Progress report by the KAN "PPE against fault arcs" working group

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A) Targets of the working group and acknowledgement of the progress made in discussion

1. Short-circuits may arise between live parts and potentially lead to fault arcs, for example as a result of errors during work on or near live parts, or as a consequence of lightning strikes or foreign objects in the isolation paths of electrical installations. The fault arcs cause huge amounts of energy to be released which are capable of destroying the affected installation and seriously injuring persons in the vicinity, possibly even fatally.

   The KAN working group was formed after differences of opinion were expressed during the 1/2009 meeting of KAN on the subject of protection against fault arcs. The group's purpose is to provide KAN with a picture of the technical situation and to define expectations from the perspective of prevention. If necessary, the need for any action (including but not limited to standards) is to be identified, and its implementation supported. The KAN working group met eight times between June 2009 and February 2012.

   Standardization, and therefore KAN's scope of influence, has a direct impact upon both the installations and the methods employed for the testing of personal protective equipment. The principal target of the KAN working group was therefore to discuss the various viewpoints concerning the parameters and conditions which were to form the basis for type examinations of clothing for protection against fault arcs. The initial discussions quickly revealed that closer study was needed of the diversity and complexity of the hazards associated with fault arcs. It became clear equally quickly that employers require better support in risk assessment and in the associated selection of suitable PPE.

2. At present, Parts 1-1 and 1-2 of the EN (IEC) 61482 series of standards describe two different test methods for determining the level of protection provided by the material used in the PPE against the thermal effects of a fault arc. The working group found that certain aspects of both test methods required further study and improvement. Equally, these test methods were found, subject to the assumptions and constraints upon which they are based, to reflect adequately the present state of the art and therefore the protective action of the materials against thermal effects.

   Further research in the future was however considered necessary, and would therefore also have to be funded. This includes research into whether tougher thermal testing of PPE, by means of methods that have not yet been standardized, would enable forms of live work on high-energy installations to be conducted responsibly where such forms of work are covered either inadequately or not at all by the two standardized test methods. Further research is also required in particular into radiation exposure associated with fault arcs.

   In addition, the working group confirms that the future BGI/GUV-I 5188 and also IEEE 1584 and NFPA-70E provide methods with the aid of which the assessed thermal hazard presented by a fault arc at a specific workplace and the properties of the PPE tested against the two methods described in the standards can be related to each other.

The working group also considers it necessary for a harmonized standard to be made available for clothing worn for protective purposes: specifically, prEN 61482-2, published to date only in the form of an international standard, must be completed and harmonized at European level.

B) Background

3. As suggested above, fault arcs are frequently caused by a failure to perform maintenance properly, and occasionally also by the unrestricted addition of equipment to installations. For this reason, organizational measures taken among users are a very effective way of improving the situation.

4. Of the possible hazards, thermal exposure caused by heat, splashed hot material and gases has the most devastating physiological effects. Thermal exposure has therefore been and remains the primary focus of risk assessment and the development of personal protective equipment. Further hazards also arise to varying degrees. These include pressure waves, sound, metal vapours, toxic pyrolysis products, and damage to the skin and eyes caused by UV, IR and visible radiation. Even the incidence of short-wave UV radiation, which has not yet been adequately studied, cannot be ruled out during arcing.

5. However, the hazards can be reduced not only by organizational measures, but also by technical measures on the installation (such as compartmentalization, insulation or systems for protection against fault arcs) and by personal protective equipment. In the interests of prevention, the usual hierarchy of protective measures must therefore be observed: the hazard should first be reduced as far as possible by technical measures, and only then by organizational measures or by the use of personal protective equipment. The trend towards ever smaller installations, particularly low-voltage installations, may have increased the risk of fault arcs. In companies, the persons responsible for the safety of installations could make greater use of the risk assessment in order to persuade purchasers to procure installations that are immune to fault arcs.

