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Summary report of classification tests with fireworks

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Summary

This report describes the classification tests performed in the aftermath of the fireworks explosion in the city of Enschede, the Netherlands on May 13th, 2000. The details of the tests are meant to inform the UN Sub-Committee of Experts on the Transport of Dangerous Goods and its informal Working Group tasked with developing a system of default classification of fireworks.

The report will also be made available for the working group on Explosives, Propellants and Pyrotechnics (EPP) of the International Group of experts on the explosion risks of Unstable Substances (IGUS) of OECD and all other interested authorities.

This report supports the following default classifications:

- report shells of all sizes: 1.1G
- colour shells of diameter = 200 mm: 1.1G
- smaller colour shells: 1.3G
- Roman candles with a diameter = 50 mm: 1.2G
- Roman with a diameter of < 50 mm: 1.3G
- batteries with report as primary effect: 1.1G
- batteries with colour as primary effect, all sizes: 1.3G

Examples of classification of various other articles is given as well.

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1 Introduction

On May 13th, 2000 an explosion in a fireworks storage facility caused 22 fatalities, over 900 wounded and about €500,000,000 of material damage. Several extensive investigations have been conducted, one of which concentrated on the classification of the fireworks stored in the facility. The company had permission to store 159,000 kg of 1.4 fireworks or 147,000 kg 1.4 and 2000 kg of 1.3 fireworks in 4 designated storage cells.

Based on about 70 classification tests, it was found that a very large portion of the fireworks was wrongly classified. A substantial amount of the products has to be classified as 1.3, some Roman candles needs to be assigned to hazard class 1.2 and a number of products should even be assigned to class 1.1. Further investigations with fireworks from other storage facilities confirmed these conclusions.

Based on these findings, the Netherlands proposed to the UN Sub-Committee of Experts on the Transport of Dangerous Goods (SCETDG) to introduce a list of default classification of fireworks. The Sub-Committee agreed to establish an informal Working Group to develop the list under the following mandate:

- (a) Basic agreement on the interpretation of the test results of series 6 (a), 6 (b) and 6 (c);
- (b) Development of a classification system by default based on existing systems and proposals on how such a system could be introduced into the Recommendations.

The proposals from the Netherlands are largely based on the above mentioned classification tests. Since the original reports were to be used in legal procedures they could not be disclosed to the SCETDG. Even if the reports could be disclosed, they were written in the Dutch language.

This reports gives details of about 70 classification tests to inform the SCETDG and the members of the informal Working Group. Most tests were performed at the premises and with the assistance of the 'Bundesanstalt für Materialforschung und -prüfung' (BAM) in Germany.

Working Paper 13 (dated January 18, 2002) contains guidance on the information necessary for the Working Group, based on both the Model Regulations and the Manual of Tests and Criteria but recommends some additional information to better understand the occurring phenomena. The recommended information is included in this report.

Because of the limited amount of samples no full set of classification tests could be performed. In most cases no 6(a) tests and only one 6(b) test was carried out, instead of the prescribed triplicate tests. When a mass explosion is found in the 6(b) test, there is no need to perform the rest of the three tests. So, in case a mass explosion is found in tests described in this report, full compliance with the Manual exists.

2 Details of the test set up and chemical analysis

Wherever possible, the description of the UN Manual was followed. A couple of points should be mentioned here.

2.1 Orientation of packagings

It was found that in particular the Manual does not give guidance on how the orientation of the packagings should be. That was the reason that the orientation of the packagings was varied at various tests. In some cases the orientation has influence on the final result of the test, the competent authority should have insight in the construction and functioning of the articles under test and, based on this knowledge, should perform the test in the most severe orientation.

2.2 Witness plate in 6(a) and 6(b) test

The test description in the UN Manual states: "...The package is placed on a steel witness plate on the ground..." In the first series of tests, the steel witness plate was indeed placed flat on the ground (tests R8, C21, C23, C25, C27, C29, C30, V1 and V2). Particularly in test C29 and C30, a rather violent explosion occurred, leading only to a small local dent in the witness plate.

It was concluded that the velocity of the explosion is relatively low, leading to relatively low pressures. If the pressure is not high enough, the steel from the witness plate will not behave in a hydrodynamic way, so no hole will be punched in the plate. This conclusion is confirmed by test R4, where the report shells left the witness plate totally undamaged, but only slightly pressed in the ground.

This was the reason why the remaining tests (all of them 6(b) tests) were performed with wooden beams of about 5 cm under the edges of the plate. In this way, the force of the explosion may have the opportunity to deform the witness plate.

The fact that in the above mentioned nine tests no wooden beams were used under the witness plate, does not mean that the results and conclusions are not valid. In all cases, the other indications were unambiguous enough to draw conclusions. For instance, in test R8 26 unreacted articles were recovered, indicating that no mass explosion occurred (at the given confinement).

2.3 Indications to assess the results in the 6(a) and 6(b) test

The UN Manual states the following indications to assess a mass explosion:

“Evidence of such an indication includes:

- a crater at the test site;
- damage to the witness plate beneath the package;
- measurement of a blast; and
- disruption and scattering of the confining material.

for the 6(a) test, and for the 6(b) test:

- a crater at the test site appreciably larger than that given by a single package;
- damage to the witness plate beneath the stack which is appreciably greater than that from a single package;
- measurement of blast which significantly exceeds that from a single package; and
- violent disruption and scattering of most of the confining material.

It should be noted that the confinement in the 6(a) and 6(b) test was obtained by digging a hole of suitable size and depth in the ground and placing the witness plate on the bottom of that hole (on wooden beams). The package(s) were placed and the hole filled with earth again. In this way, if a crater occurs, it is formed by a different mechanism than when the test is performed at ground level, with boxes of earth in all directions to give the confinement. In a similar way as described for the (lack of) hydrodynamic behaviour of the witness plate, it can be explained why no crater would appear when the test is performed at the surface.

The results of the tests indicate that different articles gives different sizes of crater. The size of the crater is an indication of the force of the explosion (power to displace ground).

In most cases, no 6(a) test was performed, so comparison of the crater, damage to witness plate and blast to a single package is not possible.

Apart from the indication mentioned in the Manual, the number of explosions observed (in relation to the number of articles present) and recovered unreacted articles (if any) were taken into consideration as well.

In all cases, an electric match (squib) was used to initiate an article, the squib was attached to the fuse of the article.

2.4 Set up of the 6(c) test

The 6(c) test was performed according to the description in the UN Manual. The specified quality of aluminium witness screens is not available in Europe. It has been demonstrated experimentally, that the quality we did use has the same properties as the one mentioned in the Manual (this is: perforation at a kinetic energy of 20 J and an indentation of 4 mm with an energy of 8 J, al with the standard NATO fragment of 1.1 gram)

The experience in earlier tests was demonstrated that:

- reaction of all articles occurred within maximally 10 minutes after the start of the fire; and
- frequently, the reaction of the first article threw of a considerable part of the articles in test.

For that reason it was decided to use an amount of wood fitted for this reaction time, a stack of wood of 70 cm high.

Furthermore it was decided to use metal wire to strap the packagings to the test table to keep the packages together.

The air dried wood was put under the test table in layer perpendicular to the previous layer. The spacing between the beams is about a wide as the thickness of the wood ensuring enough air supply. Paper was used in the lower part of the stack to ensure a quick, even spread of the fire. (See photo.)



The fire was started at two opposing corners of the wood stack, using electric matches, tubular primers and black powder. Shortly before starting the fire, the wood stack was sprayed with petrol to enhance propagation of the fire. In this way, a very good development of the flames is obtained, resulting in a rapid, complete engulfment of the packages.

2.5 Chemical analysis

The samples taken from the fireworks were mainly analysed with X-ray diffraction and X-ray fluorescence techniques.

The former is capable of identifying crystalline compositions and only gives qualitative results. The latter method is capable of identifying chemical elements and can be used qualitatively and (semi-)quantitatively. The sample needs to be powdered and homogeneous and reference mixtures of known composition should be available.

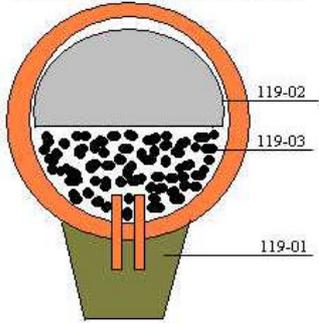
Both techniques are especially suitable for the analysis of inorganic compounds, but organic compounds can not be identified and measured. Most pyrotechnic mixtures contain organic compounds (as a binder or as fuel), from the X-ray techniques an impression of the amount of organic material (and elements with a low atomic number) was found. This is included in the tables as “rest”.

From the X-ray spectrum a reasonable impression can be obtained about the relative amounts of the compounds and thus of the composition. In a number of cases, this is less reliable, especially with coarse metal parts. This is the reason why the amount of titanium in the report shells is placed between brackets. In a number of cases, the composition of the flash powder was also determined by the selective extraction with different solvents. The agreement between the two methods was reasonable, but higher percentages of Ti and Fe were found in this way.

It should be noted that the analysis of the colour effects is mostly performed on only a part of one star (effect charge). The sample may therefore not be very representative for the entire charge. On the other hand, it is believed that the composition of the stars does not have much influence on the result of the classification tests. Further attention will be given to this in the discussion on colour shells (see the end of chapter 4).

