Subject: The present technical information has been prepared for the purpose of serving as a polemical essay during the IEC ExTAG meeting in Bern covering the Hungarian standpoint in the subject: „Test for non-transmission of an internal ignition”, being at the same time the standpoint on the basis of the results of the experiments performed in the meantime. It contains divergences compared to the previous materials.

During the past years the Hungarian BKI Ex V.Á. has performed series of tests as well as analysing and development activities aiming at the theoretical and practical aspects of non-transmission of an internal ignition.

During this testing and research work the following statements were made:

I. The first alternative of the test for non-transmission of an internal ignition according to IEC 60079-1 resp. EN 50018 wishing to provide for the appropriate safety of the enclosure by increasing the gaps, is a theoretically incorrect method. That is to say, the increasing of the gap in case of enclosures of different shape and volume results in diverse safety values. On the other hand, from technical point of view, no reproducible results can be obtained, as it would be expected.

II. The second process is already a more reasonable one, since the safety factor is obtained by means of the increased flame transmission capability of the gas-air mixture, which better approaches the theoretically correct test process.

1. Explosion groups, Maximum Experimental Safe Gap

On the basis of the MESG the different flammable gases-vapours can be classified into groups of application from the point of view of safety technique. The basis of the classification is the MESG value characteristic of the group.

The MESG values are determined by means of the device described in the IEC 79-1A (1975) publication. Table 1 shows the classification into groups.

Flammable gas		Group	Most incendive mixture, vol.%	MESG g_0 mm	Rang. mm
Methane	CH_4	I	8,2	1,14	1,14
Propane	C_3H_8	IIA	4,2	0,92	> 0,9
Hexane	C_6H_{14}		2,5	0,93	
Methanol	CH_3OH		11,0	0,92	
Ethanol	C_2H_5OH		6,5	0,89	
Ethylene	C_2H_4	IIB	6,5	0,65	> 0,5 but < 0,9
Ethylene oxide	C_2H_4O		8,0	0,59	
Ethylene ether	$C_4H_{10}O$		3,47	0,87	
Hydrogen	H_2	IIC	27,00	0,29	< 0,5
Acetylene	C_2H_2		8,5	0,37	
Carbon disulphide	CS_2		8,5	0,34	

Table 1.
Grouping of gases, vapours on the basis of the MESG values

2. Representative gases

In respect of the test the representative gases of the given gas groups are determinative, covered by Table 2. (K = 1)

Group	Gas		Most incendive mixture vol.%	MESG (mm)		g_{100}-g_0 (mm)
				g_0	g_{100}	
I	CH_4	Methane	8,20 ± 0,2	1,14	1,25	0,110
IIA	C_3H_8	Propane	4,20 ± 0,2	0,92	0,95	0,030
IIB	C_2H_4	Ethylene	6,50 ± 0,2	0,65	0,67	0,020
IIC	H_2	Hydrogen	27,00 ± 0,2	0,29	0,30	0,010

Table 2
Parameters of representative gases

3. Electrical apparatus of Groups I, IIA and IIB

On the basis of the Table it can be established that the most incendive gases of those classified into groups I and IIC are the representative gases of the group, i.e. the methane and the hydrogen. The MESG value (g_0 [mm]) of the representative gas of group IIA (propane) does not considerably differ from the MESG value (g_0 = 0,9 mm) characteristic of the group.

The situation is considerably different in case of the representative gas of group IIB, the ethylene. The MESG g_0 value of ethylene is 0,65 mm, while the MESG g_0 value characteristic of the group is 0,5 mm. The safety factor is the ratio of the lowest MESG g_0 limit value characteristic of the gas group and the MESG g_0 value of the test gas – in this case ethylene.

Thus, so that the ratio, similarly to the other groups, be K = 1, the supplementary safety factor of $\frac{0,65}{0,5}$ = 1,3 should be applied. Consequently, the safety factor concerning the ethylene as the representative gas is: K = 1.3 × 1.5 = 1.95. Accordingly, the test gases covered by Table 3 are to be applied in gas groups I, IIA and IIB.

