



NATO EOD DEMONSTRATIONS & TRIALS 2014

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Sympathetic detonation for breaching in minefields

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AGENDA

- 1. Introduction**
- 2. Sympathetic detonation**
- 3. Experimental tests**
- 4. Numerical simulations**
- 5. Conclusions**

1. Introduction

Countermine operations

- Breaching
- **Clearing**

Mine clearance

- removal
- rendering inoperative

mine = mine neutralization

1. Introduction

Mine neutralization

- Mechanical neutralization
- Explosive neutralization
- Directed energy neutralization
- Signature duplication and reduction
- Others (chemical, thermal, kinetic neutralization)

1. Introduction

Explosive neutralization

- Fuel – Air Explosives
- Dispersed Explosives
- Explosive Foams
- In – ground Heterogeneous Explosives
- High Explosives Line Charge Systems
- Shaped Charges

1. Introduction

High Explosives Line Charge Systems – types of mine neutralization



physical
destruction and
propulsion off the
minefield



Pressure
activated
fuzes



Sympathetic
detonation



physical
destruction and
propulsion off the
minefield

2. Sympathetic detonation

Factors influencing sympathetic detonation

- **donor** – *explosive line charge*

- shape and size
- type of explosive
- position of detonation point

- **acceptor** – *mine*

- shape and size
- type of explosive
- presence of a case
- type of case (metallic, plastic etc.)

- **ensemble donor-acceptor**

- type of explosion
- position of acceptor to donor
- type of transmission medium for the shock wave

donor



acceptor



2. Sympathetic detonation

Criteria Needed for Sympathetic Detonation

- Critical Energy Fluence must be exceeded
- Shock run distance must be established
- Sufficient donor charge diameter

2. Sympathetic detonation

Energy Fluence

- Energy Fluence: Average energy per unit area being transferred into the acceptor charge

- $$E = \frac{P^2 * t}{\rho_o * U} , \text{ J/cm}^2 \text{ or cal/cm}^2$$

- P = pressure (kPa)
- t = Shock pulse duration (ms)
- ρ_o = Uncompressed material density (gm/cm³)
- U = Shock wave velocity (mm/ms)

2. Sympathetic detonation

Critical Energy Fluence (E_c)

E_c is the minimum amount of energy fluence needed to reach a steady state detonation:

- 50% probability of detonation
- varies from one explosive to another

Explosive	E_c (cal/cm²)
TATB	226
Comp-B	44.2
TNT	34
Comp-B3	33.4
PBX 9404-3	15
Tetryl	10
Lead azide	0.03

2. Sympathetic detonation

Type of explosion

Blast waves
Explosion products



$$R = 0$$

Contact detonation

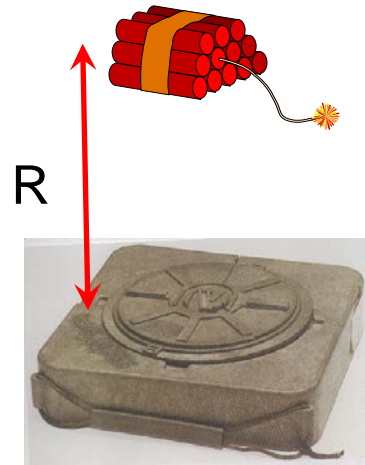
Blast waves
Explosion products



$$Z < 0.2 \text{ m/kg}^{1/3}$$

Near detonation

Blast waves



$$0.2 \text{ m/kg}^{1/3} < Z < 198.5 \text{ m/kg}^{1/3}$$

Hemispherical
Surface Burst

$$Z = \frac{R}{\sqrt[3]{W}}$$

2. Sympathetic detonation

Contact detonation

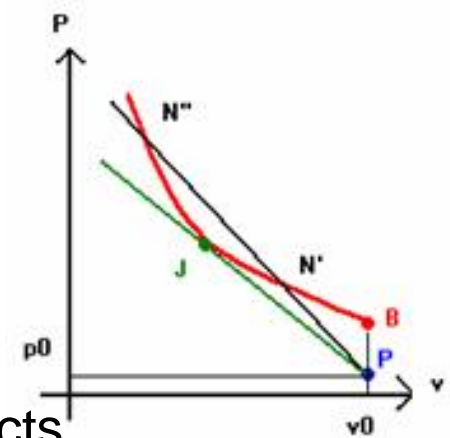
$$E = \frac{P^2 * t}{\rho_o * U}$$



Parameters for CJ steady state

Pressure of detonation products:
$$p_{CJ} = \rho_0 \frac{D_{CJ}^2}{\Gamma_{CJ} + 1}$$

Velocity of detonation wave:
$$D_{CJ} = \sqrt{2(\Gamma_{CJ}^2 - 1) Q_E}$$



- Γ_{CJ} = polytropic constant for the detonation products
- Q_E = explosion energy, (J/kg)
- ρ_o = initial density of explosive, (kg/m³).

2. Sympathetic detonation

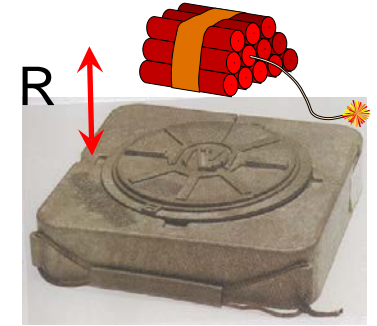
Near detonation

Pressure of detonation products:

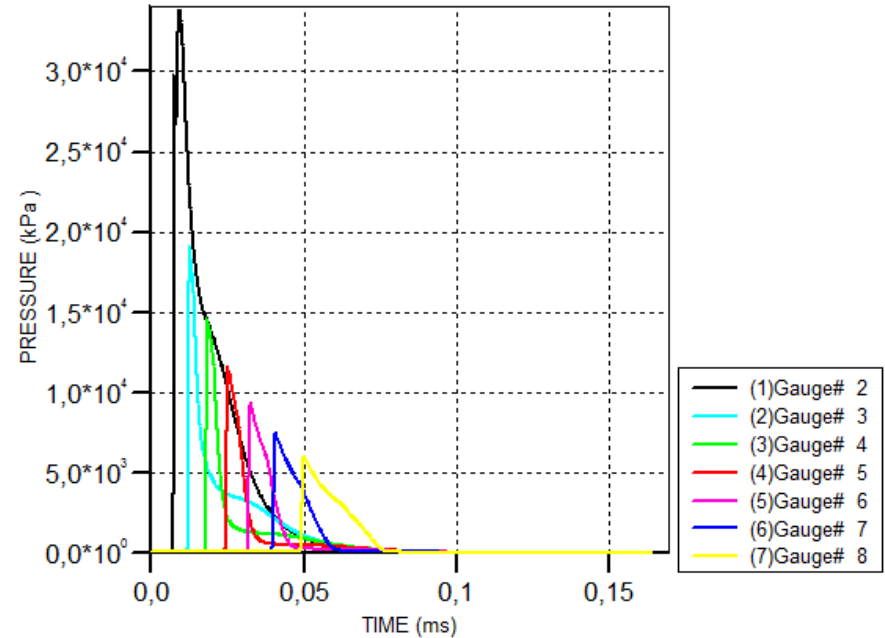
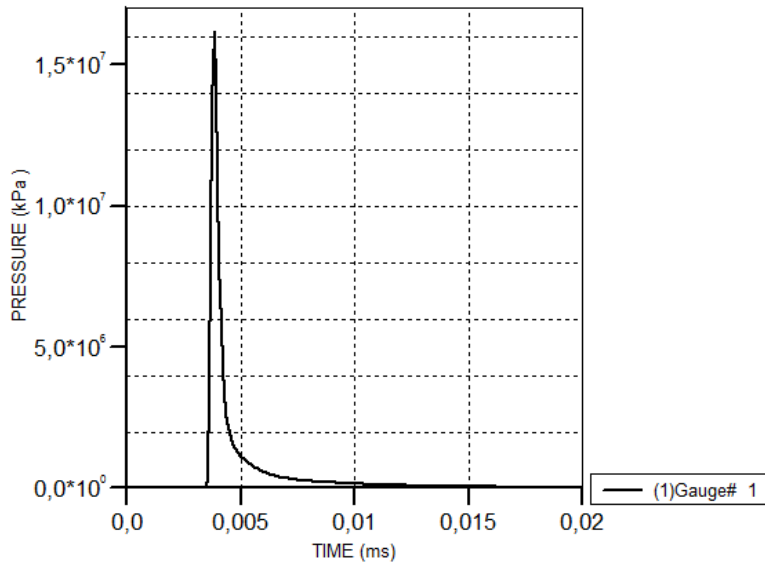
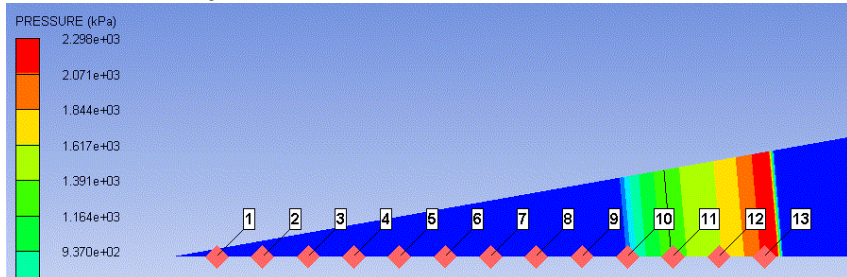
$$p_{CJ} = \rho_0 \frac{D_{CJ}^2}{\Gamma_{CJ} + 1}$$

Velocity of detonation wave:

$$D_{CJ} = \sqrt{2(\Gamma_{CJ}^2 - 1) Q_E}$$



$$Z < 0.2 \text{ m/kg}^{1/3}$$



2. Sympathetic detonation

Hemispherical Surface Burst

Kingery and Bulmash equations:

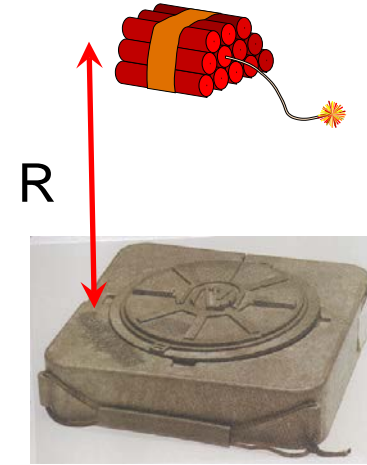
$$E = \frac{P^2 * t}{\rho_o * U}$$

$$\Delta p_f = \text{Exp}(A + B \cdot \ln Z + C \cdot (\ln Z)^2 + D \cdot (\ln Z)^3 + E \cdot (\ln Z)^4)$$

$$t_p = \text{Exp}(A + B \cdot \ln Z + C \cdot (\ln Z)^2 + D \cdot (\ln Z)^3 + E \cdot (\ln Z)^4 + F \cdot (\ln Z)^5)$$

$$\Delta p_f = \frac{2 \cdot \rho_o}{k + 1} \cdot (U^2 - a_0^2)$$

- a_0 = speed of sound, (m/s)
- k = specific heat ratio



$$0.2 \text{m/kg}^{1/3} < Z < 198.5 \text{ m/kg}^{1/3}$$

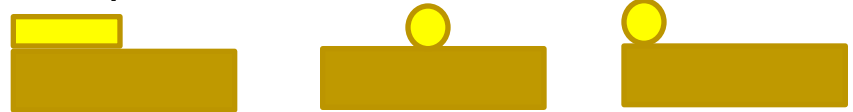
Range, Z (m/kg ^{1/3})	A	B	C	D	E	F
Overpressure, Δp_f						
0.2-2.9	7.1206	-2,1069	-0.3229	0.1117	0.0685	0
Positive phase duration, t_p						
0.2-2.9	0.5426	3.2299	-1.5931	- 5.9667	-4.0815	-0.9149