3 Report shells

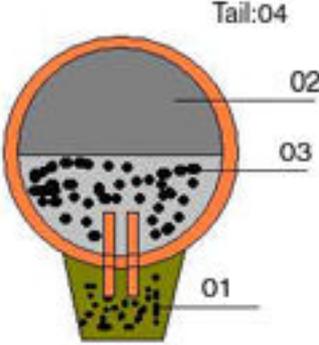
In total, eight tests have been performed with report shells: 5 6(b) tests and 3 6(c) tests. Although not performed for classification purposes, the information of two tests where packages of reports shells and colour shells are tested together is included as well in this chapter.

Test number:	R1; 6(b) test		C29-7		
Article name:	Titanium salute; report shell with a diameter of about 100 mm				
Construction of the article:	<p>Titanium salute Artikel nr. 42.200. JA008</p> 				
Mass and composition:		Explosive	mass (g)	composition	
	01	lift charge	53.2	black powder	
	02	break charge	72.0	Mg-Al SiO ₂ KClO ₄ rest (C/ binder)	1% 1% 66% 32%
	03	effect charge	157.4	Mg-Al S KClO ₄ Ti Fe rest	22% 13% 42% (5) coarse particle 3 15
Number of items in test:	3 fibreboard boxes, each with 9 fibre board inner boxes containing 4 articles: 108 articles in test				
Packaging:	4G/Y25/S/95 CN/1100/04				
Test arrangement:	the three boxes were placed in an "L-shape"; initiation at the article most central in the box (corner of the "L") by fuse of the lift charge with an electric match				
Observations:	<ul style="list-style-type: none"> - earth was thrown to a height of 50 metre - crater with diameter 6.2 m and depth of 2.1 m - witness plate dented - maximum pressure at 2 metre: 110 kPa; at 5 metre: 17 kPa ? mass explosion 				

Test number:	R2; 6(b) test		C29-12	
Article name:	Titanium salute; report shell with a diameter of about 75 mm			
Construction of the article:	See test number R1			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	26.1	black powder
	02	break charge	23.2	black/ grey powder on rice grains; contains: KClO ₄ , Mg, Si, Al, C
	03	effect charge	74.4	Mg-Al S KClO ₄ Ti Fe rest
Number of items in test:	three fibre board boxes; each containing 12 inner boxes with 6 articles; in total 216 articles in test			
Packaging:	4G/Y17/S/00 CN/4300 59 PI:063			
Test arrangement:	three boxes on top of each other, initiation in the middle box			
Observations:	<ul style="list-style-type: none"> - earth was thrown to a height of 60 metre - crater: diameter: 6.3 x 5.8 m; depth: 2 m - witness plate dented, deformed and torn - pressure at 5 m: 7kPa; at 10 m: 5 kPa ? mass explosion 			

Test number:	R3; 6(c) test	C29-13
Article name:	SEE TEST R2	
Construction of the article:		
Mass and composition:		
Number of items in test:		
Packaging:		
Test arrangement:		
Observations:	<ul style="list-style-type: none"> - first reaction observed after about 2 minutes - duration of the reactions: about 3 seconds - two distinct reactions (black powder lift charges); after regular delay time a mass explosion occurred - objects were thrown over 130 metre, fireball 20 m, witness screens and test table completely destroyed - one pressure peak 180 kPa; 5 ms @ 5m.; 60 kPa; 10 ms @ 10 m. ? mass explosion 	

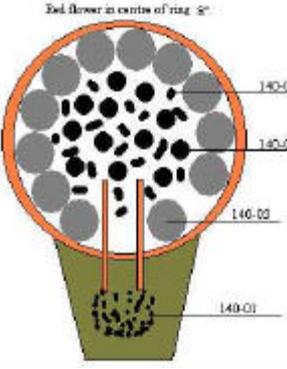
Test number:	R4; 6(b) test UNCONFINED	C29-20
Article name:	SEE TEST R1	
Construction of the article:		
Mass and composition:		
Number of items in test:		
Packaging:		
Test arrangement:		
Observations:	<ul style="list-style-type: none"> – after initiation five separate flashes, within 2 seconds one other flash, followed by a mass explosion – fireball about 20 metres – witness plate undamaged; slightly pressed into the ground – one pressure peak of 180 kPa @ 5m ? mass explosion 	

Test number:	R5; 6(b) test	C49-19			
Article name:	Titaniumsalut mit komet; report shell with a diameter of about 62 mm				
Construction of the article:					
Mass and composition:	Explosive	mass (g)	composition		
	01	lift charge	17.1	black powder	
	02	effect charge	27.6	Al-Mg S KClO ₄ Ti Fe ₂ O ₃ rest	33% 13% 38% 9% 3% 4%
	03	break charge	17.2	black powder	
	04	tail	6.0	KClO ₄ + Al-Mg + binder	
Number of items in test:	three boxes with each 50 articles without inner packaging; 150 articles involved in the test				
Packaging:	4G/Y15/S/99/D/BAM/3803-WPLA/80				
Test arrangement:	 <p>three boxes places on the side, initiation in the centre of the middle box</p>				
Observations:	<ul style="list-style-type: none"> - all reactions within 4 seconds, some functioning articles thrown to 35 metre - crater of 3.5 m diameter and 1.8 m deep - witness plate deformed (curved) ? mass explosion 				

Test number:	R6; 6(c) test	C49-20
Article name:	SEE TEST R5	
Construction of the article:		
Mass and composition:		
Number of items in test:		
Packaging:		
Test arrangement:	similar to test R2	
Observations:	<ul style="list-style-type: none"> – first reaction about 2 minutes after ignition of the fire – duration of the reactions: 11 seconds – projections up to 63 metres – it seemed that the reaction occurred one box at a time ? borderline yes or no mass explosion 	

Test number:	R7; 6(b) test	C49-21		
Article name:	Titanium salute 2.5; report shell with a diameter of about 62 mm			
Construction of the article:	similar to R5, without tail			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	19.1	black powder
	02	break charge	11.9	black powder
	03	effect charge	29.7	Al-Mg S KClO ₄ Ti Fe ₂ O ₃ rest
Number of items in test:	four fibreboard boxes; each with 12 inner packages containing 8 articles; in total 384 articles involved in test			
Packaging:	4G/Y15/S/98 CN/430043 PI:058			
Test arrangement:	three boxes placed on the side, one box flat on top of that; initiation in the centre of the bottom middle box			
Observations:	<ul style="list-style-type: none"> – crater 2.5 m diameter and 1.4 m deep – many individual reactions observed during 20 seconds – about 80 unreacted articles recovered around the crater (whole box?) – witness plate curved over the surface 			
				

Test number:	R8; 6(c) test	C121-2	
Article name:	Titanium report with whistle; cylinder report shell with a diameter of about 75 mm		
Construction of the article:			
Mass and composition:	Explosive	mass (g)	composition
	01 lift charge	38.4	black powder
	02 break and effect charge	49.8	11% Al, 3% SiO ₂ , 4% S, 57% KClO ₄ , 5% Ti, 2% Fe, 18% rest
	03 whistle	7.2	59% KClO ₄ , 12% KC ₈ H ₅ O ₄ , 39% rest
	04 inert plug		
Number of items in test:	three fibreboard boxes with each 60 articles		
Packaging:	UN 4G/Y/20/S/00/CN/4400/XFY		
Test arrangement:	similar to test R3		
Observations:	<ul style="list-style-type: none"> - 17 unreacted articles recovered at distances of 10 metre form the test table - large number of indentations in witness screens to a depth of 28 mm - video shows individual and multiple explosions with increasing intensity and frequency, due to lack of confinement (?) no acceleration to mass explosion - also test in 6(a) test: witness plate not dented (flat on the ground); 26 items recovered; several pressure peaks 		

Test number:	Mix9; 6(b) test	C29-15		
Article name:	(a) one box titanium salute report shell with a diameter of about 100 mm (see test R1 for further details) (b) two boxes of Red Flower in Centre of Ring; colour shell with a diameter of about 200 mm. (see below for further details)			
Construction of the article:				
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	193.8	black powder
	02	break charge	642.7	contains Al, Mg, SiO ₂ , KClO ₄ , C
	03	effect charge	1407.7	Mg-Al 11% S 7% KClO ₄ 20% KNO ₃ 10% CuO 1% Ba(NO ₃) ₂ 19% rest 32
	04	effects	257.1	16% Mg-Al, 7% S, 34% KClO ₄ , 8% KNO ₃ , 32% rest
Number of items in test:	each box contains four inner packagings with one article; in total 8 colour shells and 36 report shells involved in the test.			
Packaging:	(a) 4G/Y17/S/00 CN/4300 59 34 (b) 4G/Y30/S/99 CN/3724 01 T020			
Test arrangement:	L-shaped, report shells in corner of "L", initiation in the centre of box with report shells			
Observations:	<ul style="list-style-type: none"> - earth was thrown to a height of 70 metre - one explosion observed on videos - crater with diameter 5.5 m and 2 m depth - witness plate dented and curved - projections thrown to a distance of 110 metre - three pressure peaks: after 50 ms (40 kPa); 100 ms (10 kPa) and after 620 ms (80kPa) ? mass explosion 			