   - It must be remembered however that the Low-voltage Directive is a Single Market Directive, i.e. it describes how products are to be *placed on the market*. If a switchgear assembly (switchgear panel) is placed on the market *complete* or *with clear manufacturer's instructions* for its completion, the (described) assembly constitutes a product falling within the scope of the Low-voltage Directive. Conversely, should an operator have a switchgear panel assembled or assemble it himself *on his own responsibility in situ*, the combination does not fall within the scope of the Low-voltage Directive (in such cases, the directive covers only the individual components fitted), and must instead satisfy the national safety regulations governing installations. The following conclusions may therefore be drawn:
     Some parts of the EN 61439-x series of standards require a type-test[1], or state circumstances in which a type-test is required (**<u>for example</u>** for

[1] <u>Note</u>: type-testing to EN 61439 should not be confused with EC type-examination, for which in any case provision is not made for low-voltage products.

switchgear assemblies intended to be installed in places where unskilled persons have access for their use or switchgear assembles for power distribution in public networks). It can therefore be assumed that the responsible standards committees consider switchgear assemblies for applications of this kind to be safe only when they are type-tested. Since a switchgear assembly placed on the market is then identical in type to that tested, switchgear assemblies for applications of this kind may generally be assumed to fall within the scope of the Low-voltage Directive.

- Hazards arising through live working on a product are *not* generally covered by the Low-voltage Directive, since live working is in principle not compatible with the safety objectives of Annex 2 of the Low-voltage Directive (such as protection against direct and indirect contact). Where performed, responsibility for live working rests solely with the employer operating the switchgear assembly, and not with the manufacturer. This means that hazards caused by fault arcs which, though they do *not* arise through *intended use,* may however be caused for example by *reasonably foreseeable errors during maintenance work*, do not need to be considered when switchgear assemblies in the sense of the Low-voltage Directive are placed on the market.

The employer's obligations under the national OSH provisions are however not affected by these considerations. Whether he must anticipate fault arcs during the intended use of his switchgear assemblies, including their reasonably foreseeable misuse, is ultimately determined by his risk assessment. It is his duty to draw conclusions from the risk assessment concerning the technical design of the installation (e.g. greater inherent safety), work organization (training, work procedures) and personal protective equipment.

6. The hazard presented by fault arcs is not easily, and most importantly – in contrast for example to noise exposure – not unambiguously *quantifiable* for the risk assessment. One difficulty is that of extrapolating the impact upon human beings from the characteristics of the installation and the potential emissions, and in particular of setting out tolerable limits for this impact. The characteristics of an installation are however the only means by which its operator is able to analyse the hazard and to decide whether he may allow his employees to work safely on it.

7. BGI/GUV-I 5188, "Unterstützung bei der Auswahl der Persönlichen Schutzausrüstung bei Arbeiten in elektrischen Anlagen", which is to be published shortly, provides recommendations for the selection of PPE against thermal hazards associated with fault arcs, based upon technical and scientific findings of the box test to EN 61482-1-2. In addition, it demonstrates that the hazards should be reduced to a minimum not only by the use of PPE, but if at all possible at an earlier stage by technical measures on the installation and/or organizational measures taken by the operator. The BGI does not contain recommendations for the selection of PPE for higher incident energy levels. Whether PPE subjected to more rigorous thermal testing is able to cover a substantially wider spectrum of high-energy installations should be made the subject of further studies.

8. Should an item of PPE be able to provide effective protection against a severe thermal hazard and thereby enable work to be performed on installations presenting such a hazard, the risk assessment must also examine the physiological consequences of the other hazards.

9. In view of the sum of all hazards presented by a fault arc, it is legitimate to question whether employees should be exposed to such hazards (such as the pressure wave or the optical radiation) at all, even when equipped with PPE providing effective thermal protection.

C) Difficulties presented by risk assessment

C.1 Rating of the thermal hazard

10. The essential value for quantifying the thermal hazard presented by fault arcs is the maximum incident thermal energy. Under the extreme heat transmission conditions of the box test to EN 61482-1-2, the relationship between the electrical arc energy and the maximum incident thermal energy is known. The DGUV's electrical technology expert committee is currently developing a BGI/GUV-I 5188 publication based upon these findings. This is to provide operators with a description of the hazards presented by fault arcs and with assistance in risk assessment. This BGI can be used by the operator to estimate the potential *electric arc energy* of a fault arc from the parameters of electrical installations that can be obtained with reasonable effort (such as the system supply voltage, short-circuit current level, de-energization time, distance between the electrodes), and in turn to select suitable personal protective equipment.

