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Testing the constructive strength of a container arranged as a mobile deposit of explosive materials

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Abstract. Today, due to the diversity of the conditions in which the blasting works are executed, they often require a special organization regarding the transportation and storage of the explosive goods near the blasting field. If for explosive storage arranged for long-term use such as those of the producers, there are detailed regulations regarding the constructive and security requirements that they must meet, for the temporary storage facilities, there are not enough details regarding the constructive requirements that they must comply with. One of the most important aspects taken into account when designing and arranging a mobile explosive depot is the limitation to the maximum of the dynamic action and the throw effect of pieces of material under the pression of an accidental detonation. The paper describes the results obtained after testing a container prototype designed for the storage of explosives. Following the tests performed and the evaluation of the dynamic effects of explosions inside and outside the container as well as the analysis of the measurement regarding the pressure generated by the detonation of explosive charges, it turned out that the construction and detonation behavior of the tested container complies with the purpose and safety requirements for setting up a mobile explosive depot.

1 Introduction

Every year, over 20,000 unexploded ordnance items are found on the Romanian territory, most of them from the First and the Second World War and the specialists from the General Inspectorate for Emergency Situations – IGSU operate in order to destroy them. Usually, various types of projectiles are found, with different capacities and properties, being situations when over 600 such projectiles were stored during one action.

Because destruction procedures are cumbersome and discovered ammunition must be stored in a safe place - often away from where it was found, and from where, over time, it

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must be taken to the locations where it is destroyed, arose the need to arrange temporary mobile depots to store ammunition products in the immediate vicinity of the place where those are identified.

Arranging such a mobile depot is a first activity in Romania. Such types of mobile depots like containers are also used by other European armies, but the concept has been adapted to the needs and particularities of their use in our country [1, 2]. The container has been designed and dimensioned for loads that can reach 50 kg. TNT equivalent, 1000 detonators and/or infantry ammunition (cartridges of different calibers, offensive or defensive hand grenades), being armored inside so that it withstands the detonation of a 100 mm explosive projectile containing 1.5 kg of TNT as well as the detonation of a grenade placed outside, at the top of the container.

In order to test the behavior of the container in case of accidental detonation of different TNT type explosive charges - located in different configurations both inside and outside it, in the Polygon - explosives testing facility of INSEMEX Petrosani were made a series of measurements on the pressure level in front of the wave shock generated by the detonation of explosive charges and the dynamic effects of the pressure on the resistance of the container structure were monitored so that it could withstand and respect the measures regarding the safety and protection distances from the objectives and the human factor placed in the immediate vicinity [3].

2 Previous work

2.1 Construction and arrangement of mobile explosive depot

According to the legislation for activities carried out in quarries or blasting engineering works the explosives can be stored also in mobile metal or concrete niches. The way how these depots have to be arranged is described in a project which follow the legislative requirements regarding the construction and arrangement of explosives depots and need to be approved by authorities [4].

An ISO 1C type container was arranged as a mobile depot so as to allow the storage of both explosives and detonators. The container was divided into two compartments, being armored inside with steel plates - type ARMOR S- 500 of 6.5 mm thickness so as to ensure that it can withstand the accidental detonation of a load of 1.5 kg. TNT equivalent. In the first compartment was arranged a number of 20 boxes having a total storage capacity of 25 kg TNT equivalent, with a quantity of 1.3 kg TNT equivalent per each box, being arranged five boxes by four rows. [5] (Figure 1). The second container compartment was arranged for the storage of unexploded ammunition in quantity up to 25 kg TNT equivalent.

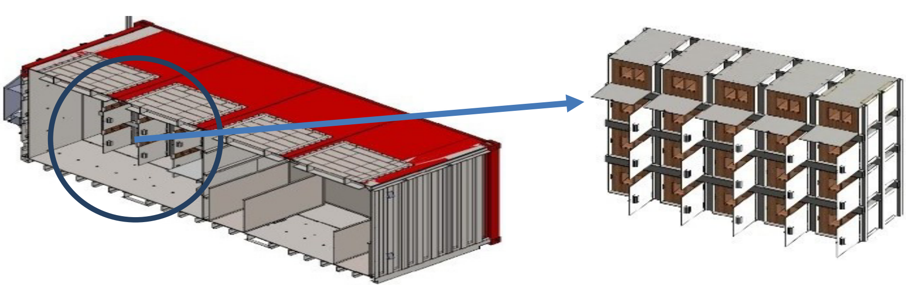

Fig. 1. Modification of an ISO 1C container in mobile explosive depot.

