6.1.3 Criteria to determine ignition

Ignition shall be considered to have occurred if a temperature rise of at least 100 K is measured by a 0,5 mm diameter thermocouple bead located 100 mm above the reference absorber, or if the appearance of a flame is visually observed.

6.2 Verification of suitability of test set-up for type tests

6.2.1 Reference gas

To check whether the test set-up is suitable for type tests according to 6.3, ignition tests shall involve a propane-air-mixture in accordance with the following:

- For continuous wave radiation and for pulsed wave radiation above 1 s duration: propane-air-mixture of either 5 % or 4 % by volume, quiescent mixture.
- For pulsed wave radiation equal to or less than 1 s and for all pulse trains: propane-air-mixture of 4 % by volume, quiescent mixture.

See Table A.1 for additional background on the application of the propane-air-mixture.

If the set-up is used only for either continuous wave or pulsed radiation, only the applicable of the two reference tests is necessary.

6.2.2 Reference absorber

Absorption at investigated wavelength above 80 %, to be applied on the transmission fibre tip (fibre optics), or compressed respectively applied to an inert substrate (free beam transmission).

NOTE Experiments show that for pulses in the micro and nanosecond range a carbon black absorber gives the lowest igniting pulse energies (absorption 99 %, combustible, high decomposition temperature) [1,4,6 [1]].

6.2.3 Reference test for continuous wave radiation and pulses above 1 s duration

The irradiated reference absorber shall be physically and chemically inert for the duration of the test. The absorber needs to have very high absorption to act as nearly a black body. The set-up shall be tested with the reference gas and absorber at 40 °C ± 5 K. For the testing of fibre optics, the absorber shall be applied to the fibre tip in a very thin layer (approximately 10 µm) (e.g. applied as a powder in suspension and dried afterwards). The reference values are given in Table A.1. The test setup is acceptable if the achieved ignition values are not more than 20 % above the data from Table A.1. The absorber shall be undamaged at the end of the test.

For the testing of free beam transmission the smallest diameter of the beam shall hit a plane layer of the target material applied to a substrate or in a compressed form as a pellet. The reference values are to be taken from Table A.1 for the respective beam diameter. The test setup is acceptable if the achieved ignition values are not more than 20 % above the data from Table A.1. The absorber shall be undamaged at the end of the test.

6.2.4 Reference test for pulsed radiation below 1 ms pulse duration

The irradiated reference absorber shall be irradiated from the front (free beam irradiation) during all pulse tests. For the testing of free beam transmission the smallest diameter of the beam shall hit a plane layer of the target material applied either to a substrate or to a compressed form as a pellet. The reference value for a beam diameter of 90 µm is 499 µJ pulse energy for pulses of 90 ns and 600 µJ for pulses of 30 ns. The set-up shall be tested

[1] Numbers in square brackets refer to the bibliography.

with the reference gas and absorber at 40 °C ± 5 K. The test setup is acceptable if the achieved ignition values are not more than 20 % above the data from Table B.1.

NOTE Background information for the reference values are given in the bibliography [4].

6.3 Type tests

6.3.1 Ignition tests with continuous wave radiation and pulses above 1 s duration

The ignition tests for continuous wave radiation and for pulsed wave radiation above 1 s duration shall involve a gas-air-mixture in accordance with the following:

- For T6/IIC atmospheres: CS_2 in air, 1,5 % by volume, and Diethyl ether, 12 % by volume. If only diethyl ether is used, the minimum ignition powers or irradiances obtained shall be divided by a factor of 4 when applying the acceptance criteria.
- For T4/IIA, T4/IIB and T4/IIC atmospheres: diethyl ether, 12 % by volume.
- For T3/IIA and I atmospheres: propane in air, 5 % by volume.
- For special applications: the atmosphere under consideration.