11. The approach described in BGI/GUV-I for rating of the hazard is based upon EN (IEC) 61482-1-2[2] and IEC 6148-2-2, since the anticipated arc energy is the decisive factor for determining the required test/protection class of an item of PPE to EN 61482-1-2 in the risk assessment for the case concerned. The box test employed in this standard verifies that the protective action of an item of PPE is assured up to the incident thermal energy characterized by the test/protection class in question: in the statistically validated relationship between the incident energy and the electric arc energy of the test circuit in the box test, *the arc energy is known which corresponds to this incident energy under the distance and transmission conditions of the test*. For conditions deviating from these, an *equivalent arc energy* can be determined by means of correction values which can then be used for comparison with the *anticipated arc energy* of the application in question. The *anticipated arc energy* must not exceed the *equivalent arc energy*. The thermal incident energy is also the decisive factor in the hazard rating strategy of IEEE 1584 based upon EN 61482-1-1[3]. The incident energy

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[2] EN 61482-1-2:2007 "Live working – Protective clothing against the thermal hazards of an electric arc" – Part 1-2: Test methods – Method 2: Determination of arc protection class of material and clothing by using a constrained and directed arc (box test)"

[3] EN 61482-1-1:2009 "Live working – Protective clothing against the thermal hazards of an electric arc – Part 1-1: Test methods – Method 1: Determination of the arc rating (ATPV or EBT50) of flame resistant materials for clothing"

anticipated in the application must not exceed the arc rating for the protective clothing. In other words, protective clothing must be selected possessing an arc rating greater than the incident energy anticipated in the application and calculated for example with reference to IEEE 1584.

12. In a second phase, the BGI/GUV-I can be developed into a standard for the selection of PPE against fault arcs. This is also necessitated by the fact that the BGI/GUV-I is not relevant in other countries which also use the international or European PPE standards. NFPA 70E procedures for risk analysis are also available. Test results from EN (IEC) 61482-1-1 are used in this case for selection of the PPE.

13. In the former German Democratic Republic, the short-circuit current and the total de-energization time, as used in the "ISA curve"[4] (see below), were employed rather than calculation of the incident energy. These parameters were determined in the 1970s by direct testing of complete protective overalls of the type then available, in combination with the ISA 2000 switchgear systems commonly used in East Germany at the time. Exposure limits are determined in this case in consideration of the measured thermal resistance of the protective clothing in use at the time and of the pressure generated by the triggered fault arcs. The risk of second-degree skin burns is not explicitly measured or assessed in the tests. The values determined are the installation characteristics of the *arc short-circuit current* (the primary value) and the *arc duration*. The ISA curve is however specific to the effectiveness of the protective clothing/protective equipment and to the installation characteristics of the period, and cannot reflect the technical developments in protective equipment and switchgear and controlgear that have taken place over the past 30 years. In addition, the ISA curve makes no distinction between rated voltages of 690 V/760 V and those differing from them (e.g. 400 V), instead employing a worst-case scenario; furthermore, the arc short-circuit current can again only be approximated and with significant effort, and is also therefore not easily managed by the user.

C.2 Assessment of further hazards

C.2.1 Quantification of the arc spectra

14. Since July 2011, the BG ETEM (the German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors) has made a spectrometer available to the TU Ilmenau. The arc tests normally performed in Ilmenau (i.e. employing one aluminium and one copper electrode) are to be supplemented by radiation measurements for a wide range of purposes, thus yielding comprehensive data. The initial focus will however not lie upon special spectral analyses, for example of the proportion of short-wave UV radiation. As soon as findings in this area for the 300 nm to 800 nm wavelength range covered by this instrument are available, investigations could begin into the pathophysiological modes of

[4] Montage-, Bedienungs- und Wartungsvorschrift ISA-2000SF, -SG, SK, SS Nr. 13-990-00/00.41.00 09-4 Magdeburg: VEB Starkstrom-Anlagenbau, Magdeburg

action upon the skin, cornea and retina at arc exposures lasting less than 1 second. Further studies are also required for the adjacent frequency ranges.