In the ceiling area, the two compartments were provided with pressure relief and the side walls with slots in order to provide natural air ventilation.

2.2 Test results of the storage boxes placed inside the mobile depot

One of the main targets was to study how the storage boxes withstand to the effects of an accidental detonation in order to ensure the integrity of the container and security in its close vicinity. In this view were established 3 constructive alternatives of storage boxes and tested at the explosion. TNT explosives and electrical detonators were used in the tests [9,10]. Based on the observed effects of explosion, changes were made to the boxes to increasing their resistance [3].

2.2.1 Test no.1

The explosion resistance of a set of two boxes with a rectangular shape was checked, 1.3 kg of TNT being introduced inside each box, one being initiated with an electric detonator and the other load being used as a control sample (Figure 2 a). Under the effect of the explosion, the box in which the detonation occurred was completely dismantled (Figure 2 b), the shock wave propagating in the second box dislocating the door and its side wall (Figure 2 c), and the control TNT explosive was disintegrated.

a) Set of two boxes b) First box c) Second box

Fig. 2. Results of blast test.

Looking to the blast test results, it was decided to improve the amour steel box construction by welding on its outer edges corner reinforcements and to introduce inside a three compartments wood storage box for better storage and protection of explosives. (Figure 3).

2.2.2 Test no.2

The explosion resistance of a set of two boxes with improved reinforcements was checked, 1.3 kg of TNT being introduced inside each steel box, in the middle of tego wood boxes (Figure 3).

Fig. 3. Arrangement of steel box with stiffening elements and tego wooden box inside.

Under the effect of the explosion, in the box in which the detonation occurred the walls were partially dismantled but the explosive control charge from the second steel box was not initiated (Figure 4).

Fig. 4. Effects after testing the steel box.

2.2.3 Test no.3

A third constructive variant of a steel box was tested in which an armored metal pipe with a diameter of 406 mm was inserted and inside the pipe a tego wooden box was fixed. The explosion resistance of a set of two boxes with the above-mentioned improvements was checked, 1.3 kg of TNT being introduced inside each steel box, in the middle of tego wood boxes (Figure 5).

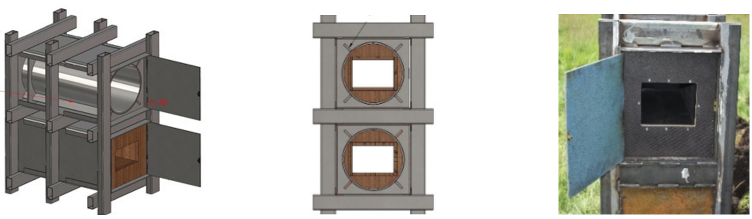

Fig. 5. Arrangement of steel box with inserted pipe and tego wooden box.

Under the effect of the explosion, in the detonation area, the tube wall was broken and the outer wall corresponding to this area was partially dislocated and as well as the door. The box next to the one where the detonation took place was not affected and the explosive charge did not detonate (Figure 6).

Fig. 6. Effects of testing the steel box with inserted pipe.

2.2.4 Conclusions after the performed tests

Following the evaluation of the results of the test action, it was concluded that the constructive variant with metal pipe inserted in the steel box is the one that confers a superior resistance compared to the other two constructive variants tested.

It has also been established to make some improvements of the steel box in terms of the welding line as well as the stiffening line of the outside box frame, in order to increase its resistance to explosion pressure.

3 Testing the resistance of the container against explosion

Following the establishment of the constructive variant of the box that has the behavior most appropriate to the requirements of the construction of the pyrotechnic container, respectively to withstand the detonation of an explosive load of 1.3 – 1.5 kg. equiv. TNT, without transmitting the detonation outside the box and without initiating other explosive charges in the neighboring boxes fixed in the container, the resistance of the pyrotechnic container (Figure 7) was checked in the Testing explosives field – Polygon of INSEMEX Petrosani.

a) Storing explosives b) Storing unexploded ordnanc c) outside of the container

Fig. 7. Arrangement of pyrotechnic container for testing in the Polygon.

