

Reflections on the procedures for testing the protective effect of Personal Safety Equipment against the effects of arcing

Dr.-Ing. Dirk Borneburg, Dipl.-Ing. Holger Walter, RWE Eurotest GmbH, Germany
Dr.-Ing. Frank Wachholz, Dipl.-Ing. Jürgen Vogler, IPH Berlin GmbH, Germany
Dr., Dipl.Ing. Helmut Eichinger, DuPont International Operations Sàrl, Switzerland

Abstract:

Persons working in the vicinity of or at energised parts of electrical systems need to be protected against the effects of possible electric arcing. All such work needs, first of all, to be subjected to a risk analysis, and the best possible technical and organisational safety systems should be used in order to reduce the risk as low as possible. Only in the last instance should protection be provided by Personal Safety Equipment in the form of protective clothing.

There are currently four different electric arc test procedures used in Germany to check the suitability of Personal Safety Equipment; and the procedures differ with regard to test structure, electrical parameters and evaluation criteria. Only two of these procedures are linked to standards (see Procedures 2.1, 2.2). Out of the two remaining procedures, one is linked to test specifications (see Procedure 2.3), the other determined in the procedure itself (see Procedure 2.4). As a result, the member of staff responsible, according to the German Safety at Work Act (Arbeitsschutzgesetz) §5 [1], for evaluating the work-related dangers for employees, the users and also the manufacturers of protective clothing find themselves faced with a profusion of testing procedures that some find difficult to understand. In particular, the procedures of interpreting the test parameters and their relationship to the parameters at the actual place of work pose a problem for many.

To clarify this unsatisfactory state of affairs, the four different procedures, their scope and implementation are described and compared below. The influence of individual test parameters is shown by means of examples. Based on the results as well as the knowledge gained from many years of test practice and occurrences of damage, deductions are made regarding the tests and their documentation. Finally, starting points as well as notes for further testing are given.

1. Introduction

The following test procedures are available for electric arc testing: procedures according to standards include DIN IEC 61482-1-1, Draft VDE 0682-306-1-1:2006-06 ("Open Arc Test")¹ [2] and DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12 ("Box Test") [3]. DIN IEC 61482-2, Draft VDE0682-306-2:2006-06 contains performance specifications for protective clothing tested according to one of the two procedures. Not contained in standards is the test procedure PIP001 [4] of RWE Eurotest GmbH or the IPH-test procedure [5] of IPH Berlin GmbH.

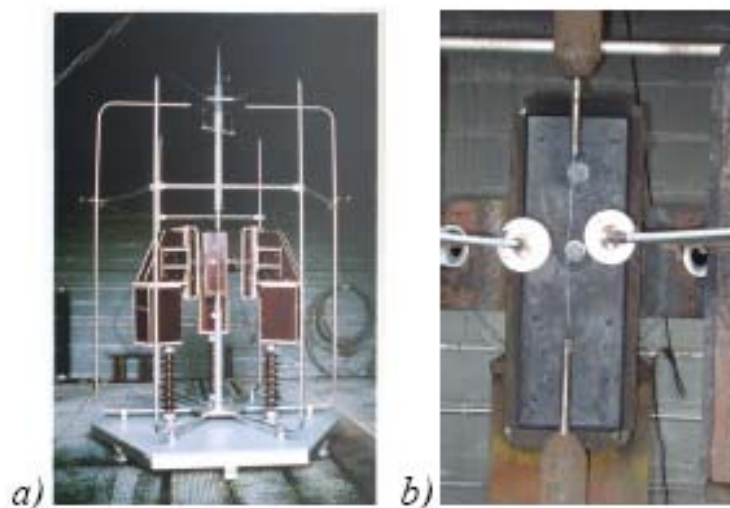
¹ The draft standard IEC 61482-1-1/CDV, essentially the same as ASTM F 1959-99, is the revision of IEC 61482-1:2002, essentially the same as ASTM F 1959-05. Tests according to IEC 61482-1:2002 and IEC 61482-1-1/CDV are carried out either by Kinectrics, Toronto, Canada or by DuPont International Operations Sàrl, Geneva, Switzerland, in co-operation with CEF, Morges, Switzerland

The individual procedures differ not only in the structure of the tests, the electrical parameters and the evaluation procedures, but also in their applicability to certain products. The procedures are, for example, designed in part for the testing of both materials and protective clothing, but in part also only for the testing of protective clothing. None of the four procedures are currently designed for the single testing of gloves or face protection equipment². In all cases a prospective short circuit current of defined strength is created with short-circuited electrodes. The ignition of the arcing is caused by the short-circuiting of the electrodes by means of a thin ignition wire. The arcing current that occurs during the test is weaker than the prospective short circuit current and displays non-linear behaviour and a time-dependent resistance. Also, all the procedures have in common a visual evaluation of the test object. In three procedures (2.1, 2.2, 2.3) the heat energy affecting the human being is also determined by calorimetric measurement, and conclusions can be drawn about possible second-degree burns.