Group	Gas	g_0	g_{100}	Mixture with K = 1.5 (g_{100})
I	Methane	$\frac{1.14}{1.5}$ = 760 µm	$\frac{1.25}{1.5}$ = 833 µm	8.25 v/v% C_2H_4
IIA	Propane	$\frac{0.92}{1.5}$ = 613 µm	$\frac{0.95}{1.5}$ = 633 µm	54.3 v/v% H_2*
IIB	Ethylene	$\frac{0.65}{1.95}$ = 333 µm	$\frac{0.67}{1.95}$ = 343 µm	21 v/v% H_2 or 34.3 v/v % H_2

Table 3
Test gases with the application of the K = 1.5 safety factor
(The relevant curves are covered by the Appendices)

Note: The values of the g_0 or g_{100} data, containing the K = 1.5 safety factor, indicated in tables 3, 5 and 6 are correct, however the safety factor can refer at the same time only to g_{100} or to g_0. The other value can be determined during the tests made with the application of the given gas concentration.
During experimental resp. testing processes it is more practicable to apply g_{100} since g_0 cannot be obtained without getting flame transmission. This is the reason why the curves cover the g_{100} data.

The relevant IEC resp. EN standards contain the following requirements.

„The explosive mixtures to be used, in volumetric ratio with air and at atmospheric pressure, are as follows:
– electrical apparatus of Group I: (12,5 ± 0,5) % methane-hydrogen
[(58 ± 1) % methane and (42 ± 1) % hydrogen]
(MESG = 0,8 mm)
– electrical apparatus of Group IIA: (55 ± 0,5) % hydrogen (MESG = 0,65 mm)
– electrical apparatus of Group IIB: (37 ± 0,5) % hydrogen (MESG = 0,35 mm)
NOTE: The explosive mixtures chosen for this test ensure that the joints prevent the transmission of an internal ignition, with a known margin of safety. This margin of safety, K, is the ratio of the maximum experimental safe gap of the representative gas of the Group concerned to the maximum experimental safe gap of the chosen test gas:

– electrical apparatus of Group I: $K = \frac{1,14}{0,8} = 1,42$ (methane),

– electrical apparatus of Group IIA: $K = \frac{0,92}{0,65} = 1,42$ (propane),

– electrical apparatus of Group IIB: $K = \frac{0,65}{0,35} = 1,85$ (ethylene)."

Note: Strictly speaking there is no MESG value. There are always two values:

g_0 – widest gap for 0 % probability of ignition
g_{100} – narrowest gap for 100 % probability of ignition

On the basis of the numerical data it follows that in principle it is the MESG g_0 values that are in question, in case of which the safety factor is K = 1.42. The IEC-EN resp. BKI comparison of the MESG g_0 values gives the following Table:

Group	g_0 IEC-EN K = 1.42 mm	g_0 IEC-EN K = 1.5 mm	g_0 BKI K = 1.5 mm
I	0.8	0.75	0.76
IIA	0.65	0.61	0.61
IIB	0.35	0.32	0.33

Table 4
Comparison of the IEC-EN resp. BKI MESG g_0 values

The Table shows that the divergence of the obtained values is within the tolerance limits.

The comparison of the applied concentrations is covered by Table 5 (K = 1.5).

Group	Gas IEC-EN	Gas BKI
I	(12.5±0.5) % methane-hydrogen (58±1) % methane and (42±1) hydrogen (MESG = 0.8 mm)	8.25 v/v% ethylene g_0 = 760 µm, g_{100} = 833 µm
IIA	(55±0.5) % hydrogen (MESG = 0.65 mm)	54.3 v/v% hydrogen g_0 = 613 µm, g_{100} = 630 µm
IIB	(37±0.5) % hydrogen (MESG = 0.35 mm)	21 v/v% hydrogen 34.3 v/v% hydrogen g_0 = 333 µm, g_{100} = 343 µm

Table 5
Comparison of the IEC-EN resp. BKI test gas concentrations

Notes:

a. Group I. On the basis of the tests performed by us the MESG values of the IEC-EN gas-air mixture are: g_0 = 810 µm, g_{100} = 840 µm, which practically correspond with the parameters of the BKI mixture.

b. Group IIA. Quite identical

c. Group IIB. If BKI 34,3 v/v% hydrogen mixture is considered, the divergence is not too significant.