The metal construction of the container was tested and the explosion pressures were measured [6] when a 1.3 kg TNT load was introduced a detonated in a box in the compartment for storing explosives and detonators (Figure 7 a), 1.5 kg. TNT load detonated inside the compartment intended for storing unexploded ordnance (Figure 7 b), respectively detonating an explosive charge of 0.100 kg TNT, located on the outside of the container (Figure 7 c).

3.1 Container testing no. 1 - 1.3 kg. TNT placed inside of a steel box

3.1.1 Test input data

- detonation of an explosive charge of 1.3 kg. TNT placed in the steel box located in the middle of the second row of the first compartment dedicated for the storage of explosives and detonators (Figure 8);

Fig. 8. Location of the explosive charge in compartment no. 1 of container.

- placement of 3 pressure sensors inside the pyrotechnic container, in compartment no.1, one in the area of the vent located on the right side of the access door – sensor SP 1, another one on the left side of the access door – sensor SP 2, both in a direction perpendicular to the metal boxes and the third one – sensor SP 3, positioned in the upper left corner of compartment (Figure 9);

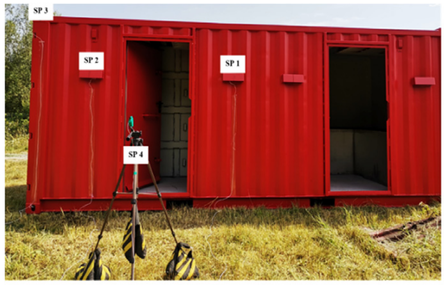

Fig. 9. Container test no. 1 - arrangement of the 4 pressure sensors.

- placement of a pressure sensor outside the pyrotechnic container – sensor SP 4, facing the access door in compartment no.1, at a distance of 2.0 m from it and collinear with the explosive charge (Figure 9).

3.1.2 Measurement results

Visualization of the air pressure wave for the 1.3 kg TNT test, located inside the steel box from compartment no. 1 of the pyrotechnic container - fast video shooting at 9000 frames per second, is presented in the screenshots from Figure 10.

Fig. 10. Visualization of detonation and air shock wave propagation test no. 1.

The appearance of the air shock waves - overpressures in the wavefront for the explosive charge of 1.3 kg. TNT are shown Figure 11.

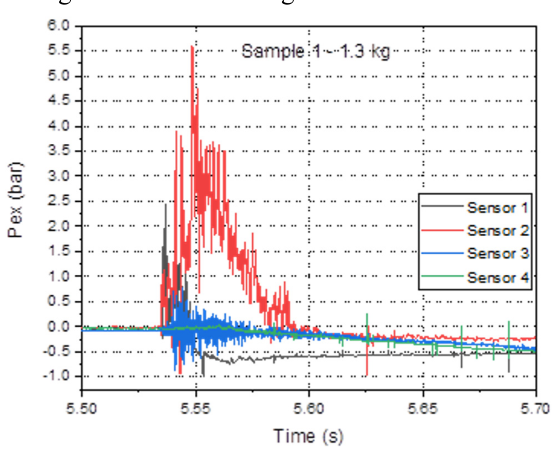

Fig. 11. Representation of the overpressure in time interval 5.50 – 5.70 s, test no. 1.

The maximum measured values of the overpressure at points SP1, SP2, SP3 and SP4 are shown in Table 1.

Table 1. Measured values of overpressure test no. 1.

SP_1 - int. (bar)	**SP_2** – int. (bar)	**SP_3** – int. (bar)	**SP_4** – ext. (bar)
2.44740	5.59507	0.77329	0.28065

3.1.3 Dynamic effects following the detonation of the explosive charge

Following the detonation of the 1.3 kg TNT load, placed inside a steel box in compartment no. 1 of the pyrotechnic container, the following were found:

- a deformation of the access door in the compartment and of its supporting frame (Figure 12 a) as well as a slight deformation of the container wall, on the opposite side of the access door;

- the two pressure relief devices related to compartment no. 1 were operated following the detonation and were projected at distances of over 30 - 40 m (Figure 12 b);

- under the dynamic effect of the detonation, the doors of the boxes were opened, some with broken hinges (Figure 12 c), the door corresponding to the box in which the detonation took place being torn off;

a) Container outside deformation b) Pressure relief devices after blast c) Effects on the inside boxes

Fig. 12. Dynamic effects in compartment no. 1.