6.3.2 Ignition tests with single pulses less than 1 ms duration

The ignition tests for pulsed wave radiation less than 1 ms duration shall involve a gas-air-mixture in accordance with the following:

- For IIC atmospheres: H_2 in air, 12 % and 21 % by volume, or CS_2 in air, 6,5 % by volume.
- For IIB atmospheres: ethene in air, 5,5 % by volume.
- For I and IIA atmospheres: diethyl ether, 3,4 % by volume, or propane in air, 4 % by volume. If propane in air is used, divide minimum ignition energies obtained with propane by 1,2 when applying the acceptance criteria.
- For special applications: the atmosphere under consideration.

6.3.3 Tests for pulse trains and pulses from 1 ms to 1 s duration

The ignition tests for pulsed wave radiation from 1 ms to 1 s and for all pulse trains shall involve a gas-air-mixture in accordance with the following:

- ignition tests performed with gas-air-mixtures in accordance with the above “pulsed wave radiation above 1 s duration”, followed by
- ignition tests performed with gas-air-mixture in accordance with the above “pulsed wave radiation less than 1 ms duration”.

6.3.4 Absorber targets for type tests

The absorber target shall be maintained at the same temperature as the gas-air-mixture.

When irradiated, the absorber target shall be physically and chemically inert for the duration of the test. It is necessary for the absorber to have very high absorption so as to act as nearly a black body.

For all optical transmission sources, the absorber target shall have an absorption property above 80 % at the involved wavelength. Additional background on the selection of the reference absorber is given below.

The absorber target shall be positioned at the closest point of access to the output of the optical source. For optical fibre transmission sources, the reference absorber shall be applied to the fibre tip in a very thin layer. For other than optical fibre transmission sources (free beam transmission), the reference absorber shall be applied in a very thin layer to an inert substrate, or compressed to form a pellet, and located at the output of the optical source.

Alternatively, for optical sources recessed a given distance within the enclosure, the absorber target can be positioned this given distance from the optical source. For all optical transmission sources, the absorber shall be applied in a very thin layer to an inert substrate, or compressed to form a pellet, and located this given distance from the output of the optical source. This alternative approach is only an option if the enclosure complies with recognised types of protection for electrical apparatus designed to contain an internal ignition (such as a flameproof "d" enclosure) according to IEC 60079-1, or where it is not to be expected that there are absorbing targets inside the enclosure according to the ignition hazard assessment (such as an IP 6X enclosure, pressurised "p" enclosure, restricted breathing "nR" enclosure, etc).

Application of this very thin layer shall be achieved by having the absorber begin as a powder in suspension, and then dried afterwards at a recommended thickness of approximately 10 μm.

NOTE Experiments show that for pulses in the micro and nanosecond range, a carbon black absorber gives lowest igniting pulse energies (absorption 99 %, combustible, high decomposition temperature) [17][22][24].

6.3.5 Test acceptance criteria and safety factors

Where ignition is considered to have occurred and the absorber is undamaged, these results can be treated as inherently safe data under the following conditions:

- A safety factor as follows is applied to the achieved igniting power:
  - For continuous wave radiation and for pulsed wave radiation greater than 1 s duration: A safety factor of 1,5 shall be applied.
  - For pulsed wave radiation less than or equal to 1 s and for pulse trains: A safety factor of 3 shall be applied.
- After application of this safety factor, the adjusted igniting power is not more than 20 % above the data from Table A.1.

Where no ignition is considered to have occurred (e.g. because the power or energy cannot be increased further more in the test) and the absorber is undamaged, these results can be treated as inherently safe data under the following conditions:

- A safety factor as follows is applied to the highest non incendive beam power as follows:
  - For continuous wave radiation and for pulsed wave radiation greater than 1 s duration: A safety factor of 1,5 shall be applied.
  - For pulsed wave radiation less than or equal to 1 s and for pulse trains: A safety factor of 3 shall be applied.
- After application of the above safety factors, the adjusted non-incendive beam power is not more than 20 % above the data from Table A.1.

Another possibility to obtain inherently safe beam strength data (including application of a safety factor) is to use an alternative reference gas that is more sensitive to ignition. As an example, for continuous wave radiation and for pulsed wave radiation greater than 1 s duration that is to be used in IIA/T3 atmospheres, this alternative test gas can be ethene (C_2H_4) up to a size of the beam area of about 2 mm^2. Ignition shall not be considered to have occurred at the end of the test and the absorber shall be undamaged.