Test number:	Mix10; 6(c) test	C29-18
Article name:	(a) one box of titanium salutes with a diameter of about 100 mm (b) one box of Assorted China shells (about 62 mm) (c) one box of Brocade Purple (about 150 mm) (d) one box of Assorted China shells (about 100 mm) (used in earlier test, thrown up during a 6(b) test; was recovered with content totally unaffected, fibreboard was somewhat scorched)	
Test arrangement:	 <p>bottom row: left: report shells; right: 62 mm shells top row: left: 150 mm shells; right: 100 mm shells</p>	
Observations:	<ul style="list-style-type: none"> – individual explosions observed at right hand side of the stack (probably from the 100 mm shells; fibreboard was already scorched, catches flames earlier) after about two minutes; after 16 seconds a mass explosion took place – fire was extinct after explosion, witness screens destroyed, wood fragmented – projections up to 75 m, fireball with a diameter of 28 metres ? mass explosion 	

3.1 Discussion on results of tests with report shells

- Most of the tested report shell give a mass explosion, even without confinement (see R3 and R4). There are indications that smaller sizes may need confinement (see R6). Following the normal sequence of Test Series 6 will lead to the correct classification (given the remarks in Chapter on performing the 6(b) test).
- It has been demonstrated that combinations of report (1.1) and colour shells (1.3) reacts as 1.1 (see RC8 and RC9). Transport (and storage) rules already took this as a starting point, but it is good to have if confirmed experimentally.
- Most of the current report shells will have a similar composition and comparable amounts of flash powder, for a given size. The smallest shell tested here, was 62 mm diameter, but the UK has tested 50 mm report shells and also found mass explosive behaviour. The 62 mm shells contain about 30 gram of flash powder, the estimation for a 50 mm is about 15 gram. Shells, smaller than 50 mm are hardly ever user, if they exist at all.
- The result of the cylinder report shell, indicated that the shell may need confinement to give a mass explosion, but no 6(b) could be performed to confirm that.

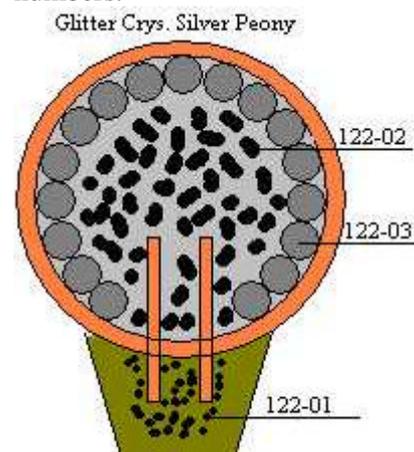
Based on the results and the discussion above, it can be concluded that report shells should be classified as 1.1G in the default system.

4 Colour shells

In total 30 tests were performed with colour shells; 4 times the 6(a) test, 14 times the 6(b) test and 12 times the 6(c) test.

In an attempt to explain, or even predict, mass explosion behaviour of the colour shells several comparisons have been tried, some of them are included in this report. Such comparisons are particularly useful for explaining and predicting 1.3 behaviour.

Given the products that the company involved purchased and sold, the nature and construction of the colour shells are mainly similar. However, in a few cases some different types of shells are tested as well, like smoke shells and 'shell of shells'. The largest part of the products were constructed as spheres made from paper and cardboard. At the bottom a lift charge, in all cases consisting of black powder, was attached to the bottom of the sphere or cylinder. The lift charge also ignites two delay fuses, the fuses lead to the centre of the sphere giving central initiation of the break charge. Bare colour stars are located along the inner circumference of the sphere, the inner part is filled with the break (or burst) charge, usually consisting of rice grain or rice husk coated with an explosive powder. Since the power of the break charge may be of influence on the reaction in the classification tests, an indication of the composition of the break charge will be given in the following tables when available, together with the mass of the various explosive components. A typical construction of the colour shells is given in the following figure, where the number 01 represents the lift charge; 02 the break charge (burst) and 03 the effect charge. In some cases, the inner contents of the sphere contains extra effects, or a tail or whistle is present. These energetic materials are indicated with separate numbers.



Test number:	C1; 6(c) test	C29-5	
Article name:	Red to Green and Crackling Stars; colour shells; diameter of about 100 mm		
Construction of the article:	typical		
Mass and composition:	Explosive	mass (g)	composition
	01 lift charge	36.5	black powder
	02 break charge	81.2	contains KClO_4
	03 effect charge	201.3	contains KClO_4 , Mg-Al alloy, $\text{Ba}(\text{NO}_3)_2$ and SrCO_3
	04 crackling	81.2	contains KNO_3 ; Pb_3O_4 and CuO
Number of items in test:	three boxes containing 36 articles separated by cardboard dividers		
Packaging:	4G/Y30/S/2000 CN 360011		
Test arrangement:	 <p>two boxes next to each other, one box placed centrally on top</p>		
Observations:	<ul style="list-style-type: none"> - reactions starts after 3.5 minutes with a duration of about 22 seconds - three individual fireballs are observed; seven separate explosions could be seen from the video - projections are thrown to a distance of 55 metre - witness screen dented to a depth of 35 mm 		

Test number:	C2; 6(c) test			C29-6
Article name:	Red Bees Comet with Report; colour shells of about 150 mm diameter			
Construction of the article:	typical			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	97.8	black powder
	02	break charge	233.0	black powder
	03	effect charge	486.3	63 tubes containing 215 g explosive
Number of items in test:	four boxes each containing 9 articles; in total 36 items per test			
Packaging:	4G/Y30/S/2000 CN 360011			
Test arrangement:	two rows of two boxes			
Observations:	<ul style="list-style-type: none"> – reactions started about 1.5 minutes after start of the fire and lasted for 25 seconds – projections up to 36 meters – very dense smoke development, obscuring most reactions 			

Test number:	C3; 6(b) test			C29-8
Article name:	Red Flower in Centre of Ring; colour shells of 250 mm diameter			
Construction of the article:	typical			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	391.2	black powder
	02	break charge	1847.5	contains KClO_4 , KNO_3 and C; traces of Mg, Al, S, Si and Na
	03	effect charge	2578.1	
Number of items in test:	three boxes with each two articles; six articles in total			
Packaging:	4G/Y30/S/99 CN/3724 01 P009			
Test arrangement:	“L-shaped” ignition in corner of the “L”			
Observations:	<ul style="list-style-type: none"> – earth thrown to a height of 25 metre – projections over more than 40 metre – witness plate dented – three separate explosions observed ? mass explosion 			

Test number:	C4; 6(c) test			C29-9
Article name:	Red Flower in Centre of Ring			
Construction of the article:	typical			
Mass and composition:	SEE TEST NUMBER C3			
Number of items in test:				
Packaging:				
Test arrangement:	see test C1			
Observations:	<ul style="list-style-type: none"> – reactions started after about 1.5 minutes and lasted for 23 seconds – three to four individual explosions observed – projection of burning material to a distance of about 150 metre 			

Test number:	C5; 6(b) test		C29-10	
Article name:	Brocade Purple Chrysanthemum; colour shell of about 150 mm diameter			
Construction of the article:	typical			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	NOT DETERMINED	
	02	break charge		
	03	effect charge		
Number of items in test:	Three boxes with each nine articles, separated with cardboard dividers; 27 articles per test			
Packaging:	4G/Y30/S/2000 CN 360011			
Test arrangement:	three boxes on top of each other, initiation in the centre of middle box			
Observations:	<ul style="list-style-type: none"> - six individual explosions observed, two non reacted articles recovered at 6 and 15 metre - witness plate not damaged 			

Test number:	C6; (6b) test		C29-14	
Article name:	China Assorted Shells; two boxes of colour shells with diameter 100 mm and one box with colour shells of diameter 75 mm			
Construction of the article:	typical			
Mass and composition:	NOT DETERMINED			
Number of items in test:	two fibreboard boxes with nine inner packagings containing 6 articles and one box with 12 inner packagings containing 6 articles; in total 180 articles			
Packaging:	4G/Y25/S/95 CN/1100/04			
Test arrangement:	two boxes with 100 mm shells on top of each other; the box with 75 mm shells placed next to the stack on its side			
Observations:	<ul style="list-style-type: none"> - the entire top box with 100 mm shells was thrown out (contents totally unaffected, fibreboard scorched), 11 extra 100 mm shells recovered - witness plate undamaged - not enough confinement? 			