- the cylindrical walls of the box in which the detonation took place were broken, but the shock wave did not propagate to the neighboring boxes, the explosive control introduced in the box next to the detonated one, not being initiated.

3.2 Container testing no. 2 - 1.5 kg. TNT introduced into the compartment for the storage of unexploded ordnance

3.2.1 Test input data

- detonation of an explosive charge of 1.5 kg. TNT suspended from the ceiling in the middle of compartment no. 2 of unexploded ordnance storage and at a distance of 1.0 m from the ceiling (Figure 13 a);

- placement of 3 pressure sensors inside the pyrotechnic container, in compartment no.2, one in the area of the vent located on the right side of the access door – sensor SP 3, another one on the left side of the access door – sensor SP 5 and the third one – sensor SP 6, located on the upper right-side wall of the container, sensor in the direction perpendicular to the suspended explosive charge (Figure 13 b);

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a) Suspended charge of 1.5 kg. TNT

b) Arrangement of the 4 pressure sensors

Fig. 13. Container test no. 2 - location of the explosive charge and arrangement of the 4 sensors.

- placement of a pressure sensor outside the pyrotechnic container – sensor SP 4, facing the access door in compartment no.2, at a distance of 2.0 m from it and collinear with the explosive charge (Figure 13 b).

3.2.2 Measurement results

Visualization of the air pressure wave for the 1.5 kg TNT test, suspended inside of compartment no. 2 of the pyrotechnic container - fast video shooting at 9000 frames per second, is presented in the screenshots from Figure 14.

Fig. 14. Visualization of detonation and air shock wave propagation test no. 2.

The appearance of the air shock waves - overpressures in the wavefront for the explosive charge of 1.5 kg. TNT are shown Figure 15.

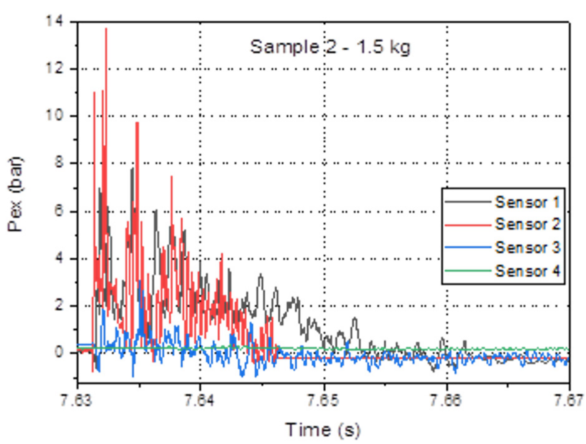


Fig. 15. Representation of the overpressure in time interval 7.63 – 7.67 s, test no. 2.

The maximum measured values of the overpressure at points SP3, SP4, SP5 and SP6 are shown in Table 2.

Table 2. Measured values of overpressure test no. 2.

SP$_3$ - int. (bar)	**SP$_4$** – ext. (bar)	**SP$_5$** – int. (bar)	**SP$_6$** – int. (bar)
3.10843	0.72097	7.84792	13.75198

3.2.3 Dynamic effects following the detonation of the explosive charge

Following the detonation of the 1.5 kg TNT load, suspended inside of compartment no. 2 of the pyrotechnic container, the following were found:

- a deformation of the access door in the compartment and of its supporting frame (Figure 16 a) as well as a slight deformation of the container wall, on the opposite side of the access door;
- the two pressure relief devices related to compartment no. 2 were operated following the detonation and were projected at distances of over 40 - 60 m (Figure 16 b);
- welding failure in the area of the support beam of the ventilation system located at the ceiling of the compartment, as well as the sectioning of the hinge clamping system between the compartment door and its support frame (Fig. 16 c).

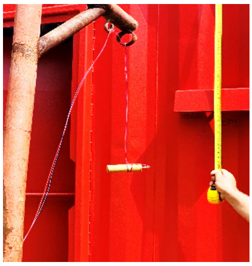
a) Container outside deformation b) Pressure relief devices after blast c) Effects in the acces door area

Fig. 16. Dynamic effects in compartment no. 2.