NOTE As ignition by a small hot surface is a process containing considerable statistical deviations, a safety factor is justified. For the same reason, great care is to be applied when judging experiments as non-incendive because small variations in test parameters may influence the results remarkably.

7 Marking

The equipment using optical radiation shall include all markings required by the other applicable equipment protection techniques, if any, (such as flameproof enclosures, "d", and intrinsically safe apparatus, "i"). Electrical equipment, parts of electrical equipment, and Ex components emitting optical radiation and protected by the types of protection specified in this standard shall be marked in accordance with IEC 60079-0, with the following additional marking:

a) the symbol for the type of protection used:

   "op is": for inherently safe optical radiation;

   "op pr": for protected optical radiation;

   "op sh": for optical system with interlock.

b) the symbol of the temperature class and Group and the suffixes A, B or C as stated in IEC 60079-0, but:

For equipment not suitable for installation in a hazardous area, but providing optical radiation, the marking for 'Associated Equipment' shall apply. If Table 2 requires a restriction of the temperature class, this shall be indicated following the type of protection.

Example: [Ex op is IIC T4 Gb]

Determining compliance with Table 2 may involve the use of a column from Table 2 for optical power or irradiance values associated with a temperature class other than the temperature class that is part of the Ex marking string for the other applicable electrical equipment protection technique(s). Only the more restrictive temperature class value shall be marked on the equipment. More than one temperature class marking shall not be allowed.

Examples of marking

- Equipment which conforms to EPL Ga:

  Ex op is IIC T6 Ga

- Equipment which conforms to EPL Gb:

  Ex op pr IIC T4 Gb

- Equipment, which is installed outside the hazardous area and provides optical radiation to the hazardous area, limit values taken from Table 2 or Table 4:

  [Ex op is IIA T3 Ga]

- Equipment with an optical source protected by type of protection encapsulation 'm' and type of protection 'op is'

  Ex mb op is IIC T4 Gb

The certificate shall identify the relevant EPL of the equipment (there may be more than one EPL for the different parts of the equipment).

Annex A
(informative)

Reference test data

Table A.1 gives reference values for ignition tests with a mixture of propane in air at 40 °C mixture temperature. The absorber was attached to the end of an optical fibre and irradiated continuously.

Table A.1 – Reference values for ignition tests with a mixture of propane in air at 40 °C mixture temperature

Fibre core diameter µm	**Minimum igniting power at 1 064 nm (absorption: 83 %, 5 % propane by volume)** mW	**Minimum igniting power at 805 nm (absorption: 93 %, 4 % propane by volume)** mW
62,5 (125 µm cladding)	250	
400	842	690
600		1 200
1 500		3 600
NOTE Other reference test data (e.g. for 8 µm core diameter, 1 550 nm wavelength) are currently not available		

Annex B
(informative)

Ignition mechanisms[2]

The potential hazard associated with optics in the infrared and visible electromagnetic spectrum depends on:

- laser wavelength (absorption properties);
- absorber material (inert, reactive);
- fuel;
- pressure;
- irradiated area;
- irradiation time.

There are an immense number of combinations of these factors that will influence the hazard of optics in explosive atmosphere and at least the ignition mechanism. Worst case conditions arise when an absorber is present. When the dimensions of the radiation and/or the absorber fall below the quenching distance of the explosive gas, the ignition can be seen as a point ignition. However, radiation from the end of a fibre optic cable diverges rapidly and the irradiated area may reach dimensions of square centimetres. The conditions for ignition can be characterised in terms of the fundamental parameters energy, area and time.

	area tends to	time tends to	ignition criterion
(1)	zero	infinity	minimum power
(2)	infinity	infinity	minimum irradiance
(3)	zero	zero	minimum energy
(4)	infinity	zero	radiant exposure