2. Sympathetic detonation

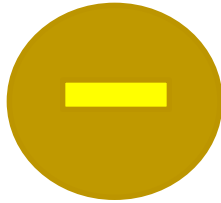
Position of acceptor to donor



Top detonation



Contact detonation



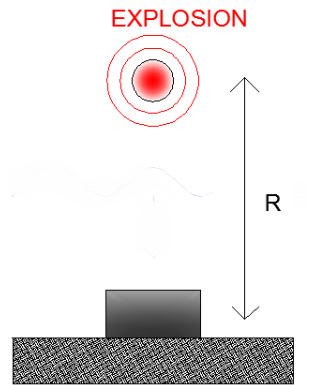
Lateral detonation



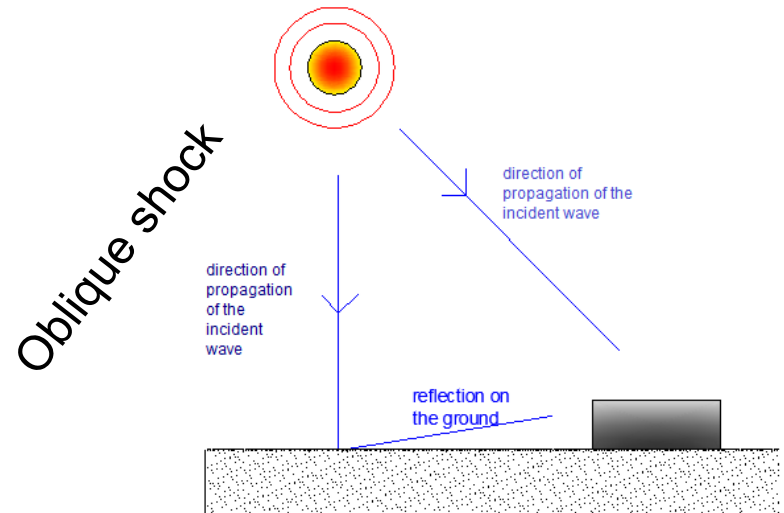
Near detonation



Hemispherical surface burst

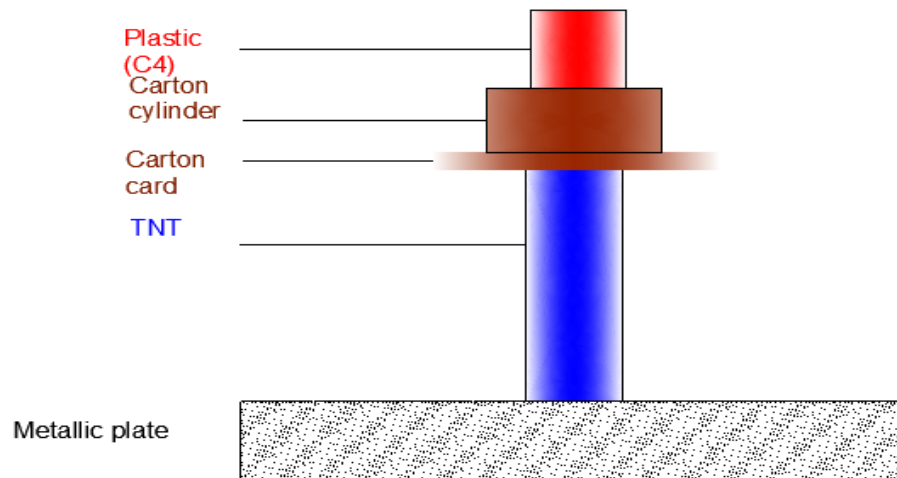


Normal shock



3. Experimental tests

Top configuration

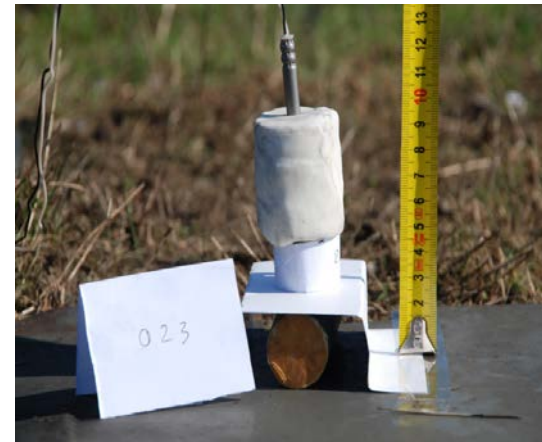
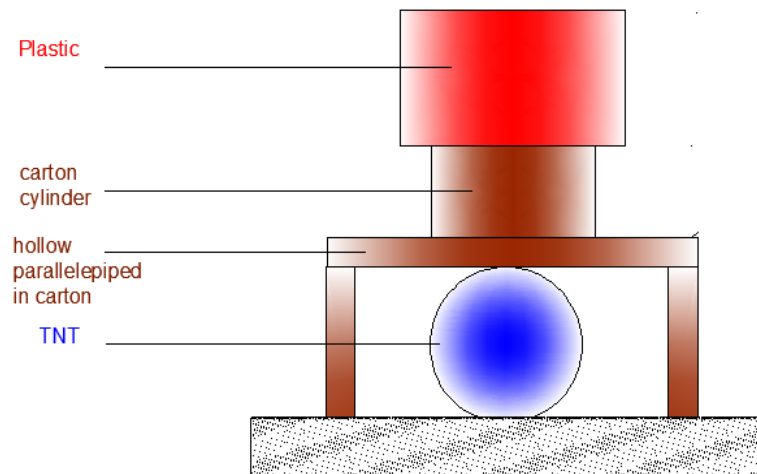


Donor: 100 g plastic explosive, $\rho_o = 1.42 \text{ g/cm}^3$, $D = 7000 \text{ m/s}$
diameter $\sim 4 \text{ cm}$

Acceptor: TNT cartridge (100g), diameter - 3cm
B-comp. cartridge (75 g), diameter - 2.5cm

3. Experimental tests

Lateral configuration



Donor: 100 g plastic explosive, $\rho_o = 1.42 \text{ g/cm}^3$, $D = 7000 \text{ m/s}$
diameter $\sim 4 \text{ cm}$

Acceptor: TNT cartridge (100g), diameter - 3cm
B-comp. cartridge (75 g), diameter - 2.5cm

3. Experimental tests

Standard configuration:

- Donor – plastic explosive, 100g
- Acceptor – TNT, 100g

- Metallic case – No
- Depth of detonator – 2cm

Top configuration

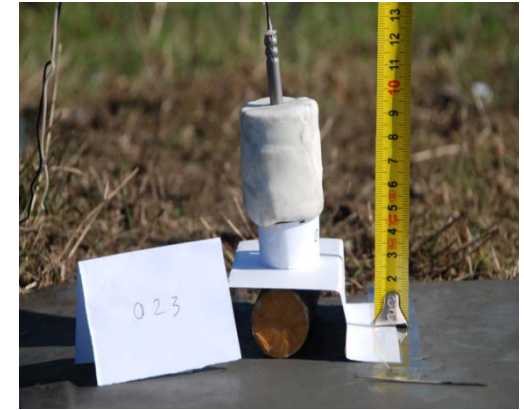
No.	Acceptor charge	Distance donor to acceptor, [cm]	Metallic case, [mm]	Depth of the detonator, [cm]	Initiation
1	TNT	2.0	none	2	no
2	TNT	1.5	none	2	yes
3	TNT	1.7	none	2	yes
4	TNT	1.9	none	2	no
5	TNT	1.8	none	2	yes
6	TNT	1,8	1.2	1	yes
7	TNT	2.0	1.2	1	yes
8	TNT	2.3	1.2	1	yes
9	TNT	1.8	none	1	yes
10	TNT	2.0	none	1	yes
11	B-comp.	2.0	none	1	yes
12	B-comp.	3.0	none	1	yes
13	B-comp.	4.0	none	1	yes
14	B-comp.	5.0	none	1	yes

Lateral configuration

No.	Acceptor charge	Distance donor to acceptor, [cm]	Metallic case, [mm]	Depth of the detonator, [cm]	Initiation
1	TNT	1.7	none	2	yes
2	TNT	1.5	1.2	2	yes
3	TNT	2.0	none	2	yes
4	TNT	2.2	none	2	yes
5	TNT	2.3	none	2	yes
6	TNT	2.6	none	2	yes
7	TNT	2.8	none	2	yes
8	TNT	3.2	none	2	yes
9	TNT	3.3	none	2	no
10	TNT	3.2	none	2	yes