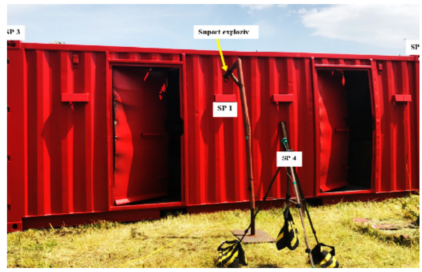
3.3 Container testing no. 3 – 0.100 kg. TNT suspended in front of the container

3.3.1 Test input data

- detonation of an explosive charge of 0.100 kg. TNT located outside the pyrotechnic container, on the right side of the access door in compartment no. 1, suspended on a support, at a height of 1.5 m and at a distance of 0.5 m from the wall of the pyrotechnic container (Figure 17 a);
- placement of 3 pressure sensors outside the pyrotechnic container, one in the area of the vent located on the right side of the access door in compartment no. 1 – sensor SP 1, another one on to the right of the access door in compartment no. 2, in the top corner – sensor SP 2 and the third one – sensor SP 3, located to the left of the access door in compartment no. 1, in the top corner (Figure 17 b);
- placement of a pressure sensor outside the pyrotechnic container – sensor SP 4, facing the access door in compartment no.1, at a height of 1.5 m and at a distance of 0.5 m from it and collinear with the suspended explosive charge (Fig. 17 b).



a) Outside charge of 0.100 kg. TNT



b) Arrangement of the 4 pressure sensors

Fig. 17. Container test no. 3 - location of the explosive charge and arrangement of the 4 pressure sensors.

3.3.2 Measurement results

Visualization of the air pressure wave for the 0.100 kg TNT test, suspended in front of the pyrotechnic container at a distance of 0,5 m from it - fast video shooting at 9000 frames per second, is presented in the screenshots from Figure 18.

Fig. 18. Visualization of detonation and air shock wave propagation test no. 3.

The appearance of the air shock waves - overpressures in the wavefront for the explosive charge of 0.100 kg. TNT are shown Figure 19.

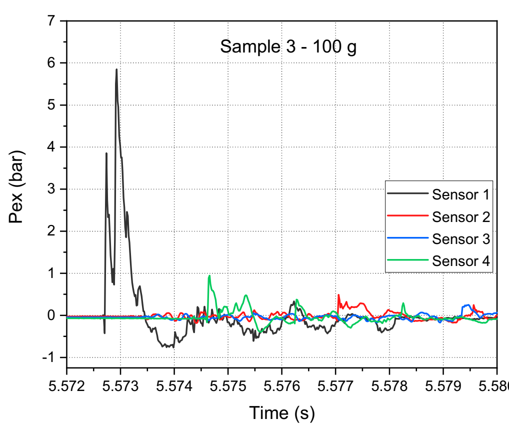


Fig. 19. Representation of the overpressure in time interval 5.57 – 5.58 s, test no. 3.

The maximum measured values of the overpressure at points SP1, SP2, SP3 and SP4 are shown in Table 3.

Table 3. Measured values of overpressure test no. 3.

SP_1 - ext. (bar)	**SP_2** – ext. (bar)	**SP_3** – ext. (bar)	**SP_4** – ext. (bar)
5.84847	0.48991	0.2861	0.94659

3.3.3 Dynamic effects following the detonation of the explosive charge

Following the detonation of the 0,100 kg TNT load, located outside the pyrotechnic container, on the right side of the access door in compartment no. 1, suspended on a support, at a height of 1.5 m and at a distance of 0.5 m compared to the wall of the pyrotechnic container, only a slight deformation of the container sheet was found near the area where the explosive charge was suspended and initiated.

4 Evaluation of results

4.1 Constructive improvements of the pyrotechnic container

Analyzing the results of the three tests performed with reference to the behavior of the pyrotechnic container with respect to the dynamic action of the explosions, the following improvements were agreed:

- in order to limit the throwing of pressure relief devices under the dynamic action of explosions, a grid protection system shall be mounted above them, on one third of their surface starting from the area of the access doors in the container;
- in order to ensure a better natural ventilation of the pyrotechnic container, the number of holes in the ventilation areas will be supplemented;
- each door from the boxes in compartment no. 1 shall be provided with a safety cable (fixed between the box door and its frame) so as to allow the door to be opened at an angle of 30 ^{o}. The safety cable shall be fixed at one end and detachable at the other;
- protection of the area of the locks from the two access doors in the container compartments with a pocket-type protection, similar to those in the area of the ventilation holes made in the walls of the container.