Infinite time means continuous wave radiation. The research results for small and big areas are given in Table B.1, Figure B.1 and Figure B.2. In both regimes ignition takes place via hot surface ignition when the beam hits an absorber. The smaller the surface, the higher the igniting irradiance. This means that a smaller surface has to be heated to higher temperatures to cause an ignition. No ignition was observed below 50 mW optical power for all gas/vapour mixtures (excluding carbon disulfide). This supports the maximum permissible power value of 35 mW including a safety margin, which also has to consider the non-ideal grey body absorption of the inert absorber. Experiments with reactive absorbers (coal, carbon black and a toner) showed that even though they have higher absorption, they were less effective as ignition sources. The n-alkanes do not ignite below 200 mW (150 mW including safety margin). For bigger irradiated areas a permissible value of 5 mW/mm^2 is much more realistic than a restrictive power criterion.

In the small area short time regime a laser pulse can create an ignition source similar to an electric spark by a breakdown in air. It is known from the literature [10] that such spark with an energy approaching the electrical minimum ignition energy (MIE) is able to ignite an explosive mixture under optimised conditions (μs and ns pulses).

The effectiveness of this ignition process depends on

- pulse length and repetition rate;
- wavelength;

2 The information provided in this annex is taken from [1].

- target (absorber) material;
- irradiance and radiant exposure.

Microsecond pulses and nanosecond pulses with energies close to the MIE were found to ignite explosive mixtures as shown in Table B.2. In this case the combustible carbon black target is the most effective absorber. The properties of carbon black support this breakdown in comparison to the inert material chosen in the continuous wave experiments (very high absorption, high decomposition temperature, electron-rich structure and combustibility). For pulses in the millisecond range without a breakdown process but heating of the target, ignition energies are more than one order of magnitude higher than the electrical MIE. Here the inert grey body is the ideal absorber. Pulses longer than 1 s should be treated as continuous wave radiation.

For pulse trains the ignition criterion for each individual pulse is the energy criterion given above when the pulse is less than 1 s. With higher repetition rates the previous pulse might have an influence on the behaviour of the irradiated area with the actual pulse. For repetition rates greater than 100 Hz, the average power should be restricted to the continuous wave limit. This limitation forces a maximum repetition rate for a defined pulse energy. The shorter the pulse, the higher the permissible peak power, but the longer the duty cycle. This gives time for cooling of the target or decay of a spark or plume of hot material. Experiments showed [4] that for nanosecond pulses in the range of the MIE (up to 400 μJ) a spark lifetime of more than 100 μs is not to be expected for a beam diameter of 90 μm. For long pulse duration > 1 s the peak power should be restricted to the corresponding cw-limit.

The remaining combination of fundamental parameters i.e. short times over infinite area can be evaluated by the results for the other regimes.