2. Procedures for electric arc testing

2.1 DIN IEC 61482-1-1, Draft VDE 0682-306-1-1:2006-06 ("Open Arc Test")

The test procedure according to DIN IEC 61482-1-1, Draft VDE 0682-306-1-1:2006-06 is known as the "Open Arc Test" or DuPont^{TM3} ArcManTM testing structure of DuPont. This is a coaxial, single-phase testing arrangement as shown in Picture 1. The electric arc is ignited between two stainless steel electrodes at a distance of 30 mm to 300 mm in the centre of the arrangement. Aluminium or copper electrodes can also be used, for example to investigate the effects of hot particles and splashes of metal. The prospective short circuit current can be set between 1 kA and 20 kA. The test voltage must be sufficient to sustain an electric arc across the distance between the electrodes in each case (typically between 400 V and 700 V). The spark duration of the arc is used to vary the effective energy on the surface of the material to be tested or the protective clothing (typically between 200 ms and 2000 ms).



Picture 1: Test structure in accordance with DIN IEC 61482-1-1, Draft VDE 0682-306-1-1:2006-06.

² IEC 61482-1 or IEC 61482-1-1/CDV, both essentially the same as ASTM F 1959-99 and ASTM F 1959-05, may with the addition of a test head be upgraded to a test procedure for facial protection in compliance with ASTM F 2178-02.

³ DuPontTM and Arc-Man are trademarks or registered trademarks of DuPont or its subsidiary companies.

Three test support bodies are placed around the two electrodes arranged at an angle of 120°. For testing materials, corresponding samples are arranged on vertical plates measuring 550 mm x 200 mm, into which the two calorimeters, as shown in Picture 1b, have been installed. The plates are adjusted to a distance of 200 mm to 600 mm from the two electrodes. 300 mm is customary. Next to the plates on either side is a further calorimeter, which is exposed directly to the electric arc. The calorimeters directly exposed to the electric arc measure the actual effective energy. In order to determine the ATPV (Arc Thermal Performance) value according to the standard, the electric arc current shall be 8 kA, the distance between the two stainless steel electrodes 300 mm, the distance from the arc to the surface of the test body 300 mm. The ATPV will give the total calorimetric value, i. e. the incident energy (kW·s/m²), below which the material will give protection from second-degree burns. The characteristic ATPV for each sample of material is calculated from the measured calorimetric values of the directly exposed calorimeters and the calorimeters covered by material samples, in tests with differing arcing times of the electric arc. In order to be able not only to calculate an ATPV, but also confidence intervals around the ATPV values, statistical analysis has shown that at least 20 samples of material need to be tested, which means at least 7 electric arc firings need to be carried out. A further requirement is that when the material samples are affected with effective energy in the range of the ATPV, there is no afterburn lasting for more than 5 s and the material does not break open all the way through.

Instead of materials being tested, the complete protective garment or combinations of protective garments can be tested. In this case, up to three multi-sensor dummies are to be used and these are also to be arranged at angles of at least 120°. Each dummy has four thermosensors. In addition, one thermosensor will be placed on either side of the dummy. Dummies to be used are male dummy torsos in size L with a chest measurement of (1067 ±25) mm, consisting of a non-conducting glass fibre structure with synthetic resin resistant to high temperatures or made of other, non-conducting, flame-retardant, high temperature resistant materials. The dummy is positioned upright, so that at breast height the test body is at the shortest distance to the mid-line of the electric arc. The test dummy can be supplemented with a test head that has thermosensors in the eye, mouth and chin area, in order to enable facial protection testing in accordance with ASTM F2178-02 [6].

