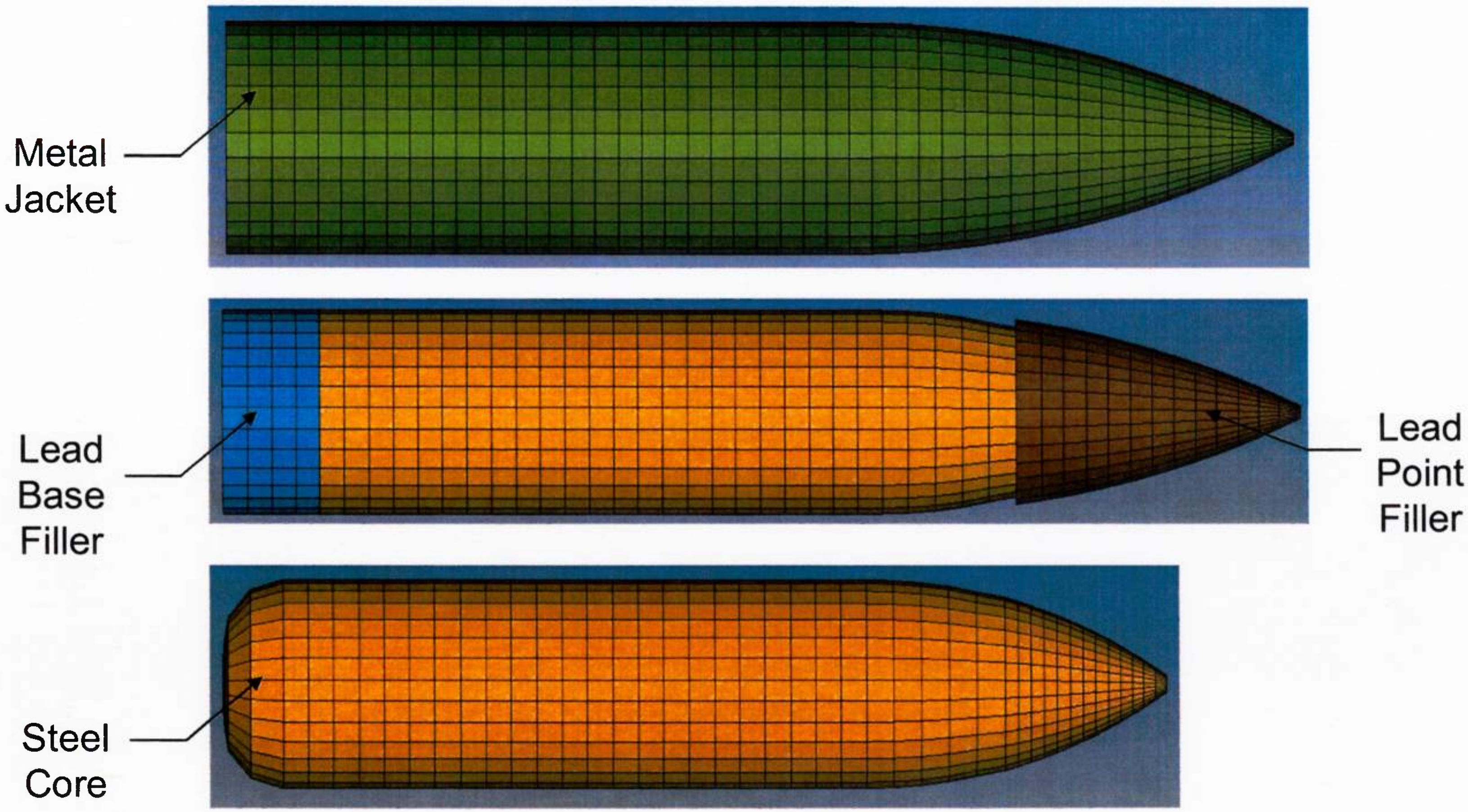


.30cal AP-M2 PROJECTILE MASS PROPERTIES



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/cm^3)	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

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)

Experimental SiC

	SiC
Density (g/cm^3)	3.20
Elastic Modulus (GPa)	455
Shear Modulus (GPa)	195
Longitudinal Wave Velocity (km/s)	12.3
Poisson's Ratio	0.14
Hardness (kg/mm^2)	2700
Compressive Strength (MPa)	3410

Ref:
ARL-TR-2219, 2000.

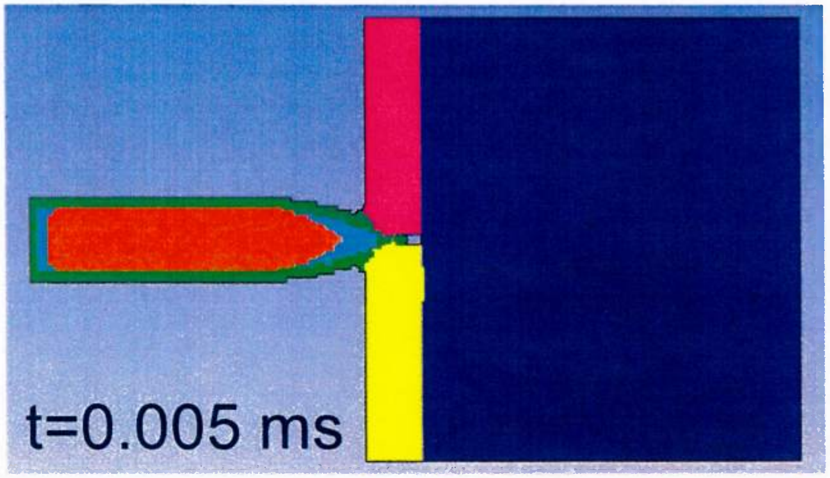
CALCULATING DEPTH OF PENETRATION

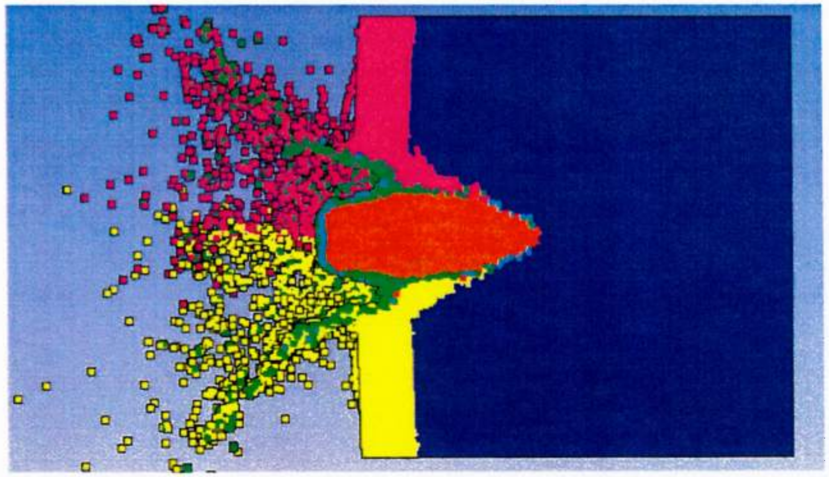
- DoP is calculated:

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

- 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

Vo = 700 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm





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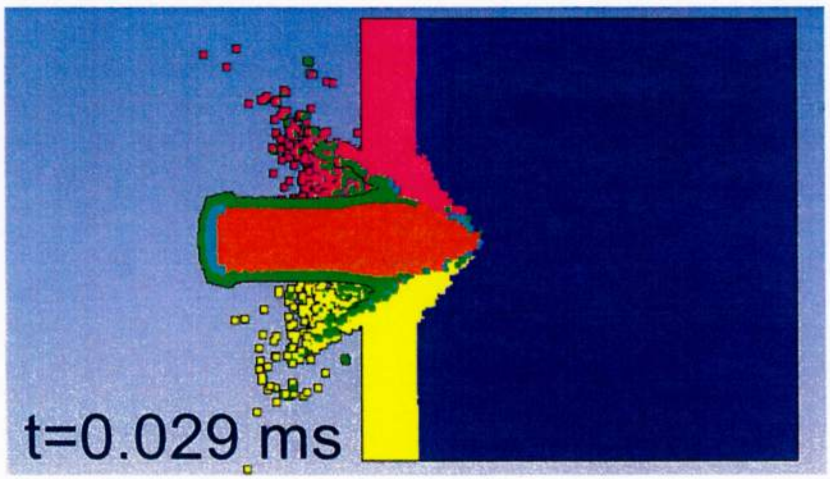
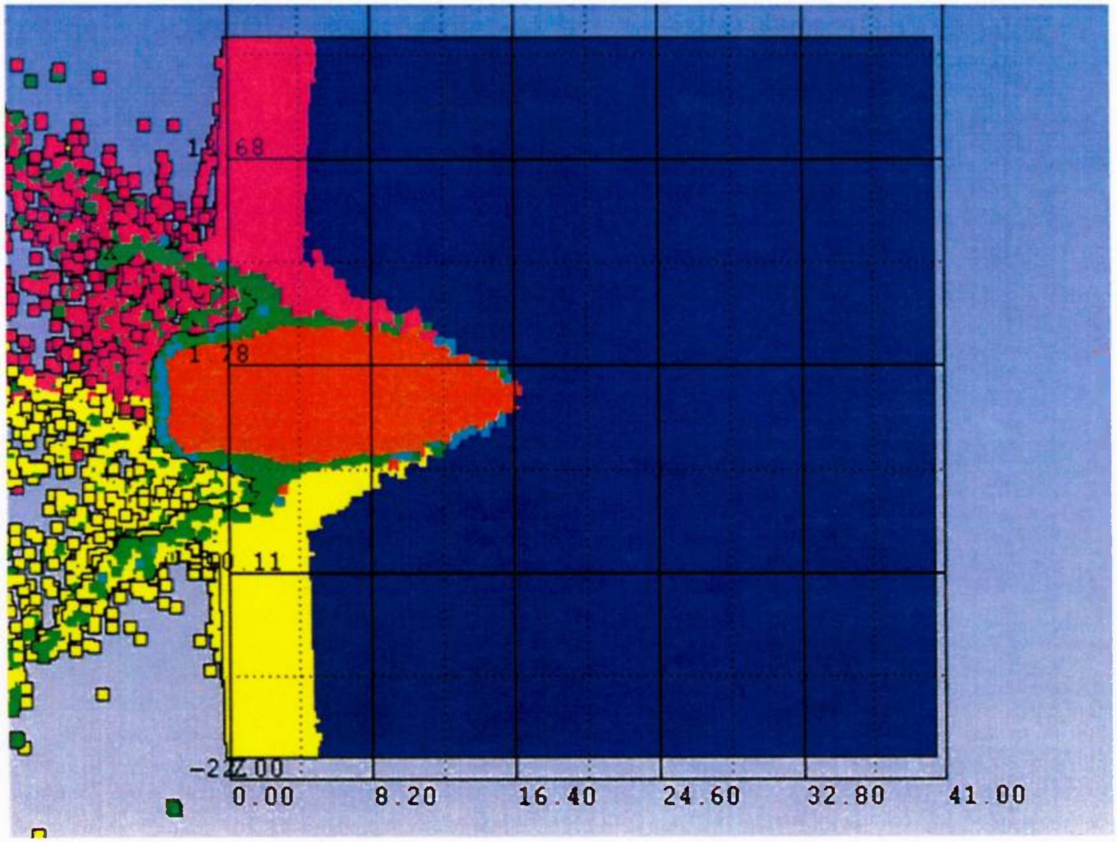
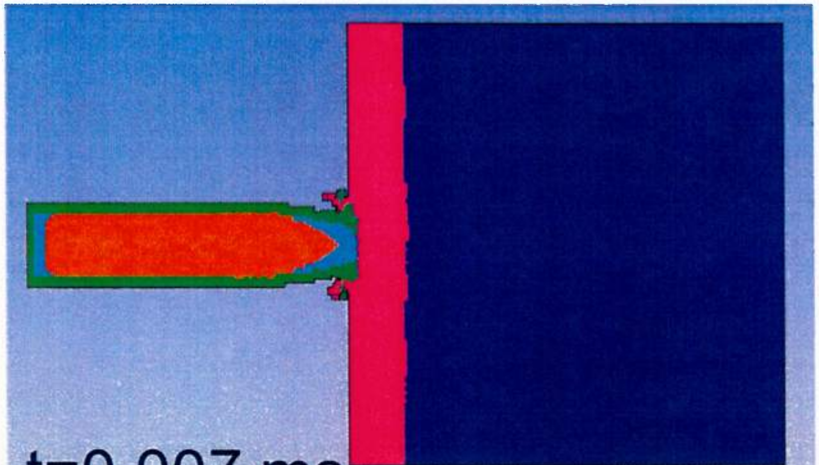


