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Sub-Committee of Experts on the Transport of Dangerous Goods

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Explosives and related matters: test series 8

Manual of Tests and Criteria

Recommendations for improvement of the Series 8(b) ANE Gap Test and other Gap Tests

Transmitted by the Institute of Makers of Explosives (IME)[1]

Introduction

1. During the thirty-ninth session, IME raised certain issues regarding the 8(b) test of the Manual of Tests and Criteria and made recommendations to resolve those issues[2], including Table 18.5.1.1 errors and the following test components:

(a) The pentolite donor,

(b) The steel tube used to hold the test substance,

(c) The PMMA rod, and

(d) The steel witness plate.

2. IME's issues and proposals regarding the 8(b) test were discussed by the Working Group on Explosives that met in parallel, and it was agreed by the Sub-Committee that

[1] In accordance with the programme of work of the Sub-Committee for 2011-2012 approved by the Committee at its fifth session (refer to ST/SG/AC.10/C.3/76, para. 116 and ST/SG/AC.10/38, para. 16).

[2] Informal documents INF.4, INF.5, INF.6 and INF.7 (39^{th} session)

IME, taking into account the conclusions of the Working Group, should prepare formal proposals for the forty-first session[3].

3. The Test 7(b): EIDS Gap Test employs similar apparatus and materials to the Test 8(b): ANE Gap Test, and hence suffers from similar difficulties in sourcing materials.

4. At the same session, the expert from Canada presented the results from a recent survey to the Working Group on Explosives[4]. This survey had been conducted amongst the IGUS[5] stakeholders to establish the scope of problems in obtaining materials for TDG testing according to the Manual of Tests and Criteria. Of all the tests in the Manual, the category of gap tests received the highest number of adverse comments, with difficulties in obtaining the confining steel tubes for these gap tests being of the greatest concern within this category.

5. Both the current Series 1(a): UN Gap Test and the Series 2(a): UN Gap Test specify that " … The test sample is contained in cold-drawn, seamless, carbon steel tube with an external diameter of 48 ± 2 mm, a wall thickness of 4.0 ± 0.1 mm and a length of 400 ± 5 mm…". While the external diameter can be accommodated by tubing of internationally standard sizing[6], the wall is of non-standard thickness. Furthermore, the tolerance of ± 0.1 mm is only a third of the ± 0.3 mm tolerance allowed by international standards[7] for steel tubing of this size and wall thickness. Consequently, no steel tubing manufactured and sized to current international standards meets the current specifications in the test manual.

6. In the annex (English only), IME discusses how the proposed amendments to the dimensions of the steel tubing would permit the use of tubing manufactured and sized to international standards.

Proposals

Section 18

7. Amend 18.5.1.2.1(b) of the 8(b) test procedure to read:

(b) 95 mm diameter by 95 mm long pellet with a density of 1 600 kg/m^3 ± 50 kg/m^3 of either 50/50 pentolite or 95/5 RDX/WAX;

8. Amend 18.5.1.2.1(c) of the 8(b) test procedure to read:

(c) Tubing, steel, cold drawn seamless, with an outer diameter of 95.0 ± 7.0 mm, a wall thickness of 9.75 ± 2.75 mm and an inner diameter of 73.0 ± 7.0 mm, and with a length of 280 mm;

9. Amend 18.5.1.2.1(e) of the 8(b) test procedure to read:

(e) Polymethyl methacrylate (PMMA) rod, of 95 mm diameter by 70 mm long. A gap length of 70 mm results in an incident shock pressure at the ANE interface somewhere between 3.5 and 4 GPa, depending on the type of donor used (see Table 18.5.1.1 and Figure 18.5.1.2);

[3] ST/SG/AC.10/C.3/78, para.18
[4] Informal document INF.25 (39th session)
[5] http://www.oecdigus.org
[6] ASME B36.10M *Welded and Seamless Wrought Steel Pipe*.
[7] ASTM/A519-06 *Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing*.

