выбор ВВ для применения следует осуществлять по совокупности всех критериев, чтобы свести до минимума влияние субъективных факторов на оценку уровня опасности.

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CONCERNING THE DISCUSSION OF EXPLOSIVES' CLASSIFICATION FOR THE DETERMINATION OF SHOCK-WAVE EFFECTS

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When studies related to the study of the properties of explosives and the purpose of their next usage are undertaken, it is necessary to determine the detonation characteristics of newly created explosives which must meet modern requirements for technological and operational safety. In practice, the degree of danger is estimated by experimental methods that reproduce certain types of impacts to explosives. In particular, a set of test methods is applied, which includes, among other things, the detection of sensitivity to shock wave impacts and detonation ones [1, 2].

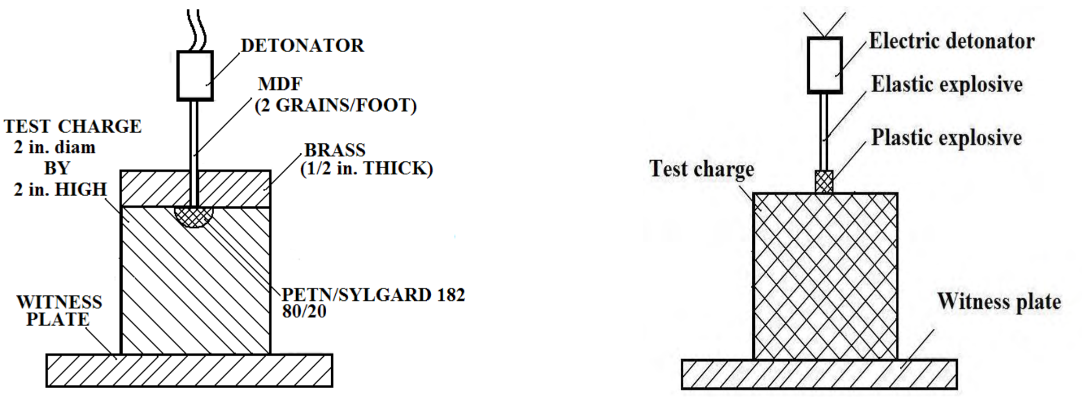
When new explosives are being developed, our organization initially calculates the main explosive characteristics with the use of the corresponding engineering techniques described in [3, 4].

In order to assess the degree of danger of explosives, JSC “GosNII “Kristall” uses the following methods: the method of sensitivity estimation to detonation effects by small-diameter charges and the method for determining the shock wave sensitivity (SWS).

Previously, in the foreign literature, there was presented the method of a minimum priming charge [5]. According to this method, a hemisphere of specified dimensions is formed in the test charge, which is filled with an intermediate detonator (Fig. 1a).

When assessing the sensitivity in the test explosive, the minimum priming charge (MPC) of the plastic explosive, which causes detonation, is determined by charges of small diameter.

Priming charges of a cylindrical shape are used, with a diameter-to-height ratio equal to unity. The MPC for various test explosives can vary from a few hundredths of a gram to several grams, this method is used in our organization (Figure 1b). As a conductor of detonation, it was used a cord of elastic explosive with minimum diameter.



a) b)

Figure 1. Diagram of the experiment realization:
a) method of the Minimum Priming Charge,
b) method for estimating the sensitivity to detonation effects by small-diameter charges

To classify explosives according to the degree of danger in determining the minimum priming charge (MPC), it is proposed to establish an evaluation criterion, and according to the established criteria, to divide the explosives into groups of hazard. In table 1 it is shown the criteria.

Table 1. The groups of explosives hazard level and the evaluation criterion in determining MPC

The groups of explosives hazard level	Criteria – minimum priming charge $d_{pc}(m_{pc})^{*}$, $mm(mg)$
Extremely hazardous	$d_{pc}(m_{pc}) \le 1(3)$
Highly hazardous	$1(3) < d_{pc}(m_{pc}) \le 3(30)$
Moderately hazardous	$3(30) < d_{pc}(m_{pc}) \le 6(260)$
Reduced hazard	$6(260) < d_{pc}(m_{pc}) \le 9(900)$
Low hazardous	$d_{pc}(m_{pc}) > 9(900)$
Note: * $d_{pc}(m_{pc})$ – the lowest priming charge, in its explosion a stable detonation of the test explosive is observed, $d_{ÈÇ}$ –the lowest diameter of a priming charge, mm, $m_{ÈÇ}$ –the lowest mass of the priming charge, g	