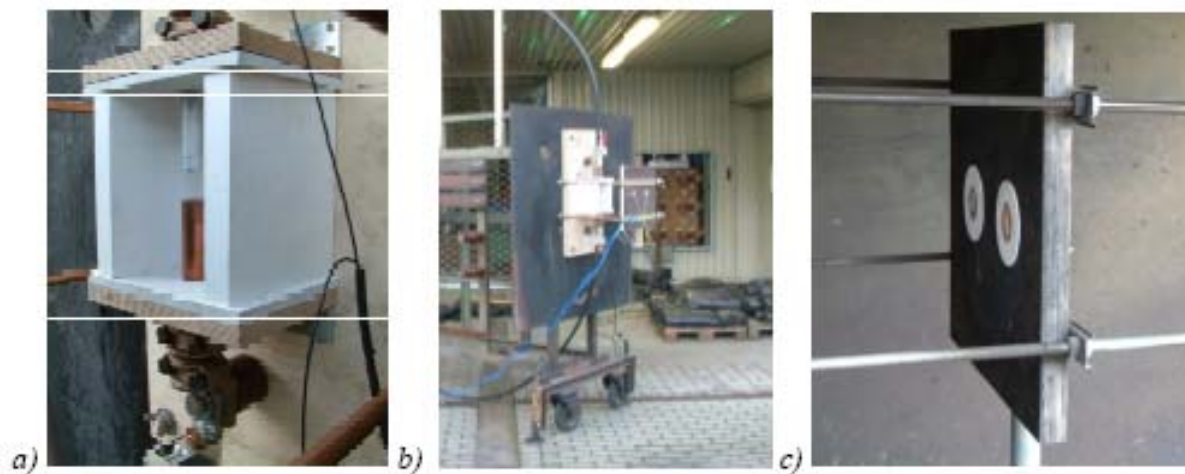
The ATPV of clothing could in principle also be tested by testing the clothing with the test dummy. This however would be more expensive, as for statistical reasons at least 20 samples of clothing would have to be used, and it is also difficult to avoid that air layers between the clothing and dummy would falsify the test results, i.e. stipulate an increased ATPV. Therefore according to the standard, the ATPV of a garment shall be determined by first determining the ATPV of the material system and then carrying out a test on the clothing made from this material at an effective energy equal to the ATPV. In this last case, attention is primarily paid to the total behaviour of the clothing, for instance whether the garments are easy to open after testing.

In order to comply with DIN IEC 61482-2, Draft VDE0682-306-2:2006-06 [7] the ATPV of material must be at least 4 cal/cm² and the clothing made from it must pass the visual "Open Arc Test" to allow clothing made from this material to be termed "Clothing for protection against the thermal effects of electric arcing" (or the material and clothing must at least pass Class 1 of the "Box Test" (see Section 2.2)). NFPA 70E defines four Hazard/Risk Classes (HRC) for work on energised equipment, according to incident energy (HRC Class 1 to 4).

With the aid of ATPV values the employee can make a qualitative assignment of appropriate Personal Safety Equipment for the incident energy risks that have been determined from the risk analysis. The levels of incident energy that may occur during his/her work on energised equipment (e.g. into what Hazard/Risk Class this work would fall) could, for example, be determined by calculations in accordance with IEEE 1584 [8]. The appropriate protective clothing or combination of protective clothing with an ATPV above the incident energy level determined by the risk analysis can then be selected.

2.2 DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12 ("Box Test")

In the "Box Test" in accordance with DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12, a single phase test structure, as shown in Picture 2, is used. This structure consists of a vertical arrangement of a pair of electrodes between which the arc is ignited. The open circuit voltage is 400 V (50 Hz) and the distance between the electrodes is 30 mm, with an aluminium upper electrode and a copper lower electrode. Both electrodes have a blind hole, in order to create a stable arc for a period of 500 ms. The two electrodes are arranged in a parabola-shaped gypsum box, enclosing the electrode space on three sides and closed at the top and bottom by an insulating plate. The arc emission and the heat flow are focused and are meant to correspond to maximum or extreme effects under the relevant conditions. The test takes account not only of the directed effect of heat, but also the effect of hot metal particles and splashes that accompany actual electric arc faults. According to the standard, a choice can be made between two levels of testing. These levels of testing differ only in the strength of the prospective short circuit current (Class 1: 4 kA, 500 ms, Class 2: 7 kA, 500 ms). The degree of testing should be selected according to the risk assessment and the subsequent deployment of protective clothing.



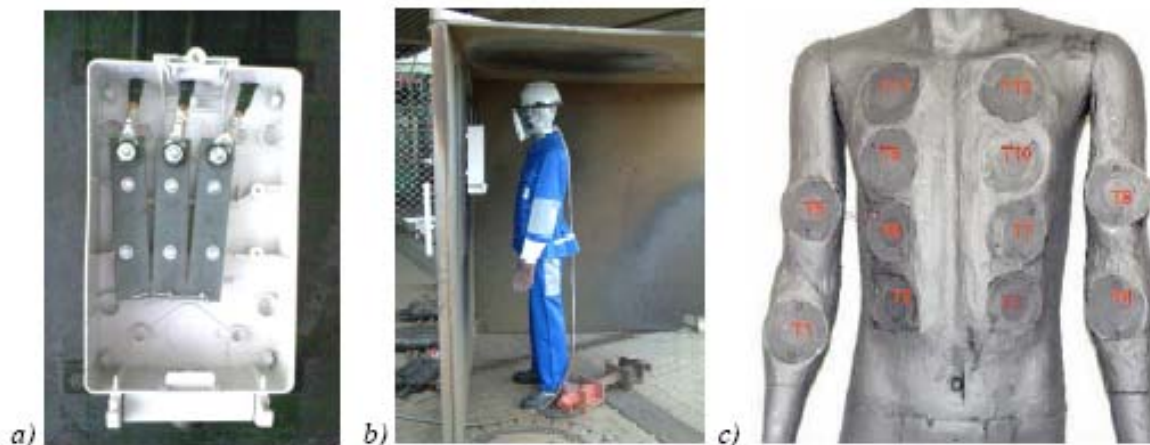
Picture 2: Test structure in accordance with DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12.