4. Electrical apparatus of Group IIC

IEC-EN requirement:
„The enclosure and the test chamber are filled with one of the gas mixtures specified for the first method at a pressure equal to 1.5 times atmospheric pressure."

The tests performed by us (BKI) resulted in diverging (more severe) test conditions (Precompression factor P_k = 2).

In case of hydrogen: g_{100} = 300 µm. (K = 1)

In case of K = 1.5 safety factor: $g_{100} = \dfrac{300\ \mu m}{1.5} = 200\ \mu m$ according to Table 4.

Group	Gas	g_0	g_{100}	Mixture with K = 1.5 (g_{100}) (Pressure = 2 bar)
IIC	Hydrogen	$\dfrac{290\mu m}{1.5} = 193\mu m$	$\dfrac{300\mu m}{1.5} = 200\ \mu m$	16.5 v/v% H_2 or 33 v/v % H_2

Table 6
Test of apparatus IIC (BKI method)
MESG values are obtained from curve MESG versus v/v % Hydrogen

5. The alternative method: Increasing the precompression factors

In this case it must be taken into consideration that the precompression does not show linear relation with the increase of the flame transmission capability.

The flame transmission capability of gases-vapours will increase as soon as the precompression increases. The starting pressure is the p_0 parameter. The relation is true also in case of the representative gases, which is shown by the data of the attached table. We carried out the test with the application of p_0 = 1000 mbar and p_0 = 1500 mbar pressure and a temperature of

$$T = 293\,^{+2}_{-0}\ K$$

Interpretation of K_0 and K_{100} indicated in the table is as follows:

$$K_0 = \frac{g_0(1000mbar)}{g_0(1500mbar)} \qquad K_{100} = \frac{g_{100}(1000mbar)}{g_{100}(1500mbar)}$$

Group	Gas		Most in-cendive mixture vol. %	MESG (mm)		g_{100}-g_0 (mm)	K_0	K_{100}
				g_0	g_{100}			
I	CH_4	Methane	8,2±0,05	0,850	0,930	0,080	1,341	1,344
IIA	C_3H_8	Propane	4,2±0,15	0,675	0,700	0,025	1,363	1,357
IIB	C_2H_4	Ethylene	6,5±0,20	0,475	0,430	0,015	1,368	1,367
IIC	H_2	Hydrogen	27 + 0,50 - 0,00	0,200	0,210	0,010	1,450	1,428

Table 6

Safety factors versus precompression factors = 1.5 for representative gases

To obtain the necessary K = 1.5 safety factor the static pressure should be increased further on. But application of this method is limited. The maximum peak pressure obtained by flame transmission test should be below the appropriate values of explosion tests.

The Table 7 shows the maximum explosion pressure for representative gases (mixtures), measured in a chamber of volume 5 dm^3 (spherical or cylindrical where L = D).

Representative gases	Mixtures for maximum pressure v/v %	Maximum peak pressure P_m (bar)
Methane	9.8	7.2
Propane	4.6	8.6
Ethylene	8.0	8.9
Hydrogen	31.0	7.4
Acetylene	14.0	10.3

Table 7

Maximum explosion pressure P_m of explosion tests (Volume 5 dm^3, initial pressure 1 bar)
The maximum explosion pressures with increased precompression factor obtained by most incendive mixtures (flame transmission) should be not higher than the appropriate pressures for explosion tests measured in the same chamber.

As for Hydrogen + air mixture 27 v/v % (see Table 6) applying a precompression factor $P_{pr.}$ = 2 the maximum pressure (worst case)

a) Flame transmission test $P_m < 2 \times 7.4$ bar = 14.8 bar (see Table 7)

at the other hand

b) Explosion test

$$P_m = 1.5 \times 10.3 \text{ bar} = 15.45 \text{ bar}$$

(Taking into account that for Group IIC the representative gas is Acetylene).
The precompression factor for H_2 + air mixture may be applied.