10. Amend 18.5.1.2.1(f) of the 8(b) test procedure to read:

(f) Mild steel plate, 200 mm × 200 mm × 20 mm;

11. Delete 18.5.1.2.1(g) in its entirety and renumber current 18.5.1.2.1(h) to be 18.5.1.2.1(g).

12. Amend Table 18.5.1.1 of the 8(b) test procedure as follows:

(a) Revise the "Barrier Pressure Value" for the 55mm gap length entry to read "4.91" instead of "4.76".

(b) Revise the "Barrier Pressure Value" for the 60mm gap length entry to read "4.51" instead of "4.31".

Section 17

13. Amend 17.5.1.2(b) of the 7(b) test procedure to read:

(b) 95 mm diameter by 95 mm long pellet with a density of 1 600 kg/m3 ± 50 kg/m3 of either 50/50 pentolite or 95/5 RDX/WAX;

14. Amend 17.5.1.2(c) of the 7(b) test procedure to read:

(c) Tubing, steel, cold drawn seamless, with an outer diameter of 95.0 ± 7.0 mm, a wall thickness of 9.75 ± 2.75 mm and an inner diameter of 73.0 ± 7.0 mm, and with a length of 280 mm;

15. Amend 17.5.1.2(e) of the 7(b) test procedure to read:

(e) Polymethyl methacrylate (PMMA) rod, of 95 mm diameter by 70 mm long;

16. Amend 17.5.1.2(f) of the 7(b) test procedure to read:

(f) Mild steel plate, 200 mm × 200 mm × 20 mm;

17. Delete 17.5.1.2(g) in its entirety and renumber current 17.5.1.2(h) to be 17.5.1.2(g).

Section 11

18. Amend the second sentence of 11.4.1.2.1 of the 1(a) test procedure to read:

The test sample is contained in cold-drawn, seamless, carbon steel tube with an external diameter of 48.0 ± 2.0 mm, a wall thickness of 4.8 ± 0.9 mm, an inner diameter of 39.3 ± 3.0 mm and a length of 400 ± 5 mm.

Section 12

19. Amend the second sentence of 12.4.1.2 of the 2(a) test procedure to read:

The test sample is contained in cold-drawn, seamless, carbon steel tube with an external diameter of 48.0 ± 2.0 mm, a wall thickness of 4.8 ± 0.9 mm, an inner diameter of 39.3 ± 3.0 mm and a length of 400 ± 5 mm.

Annex

English only

Discussion of steel tubing dimensions in Gap Tests

Introduction

1. At the thirty-ninth session of the Sub-Committee, the expert from Canada presented the results from a recent survey to the Working Group on Explosives [1]. This survey had been conducted amongst the IGUS [2] stakeholders to establish the scope of problems in obtaining materials for TDG testing according to the Manual of Tests and Criteria [3] (referred to subsequently as test manual). Of all the tests in test manual, the category of Gap tests received the highest number of adverse comments, with difficulties in obtaining the confining steel tubes for these Gap tests being of the greatest concern within this category.

2. Many of these difficulties have arisen because the dimensions specified in test manual for the confining steel tubing do not match the dimensions and tolerances of the standard sizes specified for steel tubing by current international standards [4, 5]. While paragraph 1.1.2 of the General Introduction to test manual states that “The competent authority has discretion to dispense with certain tests, to vary the details of tests, and to require additional tests when this is justified to obtain a reliable and realistic assessment of the hazard of a product”, such discretion should not be a necessary prerequisite to allow the tests to be conducted at all.

3. The intention of such gap tests is to measure the shock sensitivity of the substance under confined conditions. It is well known in detonation science that the three primary factors that determine whether or not shock initiation of explosive substances will occur in a gap test are (1) the peak pressure of the shock delivered at the interface between the substance and the donor/attenuator system, (2) the duration of the pressure pulse delivered to the interface, and (3) the curvature of the shock delivered to the interface. The reproducibility of these three primary factors is assured under the gap test conditions by controlling (1) the composition, density and physical dimensions of the donor explosive pellet, (2) the location of the detonator, and (3) the physical dimensions of the chosen attenuator. Each of these elements is adequately controlled by the specifications in test manual.