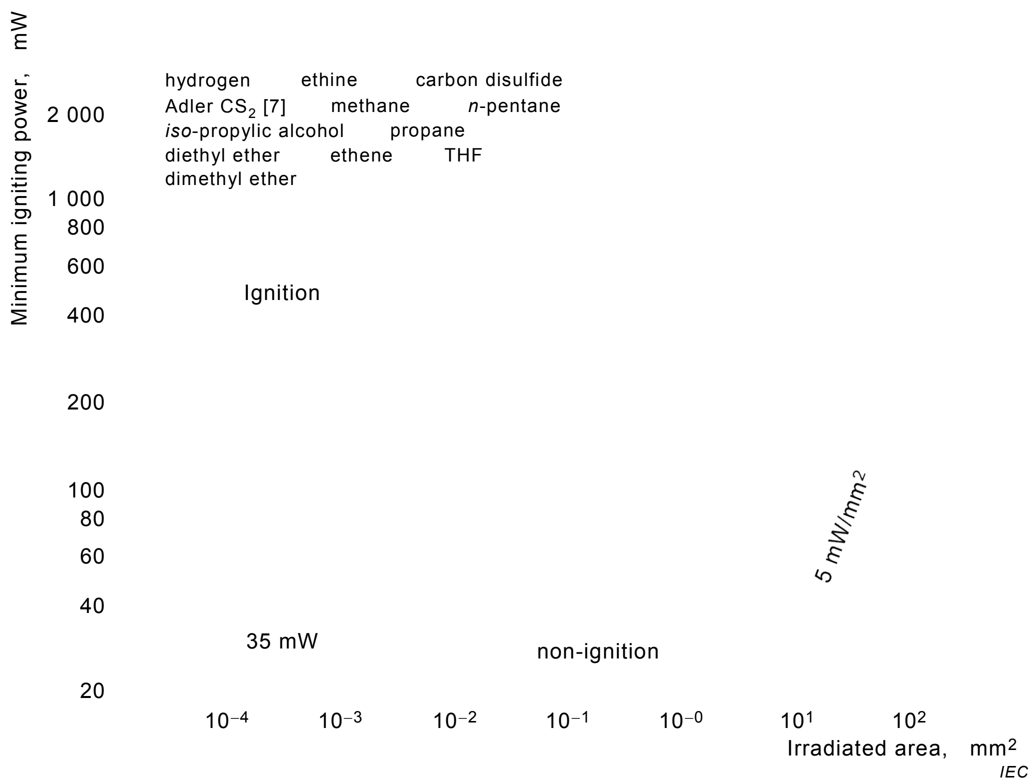
Table B.1 – AIT (auto ignition temperature), MESG (maximum experimental safe gap) and measured ignition powers of the chosen combustibles for inert absorbers as the target material ($\alpha_{1\ 064\ nm}$=83 %, $\alpha_{805\ nm}$=93)[3]

Group acc. to IEC 60079-0	Combustible in brackets: increased mixture temperature	AIT °C	MESG mm	Conc. comb. at min. ignition power PTB* (1 064 nm) % vol.	Min. ignition power 62,5 µm fibre PTB (1 064 nm) mW	Min. ignition power 400 µm fibre PTB (1 064 nm) mW	Conc. comb. at min. ignition power HSL* (803 nm) % vol.	Min. ignition power 400 µm fibre HSL (803 nm) mW	Min. ignition power 600 µm fibre HSL (803 nm) mW	Min. ignition power 1 500 µm fibre HSL (803 nm) mW
IIA	methane	595	1,14	5,0	304	1 125	6,0	960	1650	5 000
	acetone	535	1,04	–	–	–	8	830	–	–
	2-propanol	425	0,99	4,5	273	660	–	–	–	–
	n-pentane	260	0,93	3,0	315	847	3,0	720	1100	3 590
	butane	410 (365)	(0,98)	–	–	–	4,6	680	–	–
	propane	470	0,92	5,0	250	842	4,0	690	1 200	3 600
	petrol unleaded	300 (350)	>0,9	–	–	–	4,3.	720		3 650
	n-heptane (110 °C)	220	0,91	3,0	–	502	–	–	–	–
	methane/ hydrogen	595	0,90	6,0	259	848	–	–	–	–
IIB	diethyl ether/ n-heptane (110 °C)	200	0,90	4,0	–	658	–	–	–	–
	tetra-hydrofuran	230	0,87	6,0	267	–	–	–	–	–
	diethyl ether	175	0,87	12,0	89	127	23,0	110	180	380
	propanal (110 °C)	190	0,84	2,0	–	617	–	–	–	–
	dimethyl ether	240	0,84	8	280	–	–	–	–	–
	ethene	425	0,65	7,0	202	494	7,5	530	–	2 007
	methane/ hydrogen	565	0,50	7,0	163	401	–	–	–	–
IIC	carbon disulphide	95	0,37	1,5	50/24**	149	–	–	–	–
	ethyne	305	0,37	25,0	110	167	–	–	–	–
	hydrogen	560	0,29	10,0	140	331	8,0	340	500	1 620

* HSL = Health and Safety Laboratory of the Health and Safety Executive (UK),
PTB = Physikalisch-Technische Bundesanstalt (Germany)

** 24 mW was obtained for a combustible target (coal)

3 AIT and MESG were taken from [9].



NOTE The given values are for each combustible in its most easily ignitable mixture.