Test number:	C7; 6(c) test		C29-16	
Article name:	Chrysanthemum shells; red, green and blue; colour shell with a diameter of 75 mm			
Construction of the article:	typical			
Mass and composition (blue chrysanthemum):		Explosive	mass (g)	composition
	01	lift charge	27.0	black powder
	02	break charge	18.0	contains KClO ₄ , Mg, Al and C
	03	effect charge	71.8	7% S, 22% KClO ₄ , 29% KNO ₃ , 5% CuO, 36% rest
Number of items in test:	three fibreboard boxes, each containing 12 inner packagings with 6 articles; in total 216 articles involved			
Packaging:	4G/Y18/S/00 CN/4300 81 PI:001			
Test arrangement:	see test C1			
Observations:	<ul style="list-style-type: none"> - first reactions after 2.5 minutes, duration about 1.5 minutes - projections of burning material up to a distance of 45 metre 			

Test number:	C8; 6(c) test		C29-17	
Article name:	Silver Palm with Silver Tail; colour shells with a diameter of about 200 mm			
Construction of the article:	typical, with tail effect on top of the sphere			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	205.2	black powder
	02	break charge	1503.4	contains KClO ₄ , Mg, Al and C
	03	effect charge	494.8	11% Mg, 2% Al, 7% S, 1% KClO ₄ , 47% KNO ₃ , 12% Ba(NO ₃) ₂ , 21% rest
	04	tail	57.3	26% Mg-Al, 4% S, 1% Al, 12% KNO ₃ , 24% Ba(NO ₃) ₂ , 32% rest
Number of items in test:	three boxes, each containing 4 articles separated by fibreboard dividers; 12 articles involved in the test			
Packaging:	4G/Y30/S/99 CN 3724 01n PI:020			
Test arrangement:	boxes placed in “L-shape”, initiation in corner of the “L”			
Observations:	<ul style="list-style-type: none"> – two explosions are observed – projections thrown over more than 85 metre – witness plate dented – crater of 3.2 m diameter, 1.5 m deep ? mass explosion 			

Test number:	C9; 6(b) test		C29-19	
Article name:	Brocade Crown; colour shell with a diameter of about 300 mm			
Construction of the article:	typical			
Mass and composition:		Explosive	mass (g)	composition
	01	lift charge	579	black powder
	02	break charge	3566	contains KClO ₄ , Mg, Al and C
	03	effect charge	3286	contains Al, S, KClO ₄ , KNO ₃ , Ti, Fe
Number of items in test:	three boxes containing 2 articles; six articles involved in the test			
Packaging:	4G/Y30/S/99 CN/3724/01 PI:054			
Test arrangement:	boxes placed in “L-shape”, initiation in corner of “L”			
Observations:	<ul style="list-style-type: none"> – three individual explosions observed – witness plate not damaged – small crater ? no mass explosion 			

Test number:	C10; 6(c) test		C49-2
Article name:	Purple Peony; Red Ring; Green Ring; Green Peony: colour shells with diameter of about 75 mm		
Construction of the article:	typical		
Mass and composition:	NOT DETERMINED		
Number of items in test:	four boxes, each containing 12 inner packagings with 6 articles; 288 articles involved in the test		
Packaging:	4G/Y30/S/99 CN 360026		
Test arrangement:	two rows of two boxes		
Observations:	<ul style="list-style-type: none"> – first reaction after about five minutes, duration about 1 minute – projection of burning material up to 38 metres 		

Test number:	C11; 6(c) test	C49-4
Article name:	Shell in mortar; tube dimensions: length 400 mm; outer diameter 84 mm; inner diameter 75 mm	
Construction of the article:	fibreboard tube with typical colour shell	
Mass and composition:	NOT DETERMINED	
Number of items in test:	four boxes with each 16 tubes; in total 64 articles in test	
Packaging:	4G/Y14/S/99 CN/4300 42 PI:348	
Test arrangement:	boxes placed on the side (to hit witness screens), two rows of two boxes	
Observations:	<ul style="list-style-type: none"> – reactions start 1.5 minute after start of the fire, duration 1.5 minute – at first, projections mainly hit the witness screens, later on thrown over the screens to a distance of about 65 metres – witness plates dented, depth mainly 35 – 40 mm, maximum 43 mm; no perforation – six unreacted articles recovered 	

Test number:	C12; 6(b) test	C49-9																	
Article name:	Assorted 8” shells; colour shells with a diameter of about 200 mm (Red Crosette, Butterfly with Glittering Silver, Crackling Gold Palm, Golden Wave to Purple)																		
Construction of the article:																			
Mass and composition:	<table border="1"> <thead> <tr> <th></th> <th>Explosive</th> <th>mass (g)</th> <th>composition</th> </tr> </thead> <tbody> <tr> <td>01</td> <td>lift charge</td> <td>176.6</td> <td rowspan="4">NOT DETERMINED</td> </tr> <tr> <td>02</td> <td>break charge</td> <td>712.3</td> </tr> <tr> <td>03</td> <td>crosette (82)</td> <td>768.7 (gross)</td> </tr> <tr> <td>04</td> <td>effect charge</td> <td>4.2 (per item)</td> </tr> </tbody> </table>		Explosive	mass (g)	composition	01	lift charge	176.6	NOT DETERMINED	02	break charge	712.3	03	crosette (82)	768.7 (gross)	04	effect charge	4.2 (per item)	
	Explosive	mass (g)	composition																
01	lift charge	176.6	NOT DETERMINED																
02	break charge	712.3																	
03	crosette (82)	768.7 (gross)																	
04	effect charge	4.2 (per item)																	
Number of items in test:	four boxes, each containing four articles, plastic bags as inner packaging; 16 articles involved in test																		
Packaging:	4G/X14/S/99 CN/3300201 PI:010																		
Test arrangement:	three boxes placed on the side, one box on top of the middle box; initiation in the middle box (Red Crosette)																		
Observations:	<ul style="list-style-type: none"> – projections up to 40 metre – three separate explosions observed within about 8 seconds – crater 2.9 m diameter and 1 m deep – witness plate dented ? mass explosion 																		

Test number:	C13; 6(b) test		C49-13
Article name:	Assorted 8" shells; colour shells with a diameter of about 200 mm (Red Crackling Fish; Silver Crackling Fish; Green Palm Crosette Silver; Glitter Palm Crosette Silver)		
Construction of the article:	typical		
Mass and composition:		Explosive	mass (g)
	01	lift charge	170.3
	02	break charge	589.7
	03	effect charge	1777.3 (gross, 61 pcs)
	NOT DETERMINED		
Number of items in test:	four boxes, each containing four inner packagings with one article; in total 16 articles per test		
Packaging:	4G/Y22/S/99 CN/4300 78 PI:016		
Test arrangement:	as in C12		
Observations:	 <ul style="list-style-type: none"> - one explosion observed - projections up to 50 metre - crater 3.5 m diameter, 1.7 m deep - witness plate deformed ? mass explosion 		

Test number:	C14 ; 6(b) test		C49-13
Article name:	Golden Willow; colour shell with a diameter of about 200 mm		
Construction of the article:	typical		
Mass and composition:		Explosive	mass (g)
	01	lift charge	200.7
	02	break charge	631.9
	03	effect charge	1139.5
	NOT DETERMINED		
Number of items in test:	four boxes, each containing four inner packagings with one article; in total 16 articles per test		
Packaging:	4G/Y20/S/98 CN/4300 03 PI:146		
Test arrangement:	boxes placed on the side, three in a row, one box placed next to the row		
Observations:	<ul style="list-style-type: none"> - seven explosions observed - projections up to 63 metre - crater 2.4 m diameter and 1 m deep - witness plate deformed 		

Test number:	C15 ; 6(c) test		C49-14
Article name:	Purple Wave + Golden Heart + 5 Reports		
Construction of the article:	cylinder shell with a diameter of 96 mm, combined colour and report effect		
Mass and composition:		Explosive	mass (g) composition
	01	lift charge	NOT DETERMINED
	02	break charge	
	03	effect charge	
Number of items in test:	four boxes, each containing six inner packagings with four articles; in total 96 articles in test		
Packaging:	4G/Y26/S/99/CN/4400/XFJ		
Test arrangement:	two rows of two boxes		
Observations:	<ul style="list-style-type: none"> - first reaction after two minutes, duration about 40 seconds, reactions rather frequent and violent - two boxes fell of the test table, reacted much later - projections up to 65 metre - witness plate dented in some places - twelve unreacted articles recovered 		

Test number:	C16 ; 6(b) test		C49-15
Article name:	3 Times Colour Changing Peony, Japanese Assortment; colour shells with a diameter of about 250 mm		
Construction of the article:	typical		
Mass and composition:		Explosive	mass (g) composition
	01	lift charge	NOT DETERMINED
	02	break charge	
	03	effect charge	
Number of items in test:	four boxes, each containing two articles separated by a piece of fibreboard		
Packaging:	4G/X18/S/2000 CN/330230		
Test arrangement:	boxes placed on the side, two rows of two boxes		
Observations:	<ul style="list-style-type: none"> - earth is thrown to a height of 50 metre - burning parts thrown to a distance of 50 metre - three explosions observed - crater 5.2 m diameter and a depth of 2.5 m - witness plate deformed ? mass explosion 		

Test number:	C17 ; 6(c) test		C49-16
Article name:	Mother and Son		
Construction of the article:	cylinder shell with a diameter of about 125 mm diameter		
Mass and composition:		Explosive	mass (g) composition
	01	lift charge	NOT DETERMINED
	02	break charge	
	03	effect charge	
Number of items in test:	four boxes boxes, each containing four inner packagings with six articles; 96 articles involved in test		
Packaging:	4G/Y35/S/99/CN/44/XFJ		
Test arrangement:	two rows of two boxes		
Observations:	<ul style="list-style-type: none"> - reactions started two minutes after ignition of the fire, duration about 30 seconds, reactions rather frequent and violent - projections up to 42 metre - fire extinct by the explosions - witness screens heavily dented - one unreacted article recovered 		

Test number:	C18 ; 6(b) test		C49-17
Article name:	Assorted Thousand Effects; colour shell with a diameter of about 300 mm		
Construction of the article:	typical		
Mass and composition:		Explosive	mass (g) composition
	01	lift charge	NOT DETERMINED
	02	break charge	
	03	effect charge	
Number of items in test:	four boxes, each containing two articles separated by a piece of fibreboard		
Packaging:	4G/Y30/S/99 CN/3600 26		
Test arrangement:	two rows of two boxes		
Observations:	<ul style="list-style-type: none"> - three explosions observed within 10 seconds - projection of burning material up to 50 metre - crater with diameter 4 m and depth of 1.8 m - witness plate deformed on one place - two articles recovered at a distance of 100 metre (without lift charge) 		