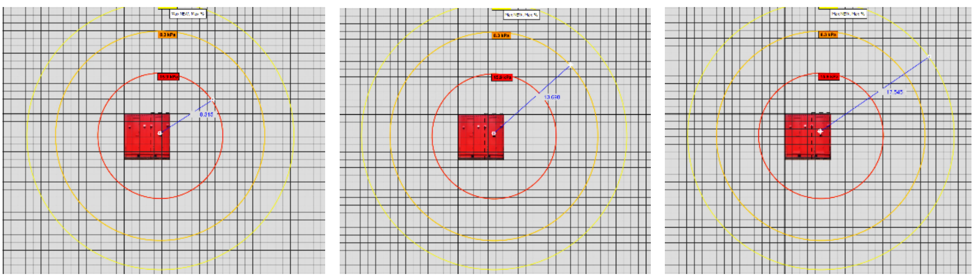
4.2 Discussions on test results

Based on the evaluation of the dynamic effects of the explosions carried out inside and outside the container, as well as the analysis of the measurements regarding the pressure generated by the detonation of the explosive charges, results the following:

- according to the data from the literature [4], the values of the pressure measured inside the container of 3.1 - 13.75 bar obtained when detonating a suspended load of 1.5 kg. TNT in compartment no.2 and 0.77 - 5.6 bar obtained by detonating a load of 1.3 kg. TNT introduced in the box, would have led to the total or partial destruction of the industrial constructions with metal frame, of the concrete or masonry buildings located in the immediate vicinity of the container. Under the conditions specified above and the measured pressure values, the dynamic effects of the detonation on the structure of the tested pyrotechnic container are limited to deformations in the area of the access doors, the failure of some welding lines inside compartment no. 2 or remote throwing of pressure relief devices. At the same time, the constructive arrangement and the detonation behavior of the explosive storage boxes, ensured the integrity of the explosives in the boxes adjacent to the one where the detonation took place.

- according with specific national legislation and worldwide literature [4, 7], the values of the pressures measured outside the container with a value of 0.28 bar when detonating a load of 1.3 kg. TNT introduced in the box and 0.72 bar when detonating a suspended load of 1.5 kg. TNT in compartment no. 2, can lead to injury to the human factor placed close to the container. The values measured outside the container, of the pressure produced by the explosion come from the dissipation of the pressure waves through the pressure relief devices mounted on the roof of the container.

By using a specialized software application - IMESAFR, it was possible to make a probabilistic assessment of the risk situations generated by the detonation of explosive charges in the two compartments of the container and the pressures generated outside it, in order to determine the level of safety or the corresponding degree of insecurity. Thus, in Figure 20 – a , show the mortality zone estimated to be within a radius of 8 m, in Figure 20 – b , shows the area of major lesions within a radius of 14 m and in Figure 20 – c , shows the area of minor injuries within a radius of 17 m around the container.



a) Mortality zone – up to 8 m b) Major lesions zone – up to 14 m c) Minor injuries zone – up to 17 m

Fig. 20. Radius of shock wave and influence on the human factor.

5 Conclusions and recommendations

When designing a mobile explosive depot, it's important to reduce at the maximum the dynamic action and the throw effect of pieces of material under the pressure generated by an accidental detonation.

The resistance of a pyrotechnic container was tested in the Explosives Polygon of INSEMEX Petrosani and following the tests performed and the evaluation of the dynamic effects of explosions inside and outside the pyrotechnic container, as well as the analysis of the measurement results regarding the pressure generated when detonating explosive charges, it resulted that the dynamic effects of detonation on the pyrotechnic container structure were limited to deformations more in the area of the access doors, to the failure of some welding lines inside the compartment no. 2 and remote throwing of pressure relief devices.

The risk assessment showed that if the container resists the detonation of various explosive charges, the shock wave generated can be dangerous to the human factor. As such, a safety distance of at least 20 from the location of the pyrotechnic container is recommended.

The experience gained in testing the pyrotechnic container can be used and extended in the field of mining and road construction, in order to design and arrange mobile warehouses needed in the activities of blasting companies who are performing works in isolated areas where there are no explosive depots nearby, contributing at the same time when complying with the safety requirements for explosives storage.

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