A vertical plate measuring 400 mm x 400 mm, is placed opposite the opening, and two calorimeters are set in this plate as shown in Picture 2c. The materials to be evaluated are fixed on the plate to cover the calorimeters and arranged at a horizontal distance of 300 mm from the pair of electrodes. The heat flow density response from the calorimeters is used to judge whether the wearer of clothing made from this material would have suffered second-degree burns. A further requirement is that there is no afterburn lasting for more than 5 s and that the burn does not penetrate all the way through the material. In addition, a dummy torso may be used, placed at a distance of 300 mm from the two electrodes, instead of the vertical plate. In this case, the finished clothing is evaluated purely visually. There is no calorimetric measurement; attention is

paid to the total behaviour of the clothing, whether for example the clothing can be opened easily after testing. To comply with DIN IEC 61482-2, Draft VDE0682-306-2:2006-06, a material and the clothes made from it must at least pass Class 1 of the "Box Test" in order for clothing from this material to be termed "Clothing for protection against thermal effects of electric arcing" (or the material must at least have an ATPV of 4 cal/cm² and the clothing made from it must pass the "Open Arc Test" (see Section 2.1)).

2.3 PIP001 as per RWE Eurotest GmbH

The RWE Eurotest GmbH three-pole test procedure as shown in Picture 3 is used to qualify ready-made protective clothing. For the test, a KH 00 100-A service connection box, in accordance with DIN 43627 with a structural design in accordance with DIN VDE 0660-505 and with three busbars of hot-rolled flat steel measuring 40 mm x 5 mm tapered to conical ends, DIN 1017-Ust 37-2, is used. The lower gap between the electrodes in this case is 5 mm maximum. The lid of the service connection box is removed for the test. The test structure is set up in a replica of a room corner with structures of non-combustible material for the front and side wall and its upper covering. The open circuit voltage is 400 V (50 Hz) and the prospective short circuit current is 10 kA; in each phase the strength of current must be maintained between 0 % to +5 %. The duration of the current flow is generally 1000 ms. In this test, the arc emission and the heat flow are also focused and correspond to maximum or extreme effects under the relevant conditions. The test takes account not only of the directed effect of heat, but also the effect of hot metal particles and splashes that accompany actual electric arc faults.



Picture 3: Test structure in accordance with RWE Eurotest PIP001.

A dummy measuring 176 to 186 cm, is used for the test. It is made from non-combustible material and equipped in the upper body region with 6 to 8 calorimeters and 2 calorimeters on each arm for measuring heat flow intensity. The completely clothed test dummy is placed at a horizontal distance of 300 mm from the electrodes in front of the service connection box. The heat flow densities determined are used to judge whether the wearer of the clothing would have suffered second-degree burns.

There is also a visual evaluation of the protective clothing according to the following criteria:

- No afterburn lasting longer than 5 s
- No penetration all the way through larger than 10 mm
- Opening of clothing possible
- No density of heat flow that could lead to second-degree burns

There is no provision for the evaluation of material samples in this test, but it is simple to put into practice analogous to the "Box Test" in accordance with DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12 [9].

2.4 IPH test procedure

Electric arcs corresponding to Pictures 4a and 4b are to be used in the three-pole test structures according to IPH test procedures. The test structure shown in Picture 4a is intended to replicate low voltage switchgear and put into practice a total test of Personal Safety Equipment. In order to avoid a number of identical test provisions, the 660 V voltage level has been set as the reference value. The open circuit voltage for the three-pole test is 726 V with a variable prospective short circuit current of 1 kA to 50 kA for effective periods of 0.1 s to 5 s. The aim of the tests is to determine the maximum values for current and effective period up to which the tested Personal Safety Equipment meets the visual evaluation criteria. At present the tests typically carried out are on individual test bodies using the simplified structure as per Picture 4b, at currents of 7, 10 or 15 kA and effective periods of 0.5 or 1 s.



Picture 4: Test structure as per IPH Procedure.