Test number:	C19 ; 6(b) test		C49-23
Article name:	Two Stages Crosette; colour shell with a diameter of about 300 mm		
Construction of the article:	typical		
Mass and composition:		Explosive	mass (g) composition
	01	lift charge	NOT DETERMINED
	02	break charge	
	03	effect charge	
Number of items in test:	four boxes, each containing two articles		
Packaging:	4G/Y23/S/99 CN/4300 42 PI:349		
Test arrangement:	as in test C18		
Observations:	<ul style="list-style-type: none"> - crater 3.9 m diameter and 2 m deep - witness plate deformed ? mass explosion 		

Test number:	C20 ; 6(b) test	C49-25	
Article name:	Golden Willow (one box)/ Green to Crackling (two boxes); colour shells with a diameter of about 300 mm		
Construction of the article:	typical		
Mass and composition:	Explosive	mass (g)	composition NOT DETERMINED
	01 lift charge	466.5	
	02 break charge	3434	
	03 effect charge	3361	
Number of items in test:	three boxes, each containing two inner packagings with one article; six articles in total		
Packaging:	4G/Y35/S/99/CN/4400/XFJ		
Test arrangement:	boxes placed in "L-shape", initiation in the Golden Willow (corner of the "L")		
Observations:	<ul style="list-style-type: none"> - earth thrown to a height of 50 metre - one explosion observed - considerable ground shock - crater 6 m diameter, 3.2 m deep - witness plate deformed, especially where the Golden Willow was ? mass explosion 		

Test number:	C21 ; 6(a) test	C121-4
Article name:	Brocade Silver with Crackling Pistil	
Construction of the article:	typical	
Number of items in test:	36 articles per box	
Packaging:	4G/Y30/S/99/CN/3724 01 PI:019	
Test arrangement:	central initiation	
Observations:	<ul style="list-style-type: none"> - 9 unreacted articles recovered - witness plate not dented (flat on the ground) 	

Test number:	C22 ; 6(c) test	C121-4
Article name:	Brocade Silver with Crackling Pistil	
Construction of the article:	typical	
Number of items in test:	36 articles per box	
Packaging:	4G/Y30/S/99/CN/3724 01 PI:019	
Test arrangement:	two boxes at bottom, one box placed centrally on top	
Observations:	<ul style="list-style-type: none"> - individual explosions observed - 5 unreacted articles recovered - projections up to 30 metre 	

Test number:	C23 ; 6(a) test	C121-5
Article name:	Red peony Shell of Shells	
Construction of the article:	typical; in stead of bare stars, small shells give the effects; colour shell with a diameter of about 200 mm	
Number of items in test:	four articles per box	
Packaging:	4G/Y30/S/99/CN/3724 01 PI:020	
Test arrangement:	central initiation	
Observations:	<ul style="list-style-type: none"> – all articles have functioned – large number of individual explosions observed – witness plate undamaged (flat on the ground) 	

Test number:	C24 ; 6(c) test	C121-5
Article name:	Red peony Shell of Shells	
Construction of the article:	typical; in stead of bare stars, small shells give the effects; colour shell with a diameter of about 200 mm	
Number of items in test:	four articles per box	
Packaging:	4G/Y30/S/99/CN/3724 01 PI:020	
Test arrangement:	as in C22	
Observations:	<ul style="list-style-type: none"> – burning projections thrown over more than 100 metre – individual explosions observed 	

Test number:	C25 ; 6(a) test	C121-6
Article name:	Red peony with Coconut Pistil; colour shell with diameter of about 200 mm	
Construction of the article:	typical	
Number of items in test:	six articles per box	
Packaging:	fibreboard box (UN marking lost)	
Test arrangement:	central initiation	
Observations:	<ul style="list-style-type: none"> – all articles have functioned – peak pressure at 1 metre: 31 kPa – witness plate not dented (flat on the ground) 	

Test number:	C26 ; 6(c) test	C121-6
Article name:	Red peony with Coconut Pistil; colour shell with diameter of about 200 mm	
Construction of the article:	typical	
Number of items in test:	six articles per box, in total 18 articles	
Packaging:	fibreboard box (UN marking lost)	
Test arrangement:	as in test C22	
Observations:	<ul style="list-style-type: none"> – peak pressure at 4 metre: 23.5 kPa – slight dents in witness screens – eight individual explosions observed, with decreasing time interval – projections of burning material up to 100 metre 	

Test number:	C27 ; 6(a) test	C121-7
Article name:	Red Peony Shell of Shells; colour shell with a diameter of about 300 mm	
Construction of the article:	typical for shell of shells	
Number of items in test:	two articles per box	
Packaging:	UN 4G/Y30/99/CN/3724 01 PI:054	
Test arrangement:	one article initiated	
Observations:	<ul style="list-style-type: none"> – peak pressure at 1 metre: 32 kPa – two pressure peaks with a time interval of 393 ms measured 	

Test number:	C28 ; 6(c) test	C121-7
Article name:	Red Peony Shell of Shells; colour shell with a diameter of about 300 mm	
Construction of the article:	typical for shell of shells	
Number of items in test:	two articles per box; three boxes in test; six articles in test	
Packaging:	UN 4G/Y30/99/CN/3724 01 PI:054	
Test arrangement:	as in test C22	
Observations:	<ul style="list-style-type: none"> – all articles reacted – witness screens dented to a depth of 34 mm – projections of burning material up to 150 metre 	

Test number:	C29 ; 6(b) test	C121-7
Article name:	Red Peony Shell of Shells; colour shell with a diameter of about 300 mm	
Construction of the article:	typical for shell of shells	
Number of items in test:	two articles per box; three boxes in test; six articles in test	
Packaging:	UN 4G/Y30/99/CN/3724 01 PI:054	
Test arrangement:	boxes placed in “L-shape”, initiation in corner of “L”	
Observations:	<ul style="list-style-type: none"> – crater with a diameter of 4.5 m and depth 1.5 m – witness plated slightly dented (flat on the ground) ? mass explosion 	

Test number:	C30 ; 6(b) test	C121-8
Article name:	Red Flower in Centre of Ring; colour shell with a diameter of 300 mm	
Construction of the article:	typical	
Number of items in test:	two articles per box, three boxes in test; six articles in total	
Packaging:	UN 4G/Y30/99/CN/3724 01 PI:054	
Test arrangement:	boxes placed in “L-shape”, initiation in corner of “L”	
Observations:	<ul style="list-style-type: none"> – crater with a diameter of 5 m and depth 1.8 m – witness plated slightly dented (flat on the ground) – ? mass explosion 	

4.1 Discussion on results of tests with colour shells

- It has been demonstrated experimentally that colour shells of 200 mm and larger given a mass explosion in many cases.
- The ignition method may have influence on the test results. As stated in chapter 2, all articles are initiated by their own means of ignition, the fuse. Ignition of the fuse leads to deflagration of the lift charge, which forms a large amount of gas. From the videos it can be seen that the typical white smoke from the black powder erupts from the ground. It may be the case that, in some cases, this amount of gas also projects the ignited and other articles. The relative orientation of the fuses and the lift charges will also play a role.

Given the relatively small amount of articles, one or two projected articles will have a large influence. In a “normal” accident situation projection of articles will occur as well, but a large number of unreacted, unaffected articles will remain. Although not confirmed experimentally, it is believed that when one shell bursts amidst other shells, the shock will be of sufficient strength to cause shock initiation in the other shells.

One way of checking this assumption is to perform classification tests with ignition of the donor charge at the delay fuses of the shells and not at the normal fuse.

- Smaller shells will have a 1.3G classification based on the projection of burning material. The exact size of shells where a 1.1 classification is no longer appropriate has not been established accurately. Only one 6(b) test with a 150 mm shell has been performed and no 6(b) tests with 175 mm shells. In any case, shells not found to have mass explosion properties will have to be classified in hazard division 1.3G because the effect stars will be projected over a distance larger than 15 metre. The amount of break charge and the mass of the effect stars determine the distance over which the stars are projected, together with the burst strength of the fibreboard sphere. In the following table, the amount of break charge and effect charge is listed, also for firework articles which have not been subjected to classification tests.

Article	Mass of explosive (g)			mass ratio of the effect and the break charge
	projection distance (m)	break charge	effect charge	
Glitter Chrysanthemum Silver Peony (75 mm)		22.73	82.0	3.6
Purple to Green Peony (75 mm)		23.67	80.3	3.4
Blue Chrysanthemum (75 mm)	45	17.96	71.8	4.0
Green Chrysanthemum (75 mm)	45	21.06	70.4	3.3
Coconut with Tail (75 mm)		50.18	45.2	0.9
Purple Peony (100 mm)		88.52	186.7	2.1
Purple to Gold Peony (100 mm)		78.65	191.8	2.4
Gold Palm (100 mm)		136.6	66.6	0.5
Red to Green & Crackling Star (100 mm)	55	81.21	227.6	2.8
Red Bees Comet with report (150 mm)	36	233.04	486.3	2.1
Red smoke (150 mm)		235.1	790.4	3.4

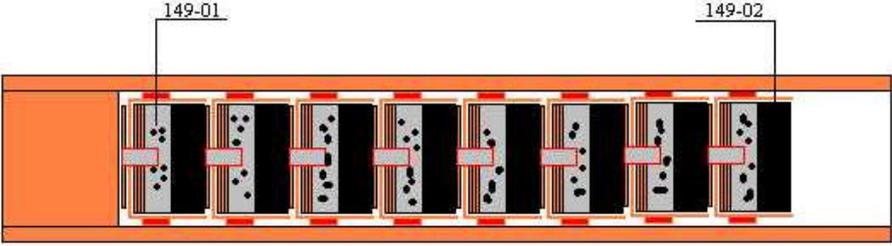
- From the table, it appears that the maximum ratio of amount of break charge and effect charge is 4.0. (This means that each gram of break charge has to propel 4 grams of effect charge.) In a classification test burning material was projected 45 metres. Although other factors like (aerodynamic) shape of the effect stars and the mass of an individual star will play a role too, this will not cut back the projection distance by a factor of three. This leads to the conclusion that all colour stars (when not mass explosive) will need to be classified in hazard division 1.3G.