3. Experimental tests

Effects

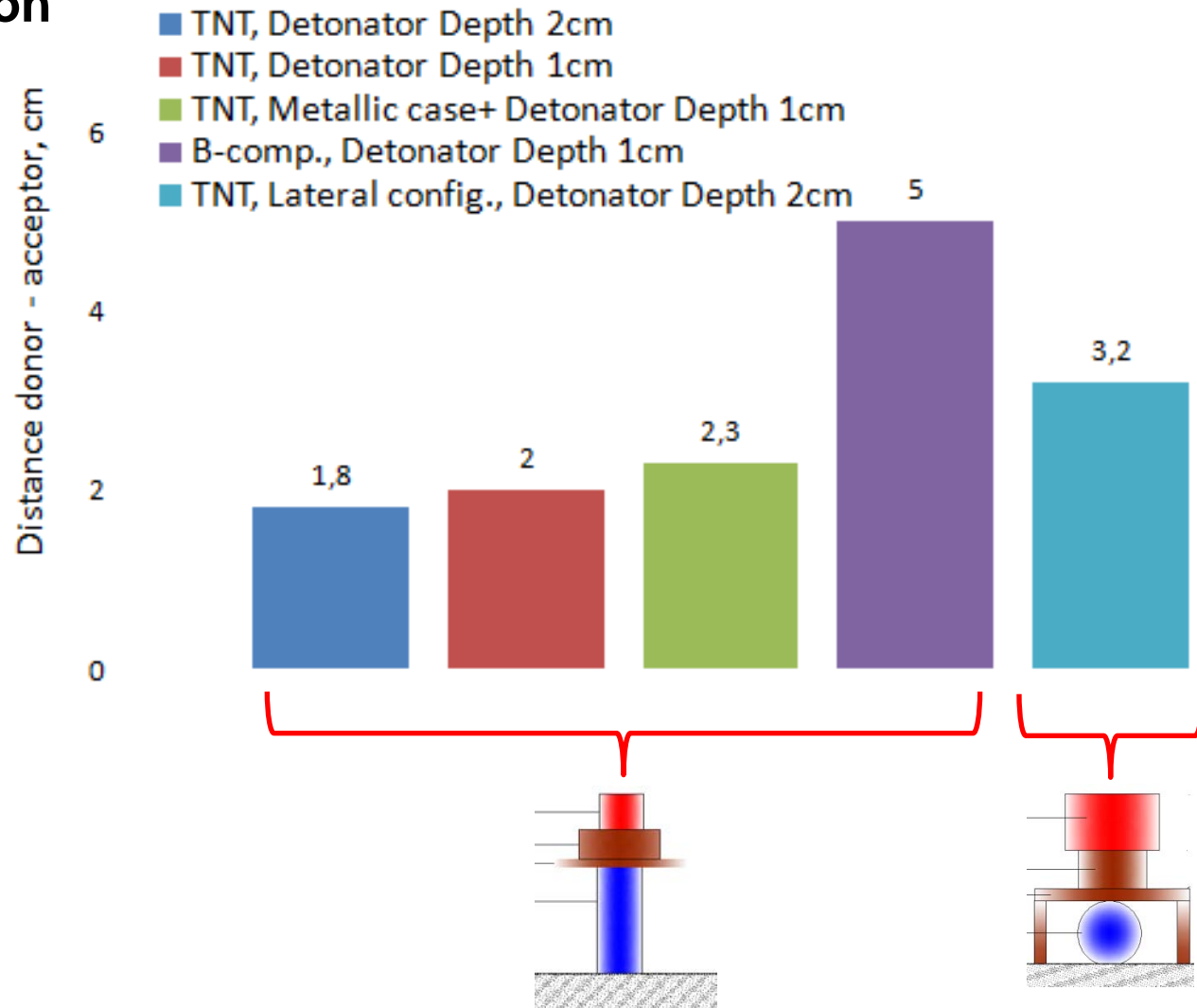


No initiation of the acceptor

Initiation of the acceptor

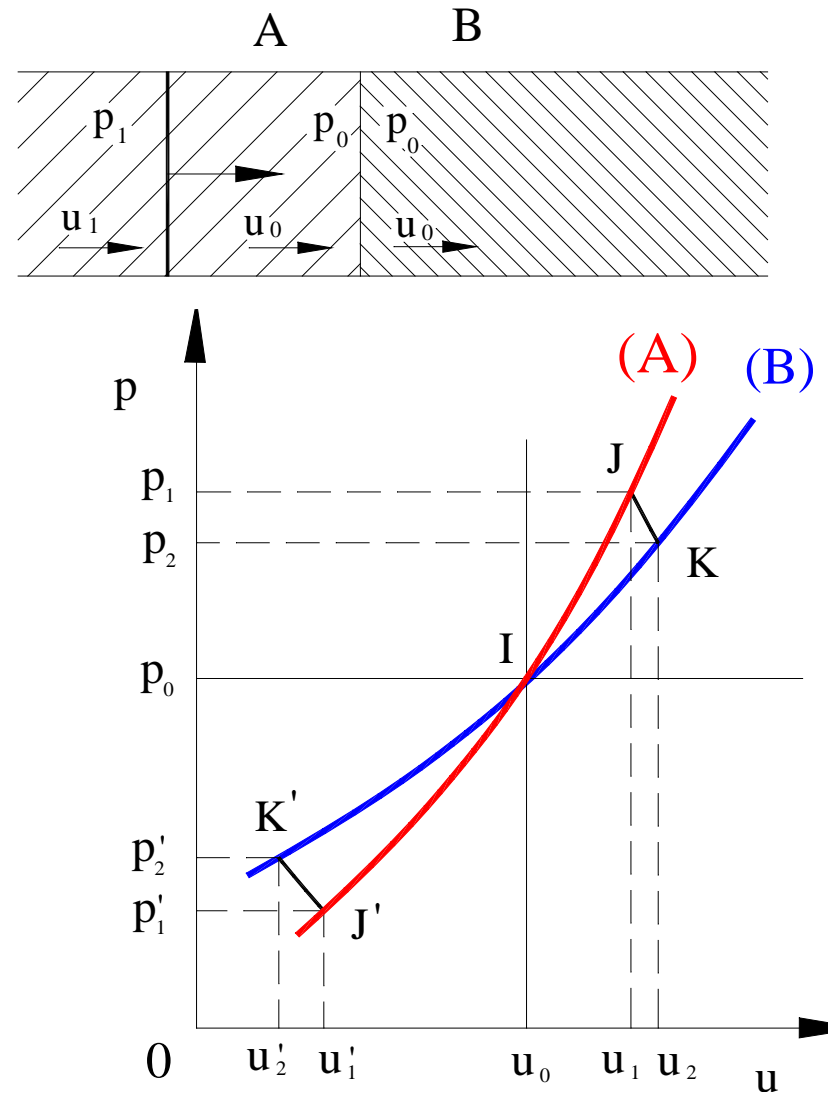
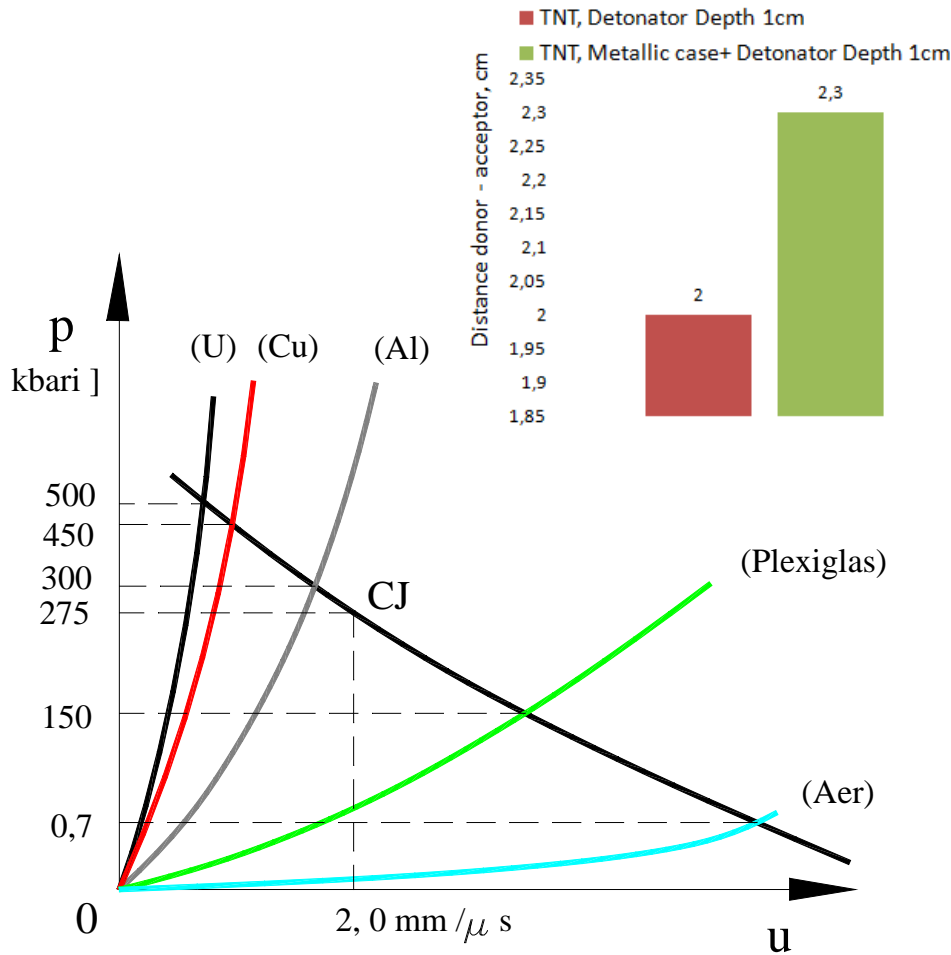
3. Experimental tests