6. Flame transmission test for Group I

As it was already mentioned the explosive mixture given in IEC 60079-1 for electrical apparatus of Group I is (12,5 ± 0.5) % methane – hydrogen [(58 ± 1)% methane and (42 ± 1) hydrogen] (MESG = 0.8 mm).
It was carried out a series of test to compare the explosion parameters of the mixture given in the standard (see above) and the mixture proposed by BKI (8.25 vol. % C_2H_4 + air).
The results are as follows:

a) Flame transmission capability

Both mixtures produce about the same flame transmission capability. Safety factor K = 1.5 MESG g_{100} = 833 µm.

b) Maximum explosion pressures and pressure increase

Table 7 shows the maximum explosion pressures and pressure increases for the IEC and BKI mixtures.
The BKI mixture (8.25 vol. % C_2H_4 + air) produces higher values in both cases.

<table>
<tr><td colspan="4">Test mixtures:</td></tr>
<tr><td colspan="2">IEC</td><td colspan="2">BKI</td></tr>
<tr><td colspan="2">(12.5 ± 0.5) % methane-hydrogen
[(58 ± 1)% methane and (42 ± 1) % hydrogen] + air</td><td colspan="2" rowspan="2">8.25 vol.% C_2H_4 + air</td></tr>
<tr><td colspan="2">7.2 vol. % CH_4 + 5.25 vol. % H_2 + air</td></tr>
<tr><td>$P_{max.}$</td><td>dp / dt</td><td>$P_{max.}$</td><td>dp /dt</td></tr>
<tr><td>6.66 bar</td><td>622 bar/s</td><td>8.46 bar</td><td>1202 bar/s</td></tr>
</table>

Table 8

Comparison of the measurement data (P_m and dp / dt) for Group I (K = 1.5, MESG g_{100} = 833 µm.

Note: The explosion curves are attached in the Annexes.

7. Inaccuracy of the mixtures for flame transmission tests

Table 9 shows the influence of the inaccuracy of the mixtures for the MESG values.

Group	Test mixtures (IEC 60079-1 EN 50018) (v/v %)	Concentration (v/v 5)	MESG g_0 (µm)	$\Delta\ g_0$
I	(12,5 ± 0,5) v/v % Methane, hydrogen (58 ± 1) v/v % methane and (42 ± 1) v/v % hydrogen	12.5 * 12.0 13.0	833 no data	no data
IIA	Hydrogen 55 ± 0.5	55.0* 54.5 55.5	650 620 680	- 60
IIB	Hydrogen 37 ± 0.5	37.0 * 36.5 37.5	350 348 355	- 7
IIC	Hydrogen (28 ± 1) at 2 bar	28.0* 27.0 29.0	295 290 300	- 10

Table 9

Concentrations versus MESG g_0 values

Note:

a) * Exact value, required by standard

b) Explosion mixture for Group I containing two flammable gases cannot be measured with the adequate accuracy.

c) The difference $\Delta g = g_{100} - g_0 = 300\ \mu m - 290\ \mu m = 10\ \mu m$ for the most incendive mixture of H_2, taking into account that equipment of Groups IIA, IIB and IIC tested by H_2, $\Delta\ g_0$ should be less than 10 µm.

8. <u>New method proposed for testing flame transmission</u>
Starting from the fact that MESG always means two values MESG g_0 and MESG g_{100}, it is obvious to apply the following test process.