5 Roman candles

In total, six tests have been performed with Roman candles: one 6(a) test and five 6(c) tests. The reaction of an initiated Roman candle hardly communicates the adjacent articles, because of the strong directional effect. After the first 6(a) test, it was decided not to perform any other 6(a) or 6(b) tests. It should be noted, however, that no tests have been performed on Roman candles with report as primary effect.

Test number:	RC1; 6(a) test		C121-1	
Article name:	Brocade Crown, 6 shot roman candle with an inner diameter of about 75 mm			
Construction of the article:	typical, see RC-3			
Mass and composition:		Explosive	mass (g)	composition
	01	expelling charge	NOT DETERMINED	
	02	effect charge		
Number of items in test:	six articles in one box			
Packaging:	4G/Y30/S/2000/CN/360011			
Test arrangement:	initiation in the centre article			
Observations:	<ul style="list-style-type: none"> - only the initiated article functioned, the other five were unaffected - no communication of reaction 			

Test number:	RC2; 6(c) test		C121-1	
Article name:	typical, see RC-3			
Construction of the article:				
Mass and composition:		Explosive	mass (g)	composition
	01	expelling charge	NOT DETERMINED	
	02	effect charge		
Number of items in test:	six articles in one box			
Packaging:	4G/Y30/S/2000/CN/360011			
Test arrangement:	two boxes next to each other, one box centrally on top; articles aimed at the left and right witness screens			
Observations:	<ul style="list-style-type: none"> - indentation of witness screens to a depth of 30 mm - projection of burning parts to a distance of much more than 35 metre (hindered by the witness screens, not visible on video) 			

Test number:	RC3; 6(c) test	C29-11		
Article name:	Crackling Tail, 8 shots roman candle with an outer diameter of about 50 mm			
Construction of the article:				
Mass and composition:	Explosive	mass (g)	composition	
	01	expelling charge	78.4	black powder
	02	effect charge	436.4	51% KNO ₃ , 8% Pb ₃ O ₄ , 6% S, 4% Mg-Al, 6% CuO; 24% rest
Number of items in test:	three boxes, each containing 12 articles; 36 articles in total			
Packaging:	4G/Y30/S/99 CN 360011			
Test arrangement:	two boxes next to each other, one box centrally on top; articles aimed at the left and right witness screens			
Observations:	<ul style="list-style-type: none"> - first reactions after about 1.5 minute, duration about 2.5 minutes - projection of burning material up to 140 metre - witness screens perforated on about ten places, one big hole with a diameter of about 20 cm 			



Hole caused by the Roman candle Crackling Tail

Test number:	RC4; 6(c) test		C49-10	
Article name:	Cracker Tail, roman candle with an inner diameter of 33 mm			
Construction of the article:	typical, similar to construction given in RC3			
Mass and composition:		Explosive	mass (g)	composition
	01	expelling charge	NOT DETERMINED	
	02	effect charge		
Number of items in test:	four boxes, each with 25 articles; 100 articles in total			
Packaging:	4G/Y/13/S/99 CN/4300 05 PI:031			
Test arrangement:	two rows of two boxes; effects directed towards witness screens			
Observations:	<ul style="list-style-type: none"> – first reaction starts after 1.5 minute, duration about seven minutes – dents in witness screens, no perforation – projection of burning material up to 65 metre 			

Test number:	RC5; 6(c) test		C49-12	
Article name:	Crackling			
Construction of the article:	typical, similar to construction given in RC3, inner diameter is 62 mm			
Mass and composition:		Explosive	mass (g)	composition
	01	expelling charge	NOT DETERMINED	
	02	effect charge		
Number of items in test:	four boxes, each containing 12 articles; 48 articles in test			
Packaging:	4G/Y31/S/00 CN/4300 42 PI:158			
Test arrangement:	two rows of two boxes, aimed at witness screens			
Observations:	<ul style="list-style-type: none"> – most projections hit the screens, burning material is thrown over a distance of 50 metre – first reaction started about 30 seconds after start of the fire, probably caused by torn fibreboard on the edges of the boxes, duration of reactions about five minutes – witness screens dented, not perforated – about 20 effect charges recovered in vicinity of test table 			

Test number:	RC6; 6(c) test		C49-24	
Article name:	Megablitz			
Construction of the article:	typical, similar to construction given in RC3, inner diameter is 75 mm			
Mass and composition:		Explosive	mass (g)	composition
	01	expelling charge	NOT DETERMINED	
	02	effect charge		
Number of items in test:	four boxes, each with 6 articles; 24 articles in total			
Packaging:	4G/Y30/S/99 CN/3209L4 PI:012			
Test arrangement:	two rows of two boxes, aimed at witness screens			
Observations:	<ul style="list-style-type: none"> – projection of burning material to a distance of 63 metre – witness screens severely dented to a depth of 50 mm 			

5.1 Discussion on results of tests with Roman candles

- One of the below listed candles is classified in hazard division 1.2G. The Manual of Tests and Criteria gives extensive guidance on how to assess metallic projections. In a footnote it is mentioned that the criteria are valid for metallic projections only, that other projections may be hazardous as well and should be included in the assessment. Objective criteria are lacking at the moment, but the Crackling Tail has been assigned to 1.2G because it perforated the witness screens.

Article	Mass of explosive (g)		Ratio effect and black powder
	black powder	effect charge	
Crackling Tail 25-C-810	8 x 16.45	8 x 54.9	3.34
Crackling Tail 22.303	8 x 9.8	8 x 54.5	5.55
Red Crackling 28.12 (52 mm)	8 x 8.5	8 x 28.7	3.38
Red Crackling 22.112 (25 mm)	8 x 14.43	8 x 46.78	3.24

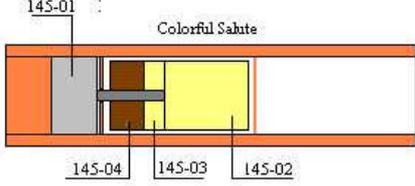
- The highest ratio of effect and expelling charge is 5.5. This article perforated the witness screens, but an article with a lower ratio (leading to higher velocities) did not perforate the screens. Classification in 1.2G can not easily be predicted. A previous German publication also states that a 1.2 classification for Roman candles = 50 mm is possible. Since the default list should be conservative and experimental evidence shows that it is possible, all Roman candles with a diameter of = 50 mm should be classified as 1.2G in the default list.
- Classification in 1.3 is simpler, this depends on the above mentioned ratio, on the aerodynamic shape of the effect stars, the individual mass of the stars and on the rigidity of the tube. The latter property is not easily quantified and is therefore not included in the considerations. Also the shape and mass of the stars is believed to have no major effect, especially since the stars are projected to distances of more than 50 metre (up to 120 metre).
- Based on the above consideration, it can be concluded that all Roman candles with a diameter < 50 mm shall be assigned to hazard division 1.3G for the default system.

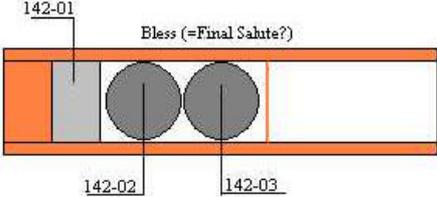
6 Batteries

Eleven tests have been performed with batteries. All of the products consists of a bundle of single shot tubes connected with a fuse to obtain a sequence of effects. Both batteries with report as primary effect and with colour effects have been tested. Furthermore, attempts have been made to find the size below which 1.3 classification (based on projection distance of burning material) is no longer necessary.