Figure B.1 – Minimum radiant igniting power with inert absorber target ($\alpha_{1064\ nm}$=83 %, $\alpha_{805\ nm}$=93 %) and continuous wave-radiation of 1064 nm

NOTE Data taken from [1],[7].

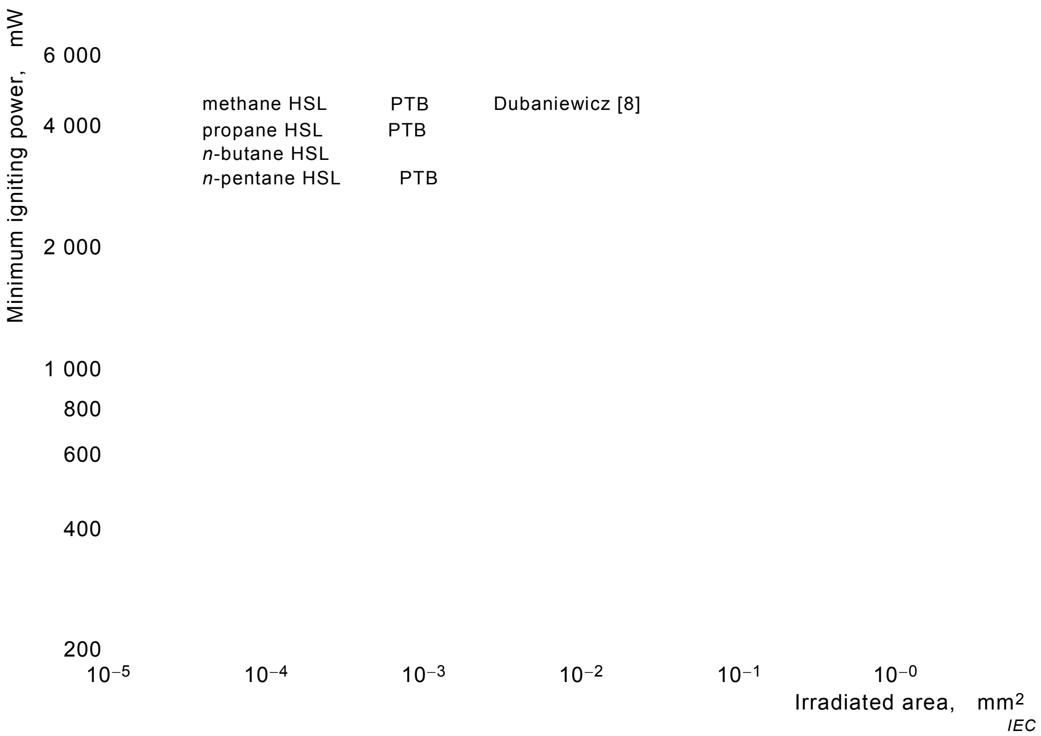


Figure B.2 – Minimum radiant igniting power with inert absorber target ($\alpha_{1\ 064}$ nm=83 %, α_{805} nm=93 %) and continuous wave-radiation (PTB: 1064 nm, HSL: 805 nm, [8]: 803 nm) for some n-alkanes

Table B.2 – Comparison of measured minimum igniting optical pulse energy ($Q_{e,p}^{i,min}$) at 90 µm beam diameter with auto ignition temperatures (AIT) and minimum ignition energies (MIE) from literature [9] at concentrations in percent by volume (φ)

Fuel	$Q_{e,p}^{i,min}$ µJ	φ %	AIT °C	MIE µJ	φ^{MIE} %	$Q_{e,p}^{i,min}$ /MIE
70 µs spiked Pulse						
n-Pentane	669	3	260	280	3,3	2,4
	>55 000	6,4				
propane	784	5,5	470	240	5,2	3,3
diethyl ether	661	3,4	175	190	5,2	3,5
	1285	5,2				6,8
ethene	218	5,5	425	82	6,5	2,7
hydrogen	88	21	560	17	28	5,2
carbon disulfide	79	6,5	95	9	8,5	9,3
Nanosecond Pulses (20 ns to 200 ns)						
propane	499	4,0	470	240	5,2	2,1
ethene	179	5,5	425	82	6,5	2,2
hydrogen	44	12	560	17	28	2,6
	46	21				2,7
NOTE The target material was carbon black.						