In a control panel as shown in Picture 4a, measuring 2000 mm x 800 mm x 800 mm, with busbar at the top, an arc is to be ignited at three points at the distribution bar, in front of the grid to which the material to be tested has been fastened or in front of the dummy clothed in the Personal Safety Equipment. The distance from the grid or the surface of the dummy is 500 mm. The uppermost Position A is mainly to test the protection offered by the face protection and the jacket, the middle Position B the jacket and gauntlet with outstretched arm in a working position and the lowest Position C the trousers and jacket. It is important that the dummy is clad in the complete clothing combination (Personal Safety Equipment) for each part of the test, as it is known that the flammable and protective behaviour of the individual material differs to some extent in combination from the behaviour in individual tests. In this test, the arc emission and the heat flow are also focused and correspond to maximum or extreme effects under the relevant

conditions. The test takes account not only of the directed effect of heat, but also the effect of hot metal particles and splashes that accompany actual electric arc faults. The effects of ageing on the clothing are to be taken into account using new clothing, clothing industrially washed 5 times and clothing industrially washed 25 times being tested in the same test parameter combination. It follows that for a test result for a particular value of arc current and arc duration, at least 9 tests with complete sets of Personal Safety Equipment must be carried out. At present, to simplify the testing, a box as shown in Picture 4b is used for testing currents up to 15 kA, which on each occasion is placed in the required position opposite the material sample or the clothed test dummy. In certain ways, these test results are also intended to be transferable to fuseboxes and service connection boxes.

The only set evaluation criteria are visual criteria. In addition, white, long cotton underclothing is used as an indicator for burns. No afterburning of the test objects is allowed in the tests. There is at present no measurement of heat flow.

3. Comparison of procedures

In none of the four procedures does the electrode arrangement represent the true reality, particularly the variety of arrangements in which electric arcing can occur in practice. In procedures 2.1 and 2.2 arcing occurs between the ends of two electrode rods placed opposite one another. In procedure 2.1 (if the APTV is being determined) and 2.3, the electrodes are made of steel because steel melts less quickly than aluminium or copper, thus allow for a more constant electrode gap during each electric arc test shot, thus more constant energy of the electric arc and incident energy onto the material test samples during each electric arc test shot, and also more repeatable energy values for subsequent test shots. In procedure 2.2 one electrode rod is made of aluminium and the other of copper; the rapid melting of the electrodes affects the stability of the electric arc during each electric arc test shot, and impairs also repeatability over different test rounds. In procedure 2.4 the electrodes are made of copper bars. The metallic material and even more the shape and size of the box in procedure version 2.4.b) have a significant effect on the intensity and behaviour of the arc. It is also important in procedures 2.3 and 2.4.a) or 2.4.b) that the three conductor electrodes are directed conically towards one another; in a parallel arrangement more closely resembling reality the electric arcs tend to extinguish quicker of their own accord rather than burning for the entire test period. With procedures 2.4.a) and b) the question arises moreover whether it makes sense to try to test protective clothing against this electrode arrangement and with arc currents up to 50 kA. If three conductors are directed straight at the worker as in both versions of procedure 2.4 and moreover if, by attaching the mannequin, the situation is simulated whereby, for structural reasons, the worker cannot be flung across the room by the pressure wave, then it would be better not to carry out live working; the strong pressure wave alone would most probably lead to critical or even fatal internal injuries. It does not therefore appear to make sense in general to test the performance of protective clothing under extreme test conditions above levels at which in reality live working should not be carried out. Instead the technical and organisational options should be thoroughly explored to the extent that personal protective equipment is only required to protect against risk which has been reduced to a minimum.

The following table 1 compares the parameters of the test set-ups and also the specifications for testing material and clothing for the four test procedures.