Test number:	B1; 6(c) test		C29-1
Article name:	Silver Chrysanthemum		
Construction of the article:	49 shots battery, tube inner diameter 30 mm, colour effect		
Mass and composition:		Explosive	mass (g) composition
	01	expelling charge	NOT DETERMINED
	02	effect charge	
Number of items in test:	four boxes, each containing 49 tubes		
Packaging:	4G/Y30/S/2000 CN/SJB0012		
Test arrangement:	two rows of two boxes		
Observations:	<ul style="list-style-type: none"> – first reaction starts after about 1.5 minutes, duration about 2 minutes – projection of burning effects to 65 metre 		

Test number:	B2; 6(c) test		C29-2
Article name:	Golden Flash/ Beautiful Garden/ Palm Forest		
Construction of the article:	49 shots batteries, tube inner diameter 45 mm, colour effect		
Mass and composition:		Explosive	mass (g) composition
	01	expelling charge	NOT DETERMINED
	02	effect charge	
Number of items in test:	three boxes, each containing 49 tubes		
Packaging:	4G/Y30/S/98 CN/3724 01 PI:014		
Test arrangement:	lower row two boxes on the side (each pointing to a screen), third box on top pointed upwards		
Observations:	<ul style="list-style-type: none"> – first reactions after about four minutes, duration 44 seconds – projection distance: > 80 m upwards; 40 – 50 metres to each side (hindered by witness screens) – indentation in screens: 30 – 42 mm deep 		

Test number:	B3; 6(b) test		C29-3
Article name:	Colorful salute		
Construction of the article:	 <p>49 shot battery, tube inner diameter 30 mm, colour effect (with reports)</p>		
Mass and composition:	Explosive	mass (g)	composition
	01 expelling charge	4.8	black powder
	02 effect	8.2	15% Al, 14% S, 43% KClO ₄ , 8% traces (Ti, Fe, Sb ₂ O ₃), 18% rest
	03 effect	1.5	73% KNO ₃ , 8% S, 4% KClO ₄ , 15% rest
	04 effect	14.0	14% Mg-Al, 41% KClO ₄ , 3% KNO ₃ , 8% SrCO ₃ , 2% Ba(NO ₃) ₂ , 27% rest
Number of items in test:	three boxes with each 49 tubes		
Packaging:	4G/Y30/S/99 CN/SJB0012		
Test arrangement:	boxes in "L-shape", ignition in corner box		
Observations:	<ul style="list-style-type: none"> - reactions continuing for about 1.5 minutes - projection of burning effect to a distance of 60 metre - witness plate undamaged - no significant crater 		

Test number:	B4; 6(c) test		C29-4
Article name:	Bless		
Construction of the article:	 <p>300 shots battery, tube inner diameter 19 mm, colour effect</p>		
Mass and composition:	Explosive	mass (g)	composition
	01 expelling charge	2.2	black powder
	02 effect charge	5.7	5% Mg-Al, 9% S, 37% KClO ₄ , 6% KNO ₃ , 7% CuO, 3% SrCO ₃ , 32% rest
	03 effect charge	5.5	5% Mg-Al, 11% S, 49% KClO ₄ , 10% CuO, 4% SrCO ₃ , 21% rest
Number of items in test:	three boxes with each 300 tubes		
Packaging:	4G/Y30/S/2000 CN/SJB0012		
Test arrangement:	two boxes below, one box centrally on top		
Observations:	<ul style="list-style-type: none"> - start of reaction after 4 minutes, duration 1minute - projection of burning material 45 – 60 metre 		

Test number:	B5; 6(c) test		RVI-1
Article name:	Silver Swallow		
Construction of the article:	600 shots battery, tube inner diameter 11 mm, colour effect		
Mass and composition:		Explosive	mass (g) composition
	01	expelling charge	NOT DETERMINED
	02	effect charge	
Number of items in test:	three boxes with each 600 tubes		
Packaging:	4G/Y25/S/95 CN/360011/4-16		
Test arrangement:	two boxes on the lower row, one box centrally on top		
Observations:	<ul style="list-style-type: none"> – burning effects are thrown to a height of 25 metre, where the effects last for a number of seconds (flight of the swallow) 		

Test number:	B6; 6(b) test		C49-1
Article name:	Superbang with Colour		
Construction of the article:	50 shot battery, tube inner diameter 41 mm, report effect		
Number of items in test:	four boxes with each 50 tubes		
Packaging:	4G/Y15/S/00 CN/4300 42 PI:256		
Test arrangement:	two rows of two boxes, boxes placed on the side, top of the boxes facing each other, one of the lower boxes initiated		
Observations:	<ul style="list-style-type: none"> – projections over a distance of 40 metre – reaction within 20 seconds – witness plate undamaged 		

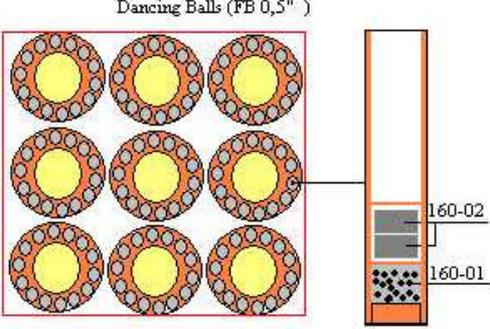
Test number:	B7; 6(b) test		C49-3
Article name:	Titanium Thunder		
Construction of the article:	49 shot battery, tube inner diameter 32 mm, report effect		
Number of items in test:	four boxes, each containing 2 articles; in total 392 tubes		
Packaging:	4G/Y18/S/99 CN/4300 80 PI:043		
Test arrangement:	lower row of two boxes upside down, top row 'normal' position		
Observations:	<ul style="list-style-type: none"> – no visible effects, slightly audible – no unreacted tubes recovered – witness plate undamaged 		

Test number:	B8 ; 6(b) test		C49-5
Article name:	Titanium Salute with Tail		
Construction of the article:	36 shot battery, tube inner diameter 61 mm, report effect		
Number of items in test:	four boxes, each containing 36 tubes		
Packaging:	4G/Y35/S/99/CN/4400/XFJ		
Test arrangement:	two rows of two boxes placed on the side, tops facing each other		
Observations:	<ul style="list-style-type: none"> – violent reactions, all within 8 seconds – projections up to 55 metre – witness plated dented at the place where the charges were located – crater 2.7 m diameter, 1 m deep ? mass explosion 		

Test number:	B9; 6(c) test	C49-6
Article name:	Titanium Salute with Tail	
Construction of the article:	36 shot battery, tube inner diameter 61 mm, report effect	
Number of items in test:	four boxes, each containing 36 tubes	
Packaging:	4G/Y35/S/99/CN/4400/XFJ	
Test arrangement:	two rows of two boxes, lower row pointed towards witness screens, top row pointing upwards	
Observations:	<ul style="list-style-type: none"> – first reaction after one minute, duration about one minute – projection of burning material over 70 m – witness screens dented, not perforated 	

Test number:	B10; 6(b) test	C49-7
Article name:	Champion Finale Box	
Construction of the article:	25 shot battery, tube inner diameter 74 mm, report effect	
Number of items in test:	four boxes, each containing 25 tubes	
Packaging:	4G/Y35/S/99/CN/4400/XFJ	
Test arrangement:	two rows of two boxes placed on the side, tops facing each other	
Observations:	<ul style="list-style-type: none"> – violent reactions, all within 20 seconds – projections up to 70 metre – witness plated dented at the place where the charges were located ? mass explosion 	

Test number:	B11; 6(c) test	C49-8
Article name:	Champion Finale Box	
Construction of the article:	25 shot battery, tube inner diameter 74 mm, report effect	
Number of items in test:	four boxes, each containing 25 tubes	
Packaging:	4G/Y35/S/99/CN/4400/XFJ	
Test arrangement:	two rows of two boxes, lower row pointed towards witness screens, top row pointing upwards	
Observations:	<ul style="list-style-type: none"> – first reaction after two minute, duration about one minute – projection of burning material over 75 m – witness screens deeply dented, not perforated 	

Test number:	B12; 6(c) test	C49-29		
Article name:	Dancing Balls			
Construction of the article:	 <p>Dancing Balls (FB 0,5")</p> <p>12 shot battery, tube inner diameter 9 mm, colour effects</p>			
Mass and composition:	Explosive	mass (g)	composition	
	01	expelling charge	1.0	NOT DETERMINED
	02	effect charge	2.9	
Number of items in test:	three boxes, each containing 8 plastic foils with 9 articles of 12 tubes			
Packaging:	4G/Y30/S/00 CN/321700L4 PI:93			
Test arrangement:	lower row of two boxes, one box centrally on top			
Observations:	<ul style="list-style-type: none"> - first reactions after two minutes, duration two minutes - projections over a distance of 40 metre 			

Test number:	B13; 6(c) test	RVI-2
Article name:	Diamond Collection Assortment	
Construction of the article:	various batteries, tube inner diameter varying from 26 to 40 mm, colour effect	
Number of items in test:	three boxes, each containing two display boxes with six different articles	
Packaging:	4G/Y30/S/00 CN/4300 86 PI:1166	
Test arrangement:	two boxes in a row, one centrally on top	
Observations:	- burning projections were thrown to a distance of 55 metre	

Test number:	B14; 6(c) test	RVI-3
Article name:	Skyline Assortment XL	
Construction of the article:	various batteries, tube inner diameter of 31 – 33 mm, colour effect	
Number of items in test:	three boxes, each containing two display boxes with six different articles	
Packaging:	4G/Y20/S/00 CN/4300 86 PI:1513	
Test arrangement:	three boxes placed upright on the test table, since the articles are laying down (otherwise would have hit the witness screens and no indication on projection distance)	
Observations:	- burning material was projected over a distance of 40 –50 metre	

6.1 Discussion on results of tests with batteries

- In some cases, in the 6(b) test, mass explosion behaviour is found for batteries with report as the primary effect. Although in the 6(b) test, the effect is rather localised, extrapolation to the effect of larger amounts or combined loads is very uncertain. Therefore, since it has been demonstrated experimentally that mass explosion behaviour can occur, the proper default classification for batteries with report as the primary effect is 1.1G.
- Considering the 1.3G classification, also in this case, the articles with the highest ration of effect and expelling charge have been tested and gave projection distances of about 60 metres. The other listed batteries have lower ratios than Bless and Colourful Salute and should have comparable projection distances.

Attempts to find the borderline, below which 1.4 classification is appropriate have not been successful. The same consideration as given above for Roman candles apply, leading to the same conclusion: the proper classification for the default system for batteries, not having mass explosion properties, is 1.3G.