DEPTH OF PENETRATION Vo = 700 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm



$$DOP = L - L_{np} = 40.08 - 23.68 = 16.40 \text{ mm}$$

Vo = 700 m/s t_c = 5.08 mm particle size = 0.4, No Gap



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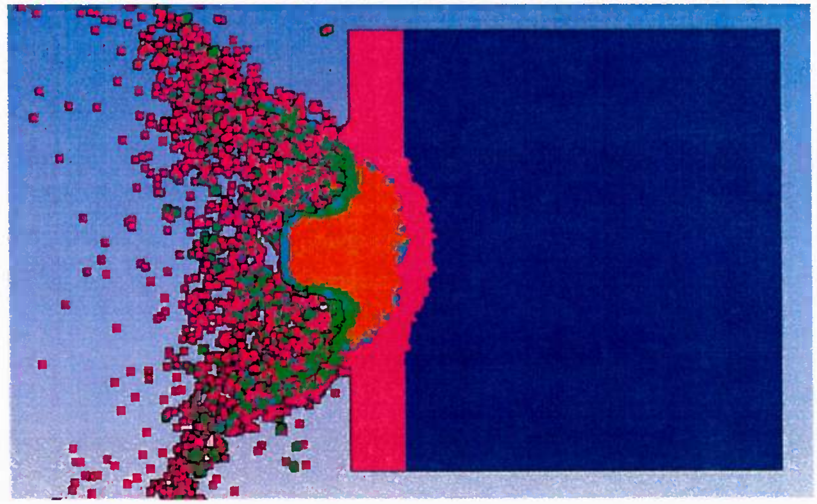
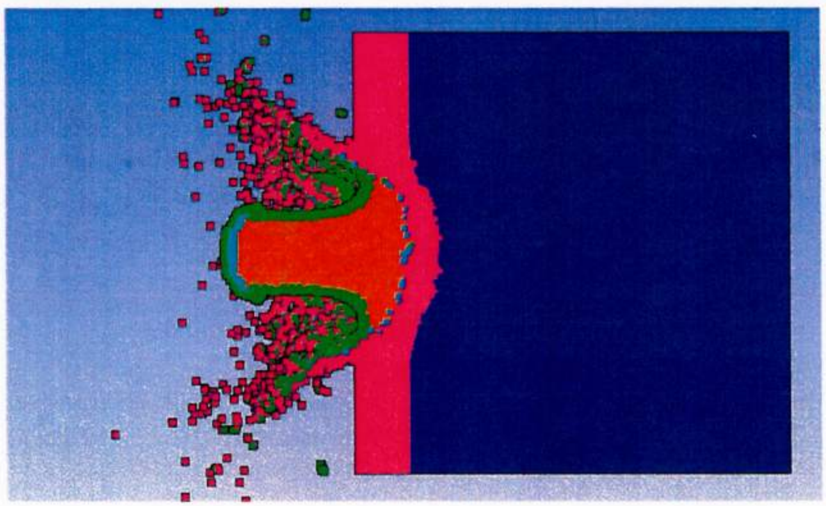
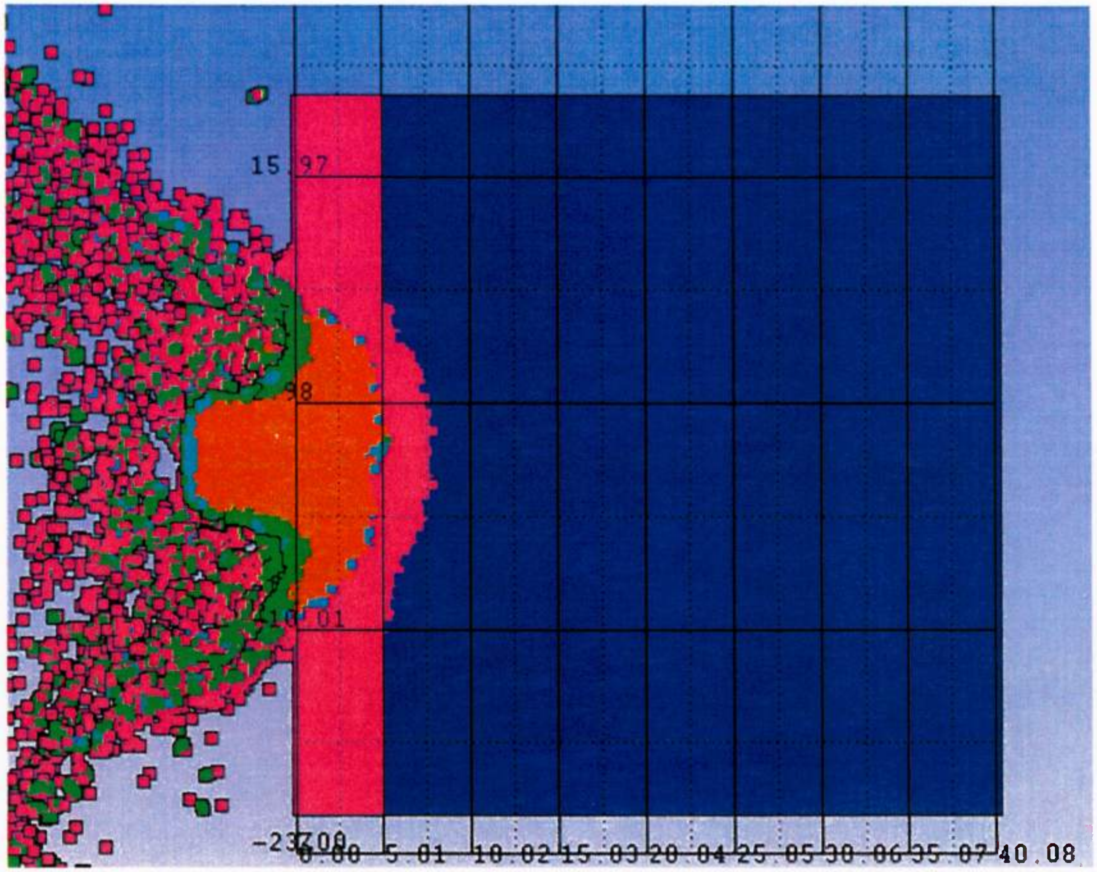


t=0.055 ms



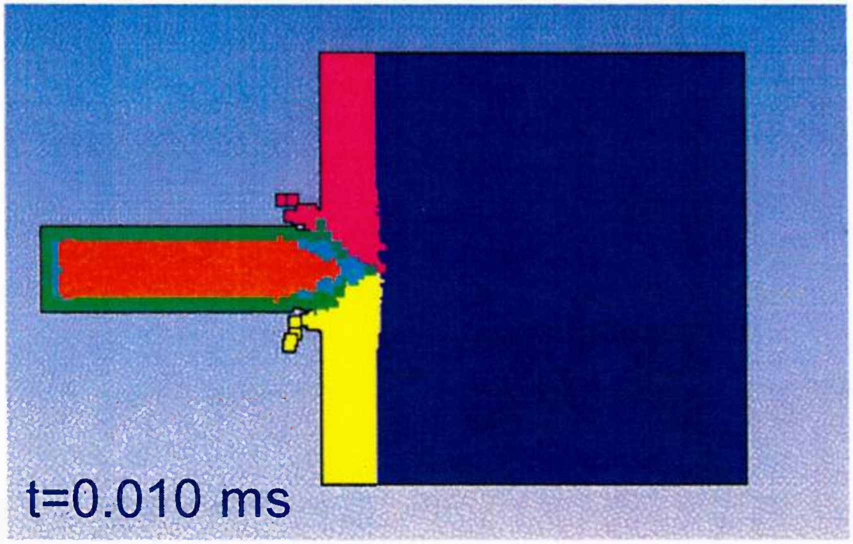
t=0.034 ms

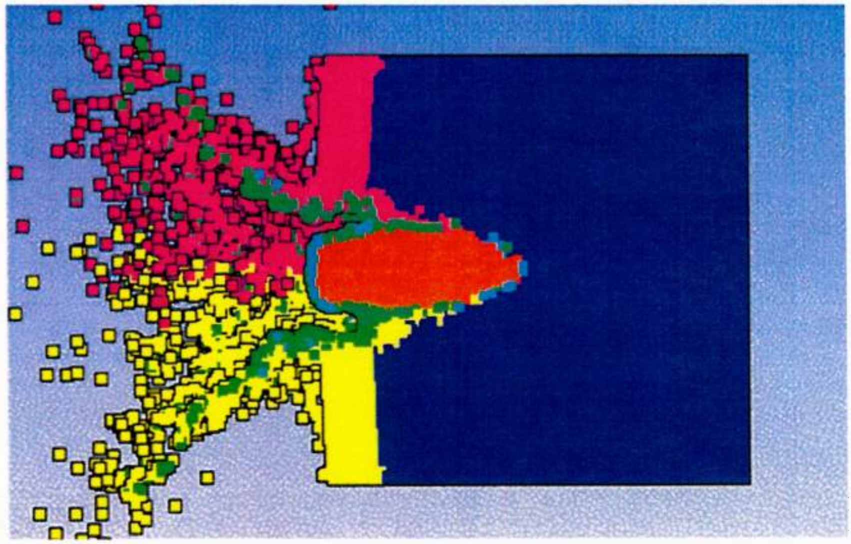
DEPTH OF PENETRATION Vo = 700 m/s t_c = 5.08 mm particle size = 0.4, No Gap



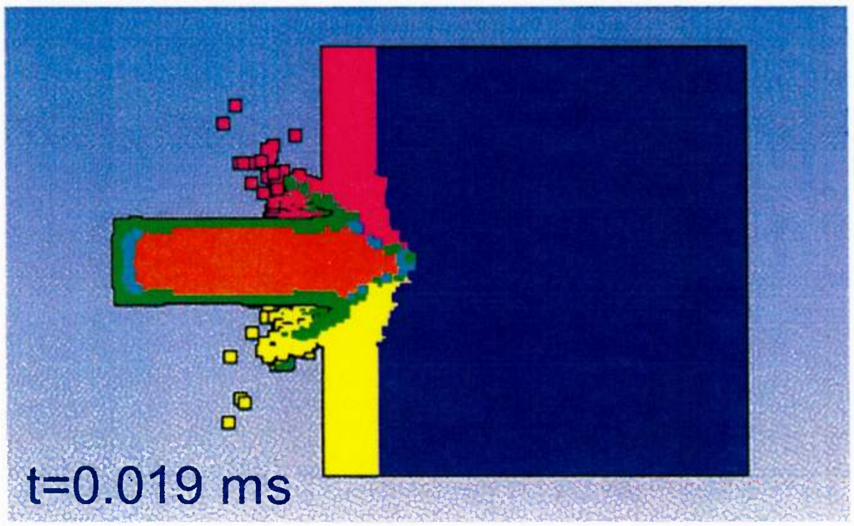
$$DOP = L - L_{np} = 40.08 - 30.06 = 10.02 \text{ mm}$$