Test procedure	“Open arc test” VDE 0682-306-1-1 (IEC 61482-1, IEC 61482-1-1/CDV)	“Box test” VDE 0682-306-1-2 (IEC 61482-1-2)	RWE Eurotest PIP001	IPH In preparation
Electric arc	Open	Directed	Directed	Directed
Phase	Single phase	Single phase	Triple phase	Triple phase
Voltage	Between 400 and 750 V	400 V	400 V	726 V
Current	1-20 kA; 8 kA for ATPV	Class 1: 4 kA Class 2: 7 kA	10 kA	1 kA up to 50 kA
Cos φ	No information	No information	No information	0.3 for $I < 5$ kA 0.2 for $I < 5$ kA
X/R	2.3	Recommended: 1 to 5	No information	No information
Time	200 ms up to 2000 ms	500 ms	1000 ms (500 ms)	100 ms up to 5000 ms
Electrodes	Aluminium, copper or stainless steel round rod 19 mm; stainless steel for ATPV	Aluminium (top) copper (bottom) round rod, 25 mm	Flat steel (40 x 5 mm), tapering	Copper bars (60x10 mm), tapering
Electrode spacing	between 30 and 300 mm; 300 mm for ATPV	30 mm	5 mm at the tip	50 mm
Distance from test specimen	200 to 600 mm; 300 mm for ATPV	300 mm	300 mm	500 mm
Ambient temperature	Up to 35 C°	15 C° up to 35 C°	15 C° up to 35 C°	10 up to 35 ° C
Relative ambient humidity	No information	25 % up to 75%	25 % up to 75%	25 % up to 60 %
Calorimetric data checked prior to testing	yes	yes	no	no
Electrical data checked prior to testing	yes	yes	yes	yes
Calorimeter calibrated	yes	yes	no	no
Material testing	yes	yes	no	yes
Number of test specimens	Min. 20 for ATPV plus confidence intervals	4 to 5 (not enough data for calculation of confidence intervals)		At least 9 (not enough data for calculation of confidence intervals)
Number of test shots	At least 7 (one on three samples)	4 to 5 (one per sample)		At least 9 (one per sample)
Test specimen pretreatment	Washed/cleaned 5 times	Washed/cleaned 5 times		New/washed 5 times/washed 25 times
Heat flux determined behind test specimen	yes	yes		no
... next to test specimen	yes	no		no
ATPV determined	yes	no		no
Arc energy determined	yes	yes		yes
Criteria	- after-flame time < 5 s - does not melt completely - no holes > 5 mm in innermost layer - no second-degree burns	- after-flame time < 5 s - does not melt completely - no holes > 5 mm in innermost layer - no second-degree burns		- no after-flame - does not melt completely - no holes > 3 mm in innermost layer - no burns in cotton underclothing
Clothing	yes	yes	yes	yes
Number of test specimens	At least 1 to 3	1	1	9
Number of test shots	At least 1	1	1	9
Test specimen pre-treatment	Washed/cleaned 5 times	Washed/cleaned 5 times	Washed/cleaned 40 times	New, washed 5 and 25 times
Heat flux determined behind test specimen	yes	no	yes	no
... next to test specimen	yes	no	no	no
ATPV determined	yes	no	no	no
Arc energy determined	yes	yes	yes	yes
Criteria	- after-flame time < 5 s - does not melt completely - no holes > 10 mm in innermost layer - possible to undo fasteners - no second-degree burns	- after-flame time < 5 s - does not melt completely - no holes > 5 mm in innermost layer - possible to undo fasteners	- after-flame time < 5 s - no holes > 10 mm in innermost layer - possible to undo fasteners - no second-degree burns	- no after-flame - does not melt completely - no holes > 3 mm in innermost layer - no burns in cotton underclothing

Table 1: Comparison of the parameters of the four different test procedures.

It quickly becomes clear from the table that it is not possible to make a direct comparison between the test results obtained by the different test methods for actual test specimen and for the assembled clothing. Some parameters are the same for all the procedures: e.g. the distance between the dummy and the electric arc in the three procedures 2.1, 2.2 and 2.3 is the same at

300 mm and the criteria for visual evaluation are similar for most of the procedures. The important parameter heat flux is only used as an evaluation criterion in the three procedures 2.1, 2.2 and 2.3 and not in procedure 2.4 however, which is surprising as, only on the basis of this parameter, can a statement be made on possible burns. Only in procedure 2.1 can the incident energy onto the test specimen measured directly during each test shot. In procedure 2.2 the incident energy is only measured once in an empty shot preceding the tests shots onto test samples. In the tripolar test procedure the energy of the arc is considered so reproducible from one test shot to another and, therefore, the resulting incident energy onto the test specimen as so constant that no direct measurements were recorded. Procedures 2.2, 2.3 and 2.4 are also not concerned with determining a value with regard to the actual incident energy, i.e. the ATPV of the material or the clothing, but with establishing whether one product withstands the particular test conditions of the test set-up or not (pass/fail evaluation) compared with other products.

To analyse the different effects of electric arcing in more detail, high-speed photographs of the different procedures were taken in the IPH Berlin and by DuPont at CEF in Morges. The box conforming to DIN EN 61482-1-2, VDE 0682-306-1-2:2007-12 and the service entrance panel conforming to PIP001 were made available to the IPH by RWE Eurotest. Figure 5 shows sample individual high-speed shots. Photos b and c were taken with the same camera settings for systematic reasons.