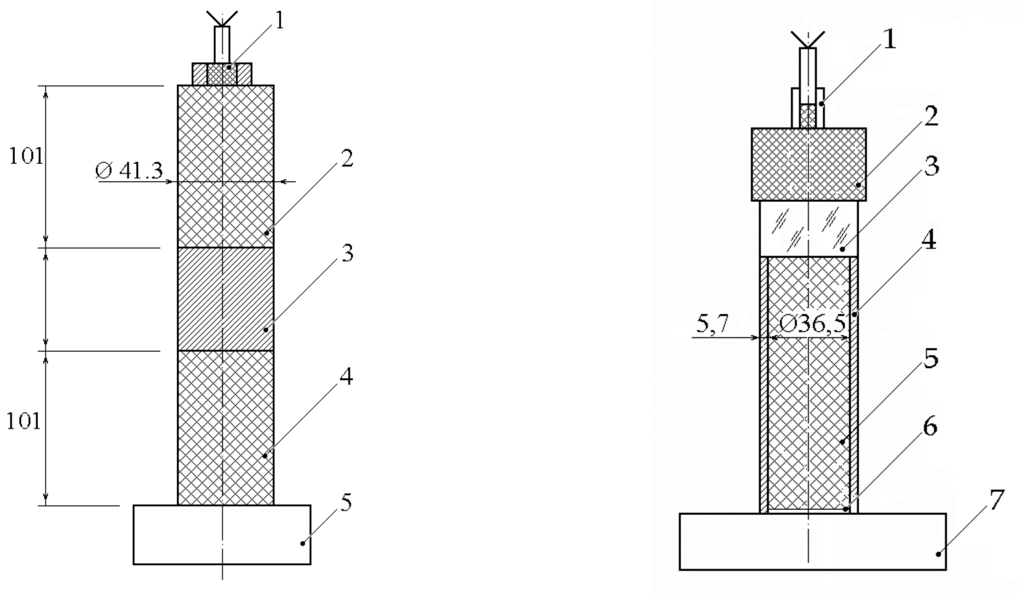
Based on the proposed criteria, the classification of explosives according to the degree of danger in the determination of MPC has been carried out. In table 2 it is shown the results of the classification.

Table2. Classification of explosives according to the hazard level when priming with small-diameter charges

Explosives	Charge density, g/sm³		Charge porosity, %	Minimum priming charge, $d_{pc}(m_{pc})$, ìì (ìã)
	$\rho_{theor.}$ g/sm³	$\rho_{exp.}$ g/sm³		
1	2	3	4	5
Extremely hazardous – $d_{pc}(m_{pc}) \le 1(3)$				
Октоген	1,90	1,74	8,4	1(3)
Тэн	1,77	1,70	4,0	1(3)
Тэн флегмат.	1,68	1,66	1,4	1(3)
ПВВ-85	1,56	1,52	2,6	1(3)
Апрол м.Т	1,87	1,70	9,0	1(3)
Highly hazardous – $1(3) < d_{pc}(m_{pc}) \le 3(30)$				
Октоген	1,30	1,80	5,3	2(10)
Гексоген	1,82	1,65	8,3	2(10)
Тротил (прессов.)	1,66	1,60	3,6	3(30)
А-IX-1	1,74	1,68	3,4	3(30)
А-IX-3Т	1,71	1,63	4,5	3(30)
Окфол 3,5	1,81	1,78	2,2	3(30)
ГАСС-8	1,81	1,77	2,2	3(30)
Moderately hazardous – $3(30) < d_{pc}(m_{pc}) \le 6(260)$				
А-IX-2	1,87	1,72	4,8	4,0/80
ГАСС-12	1,84	1,79	2,7	4,0/50
Апрол м.К	1,87	1,72	8,1	5(150)
ОЛА-8Т	1,80	1,78	1,1	5(150)
1	2	3	4	5
ОЛА-15Т	1,84	1,82	1,1	5(150)
ТГ-40 (cast)	1,75	1,72	1,7	5(150)
Апрол м.К	1,87	1,83	2,0	6(260)
Reduced hazard– $6(260) < d_{pc}(m_{pc}) \le 9(900)$				
ТАТБ	1,94	1,82	6,1	8(630)
Low hazardous – $d_{pc}(m_{pc}) > 9(900)$				
ТАТБ	1,94	1,85	4,6	10(1200)
ТАТБ (пластиф)	1,93	1,86	3,6	12(2100)
Тротил (литой)	1,66	1,56	6,0	> 13(3100)

The researches to determine SWS for wide range of explosives are conducted in JSC "GosNII Kristall". Before several organizations conducted the comparative study of methods to determine SWS which showed that relative range of the explosive sensitivity remains at different test methods.