15. A research study commissioned by the AUVA was conducted into *optical radiation associated with undesired arcing during electrical work and the protective action of the personal protective equipment*[5]. Of the particular radiation hazards referred to above, only those triggered by the *optical* radiation component were studied. The original intention had been only to study problems relating to visors. Protective clothing was however also included to some degree in the course of the project. The test arrangement was based essentially upon the provisions of the GS-ET-29 test principles for face protection for electricians, issued by DGUV Test. Deviations were however made in some of the parameters (such as the electrode material and interval), since this enabled the test arrangement to be made available more quickly. The information available from Mr Weber to date is as follows:

   - Limit values exist only up to a wavelength of 3 µm; approximately half of the emitted radiation (or very approximately, the thermal radiation component) is not therefore covered by them.
   - UV radiation occurs to a much smaller degree than during welding. A risk nevertheless exists of intense visible light causing irreversible thermal damage to the cornea.
   - The OSH limit value for thermal exposure of the cornea (intended for longer exposures) is substantially exceeded. This is also the case for other intense pulsed sources of optical broadband radiation such as photographic flash units or intense pulsed light (IPL) technology.
   - It is therefore essential that visors also provide protection against visible light, particularly in the 400 to 500 nm wavelength range. However, visors in accordance with EN 166 for protection against fault arcs do not provide adequate protection against visible and infrared light, since this standard does not yet contain any provisions in this area.
   - Further tests with aluminium, copper and possibly also steel electrodes would be necessary in order to confirm the conclusions reached to date, since it is highly likely that different electrode materials also generate different arc spectra. Wavelengths below 300 nm were not studied owing to the available instrumentation technology. Despite the more strongly weighted limit values, they are probably of lower relevance to visors in the UV range and to the textiles commonly used in modern protective clothing owing to the good protective action of these products. These wavelengths may however be relevant to new types of textile which could be placed on the market in the future by manufacturers seeking to produce more ergonomic or stylish protective clothing.

[5] The report (in German) can be ordered from: http://www.sozialversicherung.at ► Service ► Für Versicherte ► Publikationen ► Informationen bei: AUVA ► Reports

- In the interests of greater comparability of the data, it would be advantageous for these tests also to be performed in accordance with the provisions of EN 61482-1-2. A corresponding study employing a test arrangement to EN 61482-1-1 would also be advantageous.

C.2.2 Analysis of the thermally released hazardous substances

16. It is virtually impossible to predict the pyrolysis products generated primarily from man-made insulation materials (the pyrolysis of which has frequently not yet been studied) employed in electrical installations and in the PPE worn by users purely from their chemical composition. Experiments must generally be conducted on a case-by-case basis, not least owing to possible variation in the boundary conditions of pyrolysis. For accident events such as arcs and the associated boundary conditions, however, such experiments are considerably more difficult than for pyrolysis products arising under normal working conditions. The Institute for Occupational Safety and Health (IFA) of the DGUV has nevertheless conducted measurements on behalf of the electrical engineering expert committee during an arcing demonstration (65 kA/400 V, 300 ms) in the I²PS test laboratory in Bonn on a switchgear panel containing open circuit-breakers and plastic shrouds. The measurement results confirmed the expectation that the component presenting the greatest hazard is the *metal* of the rail material, i.e. copper, vaporized by the arc. This hazard was already known and is confirmed clearly by the measured quantities. Organic pyrolysis products of plastic material were not found (concentrations below the detection limit). It can be assumed that under less favourable conditions, where the switchgear panel contains a large proportion of plastic or rubber components, higher concentrations may occur. In this case too, however, this hazard is in all probability of an order of magnitude that cannot be compared to that of other hazards (heat, pressure, noise, etc.). The concentrations of nitrous gases and carbon monoxide were below the current occupational exposure limits. The KAN working group therefore agreed that the question of pyrolysis products for a serious accident, i.e. an exceptional rather than a routine situation, need not be pursued as a priority in the light of current knowledge.