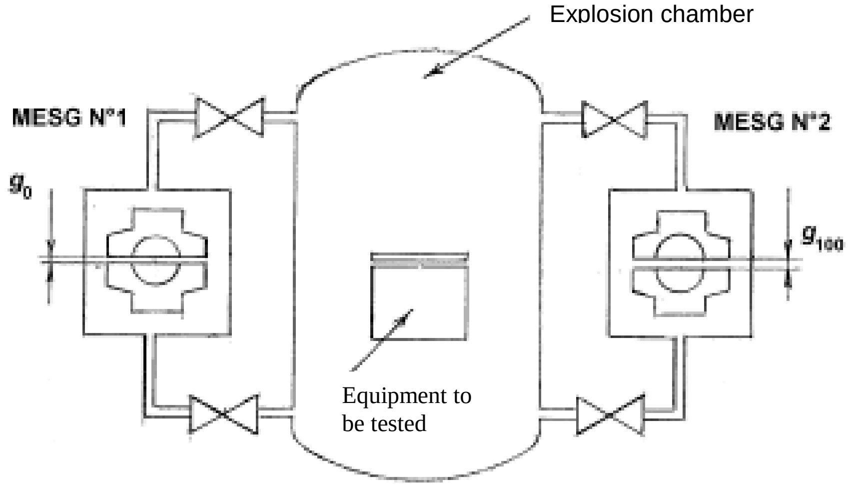

Figure No. 1

The gas - air mixture shall be checked as follows:

MESG No. 1 (g_0)	Ignition in internal chamber	Yes
	Ignition in external chamber	No
MESG No. 2 (g_{100})	Ignition in internal chamber	Yes
	Ignition in external chamber	Yes

The MESG g_0 and MESG g_{100} values should be taken from Table 5 and Table 6.

2) For the practical (routine) tests the following layout is adequate (Figure No. 2)

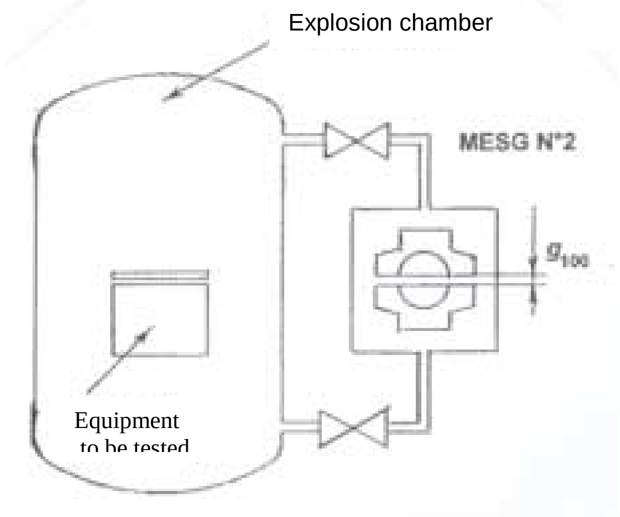

Figure No. 2

Condition of the successful test:

MESG No. 2 (g_{100})	Ignition in internal chamber	Yes
	Ignition in external chamber	Yes

The practical layout of the test is shown by Figures 3 – 4 – 5.

Note: Due to the fact that though in principle the construction of the apparatus described in IEC 79-1A is correct, it is not suitable for performing series of experiments, basically caused by the vapour and combustion products remaining in the internal space due to the explosion performed therein, which require rather long period to be cleared out.

The 1st generation apparatus developed by us is a considerably better one in this respect, however, due to its manual control, it is still not the optimal one for performing series of tests.

Due to the incorporated microprocessor control, the newest, 2nd generation apparatus automatically increases the gap between the two hemispheres (5 mm) following each explosion occurred in the internal (external) space, then makes purging, fills the apparatus with the appropriate gas-air mixture and automatically sets the originally adjusted MESG (g_0 or g_{100}) value. Thus it enables to perform considerably better and quicker tests.

9. Application of gasanalysers instead of MESG apparatus

A question presents itself, whether gas analysers can be applied instead of the MESG apparatuses. Naturally, in principle the answer is yes. During the experiments performed by us we compared the test results obtained by the MESG process with those obtained with the application of the following measuring devices as far as the accuracy, the reproducibility and the measuring uncertainty were concerned.

We applied the following gas analysers:

1. Servomex 1100 A
   Oxygen analyser
2. ABB H+B Uras 14 Infrared analyser (Developed by ABB and BKI for
   Methane
   Propane
   Ethylene
   Acetylene)
3. Sieger Ltd Searchpoint optima Infrared analyser for Methane, Propane, Ethylene
4. ABB Caldos 17
   Thermal conductivity analyser for Methane and Hydrogen.