Vo = 750 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

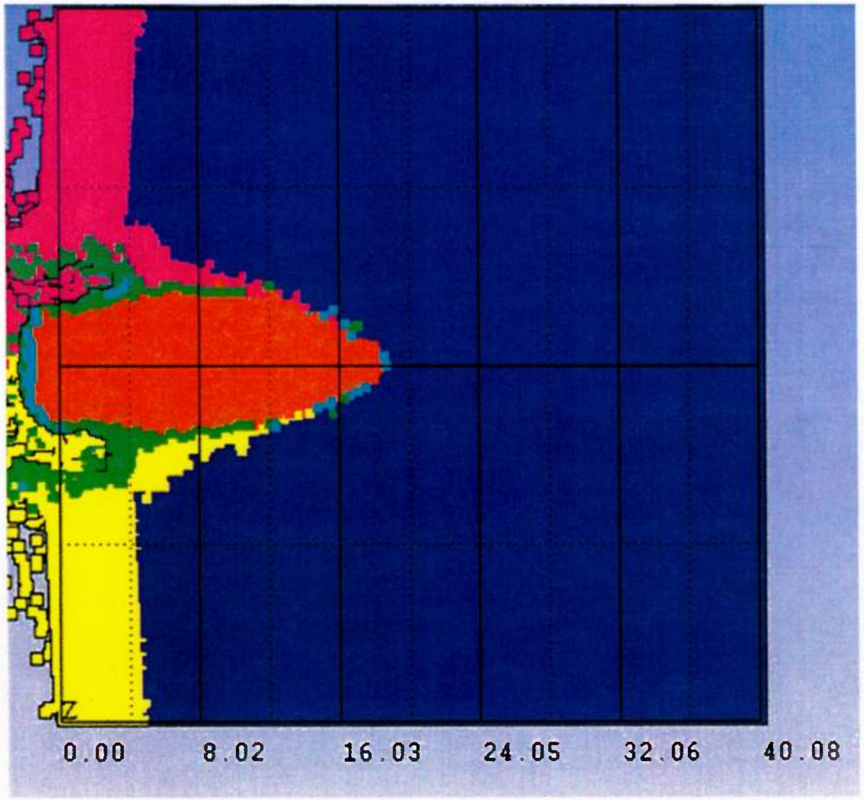




t=0.069 ms

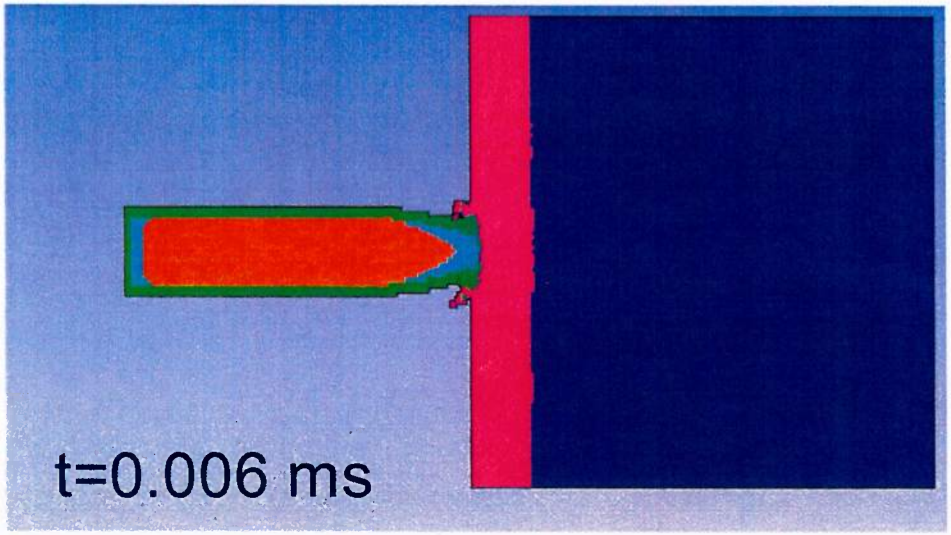


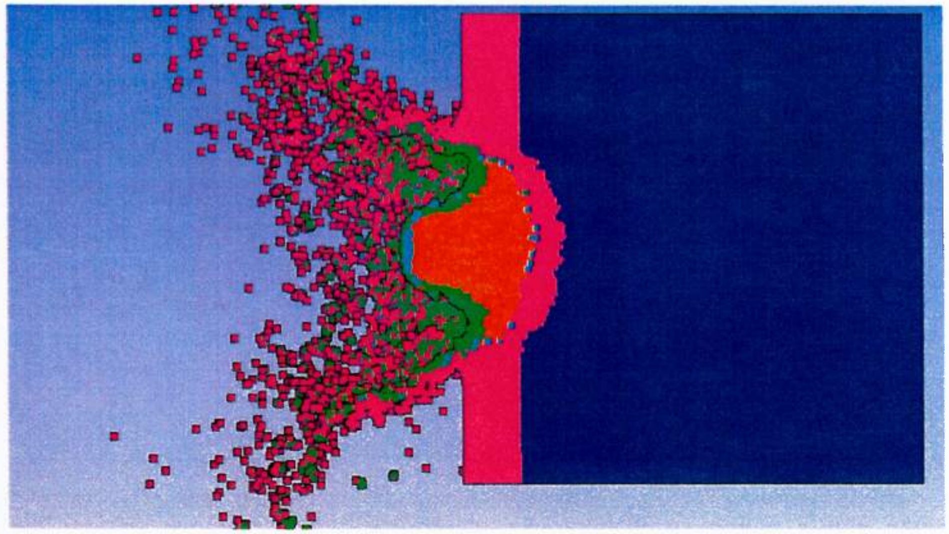
DEPTH OF PENETRATION Vo = 750 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm



$$DOP = L - L_{np} = 40.08 - 21.38 = 18.70 \text{ mm}$$

Vo = 750 m/s t_c = 5.08 mm particle size = 0.4, No Gap





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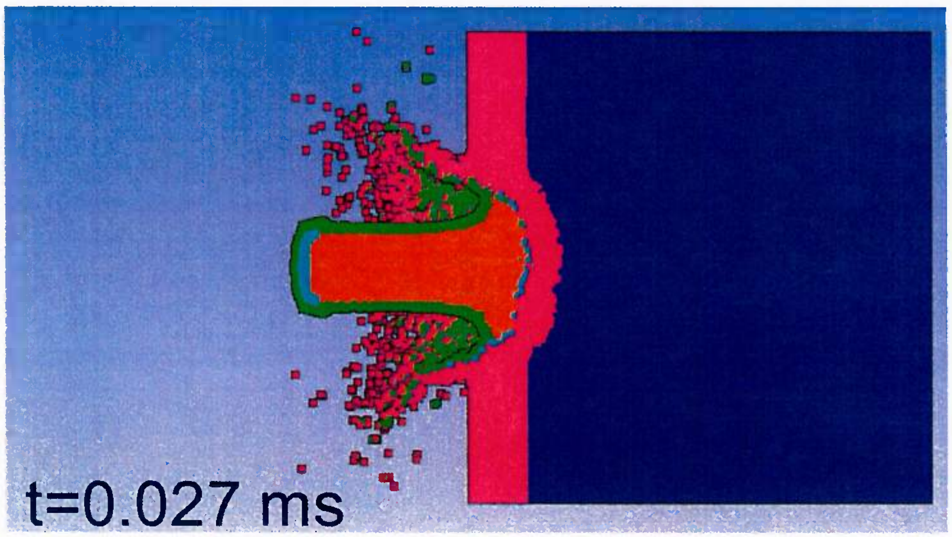
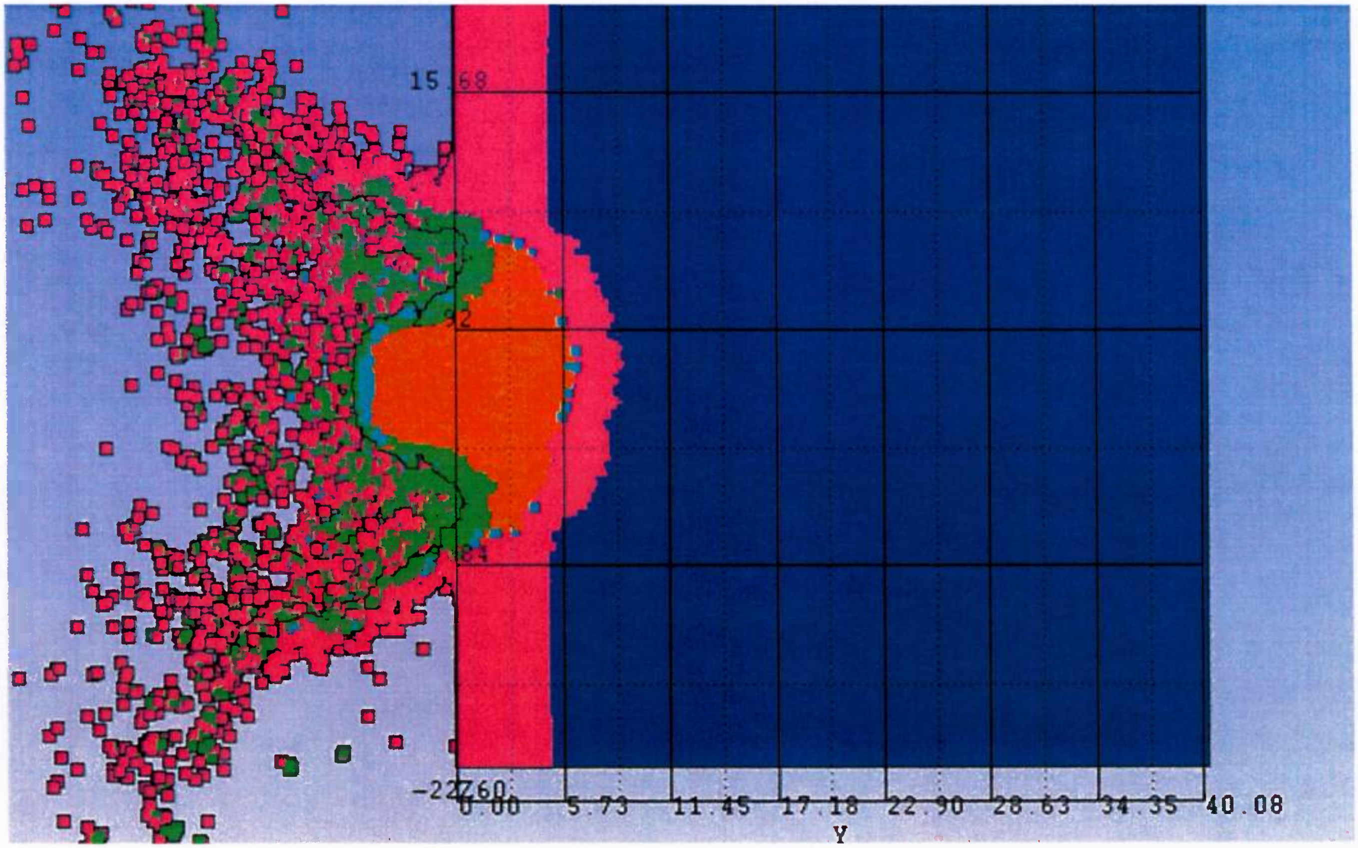
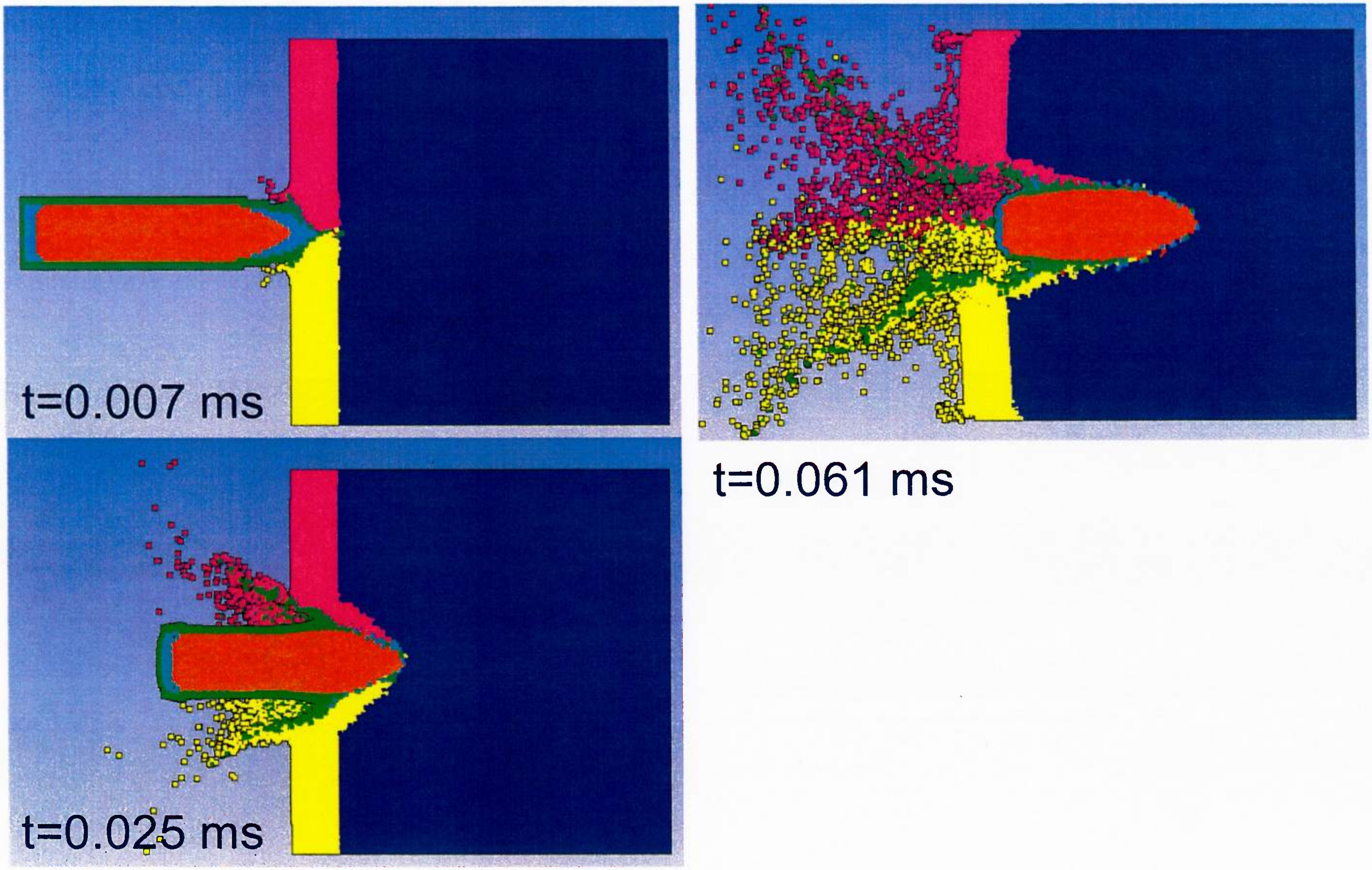