Comparison



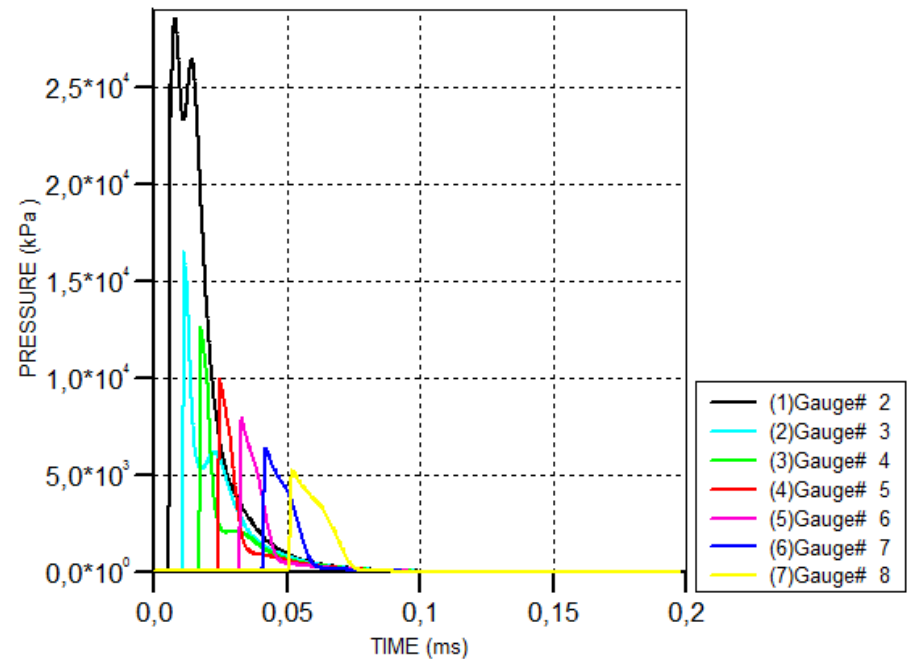
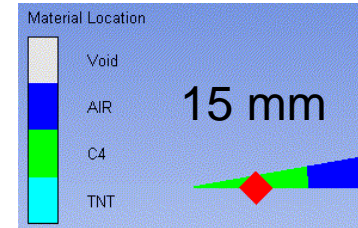
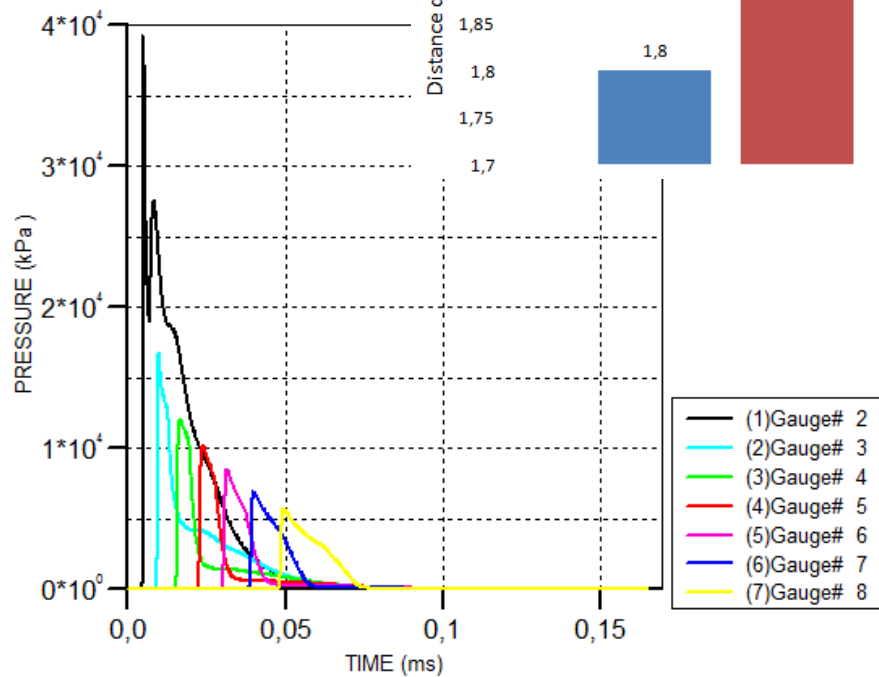
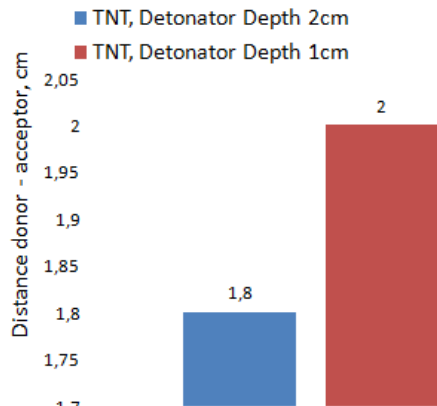
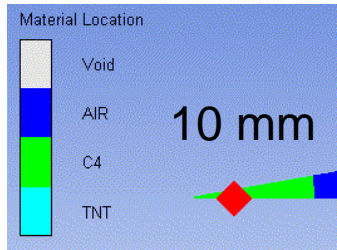
3. Experimental tests

Influence of the metallic case



3. Experimental tests

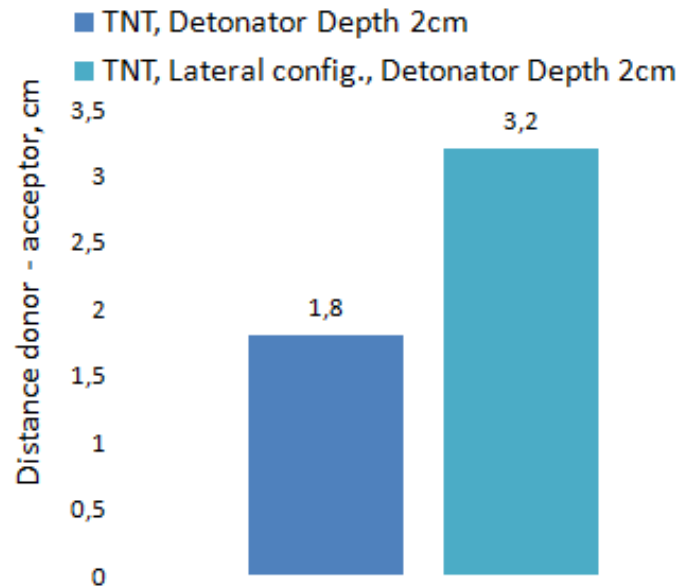
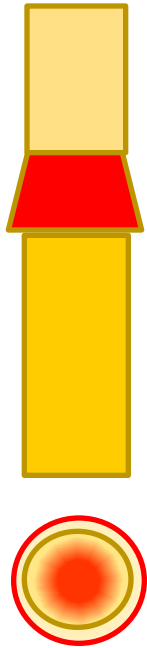
Influence of the position of the detonation point