4. The confinement plays a secondary role in these gap tests, promoting the propagation of any reactive shock away from the interface with the donor/attenuator and throughout the length of the test substance towards the witness plate. The controlling elements in the effectiveness of a confining tube are in order (1) its inner diameter, (2) the material’s shock impedance (namely the product of its density and its speed of sound), and (3) the inertia of the wall (controlled by its density and its wall thickness). It is the shock impedance that controls the initial deflection of the interface between the test substance and the wall upon shock arrival; the inertia only begins to have an influence once there has been time for multiple internal shock reverberations between the inner and outer surfaces of the wall. All grades of steel have similar densities and sound velocities (and hence shock impedances and inertias), so only the inner diameter and the wall thickness need to be specified within suitable tolerances to ensure reproducibility of gap test results.

5. This annex will discuss the justification behind the three proposals in this document recommending changes to each of the four gap tests in test manual to align the dimensions of their confining steel tubing with current international standard steel tubing sizes.

The Series 1(a) and 2(a) Gap Tests

6. Price and co-workers [6, 7] have described the development of the original Naval Ordnance Laboratory Large Scale Gap Test (NOL LSGT), starting from the early 1950s. The confining steel tubes in this test were described as “cold drawn, mechanical steel (MT-1015) seamless tube”, with nominal dimensions of outer diameter (OD) $1\frac{7}{8}$" (47.63 mm), inner diameter (ID) $1\frac{7}{16}$" (36.51 mm) and hence by subtraction, wall thickness $\frac{7}{32}$" (5.56 mm); their length was $5\frac{1}{2}$" (139.7 mm). The tolerances on these dimensions are not known here since this is a non-standard tubing size. Erkman et al. [8] provided a calibration of peak shock pressure versus gap length for their combination of a pressed Pentolite donor and polymethyl methacrylate (PMMA) attenuator.

7. The NOL LSGT was adopted by the Sub-Committee (TDG) as the basis for the Series 2(a) Gap Test. The only major change was that the length of the confining tube was more than doubled to be 400 mm in order to discriminate more reliably against fading detonations. The length and diameter of the donor explosive pellet and the diameter of the PMMA attenuator were converted from their original imperial units to the metric system and rounded off. The length of the PMMA attenuator was fixed at 50 mm, which would correspond to an incident shock pressure at the interface between the PMMA and the test substance of 2.15 GPa according to the calibration [8].

8. The Series 1(a) Gap Test is identical to the Series 2(a) Gap Test with the exception that no PMMA attenuator is used, with the explosive donor being in intimate contact instead with the test substance.

9. Of particular significance to this annex, the dimensions of the steel tubing were converted to the metric system and rounded off. The specification in test manual is currently “cold-drawn, seamless, carbon steel tube with an external diameter of 48 ± 2 mm, a wall thickness of 4.0 ± 0.1 mm, …” It is notable that the wall thickness is reduced by over a quarter from its original NOL LSGT value of 5.56 mm (for reasons unknown here), and furthermore, is specified with the unrealistically small tolerance of ± 0.1 mm. Current international standards [9] allow a tolerance of 7.5%, equivalent to ± 0.3 mm in the wall thickness, for cold-worked tubing of this inner diameter and wall thickness. Hence it is the case that no off-the-shelf steel tubing manufactured to international standards can meet current test manual specifications on the tolerance of the wall thickness.

10. Standard steel tubing of size NPS-1½ (in the North American Nominal Pipe Size designation) or DN-40 (in the exactly equivalent European Diamètre Nominal designation) meets the test manual specification of the outer diameter. However, the wall of Schedule 40 tubing is too thin, while that of the next thicker Schedule 80 tubing is too thick, to meet the test manual specification on the wall thickness. The relevant dimensions, calculated taking into account the allowable tolerances specified by ASTM/A519 [9] for the NPS-1½/DN-40 tubing, are included in Table 1.

Table 1. Ranges of tubing dimensions relevant to the Series 1(a) and 2(a) Gap tests

Derived dimensions are listed in brackets.