DEPTH OF PENETRATION Vo = 750 m/s t_c = 5.08 mm particle size = 0.4, No Gap

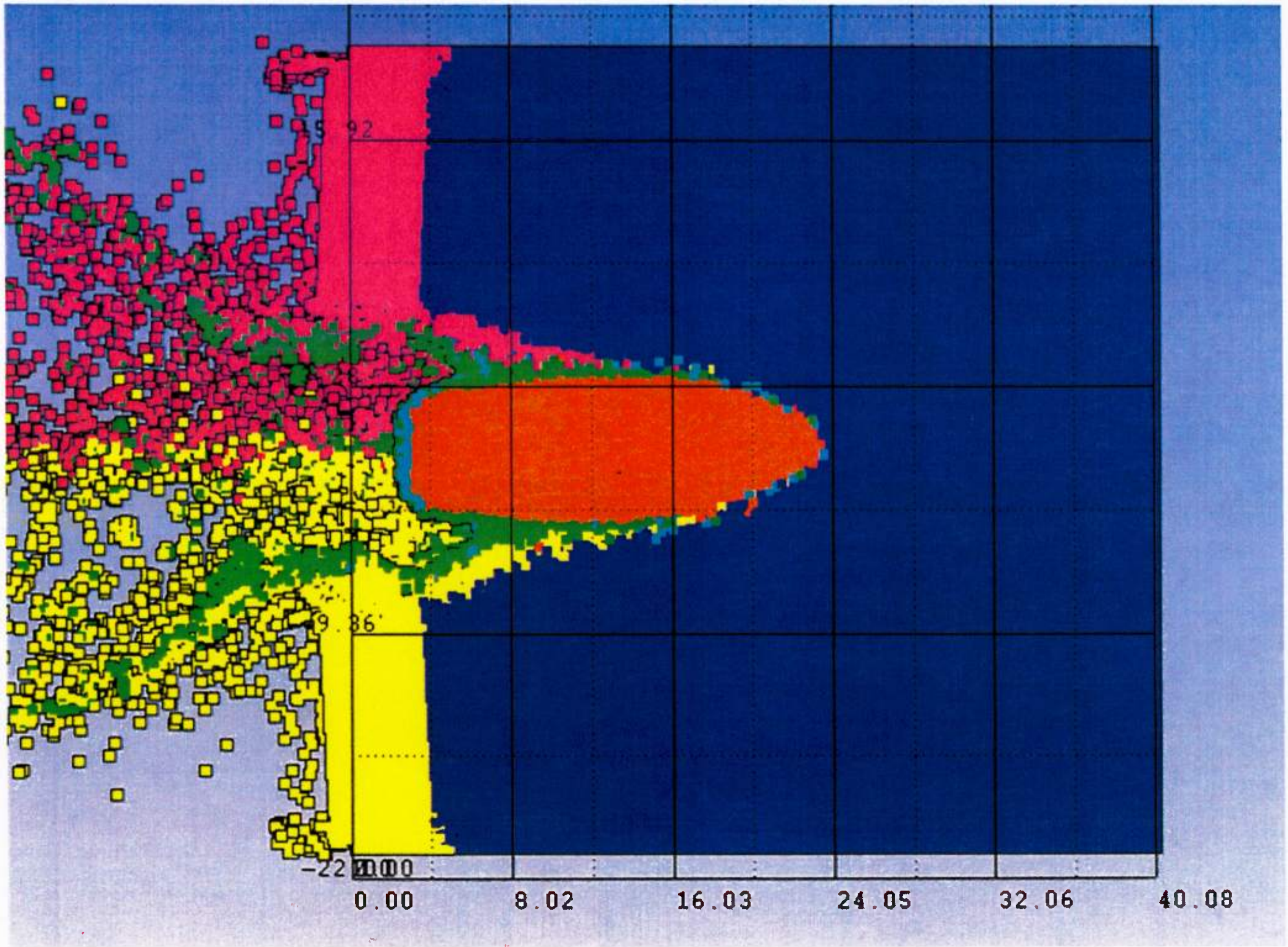


$$DOP = L - L_{np} = 40.08 - 31.49 = 8.59 \text{ mm}$$

Vo = 850 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

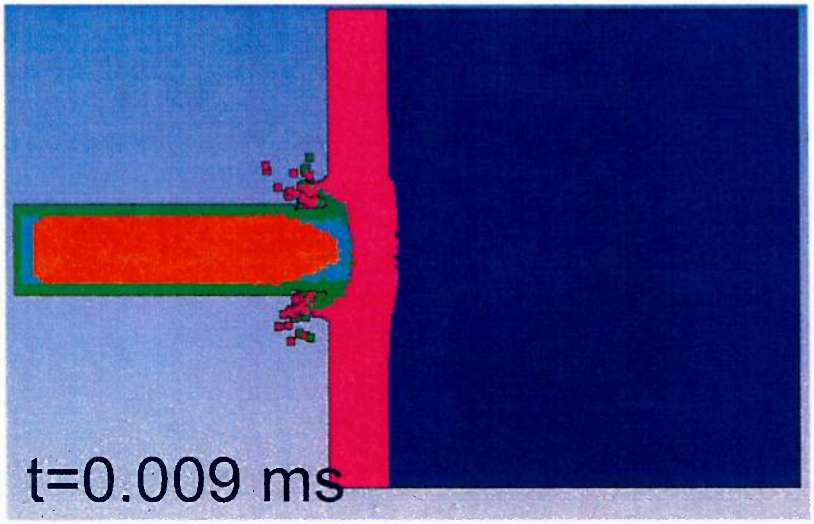


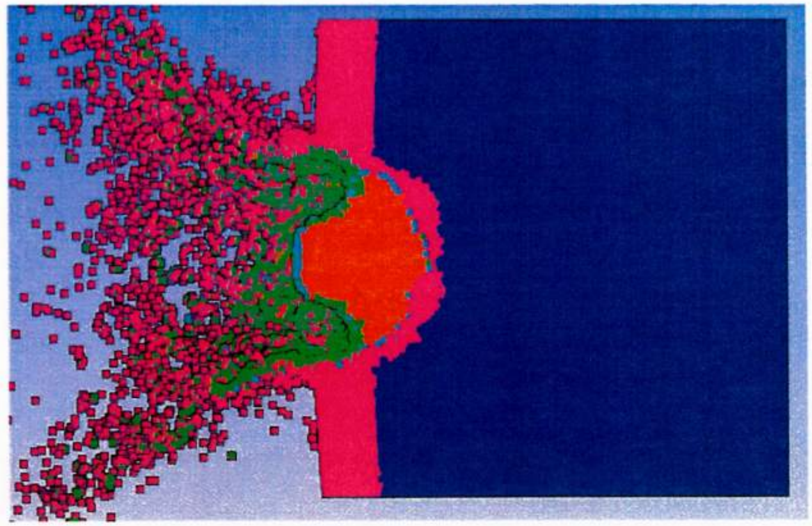
DEPTH OF PENETRATION Vo = 850 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm



DOP = L – L_{np} = 40.08 – 16.03 = 24.05 mm

Vo = 850 m/s t_c = 5.08 mm particle size = 0.4, No Gap





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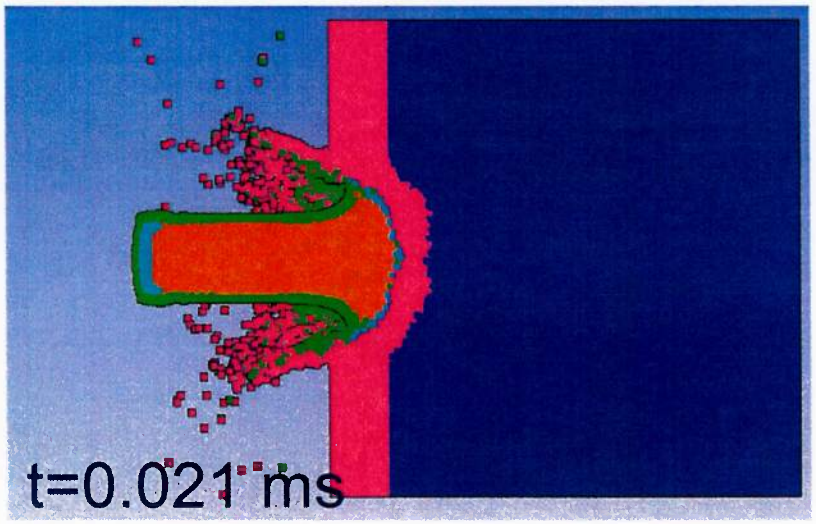
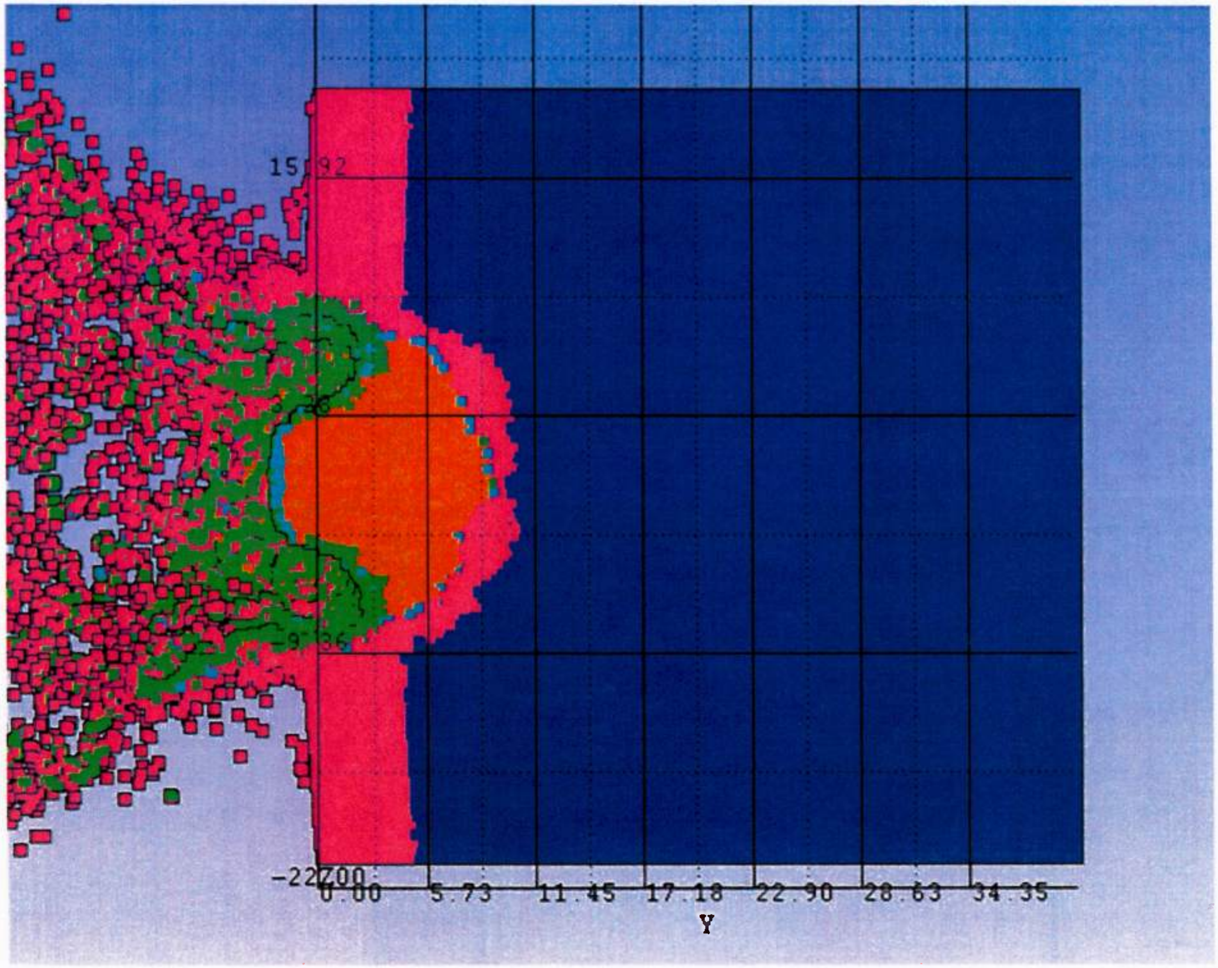
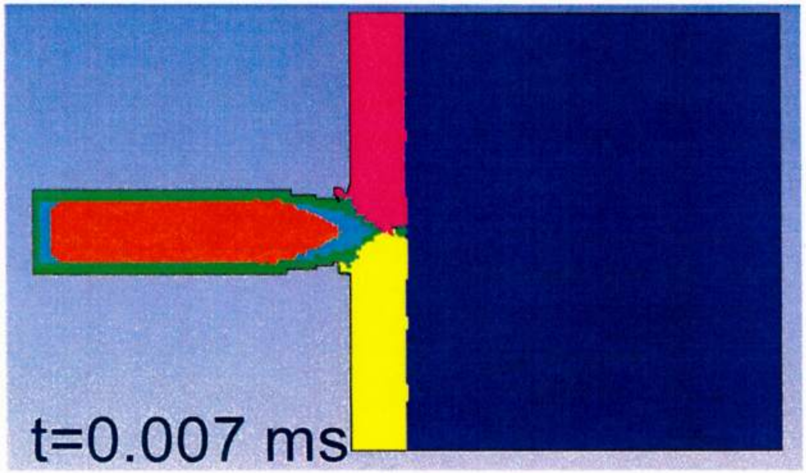


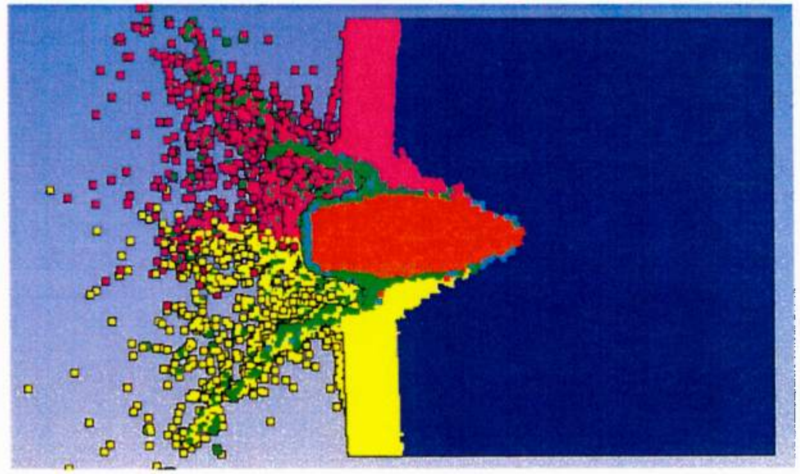
DEPTH OF PENETRATION Vo = 850 m/s t_c = 5.08 mm particle size = 0.4, No Gap



$$DOP = L - L_{np} = 40.08 - 30.08 = 10.00 \text{ mm}$$

Vo = 900 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm





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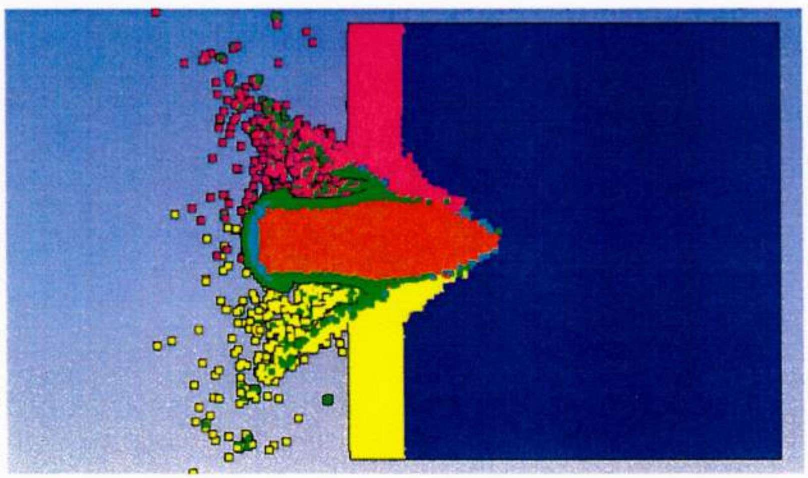
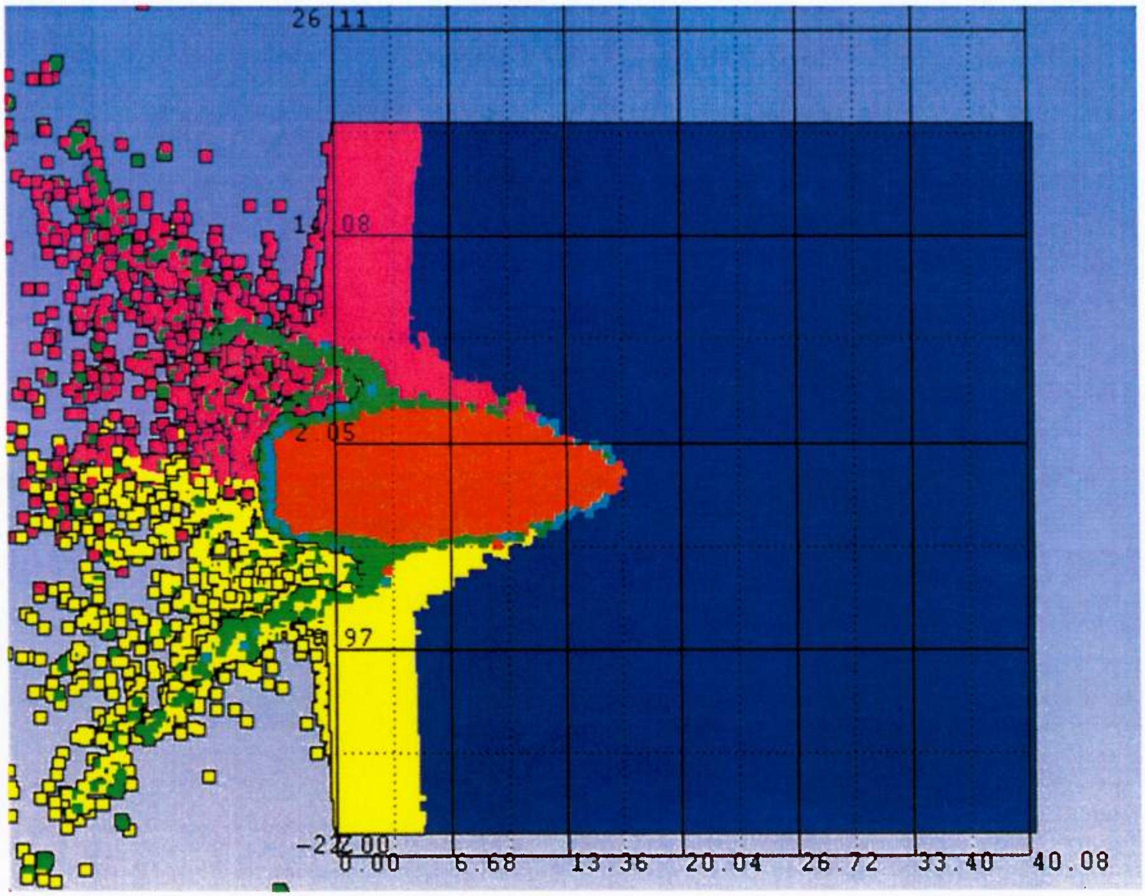


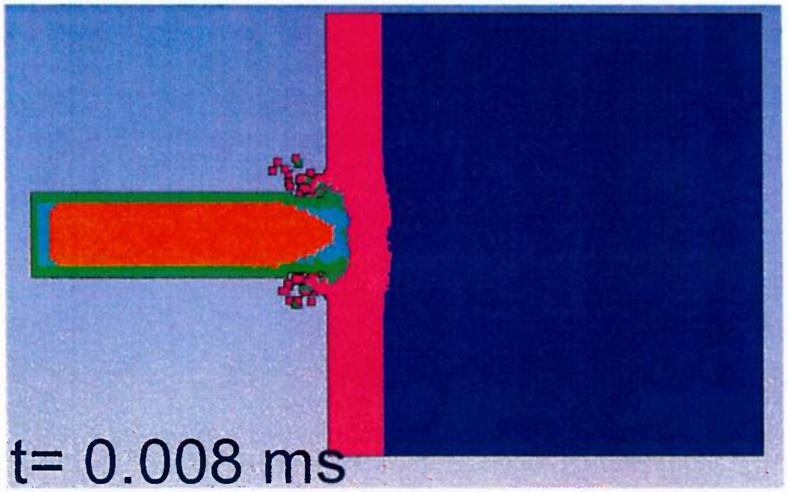
t=0.038 ms

DEPTH OF PENETRATION Vo = 900 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