For the MESG calibration the gas mixer of high accuracy was a basic device (otherwise called Gas Calibration Unit).

On the basis of the performed comparison it was established as follows:

a) MESG apparatus
  - it actually determines the property of gas-air mixtures (flame transmission capability) that is essential in respect of the physical phenomena
  - due to its sturdy construction it offers a higher mechanical reliability, which is an important factor in a Exd laboratory
  - its measuring accuracy (the determination of the flame transmission capability) repeatability is better than of any gasanalyser mentioned above.

b) Gasanalysers can determine the property of gas-air mixtures (flame transmission capability) only in indirect way.

On the basis of the performed comparison it was established that due to the laboratory design of the mentioned gas analysers, the frequency of the required recalibration, the MESG process offers higher accuracy, reproducibility and a smaller measuring uncertainty. However, in case the gas analysers meet the requirements against measuring technique (inaccuracy should be within the required tolerance), their application cannot be excluded.

10. Summary

1. On the basis of the performed development works, experiments and tests we are of the opinion that it is the test method and requirement based on the flame transmission capability of the gas-air mixtures that should be considered as the basic one (first method), in case the relation $0.9\ I_C \le I_E \le I_C$ is met. Originally, this was the intention also of those creating the standard (See Publication 79-1-1971-1975-1979).

   The implementation of quality assurance systems of the manufacturers has the effect of achieving the stipulated production parameters (gap sizes) with much smaller tolerances than previously.

   In theoretical point of view the increasing of the flame transmission capability of the gas-air mixture is unambiguous, in practical aspect it meets the requirements against the test results.

   According to our opinion this process can be applied with such a general character as the explosion test.

2. The safety factor (K) obtained in case of the tests for non-transmission of an internal ignition performed by increasing the gap size of the given product, depends on the shape and form of the enclosure. Having a safety factor K = 1.5 obtained by test method described above (Summary p. 1), the test procedure performed by increasing the gap size of given enclosures can produce safety factors K = 1.1 – 2.8 for the same enclosure.

Its accurate value cannot be determined, or can be determined with difficulties only, thus, it is practicable to be used as a test process only if the non-applicability of the first method is well-founded.

The restriction under point Summary 2 is true to a greater extent to the test processes, covered by the standard, based on an agreement between the testing-certifying body and the manufacturer. It is obvious that test method applying the increase of gap of a given enclosure may be used only if it is proved that the test results the same safety factor as using the MESG method.

3. The MESG value should be specified in the standard correctly (either g_0 or g_{100}). For the test procedure it is preferable to prescribe the necessary MESG g_{100} value, since the MESG g_0 value cannot be determined without flame transmission (see point 3).

4. For flame transmission test for Group I a 8.25 v/v % ethylene-air mixture is preferable against the (12.5 $\pm$ 5) v/v % methane-hydrogen [(58 $\pm$ 1) % methane and (42 $\pm$ 1) % hydrogen]. This mixture shall be deleted (see p. 6).

5. For flame transmission test for Group IIC a precompression factor should be used (see p. 4). Application of this test procedure for Groups I, IIA, IIB is not preferable, since the maximum peak pressure obtained by flame transmission test should always be below the appropriate values of explosion tests (see p. 5).

6. The optimum flame transmission test arrangement shall be made in accordance with Fig. 1 applying the data of Table 5 and 6.

7. Substitution of MESG apparatus by gasanalysers if their inaccuracy is within the required tolerance (see p. 9).

Finally: It is not the direct modification of the standard the present material is aimed at, but the elaboration of a test process and methods, and the making of certain technical questions unambiguous. We trust that by means of our work we succeeded in contributing to the development of the technical background, which will be favourably received on the part of IEC ExTAG. We would be pleased if this initiation of ours would continue to be developed (co-ordinated) in the frame of ExTAG or one of the working groups (WG). Naturally, on our part we will do our utmost for the success of the same.

Budapest, 21st September 2001