	Outer Diameter (mm)		Schedule	Wall thickness (mm)		Inner Diameter (mm)	
	Min	Max		Min	Max	Min	Max
NOL LSGT 6]	47.63			{5.56}		36.51	
test manual [3]	46	50		3.9	4.1	{37.8}	{42.2}
NPS-1½ DN-40 [4, 9]	48.26	48.41	40	3.407	3.959	40.74	40.89
			80	4.699	5.461	37.95	38.10
Proposals	46.0	50.0		3.9	5.7	36.3	42.3

11. Price [7] described the results of investigations into the effect of confinement on the results of the NOL LSGT. It was found that confinement had a negligible effect on the results for cast Pentolite, with the length of the critical PMMA gap corresponding to 50% initiation being 67.56 mm for an unconfined test charge and 67.06 mm for a test charge confined in steel – this difference is within experimental scatter for this gap test. The results for cast Composition B did show greater dependence on confinement, with the critical gap increasing from 36.32 mm for an unconfined test charge to 45.47 mm for aluminium confinement and to 51.05 mm for steel confinement. However, increasing the inertia of the confinement further by replacing steel tubing by lead tubing made essentially no further difference, with the critical gap increasing only very slightly to 51.82 mm with the latter. So while the presence of confinement was important for cast Composition B, its specific details were not once a certain level of inertia had been exceeded. It may be inferred that increasing the inertia of the steel confinement by increasing the wall thickness would similarly have made no significant difference to the critical gap. These results for the NOL cast Composition B are highly relevant here, since the critical gap of 51.05 mm is only slightly longer than the 50 mm gap length adopted for the Series 2(a) Gap Test. The response of this cast Composition B would have been close to the boundary between returning either a positive or a negative result in the Series 2(a) Gap Test, and hence served as a valid probe of critical behaviour and conditions in this test.

12. The current proposals are to specify the dimensions of the steel tubing in the Series 1(a) and 2(a) Gap Tests as having an outer diameter of 48.0 ± 2.0 mm, a wall thickness of 4.8 ± 0.9 mm and an inner diameter of 39.3 ± 3.0 mm. The resulting limits are included in the last line of Table 1.

13. These proposals would permit the use of standard NPS-1½/DN-40 Schedule 80 steel tubing (highlighted in Table 1) for these two tests. The inner diameter would be greater than the minimum considered acceptable previously by test manual, while the wall thickness (of nominal 5.08 mm) would be slightly thicker than that specified in test manual, but closer to that of the originating NOL LSGT.

14. Any steel tubing that complied with the test manual specifications would still comply under these proposals. Test results generated to test manual specifications could be brought forward.

15. The NOL LSGT procedure was adopted as one of the key gap test methodologies by many explosive laboratories throughout the USA (and indeed, in all probability in many explosive laboratories worldwide). It is likely that many historical explosive and propellant compositions have been subjected to gap tests employing the NOL LSGT steel tubing. However, since its wall thickness (nominal 5.56 mm) lies outside the specification of 4.0 ±0.1 mm in test manual, any results from the NOL LSGT can only be accepted under

the discretionary powers of the relevant Competent Authorities as being equivalent to testing under Series 1(a) and 2(a) conditions. The NOL LSGT steel tubing would comply under these current proposals, subject only to the proviso that its manufacturing tolerances complied with ASTM/A519 [9]. Test results generated under NOL LSGT conditions could be accepted without the need for discretionary exemptions.

The Series 7(b) and 8(b) Gap Tests

16. Swisdak [10] has recounted some of the history behind the introduction of Hazard Class/Division 1.6 in the late 1980s for articles containing Extremely Insensitive Detonating Substances (EIDS). Following the development of new types of insensitive explosives during the 1970s and 1980s, it had been recognised that new classification and testing regimes were required for military explosives which had relatively small critical diameters but were still insensitive, as distinct from Class 1.5 which was devised for commercial blasting agents which were insensitive because of large critical diameters. The US Department of Defence Explosive Safety Board (DDESB) requested that the Naval Surface Warfare Center (NSWC) review the existing protocol for Class 1.5 and IHE materials.