C.2.3 Knowledge of the peak noise levels

17. The report presented by the state office for occupational safety and health and technical consumer protection of the state of Thuringia on noise measurements conducted at the TU Ilmenau[6] confirmed as expected that the upper action value in accordance with Section 6 of the German Ordinance on noise and vibration protection (LärmVibrationsArbSchV) for the statistically validated peak sound-pressure value of $L_pC,_{peak}$ = 137 dB(C) is considerably exceeded during box tests. Mean values of approximately 151 dB and 152 dB were measured with arcs with prospective test currents of 4 kA and 7 kA respectively at a distance of 1 m.

[6] Thüringer Landesbetrieb für Arbeitsschutz und technischen Verbraucherschutz: Ergebnisbericht zur orientierenden Lärmmessung gemäß DIN EN ISO 9612 an der TU Ilmenau vom 19.10.-21.10.2012; Suhl, 24.01.2011

For arcs with prospective test currents of 4 kA and 7 kA, the drop in level at a distance of 1 m compared to a distance of 0.5 m under laboratory conditions clearly also approximates that in the field. (This result should be considered with due caution owing to the small numbers of measured values.) The duration of discharge of the arcs (durations of 100, 200 and 300 ms were studied) appeared to have virtually no influence upon the level.

18. The values determined during measurements performed at RWE Eurotest GmbH in Dortmund are essentially consistent with those obtained in Ilmenau, even when consideration is given to the differences in distances and arc parameters. It also became clear that the current level no longer had any significant influence upon the peak noise levels, which were already extreme. The mean value for $L_pC_{,\ peak}$ measured at RWE at a distance of 4 m was approximately 137 dB, which corresponds to a value of 149 dB at a distance of 1 m. At the distances below 0.5 m such as are frequently encountered, an employee experiencing an arc accident would therefore be exposed to as much as 155-157 dB.

19. The studies conducted in Ilmenau and Dortmund both showed that in the event of an arc accident, peak noise exposure levels are attained at which damage to the hearing cannot be ruled out. Only highly effective ear muffs would be able to provide adequate protection in such cases. This situation presents the employer with difficulties during risk assessment. On the one hand, acceptance among employees is likely to be low for highly effective hearing protectors in view of the low likelihood of arcing; on the other, it should be considered whether the hearing protectors themselves give rise to other hazards owing to their impairment of communication. Any measures that prevent arcs from occurring in the first instance would therefore appear all the more important. The working group recommends that the electrical engineering expert committee draw attention to these findings in the new BGI/DGUV-I 5188.

D) Simulation of thermal impact scenarios for type examinations of PPE

20. Prompted by a paper presented to CENELEC/TC 78 by Mr José Bahima, the CEN/CENELEC Consultant for PPE, the KAN working group wishes to draw particular attention to the following functions and limitations of harmonized standards for PPE:

- Satisfaction of the essential requirements of the EU PPE Directive is mandatory; the same is not true for the (harmonized) standards.
- The presumption of conformity to which a harmonized European standard gives rise is limited to the scope of the standard and the essential requirements of the EU PPE Directive actually covered by it.
- Application of the harmonized standards must deliver reproducible results, i.e. tests must be described clearly and completely.
- The requirements and tests must, as far as possible, be representative of the hazards against which the user is to be protected under the foreseeable conditions.

21. The test requirements of many PPE standards do not reproduce the actual situations arising in the field; instead, they replicate the effects against which the PPE is to provide protection by means of other parameters better suited to testing, for example in terms of their reproducibility. (This is not to say that the exposures occurring in the field are generally poorly modelled in these standards, although this is unfortunately also occasionally the case.)

22. The parameters used in standards EN 61482-1-1 and EN 61482-1-2 (together with IEC 61482-2) are also not identical to the readily verifiable characteristics of installations such as the short-circuit current level, arc duration, alternating or three-phase alternating current, etc. This is frequently a cause of confusion for operators and other affected parties, who incorrectly associate the parameters of the test apparatus with actual installation characteristics. In doing so, they overlook the fact that the standard simulates only incident energy levels with a physiological impact upon the skin, which could in theory be generated by a wide range of test constellations. Accordingly, the suitability of the PPE tested against the standard is incorrectly restricted to installations sharing the same characteristics as the test apparatus, even though the simulated incident energy levels could in fact cover a large proportion of the exposure possible in practice.