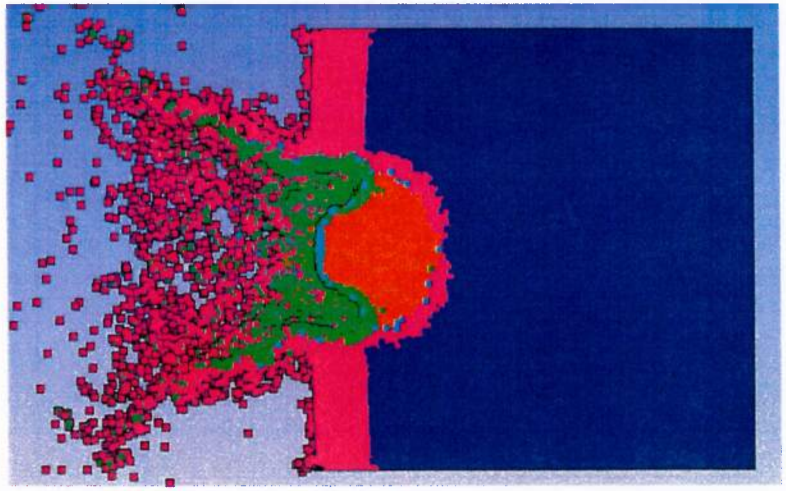


DOP = L – L_{np} = 40.08 – 20.04 = 20.04 mm

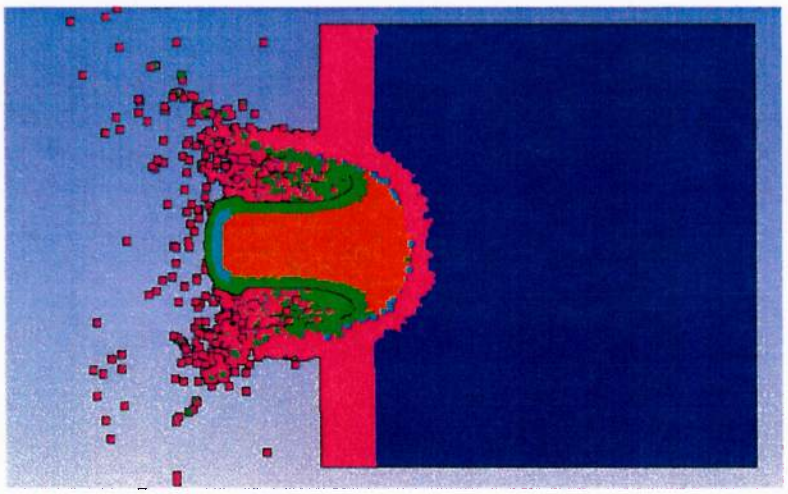
Vo = 900 m/s t_c = 5.08 mm particle size = 0.4, No Gap



t= 0.008 ms

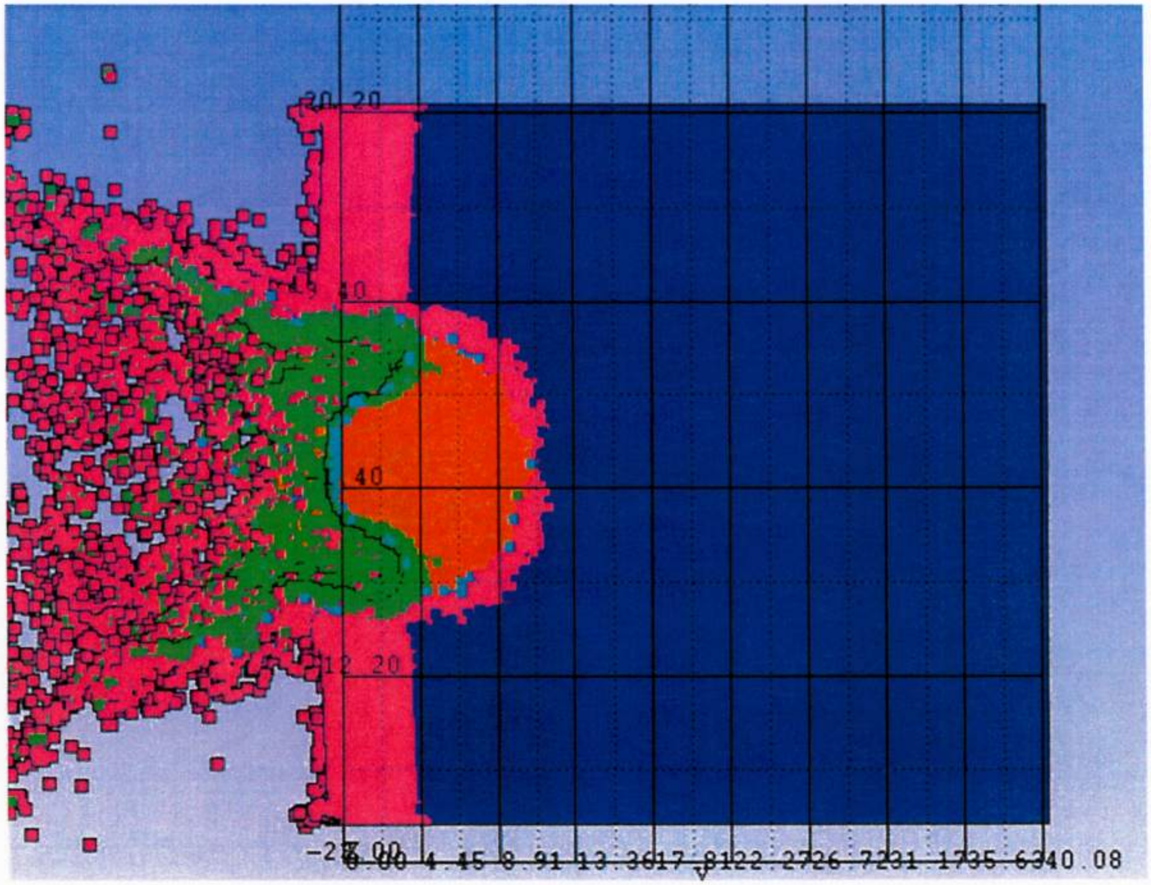


t= 0.048 ms



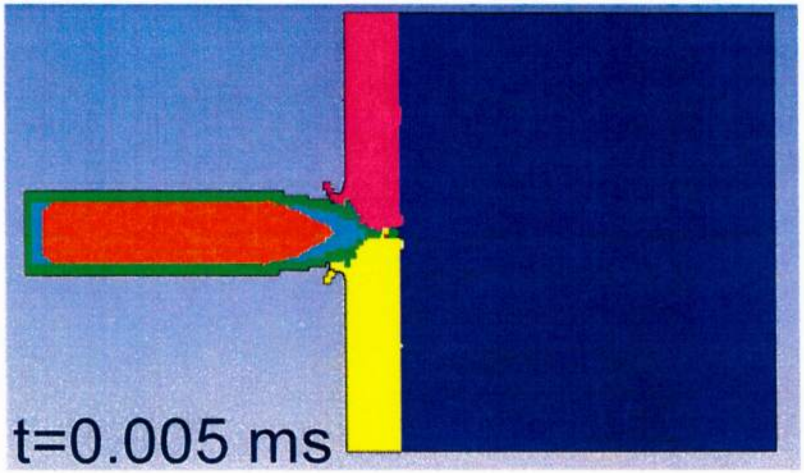
t= 0.028 ms

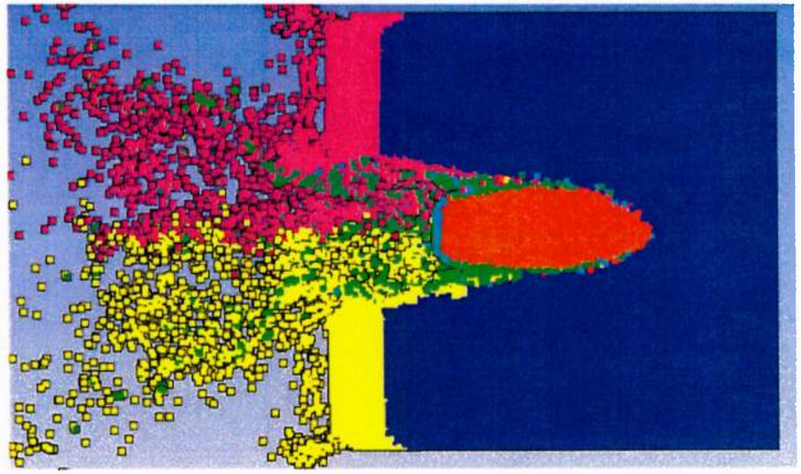
DEPTH OF PENETRATION Vo = 900 m/s t_c = 5.08 mm particle size = 0.4, No Gap



DOP = L – L_{np} = 40.08 – 28.95 = 11.13 mm

Vo = 950 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm





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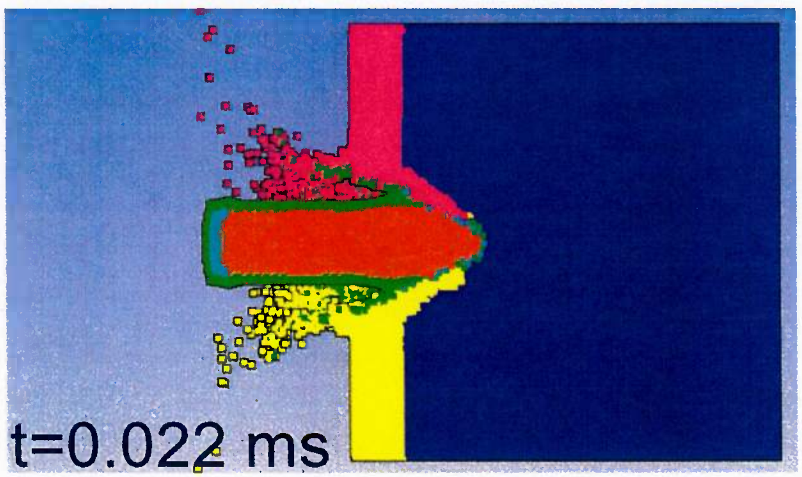
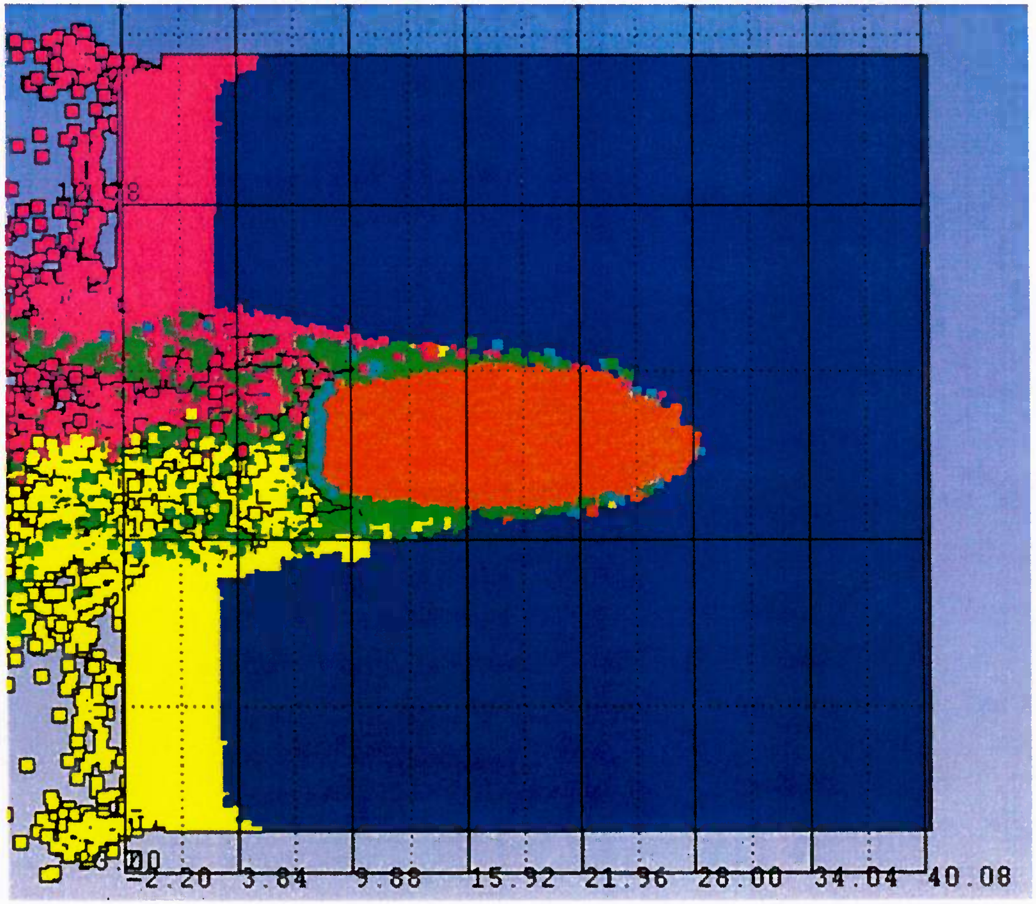
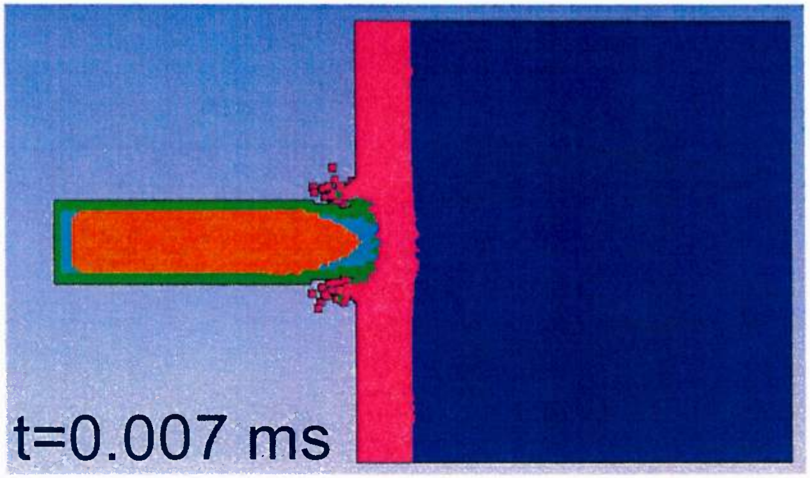