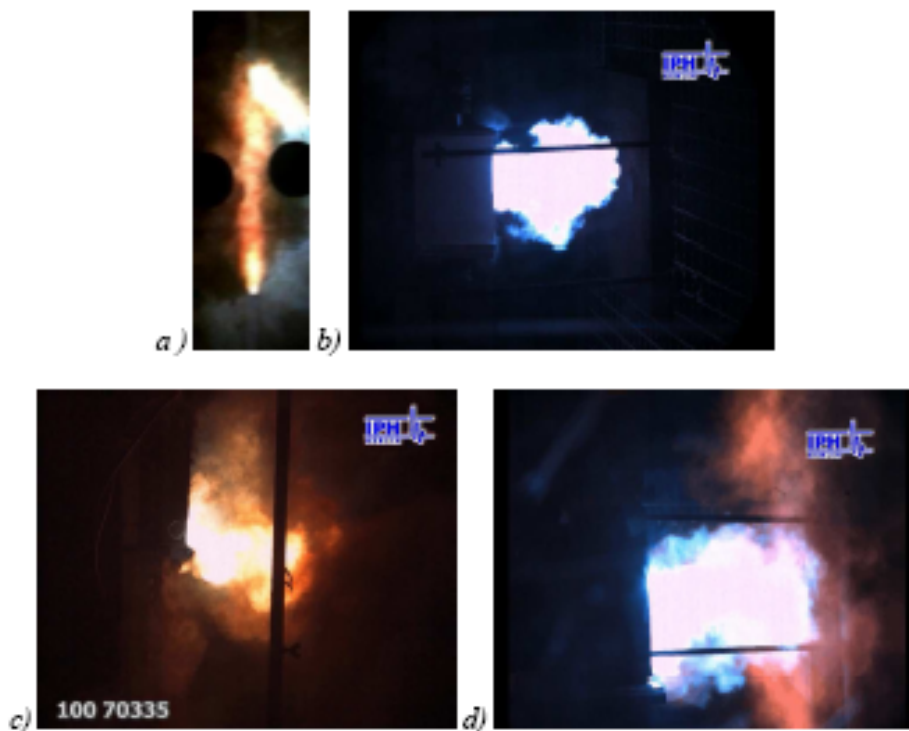


Figure 5: High-speed photographs of the different test procedures. (a: “Open arc test”, b: “Box test”, c: “RWE Eurotest procedure”, d: “IPH procedure”)

It is clear from the high-speed photographs that the different test procedures affected the test specimen differently [10]. In the single-phase procedure the electric arc pulsed naturally at 50 Hz frequency in a clearly visible manner. To some extent the photos appear to indicate that at low arc energy the electric arc initially reduces down in time with the frequency until the inner core of the arc is heated up to maximum temperature. In the “box test” the electric arc mainly

emerges frontally from the box. It is difficult to see to what extent the arc flame hits the test specimen. It can also be seen that the length of the flame emitted is dependent upon time. Unlike the undirected arc in the “open arc test”. Here the arc rotates around the extended electrode axis and the arc flame generally hits the test specimens and bare calorimeters cyclically depending on the current strength and arc duration, i.e. the extent is determined by the arc energy. These bare calorimeters enable the thermal incident energy of the electric arc to be measured directly. In the three-phase tests the electric arcs are superimposed between the three conductors giving the arc a relatively stable appearance. Also the length of the arc flame emitted is dependent upon time and could be seen to pulsate to a varying degree. Due to the arrangement of the electrodes and feed lines the electric arc emerges frontally from the arrangement in the IPH test procedure. In contrast, in the RWE Eurotest procedure, the arc emerges from the service entrance panel directed slightly downwards. It should be pointed out, however, with the photos of all the test procedures that the thick smoke which developed makes it difficult to analyse the photos. It should also generally be noted that the photos were not taken at the same arc energy. As the effects of the electric arcs differed considerably, not only as regards their intensity but also their fundamental behaviour, the results of one procedure cannot be expected to be translated directly to another procedure. It is clear from the photos that, as the photos were taken at greater arc energy, the three-phase tests consequently represented a far greater stress for the test objects as here the test specimens were subjected to the plasma core of the arc to a greater extent. The photos also show that the different procedures display different directivity. The photos in figure 6 of a face shield, tested according to the RWE Eurotest procedure and the IPH test procedure position A, demonstrate the different directivity of the two electric arcs in impressive manner. In both cases the test specimen was tested at 10 kA for 1 second and was positioned 300 mm from the electric arc. Unfortunately there were no photos of an open arc test on the test specimen at the same incident energy.



Figure 6: Face shield subjected to 10 kA for 1 second in two different test procedures and positioned 300 mm from the electric arc (left IPH Berlin, position A, right RWE Eurotest).

It can be seen that the electric arc acting frontally in the IPH test procedure position A affected the upper part of the head far more. The effect on the upper part of the head of the downwards directed arc in the RWE Eurotest procedure was virtually negligible. In contrast the thermal stress on the visor appeared much greater as witnessed in higher heat input with subsequent deformation of the visor. The same result is to be expected with the IPH procedure position B. It would be interesting to see what effects an open arc test would have had, at the same incident energy, on the face shield in positions A and B of the corresponding test arrangements. One could imagine a helmet and face shield, which had been tested according to one procedure and

found to be safe, being tested together with protective clothing in an additional test using a different procedure. As a result of various mechanisms of action the helmet or face shield might “malfunction” or the clothing might even fail due to after-flame caused by drips falling from components of the visor. Certainly with his face shield having failed the user would have problems understanding.