    The prevention lobby is therefore keen to ensure that the intended use of the PPE tested against the EN (IEC) 61482-x series of standards is communicated unequivocally. The frequently used formulation making reference to the parameters of the test apparatus is misleading and should be changed to indicate that the incident energy is the relevant aspect.

23. As an alternative to the assessment of PPE (without measurement and assessment of the incident energy), visual methods also exist, such as that set out in the withdrawn ENV 50354 or comparable methods. In these methods, visual inspection is performed under the tested PPE, with or without undergarments, of whether it has survived the test or has failed or burned. The visual methods led however to false conclusions. Consequently, the national, European and international standards committees reached a consensus some years ago no longer to rely solely upon subjective assessment methods, and instead to use heat transfer measurement as the decisive criterion for assessing the protective action of the PPE. In addition, the physiological effect of skin burns is not readily detectable, in contrast to calorimetric measurement.

24. The measurement technology of calorimeters employing round copper discs and copper-constantan thermocouples, described in EN 61482-1-1 and EN 61482-1-2, was discussed with regard to its suitability for short-time phenomena such as fault arcs and to whether the Stoll curve, the time range of which begins beyond 1 second, can be used as a basis for assessment. Studies performed by Privette[7] and by Neal et al[8] indicate

[7] Privette, A.: Progress Report for ASTM Burn Study. Report Prepared for the ASTM F-18, Committee Task Force F18.10.07 on Electric Arc Test Method Development, Duke Power Comp., June 10, 1992

however that human skin can be exposed to greater quantities of heat for less than 1 second without suffering second-degree burns than is possible for an exposure lasting 1 second. In other words, application of the Stoll-Chianta value for 1 second for the assessment of incident energy exposures lasting less than 1 second errs on the side of safety. The concerns are also countered by the fact that the calorimeters used have a time constant of approximately 0.5 seconds and that the copper disc was selected in order to simulate the capacity of human skin for thermal absorption, which in turn exhibits a comparable delay. In addition, the material used absorbs the incident energy cumulatively and conveys it to the thermocouple; for this reason, thermal measurement losses cannot be assumed. The test conditions employed in the standard have been studied in depth for uncertainty and for the correctness of measurement, and constitute the best available technology at the present time for quantifying the incident energy. Whether the radiation that occurs initially in the short-time range is able to cause deep damage in the skin and eye and must therefore be recorded separately has however yet to be studied. It must also be remembered that calorimeters cannot be used to measure temperatures. The maximum temperature rise indicated by a calorimeter is used only to determine the cumulative thermal energy. The "naked" calorimeter measurement performed directly, without material/clothing, may therefore underestimate the incident energy that is used as a reference; the consequence of this however is that the assessment of the protective action under the material errs on the side of safety. Other measurement methods may be needed if the "naked" incident energy is to be determined more precisely. A certain hiatus may pass between penetration of the clothing by the energy and the rise on the calorimeter, but does not constitute an essential problem.

25. Comparative measurements concerning the transferability of calorimetric methods as described in EN 61482-1-2 and the RWE methods were able to provide greater clarity on the relationship between the arc energy of the installation and the incident energy measured during testing. These measurements revealed that at a given arc energy, the resulting incident energy is greater in the box test than in the RWE test method. In addition, it is not possible to use the results of a test performed under certain test conditions (energy released by exothermic combustion, convection, etc.) to extrapolate characteristic values obtained under completely different test conditions.

26. Although the arc discharged in the typical three-pole installations exhibits a different pulse characteristic, the majority of members of the working group favour an arc discharged by a two-pole system for use in a test standard, owing to its reproducibility and greater ease of measurement.