17. NSWC identified the need for a larger scale gap test for EIDS whose confined critical diameters were comparable to, or larger than, the diameter of the NOL LSGT. This led to the development [11] and calibration [12] of the NSWC Expanded Large Scale Gap Test (ELSGT). Basically, most dimensions of the NOL LSGT were doubled, with the major exception being the donor pellet diameter whose size increase was limited to a factor of only 1.875 due to limitations in the size of the available pressing moulds. The witness plate thickness was doubled, but its area was not “because of handling problems” associated with the greater mass to be manhandled.

18. In particular, all dimensions of the confining steel tubing were doubled, becoming an outer diameter of $3\frac{3}{4}$" (95.25 mm), an inner diameter of $2\frac{7}{8}$" (73.03 mm) and hence by subtraction, a wall thickness of $\frac{7}{16}$" (11.1 mm), and a length of 11" (279.4 mm). The tolerances on these dimensions are not known here since this is a non-standard tubing size.

19. The NSWC ELSGT was adopted by the SCETDG as the basis for the Series 7(b) EIDS Gap Test with minimal changes. All dimensions were converted from their original imperial units to the metric system and rounded off. The length of the PMMA attenuator was fixed at 70 mm. The most significant change involved the specification of tensile strength, elongation and hardness for the steel tubing and steel witness plate, replacing the NSWC ELSGT usage of mild steel for which no mechanical properties can be guaranteed.

20. The methodology of the Series 7(b) EIDS Gap Test was adopted with minimal changes for the Series 8(b) ANE Gap Test. The requirement to machine the test substance was omitted, some information was added about the pressure delivered to the interface between the PMMA attenuator and the test substance, and the small air standoff gap between the test substance and the witness plate was omitted.

21. In particular, the test manual specification of the steel tubing for both the Series 7(b) and 8(b) Gap Tests is in part “tubing, steel, cold drawn seamless, 95 mm outer diameter, 11.1 mm wall thickness ± 10% variations …” The relevant limits are listed in Table 2, where it has been assumed that the “± 10% variations” are meant to be applied to both the outer diameter and the wall thickness. An undesirable consequence of specifying outer diameter and wall thickness is that the inner diameter becomes poorly bounded, despite the inner diameter being the more important parameter affecting detonation propagation in explosive substances. The variation of the inner diameter allowed by test manual is ± 16%.

Table 2. Ranges of tubing dimensions relevant to the Series 7(b) and 8(b) Gap tests

Derived dimensions are listed in brackets.

Version of Test	Outer Diameter (mm)		Wall thickness (mm)		Inner Diameter (mm)	
	Min	Max	Min	Max	Min	Max
NSWC ELSGT [14]	95.25		{11.1}		73.03	
test manual [3]	85.50	104.50	9.99	12.21	{61.08}	{84.52}
NATO ELSGT [16]	85.77	104.83	{2.63}	{19.48}	65.88	80.52
Proposals [7, 8]	88.00	102.00	7.50	12.50	66.00	80.00

22. NATO also based its version of the Expanded Large Scale Gap Test directly on the original NSWC ELSGT, although choosing to specify the inner diameter rather than the wall thickness. The precise wording was "Acceptor explosives are either cast or pressed into a 4340 steel tube of 279 mm in length, 73.2 mm inner diameter, and 95.3 mm outer diameter. A tolerance of up to 10% for the inner and outer diameters is allowed to accommodate standard tube sizes available in Europe…". It can be seen from Table 2 that the NATO choice has resulted in tighter specification of the inner diameter, though allowing greater leeway on the wall thickness, than the test manual specification.

23. As noted above, the dimensions of the steel tubing chosen for the NSWC ELSGT were derived by doubling those of an already non-standard size used in the NOL LSGT. Whereas at least the outer diameter of the NOL LSGT/test manual tubing can be matched by a standard tubing size, the outer diameter of the NSWC ELSGT/test manual tubing now falls exactly midway between those of two standard tubing sizes, namely 88.90 mm for NPS-3/DN-80 and 101.60 mm for NPS-3½/DN-90. Table 3 summarises the various scheduled wall thicknesses and inner diameters that are defined for these two standard sizes, together with an indication of those that fall within the allowable ranges in Table 2 (✓) and those that do not (×), taking the tolerances specified in ASTM/A519 [12] into account.