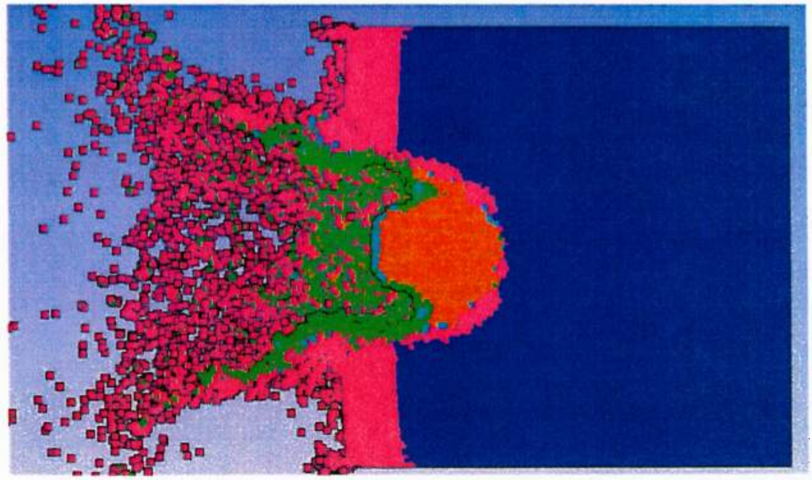
DEPTH OF PENETRATION Vo = 950 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm



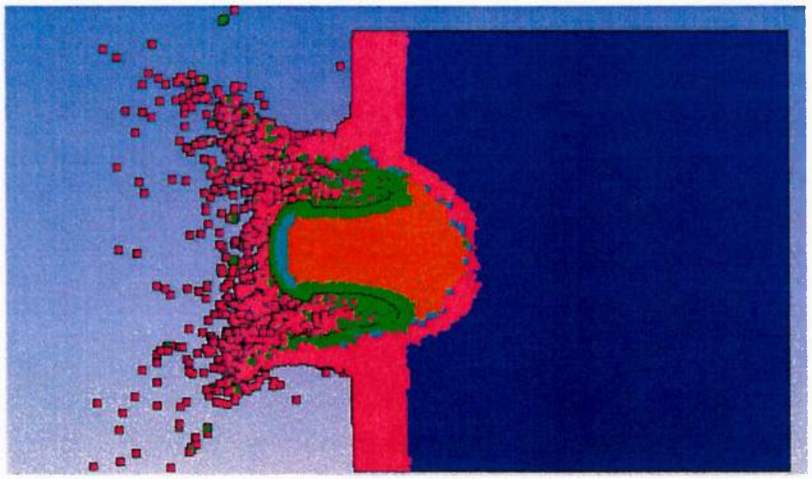
DOP = L – L_{np} = 40.08 – 12.08 = 28.00 mm

Vo = 950 m/s t_c = 5.08 mm particle size = 0.4, No Gap



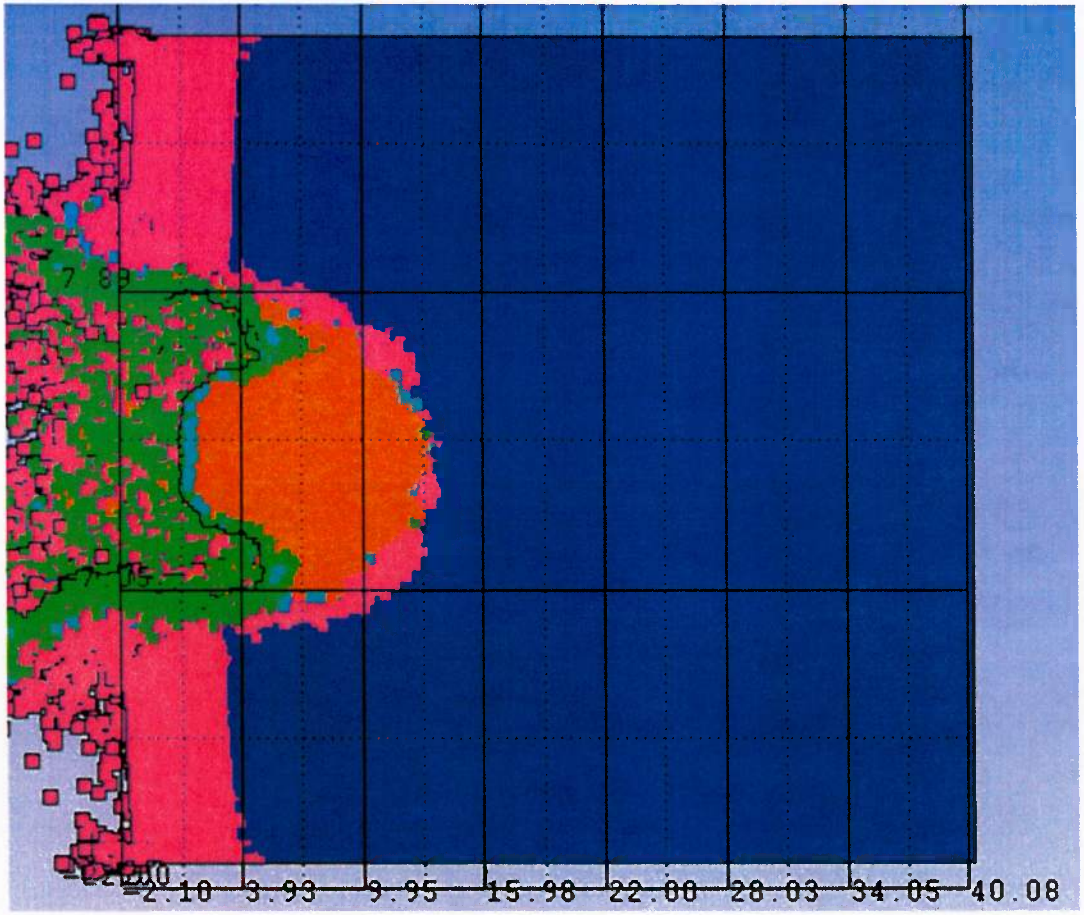


t=0.052 ms



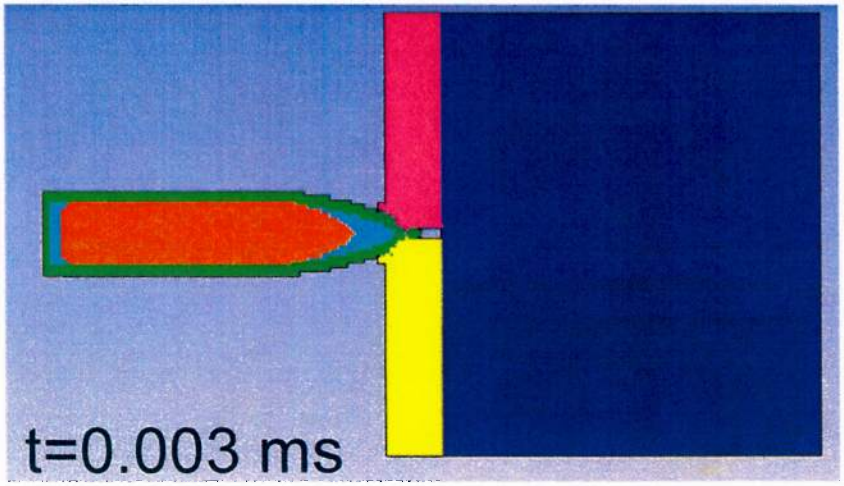
t=0.030 ms

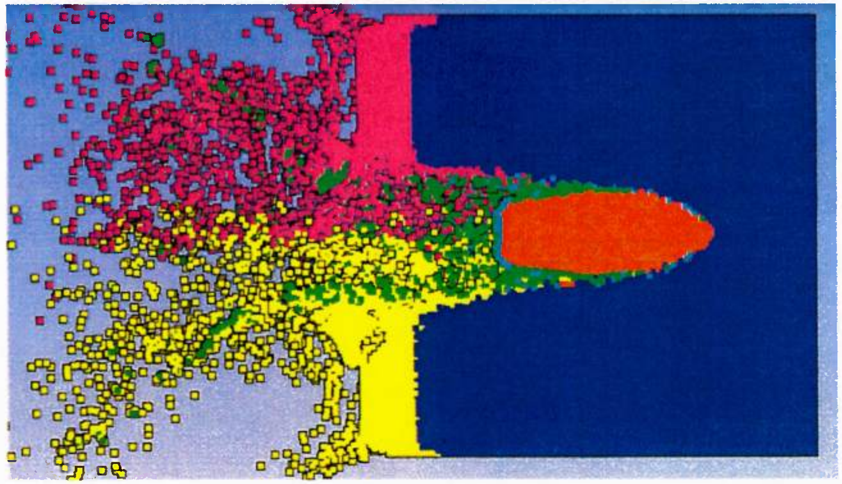
DEPTH OF PENETRATION Vo = 950 m/s t_c = 5.08 mm particle size = 0.4, No Gap



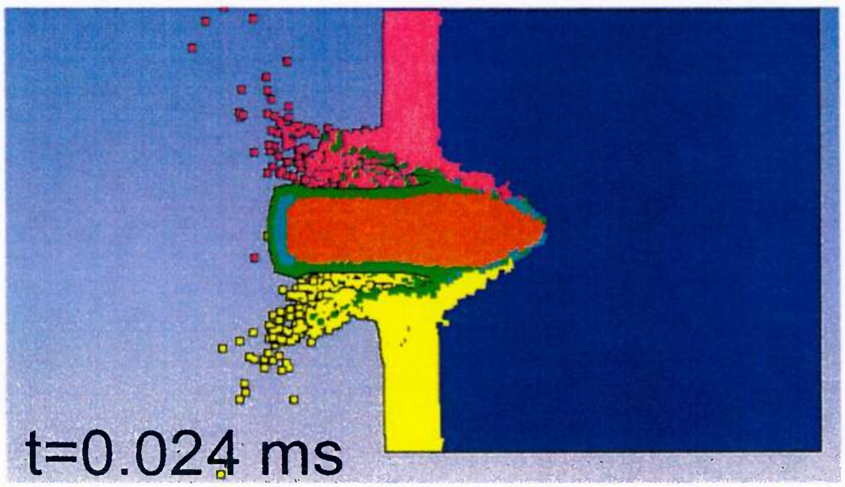
$$DOP = L - L_{np} = 40.08 - 27.12 = 12.96\ mm$$