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[8] Neal, T. E.; Bingham, A. H.; Doughty R. L.: Protective Clothing Guidelines for Electric Arc Exposures. Petroleum and Chemical Industry Conference, 1996, Record of Conference Papers. The Institute of Electrical and Electronics Engineers Incorporated Industry Applications Society, 43rd Annual, 23-25 Sep. 1996, Philadelphia, PA, USA, Paper No: PCIC-96-34, pp. 281-298, ISBN 0-7803-3587-2

27. The use of calorimeters, the test geometry and the influence of other forms of radiation require further study. The BG ETEM therefore charged the TU Ilmenau with a research project in which the box test method to EN 61482-1-2 was to be developed further. Aspects covered by the project include parameters for thermal evaluation, reasons for inhomogeneity of the temperature distribution, the influence of the formation of metal vapour and smoke upon calorimetric measurement, thermal imaging measurements, radiation spectrometer measurements, and noise/sound measurement technology. The following findings have already been reached[9]:

- The conventional copper calorimeters accurately reflect the radiated thermal energy.
- The thermocouple of a copper calorimeter has a thermal time constant of 0.1 to 0.13 seconds, the blackened copper plate of just under 0.5 seconds. The calorimeter time constant is therefore < 0.5 s. According to the Stoll-Chianta criterion, the copper plate approximates the behaviour of the skin's basal layer.
- Measurements were performed of the change over time and spatial distribution of the temperature on the rear of the copper plates of three calorimeters by means of an FLIR SC7200-MB infrared measurement system (employing a cooled indium/antimony sensor) with a sampling frequency of up to 7700 Hz (i.e. a sampling rate of 0.13 ms). This is the system with the highest sampling frequency on the market. At the same time, the temperature characteristic was recorded conventionally by means of thermocouples. The two different measurement methods yield the same characteristics: gradients and final (maximum) values are virtually identical and are within the usual deviation. Differences are evident between the spatial temperature distributions.
- The measurements confirm the temperature rise characteristic measured by means of conventional calorimeters. Infrared measurement systems can be employed in tests and permit evaluation of larger sensory areas for measurement of the maximum temperature (incident energy). The IR system employed cannot be used routinely owing to its cost (over €50,000).
- The conventional calorimeters permit adequate conclusions.
- In the box test, heat is transferred in the form of radiation, reflected radiation (box), radiation from the heated environment (gas and plasma cloud, plasma radiation, box, etc.) and convection (gas and plasma cloud flow, free swaths of plasma cloud, metal vapour). Thermal input also takes the form of splashes and droplets of molten metal, condensing metal vapour, and combustion energy and exothermic reactions of the electrode material (aluminium). Thermal conduction processes take place

[9] Schau, H.; Novitzkij, A.: Gefährdungen durch Störlichtbögen. Technischer Abschlussbericht, Bericht Nr. 2010-02/BG, commissioned by Berufsgenossenschaft Energie Textil Elektro Medienerzeugnisse (BG ETEM), 18.11.2010.

within the copper material (skin simulator). Heat transfer occurs at boundary layers. Heat transfer processes therefore continue to be a factor during the testing of PPE. With the exception of the direct radiation, arc column and plasma rays, which are present only for the duration of arc discharge of 0.5 seconds, all sources of heat and thermal mechanisms are present for longer than 0.5 seconds, in some cases considerably longer.

- The energy is fully absorbed only after several seconds; the measured maximum temperature and incident energy therefore satisfy their intended purpose. Whether the temperature conditions in front of the calorimeter surface (under direct exposure) or at the surface of the PPE are modelled correctly by the calorimeter cannot be determined; this is irrelevant to assessment of the thermal impact within the skin, for which energy flow is the determining factor. It may be assumed however that under direct exposure, the thermal impact on the surface is not fully covered by the measured incident energy. This also explains the difference between the results for a textile material in the box test and in the arc-rating (ATPV) test, in which the direct incident energy is generated almost exclusively from the radiation from the open test arc.
- The conclusion is therefore that the direct incident energy is a suitable reference value for comparable analyses and can therefore be used as a criterion for the validity of a test. This variable should not be used as a baseline quantity for absolute characterization of the actual thermal hazard (risk assessment). The electric arc energy is a more suitable criterion in this case.
- Whether the short-time incident radiation is adequately measured by this method should also be studied. Parallel measurement involving a measurement system with a higher sampling frequency would be required for this purpose.