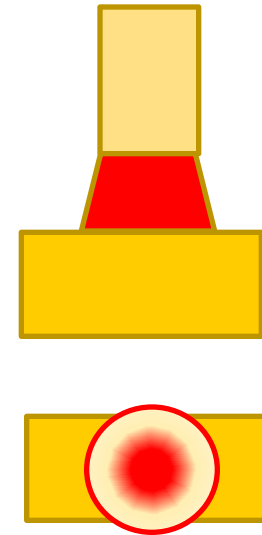
3. Experimental tests

Influence of the acceptor surface

Top configuration



Lateral configuration



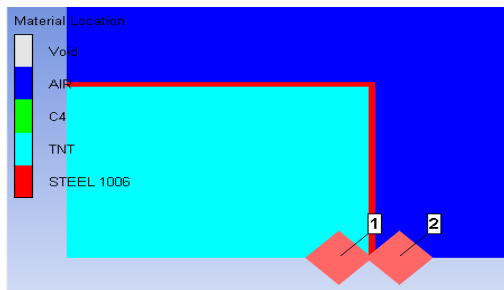
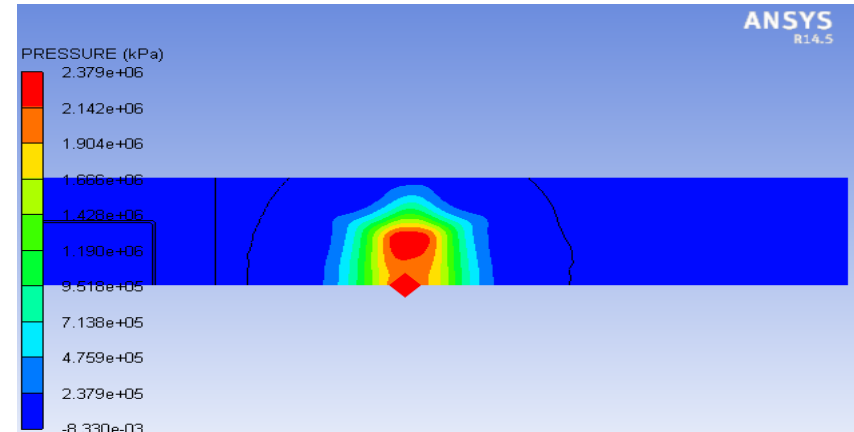
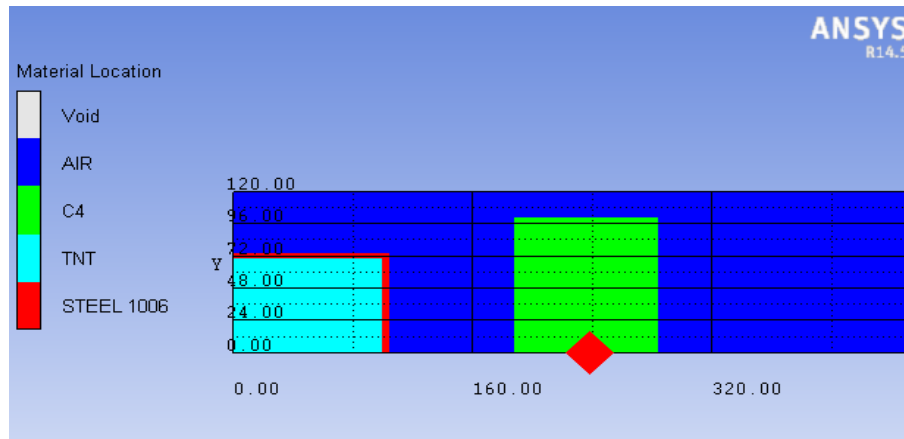
4. Numerical simulations

- Donor – 8 kg plastic explosive;
- Acceptor - 7.2 kg TNT
- Metallic case – thicknesses - 2 mm

Material	Air	Plastic explosive	Plastic explosive (Ideal)
Equation of State	Ideal Gas	JWL	Ideal Gas
	$\gamma = 1.4$	Standard	$\gamma = 1.35$
	$\rho = 1.225 \times 10^{-3} \text{ g/cm}^3$	$\rho = 1.601 \text{ g/cm}^3$	$\rho = 1.0 \times 10^{-4} \text{ g/cm}^3$
	Ref. Energy = 0.0 mJ/mg	Library Data	Ref. Energy = 0.0 mJ/mg
Initial conditions	$\rho = 1.225 \times 10^{-3} \text{ g/cm}^3$	$\rho = 1.601 \text{ g/cm}^3$	From detonation model data
	Ref. Energy = $2.068 \times 10^5 \text{ mJ/mg}$		

4. Numerical simulations

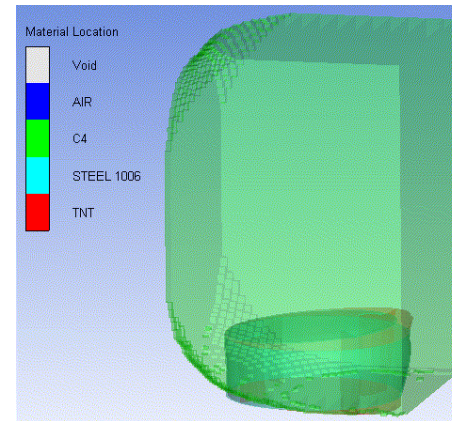
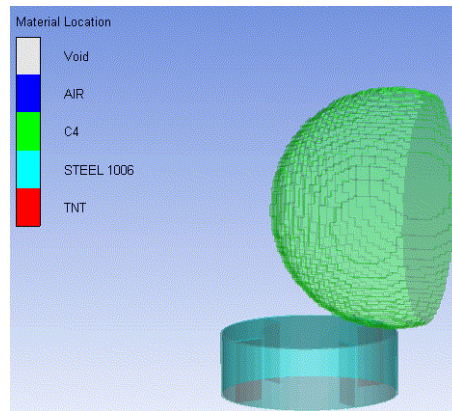
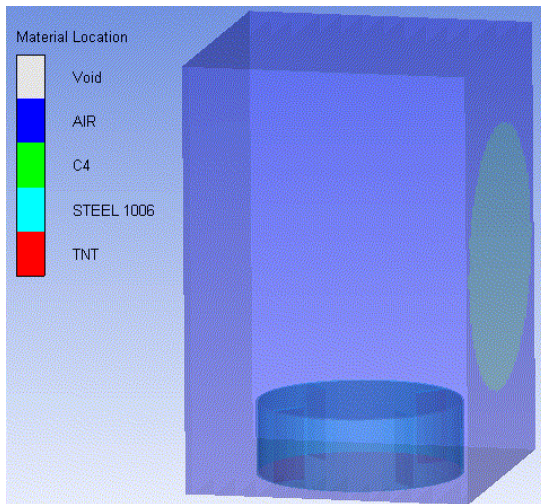
Top configuration – symmetric case