Table 3. Standard tubing sizes.

The combinations that meet all allowable ranges in Table 2 are highlighted.

Size	OD mm	SCH	Wall mm	ID mm	Conformance					
					test manual		NATO		Proposed	
					Wall	ID	Wall	ID	Wall	ID
NPS 3 DN 80	**88.90**	5	2.108	84.68	×	×	×	×	×	×
		10	3.048	82.80	×	✓	×	✓	×	×
		30	4.775	79.35	×	✓	✓	✓	×	✓
		40/STD	5.486	77.93	×	✓	✓	✓	×	✓
		80/XS	7.620	73.66	×	✓	✓	✓	✓	✓
		120	8.890	71.12	×	✓	✓	✓	✓	✓
		160	11.125	66.65	✓	✓	✓	✓	✓	✓
		XXS	15.240	58.42	×	×	×	✓	×	×
NPS 3½ DN 90	**101.60**	5	2.108	97.38	×	×	×	×	×	×
		10	3.048	95.50	×	×	✓	×	×	×
		30	4.775	92.05	×	×	✓	×	×	×
		40/STD	5.740	90.12	×	×	✓	×	×	×
		80/XS	8.077	85.45	×	×	✓	×	×	×
		120	NA							
		160	NA							
		XXS	16.154	69.29	×	✓	✓	✓	×	✓

24. Only one standard tubing size, namely NPS-3/DN-80 Schedule 160, complies with test manual, though at the expense of reducing the nominal inner diameter to 66.65 mm, somewhat less than the intended inner diameter of 72.8 mm in test manual. Six standard tubing sizes comply with the specification of the NATO ELSGT test, though at the expense of allowing what might be considered excessively thin and excessively thick walls at the extremes.

25. The current proposals are to specify the dimensions of the steel tubing in the Series 7(b) and 8(b) Gap Tests as having an outer diameter of 95.0 ± 7.0 mm, a wall thickness of 10.0 ± 2.50 mm and an inner diameter of 73.0 ± 7.0 mm. The resulting limits are included in Table 2, with the compliant standard tubing sizes highlighted in Table 3.

26. These proposals would permit the use of two additional standard sizes, namely NPS-3/DN-80 Schedules 80 (also called XS for Extra Strong) and 120 steel tubing for these two tests. Both of these additional options have inner diameters that are closer to the intended inner diameter of 72.8 mm in test manual, albeit with slightly thinner walls, than the only current compliant standard size.

27. The majority of the steel tubing that complied with the test manual specifications would still comply under these proposals. However, tubing with inner diameters at the extremes of the range allowed by test manual would no longer be compliant. Such tubes would have combined either the largest outer diameters with the thinnest walls, or the smallest outer diameters with the thickest walls, within the ranges allowed by test manual.

28. Similar comments would apply to the majority the steel tubing that complied with the NATO specifications. Only tubing with either very thin or very thick walls would not comply with the current proposals.

Concluding remarks

29. The current proposals would enable a selection of internationally standard tubing sizes to be utilised in the UN Gap Tests without requiring prior dispensation from the relevant Competent Authorities.

References

[1] Informal document INF.25 (39th session), *Difficulties in carrying out TDG classification tests*.

[2] http://www.oecdigus.org/

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[10] Michael M. Swisdak, Jr., “Hazard Class/Division 1.6: Articles containing Extremely Insensitive Detonating Substances (EIDS)”, Naval Surface Warfare Center Report NSWC TR 89-356, 1 December 1989.

[11] T.P. Liddiard and D. Price, “The Expanded Large Scale Gap Test”, Naval Surface Warfare Center Report NSWC TR 86-32, March 1987.

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[13] NATO Standardization Agency, “STANAG 4488 PCS (Edition 1) – Explosives, Shock Sensitivity Tests”, NSA/0883-PPS/4488, 12 September 2002.