V_o = 1000 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

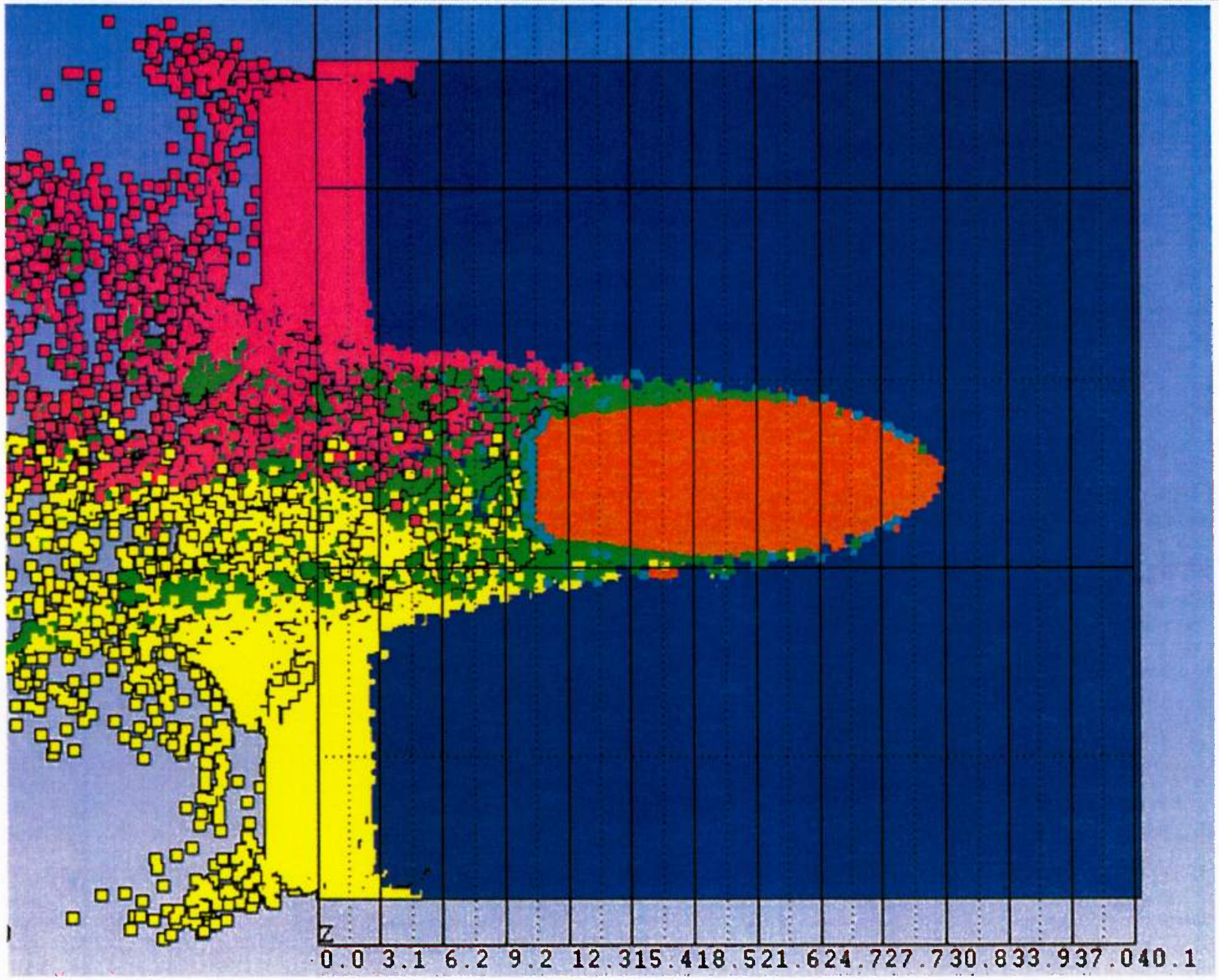




t=0.070 ms

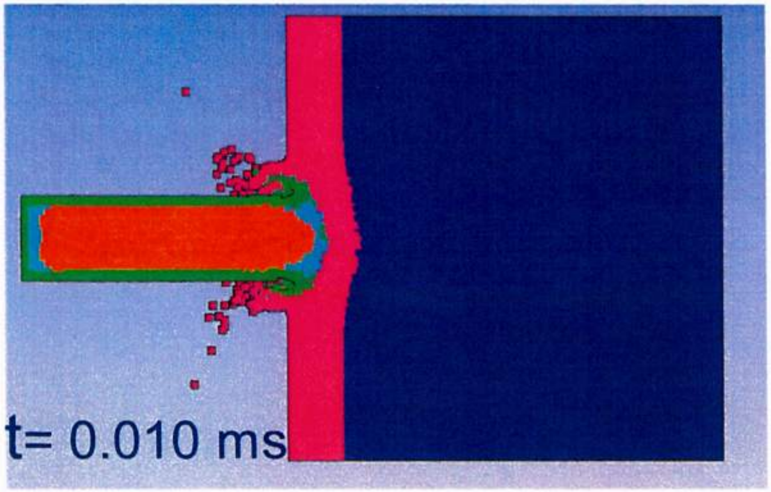


DEPTH OF PENETRATION Vo = 1000 m/s t_c = 5.08 mm particle size = 0.4, Gap = 1.2 mm

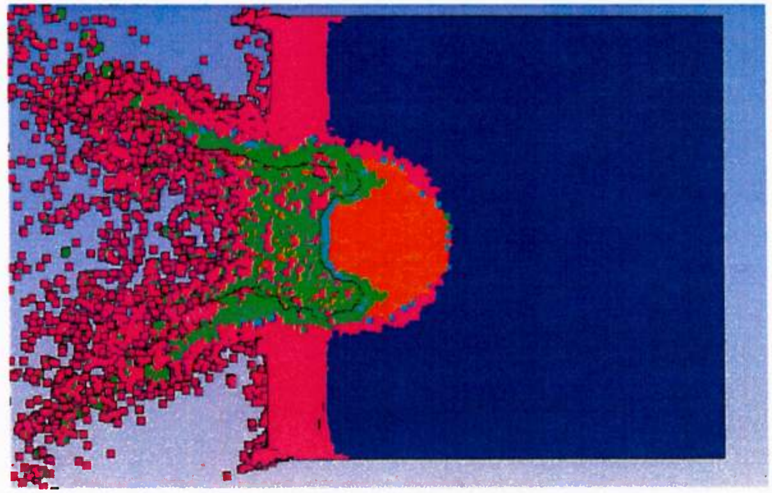


DOP = L – L_{np} = 40.08 – 9.28 = 30.28 mm

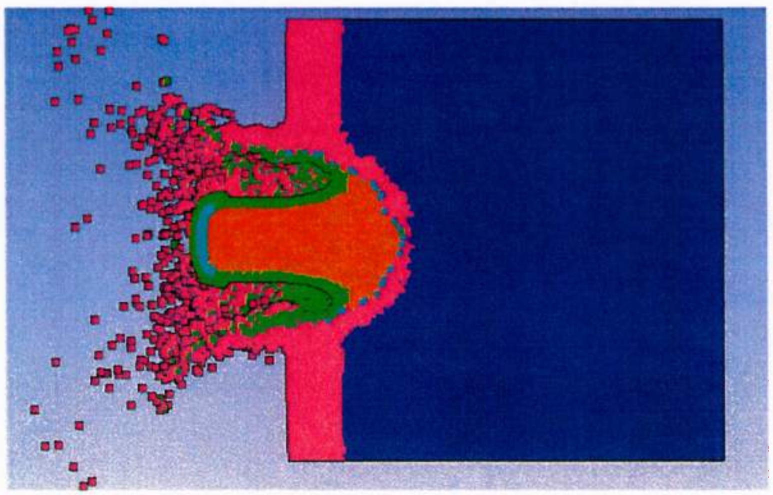
Vo = 1000 m/s t_c = 5.08 mm particle size = 0.4, No Gap



t= 0.010 ms

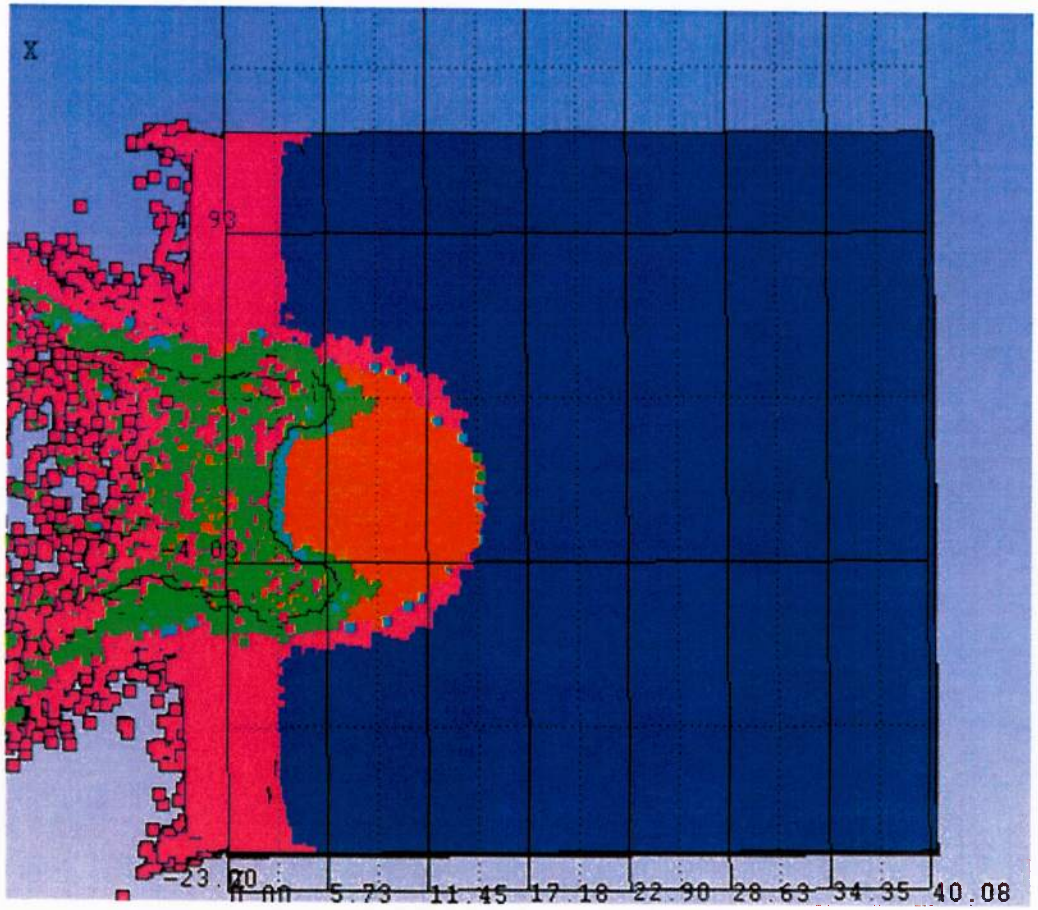


t= 0.051 ms



t= 0.026 ms

DEPTH OF PENETRATION Vo = 1000 m/s t_c = 5.08 mm particle size = 0.4, No Gap



$$DOP = L - L_{np} = 40.08 - 25.77 = 14.31 \text{ mm}$$

DEPTH OF PENETRATION

Velocity (m/s)	One Tile DOP (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