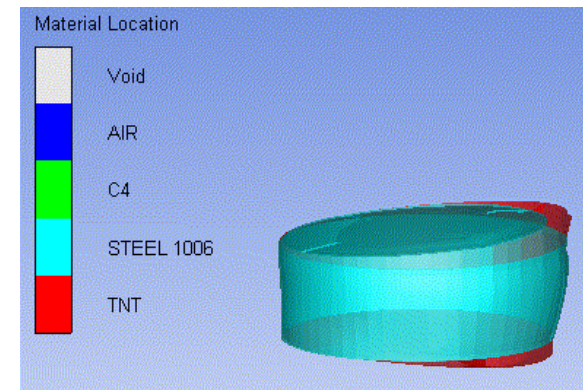
Distance (cm)	Pressure (kPa)	Time (μ s)	Eenergy Fluence (cal/cm ²)	Initiation
30	$6.9144 \cdot 10^6$	0.36	68.12	yes
33	$6.3233 \cdot 10^6$	0.20	39.62	yes
34	$3.8494 \cdot 10^6$	0.19	13.54	no
35	$3.1742 \cdot 10^6$	0.18	8.72	no

4. Numerical simulations

Top configuration – non-symmetric case

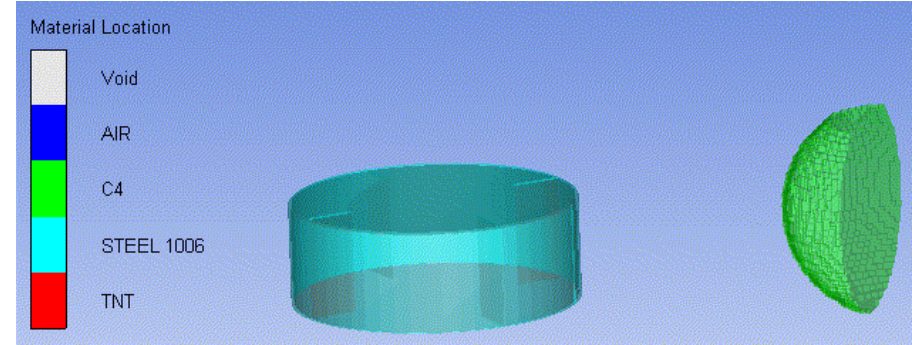
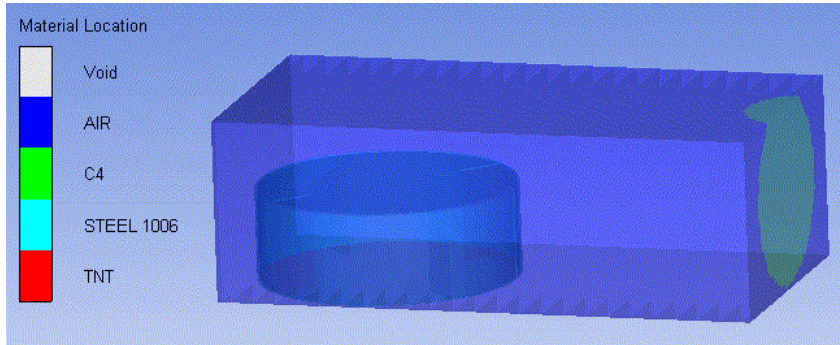


Distance (cm)	Pressure (kPa)	Time (ms)	Energy Fluence (cal/cm ²)	Initiation
24	$7.36 \cdot 10^4$	0.0064	0.16	no
17	$4.01 \cdot 10^5$	0.0026	1.9	no
13	$8.46 \cdot 10^5$	0.0039	13	no
12	$9.40 \cdot 10^5$	0.0360	152.27	yes

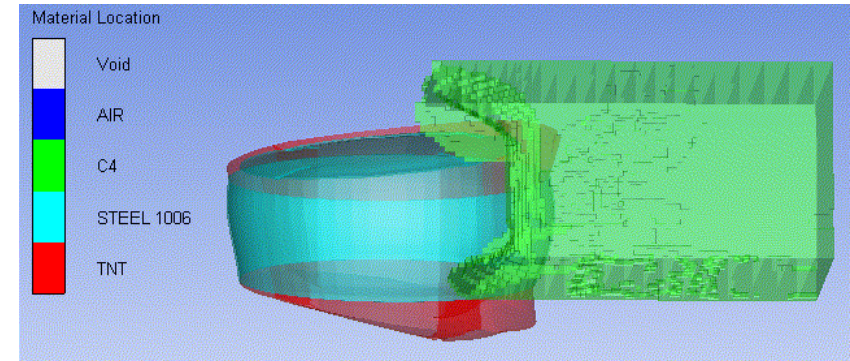


4. Numerical simulations

Lateral configuration



Distance (cm)	Pressure (kPa)	Time (ms)	Energy Fluence (cal/cm ²)	Initiation
15	$8.32 \cdot 10^6$	0.0057	1888	yes
24	$8.3 \cdot 10^6$	0.0016	527.64	yes
80	$2.01 \cdot 10^6$	0.0022	50.90	yes
100	$1.16 \cdot 10^6$	0.0021	13.52	no



5. Conclusions

- ***Sympathetic detonation can be estimated using theoretical equations, experimental tests and numerical simulations;***
- ***There are many parameters to be taken into account;***
 - ***Theoretical aspects*** - Critical Energy Fluence must be exceeded:
 - Must have sufficient pressure;
 - Must have sufficient time duration.
 - ***Experimental tests:***
 - importance of the position of the detonation point;
 - importance of the acceptor surface exposed to donor energy.
 - **Numerical simulations:**
 - necessity of computing energy fluence not only visual detonation finding.

Further work

- ***Neutralization of UXO – determination of the minimum amount of explosive charge in order to obtain a sympathetic detonation or not.***



THANK YOU FOR YOUR ATTENTION !