28. Five laboratories took part in a round-robin test to determine the accuracy of the test method to IEC 61482-1-2. The test, the results of which were interpreted with strict adherence to ISO 5725-2, was completed successfully. The interpretation addressed the control parameters of the arc energy and direct incident energy and the resulting parameter $E_{it} – E_{iStoll}$. The values determined for the reproducibility and comparability (standard deviation) are normal for textile tests. In consideration of the stochastic properties of arcs, the accuracy parameters can be described as very good. The results of the round-robin test are to be incorporated into an informative annex during revision of the standard. The new standard could be available towards the end of 2012/mid-2013.

E) Further targets

29. Information on the hazards presented by fault arcs and on corresponding constraints upon the operation of electrical installations must be made available and distributed.

30. Recording of the maximum short-circuit currents in accident reports: accident reports should take a form which requires the maximum short-circuit currents or at least approximations of them to be stated. This would appreciably improve the general picture of the hazard situations. Completion of the accident insurance institutions' accident report forms is however "optional" for the companies. Since the short-circuit current is also not generally stated, labour inspectors must generally investigate in person in any case. The BG ETEM will however endeavour to obtain as much of this information as possible.
31. Studies should be conducted into whether PPE subjected to more rigorous thermal testing is able to cover a substantially wider spectrum of high-energy installations (see Point 6).
32. The use of calorimeters, the test geometry and the influence of other forms of radiation require further study (see Point 27).
33. As soon as findings are available for the 300 nm to 800 nm wavelength range covered by the spectrometer used in Ilmenau, studies could begin of the pathophysiological modes of action upon the skin, cornea and retina at arc exposures lasting less than 1 second. Further studies are also required for the adjacent frequency ranges (see Point 14).
34. Visors in accordance with EN 166 for protection against fault arcs do not provide adequate protection against visible and infrared light, since this standard does not yet contain any provisions in this area. The standard would therefore have to be revised such that visors tested against it also protect against visible light, particularly in the 400 to 500 nm wavelength range (see Point 15).
35. Further tests with aluminium, copper and possibly also steel electrodes would be necessary in order to review the conclusions reached to date from the studies conducted in Austria for the AUVA, in order for the arc spectra to be quantified. In the interests of greater comparability of the data, it would be advantageous for these tests also to be performed in accordance with the provisions of EN 61482-1-2. A corresponding examination employing a test arrangement to EN 61482-1-1 would also be advantageous (see Point 15).
36. Whether the short-time incident radiation is adequately measured by the calorimetric method should be examined. Parallel measurement involving a measurement system with a higher sampling frequency would be required for this purpose (see Point 27).
37. Whether the radiation initially occurring in the short-time range during arcing is able to cause deep damage in the skin and eye, and must therefore be measured separately and by other methods from the absorbed thermal energy measured by means of a calorimeter, also requires investigation (see Point 24).
38. A harmonized European standard for the PPE actually to be worn still does not exist. As yet, none of the test methods discussed automatically results in suitable clothing. All of these standards are pure material test standards which confirm the essential properties of safe clothing, but not all of them. Inner linings for example which are manufactured from non-flame-retardant

materials or a seam of melting and flammable polyester thread could have severely harmful consequences for the wearer in the event of a serious incident. Inadequate dielectric strength also fails to offer shock-hazard protection against current-carrying parts and may therefore even give rise to further secondary hazards. In addition, the classic textile-specific requirements such as dimensional stability during washing and optimum tensile strength and tear-resistance are not only quality concerns but also safety concerns for a user. Finally, accessories such as reflective strips, emblems or logos will impair the safety function of an item of clothing unless they are suitable and have been appropriately tested, e.g. for their flame retardance. Until a harmonized position and strategy is reached in Europe on this issue and binding provisions implemented in the sense of prEN 61482-2, a number of crucial points will remain open. This applies equally to the other safety components such as protective gloves and facial protection, for which even less movement towards standardization at European level can be discerned.