Annex C
(normative)

Ignition hazard assessment

In all cases, where optical radiation is to be considered, the ignition hazard assessment shall be the first step. If the assessment shows that no ignition is to be expected, the further application of this standard is not necessary.

An explosive atmosphere can be ignited by optical radiation provided that the beam strength exceeds an inherently safe level and an absorbing solid exists in the beam that can cause a hot spot and an ignition source accordingly, or in case of pulses the conditions for a break down apply (threshold irradiance exceeded). See Figure C.1.

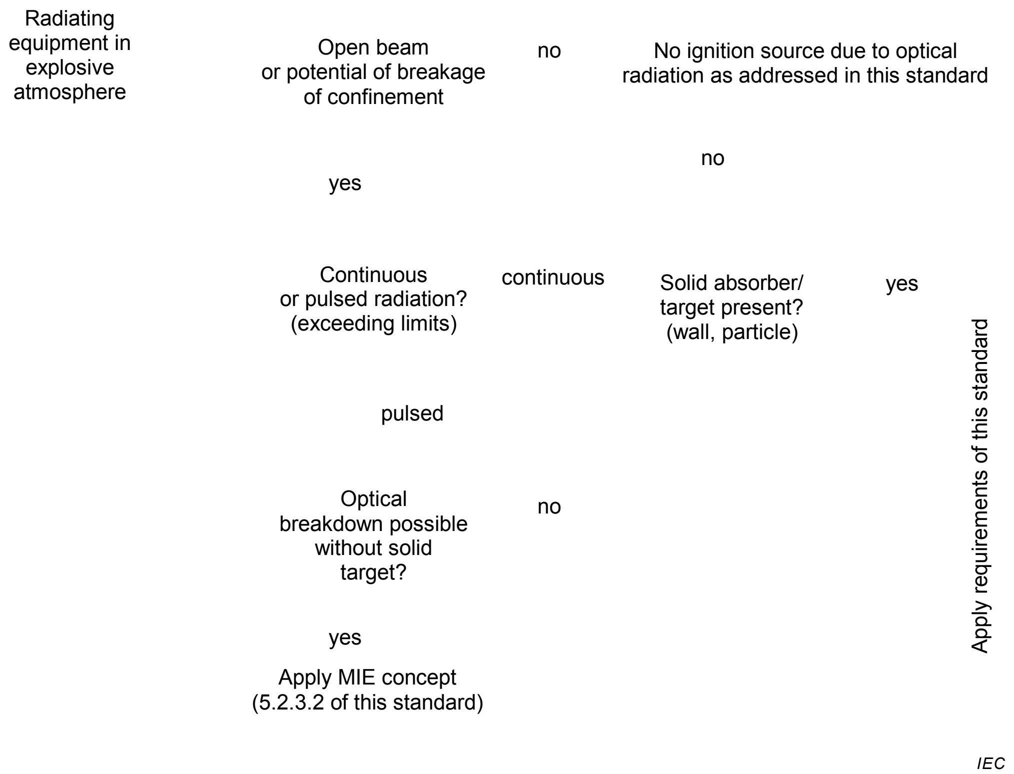


Figure C.1 – Ignition hazard assessment

Where these conditions for an ignition do not apply, an ignition hazard does not exist within the scope of this standard.

It is important to understand that even open radiation exceeding the inherently safe level does not itself lead to ignition, as additional provisions are necessary to start an ignition process. This is different from the situation of the electrical spark ignition process.

As an example, a gas analysis system where in the beam there is no absorbing target that can be heated up to be an ignition source may not create an ignition hazard with respect to the optical radiation. In this specific case, there will be absorption of optical energy in the mixture itself, but it can be easily demonstrated in most cases that there is no heating of the mixture to such an extent that it will be ignited.

The ignition hazard assessment also applies to the use of the protection concepts themselves. Where an enclosure for the beam is used that does not allow solid materials to