Foreign test methods including SWS determination are considered in the standard MIL-STD-1751A [6] using the gap test method. In Fig. 2 it is shown typical test schemes using the gap test technique including the NOL method, which found wide application in the determination of SWS explosives. The results of tests of various foreign explosives carried out using this technique are given in [6 - 8].



1 – detonator with a supplementary charge Ø12,7×12,7;
2 – initial charge PBX9205;
3 – duralumin barrier;
4 – inert charge;
5 – witness plate.

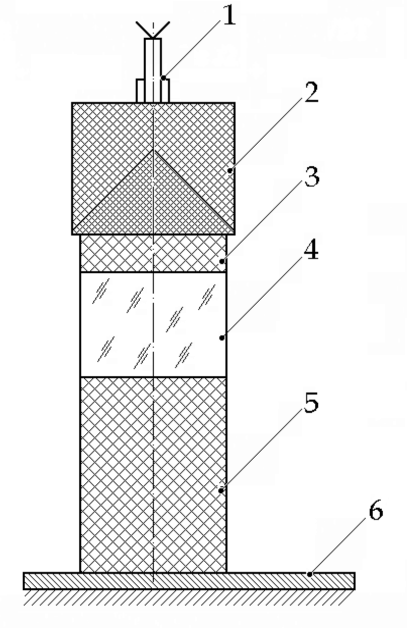
1 – detonator №6 with a supplementary charge VBT;
2 – pentolite initial charge Ø60;
3 – plexiglass barrier;
4 – steel pipe;
5 – inert charge;
6 – air gap;
7 – steel witness plate

Figure 2 – Classical exponents of a gap test – standard LANL and NOL LSGT test

The experimental determination of SWS have been carried out according to the procedure of JSC "GosNII Kristall" and consists in determining the maximum pressure of the shock wave at the exit from the inert barrier (plexiglass), in which case detonation of the test explosive is not excited (Pcr pres.).

With pressure changing, alteration of the barrier thickness takes place. The shock wave is generated by a special explosive device - a generator of flat shock wave (GFSW) made of phlegmatized RDX with a diameter of 43 mm and a stick with a diameter of 40 mm, a height of 10 mm, and a density of 1.65 g/cm^3.

During the test the smallest thickness of the barrier was selected, at which detonation of the test charge from three tests was not initiated. From the selected thicknesses of barriers and the calibration tables, their corresponding values of the shock wave pressures at the exit from the barriers were selected (Fig. 3).



1 – electric detonator with a plug fixation; 2 – plane wave generator; 3 – initial charge;
4 – Plexiglass barrier; 5 – test (inert) charge; 6 – witness plate.

Figure 3-experiment realization for determining the shock wave sensitivity of explosives

For the classification of explosives according to the degree of danger at shock-wave effects, as well as for the MPC, it is proposed to establish an evaluation criterion, and, according to the established criterion, to divide the explosives into groups of danger. In Table 3 it is shown the criteria.

Table 3. The groups of explosives hazard level and evaluation criteria at shock-wave effects

<table>
<tr><td colspan="2">The groups of explosives hazard level</td><td>Evaluation criteria – $P_{cr.\ pres.}$, kbar</td></tr>
<tr><td colspan="2">Extremely hazardous</td><td>$P_{cr.\ pres} \leq 10$</td></tr>
<tr><td colspan="2">Highly hazardous</td><td>$10 < P_{cr.\ pres.} \leq 20$</td></tr>
<tr><td colspan="2">Moderately hazardous</td><td>$20 < P_{cr.\ pres.} \leq 3\ 0$</td></tr>
<tr><td colspan="2">Reduced hazard</td><td rowspan="2">$30 < P_{cr.\ pres.} \leq 45$</td></tr>
<tr><td>Subgroup A
$30 < P_{cr.\ pres.} \leq 37$</td><td>Subgroup B
$37 < P_{cr.\ pres} \leq 45$</td></tr>
<tr><td colspan="2">Low hazardous</td><td>$P_{cr.\ pres} > 45$</td></tr>
</table>

Based on the proposed criteria, the classification of explosives according to the hazard level in shock-wave effects have been carried out (Table 4).