4. Summary and suggestions for further testing

Each procedure is legitimate for its particular purpose and has a history based upon which the appropriate test set-up has been developed. For example electric arcing in work on service entrance panels is somewhat reproduced using the RWE Eurotest set-up and electric arcs on low voltage switchboard equipment somewhat reproduced with the IPH test set-up. It cannot be assumed that the results from one procedure can be translated to another due to differing exposure to electric arcing. The electric arc in the IPH test procedure acts frontally while that in the Eurotest procedure acts slightly downwards on the test specimen. The arc in the “open arc test” rotates, generating well repeatable heat flux onto test samples. In the box test the electric arc is certainly directed frontally at the test specimen, yet on the whole it is very unstable. The “open arc test” is the only one which enables the material property of the ATPV to be determined; the three other procedures test whether or not a material or clothing passes an arc test under the specific conditions of a simulated actual equipment configuration.

Certainly all test labs can vary the different parameters such as distance, current strength, etc. within broad limits as regards technical requirements. However, in order to make an unambiguous statement based on a particular test, care should be taken to apply the test procedure solely with the parameters established in the relevant standard or test instructions and not to mix the parameters and to vary the parameters as little as possible. In this way variations in test procedures with no detailed test instructions will be avoided. If however testing does not follow the instructions rigorously, any differences should be specifically mentioned. Simply altering one single parameter in arc testing can lead to quite different results which, combined with inadequate recording, can make the test debatable or even unusable for the customer and user. Care should be taken that the results are recorded accurately. The parameters of the different procedures should not therefore be mixed. There is no sense in using the 7 kA from the box test in the IPH procedure, for example, and then describing or regarding the test as “based on DIN EN 61482-1-2”, or calling a motley test cobbled together from different procedures an “electric arc test”. Work still needs to be done on clarifying this and on ensuring that procedures used are described in a factually correct and accurate manner.

Calorimetric measurement should, in any case, be included in the box test according to DIN EN 61482-1-2 with clothing and in the IPH test procedure. Many years’ experience by RWE Eurotest and by DuPont have proven that materials and assembled garments which pass a purely visual inspection may well fail when evaluated for second-degree burns according to the Stoll-Chianta criterion. Apparently safe clothing may not be sufficient to prevent second-degree burns in the event of electric arcing. This must be prevented under all circumstances.

It is clear from the earlier example of the face shield tested using two procedures that it makes complete sense to use a separate test set-up for individual protective items such as face shield or clothing, for example. By ignoring the clothing the face shield can be tested taking into consideration the effect of the upper body or the clothing can be tested individually without regard to the face shield. An integrated test combining the separate elements must then be conducted without the individual components experiencing any change in their individual

exposure. Only the effect of the different elements upon each other is evaluated. Investigations currently being conducted at various centres to define test procedures for face shields should resort to existing test arrangements e.g. ASTM F2178-02 [6] for dummy heads. The positioning of the calorimeter inside the head and from the head to the electric arc can be adopted without further ado. The mannequin torso simulated in the standard should definitely be used, as has already been recommended in [11] and is currently being employed in ArcMan™.

Based on recent findings further tests must be conducted to see whether the radiation spectrum of the various electric arcs has a disproportionate influence in the various test procedures or whether, on the other hand, the spectra only differ in their amplitude.

As regards calorimeters, the calorimeter assigned to the Stoll-Chianta procedure should currently be used. Other types/sizes of calorimeter are definitely misleading especially for glove tests. Current studies by RWE Eurotest prove however that calorimeters which are too small may deliver different heat flux compared to normative calorimeters. Moreover major problems arise when testing gloves in practice: air pockets which necessarily exist between the gloves and model hands with calorimeters prevent reproducible measurements. In practice calorimetric measurements should only be conducted on close-fitting glove materials. The entire glove should definitely be subjected to an electric arc, however only with subsequent visual evaluation. To reduce the expense both could be carried out within an electric arc test however. Distances and test set-ups must be defined further with existing test procedures being incorporated here too.

Only by standardising procedures, by adopting existing approaches and limiting the variety can the time and costs of testing be reduced and acceptance by the user be increased. All efforts must be aimed at providing manufacturers and users with meaningful test procedures which can be conducted in different test laboratories for comparable and reproducible results as part of cost-effective testing in minimal time. These procedures must guarantee the user of the personal protective equipment a clear link with the actual equipment configuration; either by simulating actual conditions or by determining the ATPV and reliable procedures, based on this material property, for calculating the risk assessment.

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