Article	Mass (g)		Ratio effect and expelling charge	projection distance (m)
	expelling charge	effect charge		
Red Wave	3.84	10.5	2.7	
Bless	2.21	11.18	5.1	45-60
Silver Chrysanthemum				65
Golden Flash				50
Beautiful Garden				50
Palm Forest				> 80
Colorful Salute	4.75	23.78	5.0	60
Final Salute	2.41	10.72	4.5	
Crackle Mine	2.46	5.02	2.0	
Red Chrysanthemum	19.6	31.6	1.6	
Blue Chrysanthemum	19.3	34.7	1.8	
White Chrysanthemum	19.6	38.0	1.9	
Green Chrysanthemum	20.5	33.6	1.6	
Multicolour Chrysanthemum	20.4	25.9	1.3	
Multicolour peony tail	28.5	66.8	2.3	
Red to Blue peony tail	28.4	66.0	2.3	
White dove	4.5	15.1	3.6	
Dancing Balls	1.0	2.9	2.9	55

7 Various other articles

7.1 Waterfall

This article consists of a number of tubes (mostly of plastic) and is meant to be hung at a height between fixed points to produce a cascade of light effects (see photo). With this article the 6(a) test, the 6(b) test and the 6(c) test has been performed.



Test number:	V1; 6(a) test	C121-3
Article name:	Waterfall	
Construction of the article:	tubes of pyrotechnic material, covered with paper and plastic	
Number of items in test:	one box containing 2 inner packagings with 6 and 4 bundles of 20 tubes; 200 bundles in total in test	
Packaging:	4G/Y30S/99/3724 01 PI:030	
Test arrangement:	initiation at the centre of the packaging	
Observations:	– all articles functioned at the same time – witness plate undamaged (flat on the ground)	

Test number:	V2; 6(b) test	C121-3
Article name:	Waterfall	
Construction of the article:	tubes of pyrotechnic material, covered with paper and plastic	
Number of items in test:	three boxes, each containing 2 inner packagings with 6 and 4 bundles of 20 tubes; 600 bundles in total in test	
Packaging:	4G/Y30S/99/3724 01 PI:030	
Test arrangement:	boxes placed in an “L-shape” initiation at the centre of the corner packaging	
Observations:	 <ul style="list-style-type: none"> – column of fire, individual burning ‘candles’ visible – one box unaffected (next to ‘donor’ box), about 30 candles recovered – witness plate undamaged (flat on the ground) 	

Test number:	V3; 6(c) test	C121-3
Article name:	Waterfall	
Construction of the article:	tubes of pyrotechnic material, covered with paper and plastic	
Number of items in test:	three boxes, each containing 2 inner packagings with 6 and 4 bundles of 20 tubes; 600 bundles in total in test	
Packaging:	4G/Y30S/99/3724 01 PI:030	
Test arrangement:	initiation at the centre of the packaging	
Observations:	– net heat radiation: 14 kW/m ²	

Given the large heat radiation this product should be assigned to hazard division 1.3G. No smaller packages have been tested, but the construction of the articles is such, that one bundle of candles is designed to function at the same time, giving of heat and sparks. This will initiate adjacent bundles, which in turn will initiate other bundles and/ or boxes. The described process will develop very quickly, so that the whole test volume will be initiated at about the same time. All of the energy will be released within a relatively short time, leading to considerable amounts of heat radiation. It can be expected that comparable products will need to be assigned to hazard division 1.3 as well.

7.2 Mines

Test number:	V4; 6(c) test	C49-26
Article name:	Pot-a-feu, Volcano shell size 150 mm	
Construction of the article:		
Number of items in test:	four boxes each containing 10 articles, 40 articles in total in test	
Packaging:	4G/Y/35,0/S/99 E/DAPSA/H-39	
Test arrangement:	two rows of two boxes	
Observations:	<ul style="list-style-type: none"> – all articles reacted simultaneously – no mass explosion, no damage to witness screens, no projections, heat radiation below 4kW/m^2, fireball touches witness screens (at 4 metre) 	

The size of the fireball is the determining factor for classification in this case. The criterion for 1.4S classification is a fireball smaller than 1 metre. The correct assignment for this article is therefore 1.4G. No prediction of the behaviour of comparable products can be given, since it is hard to predict the size of a fireball.

7.3 Fountains

Test number:	V5; 6(c) test	C49-28
Article name:	1000 g Silver Conic Fountain	
Construction of the article:		
Number of items in test:	four boxes, each containing six inner packagings with two articles, 48 articles in total in test	
Packaging:	4G/Y/S/00 CN/4300 85 PI045	
Test arrangement:	two rows of two boxes, the fountains are directed towards the witness screens	
Observations:	<ul style="list-style-type: none"> – articles reacted individually within a time frame of about 10 minutes – the effects are spraying against the witness screens (at 4 m) with considerable velocity 	

From the velocity of the effects it can be concluded that the burning particles will be projected more than 4 metres from the fire. It is not to be expected that the distance will be more than 15 metres. The correct classification is 1.4G. Fountains are designed to produce the effects for some time. The pyrotechnic material is mostly pressed to high density resulting in a slow burning.

It is not to be expected that, under the conditions of the 6(c) test, the fountains will burn so fast that they give off large heat radiation. A 1.3 classification is not very likely for these products.

7.4 Firecrackers

Test number:	V6; 6(b) test	C49-27
Article name:	Celebration cracker, 300,000 shots	
Construction of the article:		
Mass and composition:	the article contains three different sizes of crackers, the finale crackers are not visible on the photo. The crackers contain 0.72 g; 0.51 g and 0.14 g of pyrotechnic material of the following composition: 5% Al; 20% S; 64% KClO ₃ and 10% rest	
Number of items in test:	two boxes, each containing one article of 300,000 crackers	
Packaging:	4G/Y30/S/99 CN/4400/XCC	
Test arrangement:	boxes placed on top of each other, initiation in the lower box; ignition with black powder underneath the heart of the roll (finale)	
Observations:	<ul style="list-style-type: none"> – no cratering – all articles reacted within 3 seconds – witness plate undamaged 	

Test number:	V7; 6(c) test	C49-18
Article name:	Celebration cracker, 300,000 shots	
Construction of the article:	See: test V6	
Mass and composition:		
Number of items in test:	two boxes, each containing one article of 300,000 crackers	
Packaging:	4G/Y30/S/99 CN/4400/XCC	
Test arrangement:	boxes placed on top of each other	
Observations:	<ul style="list-style-type: none"> – individual reactions – flashes stayed within the witness screens – no damage to witness plate – many dozens of unreacted articles recovered – sound pressure at 5 metres: 158 dB 	

The amount of noise is the determining criterion for classification. A sound level of 158dB at 5 metres is believed to significantly hinder fire fighters; the classification should therefore be 1.4G.

The individual crackers were all loosely rolled in paper. It can not be excluded that firecrackers with a more tight casing, will give more shock effect and a different classification.

7.5 Rockets

Test number:	V8; 6(c) test	RVI-4
Article name:	Skyline Rocket Assortment Atlantis	
Construction of the article:	typical	
Number of items in test:	three boxes each containing 18 assortments of 8 rockets and 2 Roman candles	
Packaging:	4G/Y25/S/00 CN/360016 PI:018	
Test arrangement:	two boxes on lower row, one box centrally on top; directed towards witness screens	
Observations:	<ul style="list-style-type: none">– rockets functioned over a distance of 60 – 70 metres releasing the effects (burning material) at that distance– witness screens dented	

More extensive tests, performed at the beginning of the nineties, had already showed that rockets will fly over considerable distance justifying a 1.3 classification. Since this test confirmed these earlier finding, no further experiments with rockets have been performed.

8 Authentication

The various research programmes have been performed by M.W.L. Dirkse, R. Eerligh, W Groenewegen, E.G. de Jong, P. van Ierschot, J. Koman, R.E. Krämer, J.C. Makkus, J. Mul, R. Oostdam, M.A. Schrader and A. van Zweden with the much appreciated assistance of the team of H.J. Rodner of the Bundesanstalt für Materialforschung und –prüfung (BAM), Germany

E.G. de Jong
Project leader/ Author

<p>SUMMARY: COMPANY CONFIDENTIAL</p> <p>This report describes the classification tests performed in the aftermath of the fireworks explosion in the city of Enschede, the Netherlands on May 13th, 2000. The details of the tests are meant to inform the UN Sub-Committee of Experts on the Transport of Dangerous Goods and its informal Working Group tasked with developing a system of default classification of fireworks.</p> <p>The report will also be made available for the working group on Explosives, Propellants and Pyrotechnics (EPP) of the International Group of experts on the explosion risks of Unstable Substances (IGUS) of OECD and all other interested authorities.</p> <p>This report supports the default classifications of report shells, colour shells, Roman candles and batteries.</p>	<p>SUMMARY: COMPANY CONFIDENTIAL</p> <p>This report describes the classification tests performed in the aftermath of the fireworks explosion in the city of Enschede, the Netherlands on May 13th, 2000. The details of the tests are meant to inform the UN Sub-Committee of Experts on the Transport of Dangerous Goods and its informal Working Group tasked with developing a system of default classification of fireworks.</p> <p>The report will also be made available for the working group on Explosives, Propellants and Pyrotechnics (EPP) of the International Group of experts on the explosion risks of Unstable Substances (IGUS) of OECD and all other interested authorities.</p> <p>This report supports the default classifications of report shells, colour shells, Roman candles and batteries.</p>
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