Table 4. Classification of explosives according to the degree of danger in shock-wave effects

<table>
<tr><td>Explosives</td><td>$\rho_{max.}$, g/sm^3</td><td>ρ_0, g/sm^3</td><td>Porosity, %</td><td>$P_{cr.pres}$, kbar</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td colspan="5">Extremely hazardous - $P_{cr.\ pres.} \leq 10$</td></tr>
<tr><td>ТЭН</td><td>1,77</td><td>0,38</td><td>78,5</td><td>< 10</td></tr>
<tr><td>Октоген</td><td>1,90</td><td>1,0</td><td>47,0</td><td>< 10</td></tr>
<tr><td>Гексоген</td><td>1,82</td><td>1,0</td><td>45,0</td><td>< 10</td></tr>
<tr><td>A-IX-1</td><td>1,74</td><td>1,06</td><td>39,0</td><td>10</td></tr>
</table>

1	2	3	4	5
А-IX-2	1,87	1,06	43,0	10
Highly hazardous – $10<P_{cr.\ pres}\leq 20$				
Гексоген	1,82	1,29	29,1	11
ЭГ-85	1,60	1,20	25,0	13
БТФ	1,93	1,88	2,6	14
Гексанон	1,93	1,87	3,1	16
А-IX-2	1,87	1,35	28,0	17
Окфол-3,5	1,82	1,00	45,0	18
Октоген	1,90	1,83	3,7	19
ТЭН флегмат	1,68	1,65	1,8	19
Moderately hazardous - $20< _{cr.\ pres}\leq 30$				
ОКФ-2М	1,89	1,81	4,2	21
ЭГ-85	1,60	1,30	18,8	23
ТНТ	1,66	1,48	11,0	23
		1,55	5,5	25
Окфол -3,5	1,82	1,76	3,3	25
А-IX-2	1,87	1,67	10,7	25
		1,72	8,0	28
А-IX-1	1,74	1,64	4,0	26
ПВВ-85	1,56	1,55	0,7	27
Гексоген	1,82	1,80	1,2	27
Гексоген/флегм/Al (75/10/15)	1,69	1,62	4,1	28
		1,65	2,3	30
ТКФ-А	1,57	1,54	1,9	28
ТГ-40	1,75	1,69	3,4	29
КТО, КТО-Т	1,88	1,86	1,1	29
ОМА	1,87	1,82	2,3	29
ГАСС-8	1,81	1,79	1,1	30
ГАСС-12	1,84	1,79	2,6	30
А-IX-1/Al (70/30)	1,95	1,83	6,0	30
Reduced hazard, subgroup A – $30<P_{cr.\ pres}\leq 37$				
Апрол м.К	1,87	1,80	3,8	32
ОКФ-2М	1,89	1,87	1,0	34
ОЛА-8Т	1,80	1,79	0,6	35
ОЛА-15Т	1,84	1,83	0,4	36
ГТФ-А	1,90	1,85	2,8	36
МС-2Ц	1,82	1,75	3,8	36
Reduced hazard, subgroup B – $37<P_{cr.\ pres.}\leq 45$				
ЛД-70	1,37	1,37	0	39
Тротил литой	1,66	1,56	6,1	40
ЭГ-85	1,60	1,59	0,6	42
Апрол пластиф.	1,86	1,80	2,3	42
ТГ-40М	1,70	1,67	1,9	43
ЛП-30Т	1,93	1,91	1,0	43
Low hazardous – $P_{cr.\ pres.}>45$				
ТНБ	1,69	1,68	0,6	48
ТАТБ	1,94	1,87	3,5	61

1		2	3	4	5
ТАТБ пластиф.		1,93	1,86	3,6	54
			1,89	2,1	71
Гексоген/H_2O	87/13	1,64	1,55	5,4	75
	80/20	1,56	1,51	3,2	112

The main part of data given for explosive charges is in the third and fourth group of danger, which corresponds to a moderate and reduced degree of danger. In Fig. 4 it is represented a part of the classification diagram of explosives according to the degree of danger in shock-wave effects.

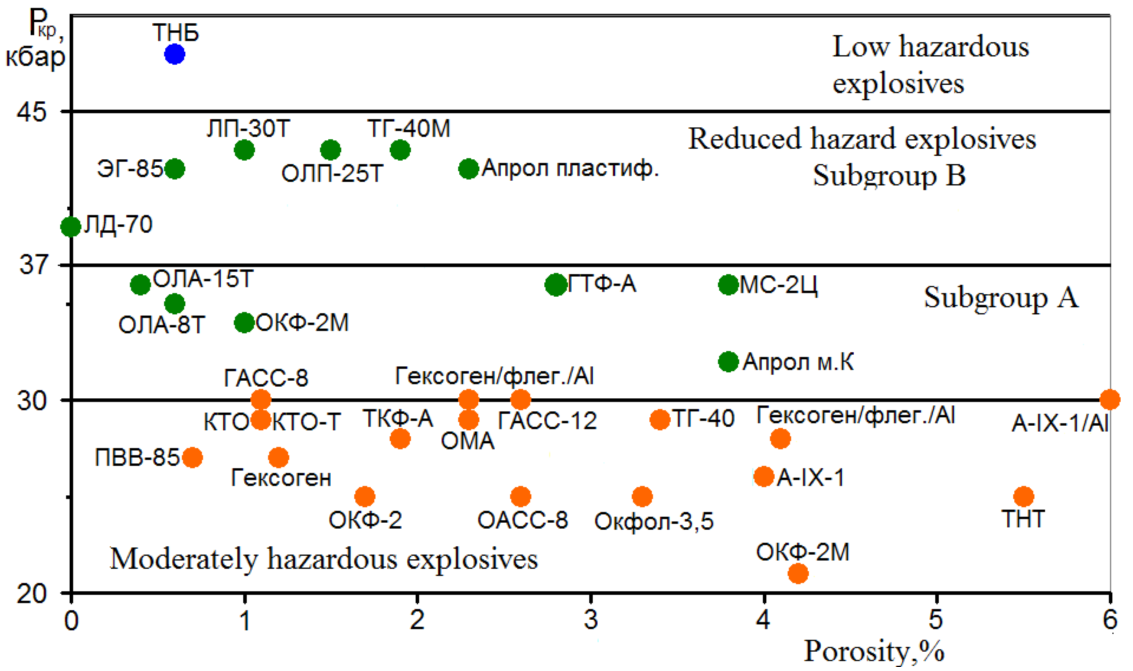


Figure 4. Classification diagram of explosives according to the degree of danger in shock-wave effects

The development of criteria and the proposal for the classification of explosives were carried out on the basis of statistical data that were obtained by the method of assessing the sensitivity to detonation effects by small-diameter charges and in determining the shock-wave sensitivity. This approach is necessary for developing independent and adequate criteria for specific types of effects. The independence of the approach is in processing of data only by one of the methods used by us. In the future it is planned to classify explosives for other test methods.

As a result, a system of criteria for specific types of effects should be obtained, which will make it possible to make a qualitative choice of explosives for solving the tasks posed.

Conclusion

1 The results of investigations of explosives sensitivity to detonation effects by small-diameter and shock-wave charges are summarized, and criteria for estimating their degree of danger are proposed.

2 According to the proposed criteria, the classification of explosives according to the degree of danger at detonation and shock wave effects was classified and divided into groups of danger: extremely hazardous, highly hazardous, moderately hazardous, reduced hazard and low hazardous.

3 In the future, it is planned to develop a system of criteria for assessing the degree of danger and for other types of effect (thermal, chemical, detonation, etc.). The classification and selection of explosives for usage should be based on a combination of all criteria in order to minimize the effect of subjective factors on the assessment of the danger degree.

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ПРЕДЛОЖЕНИЯ ПО ОЦЕНКЕ СТЕПЕНИ ОПАСНОСТИ ВЗРЫВЧАТЫХ ВЕЩЕСТВ И ИХ КЛАССИФИКАЦИЯ

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На практике степень опасности ВВ оценивается экспериментальными методами, которые в какой-то мере воспроизводят те или иные воздействия на ВВ. Применяется комплекс методов, который включает методы испытаний: термической стойкости, чувствительности к механическим и детонационным воздействиям и др. По легкости возбуждения или отсутствия взрыва проводят оценку относительной степени опасности ВВ.

В 1987 г. нами была предпринята попытка оценить степень опасности индивидуальных ВВ по бальной системе, учитывающей различные виды воздействия на ВВ. Определялся средний балл опасности ВВ без последующей классификации их по группам опасности. При этом было показано, что чувствительность ВВ к различным видам воздействия зависит не только от химического строения ВВ, но и от многих других факторов: дисперсности, пористости, температуры плавления, наличию оболочки и др. Поэтому, говоря о степени опасности ВВ, необходимо иметь ввиду чувствительность его к конкретному виду воздействия при определенном состоянии ВВ [1].

В 1992 г. профессором Б.Н. Кондриковым были предложены критерии оценки промышленных ВВ к различным видам воздействия и их классификация по степени опасности. Для оценки степени опасности ВВ выбраны в основном зарубежные методы (методы «Рекомендаций ООН» [2]). В России же есть множество отечественных методов оценки опасности ВВ, которые не