



# Ignition risk due to optical radiation

## in hazardous areas

by Heino Bothe, Mario Graube and Ulrich Johannsmeyer

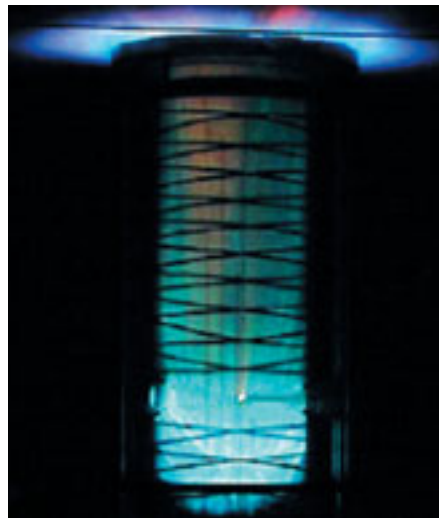


Figure 1: Ignition of a gas/air mixture by optical radiation at the soiled end of the optical fibre

### Introduction

In industrial sectors, such as measurement and control systems for process plants, equipment that utilizes optical radiation is increasingly used. For example, optical fibre technology is very highly valued due to its high data transmission speed, as well as, its immunity to external interference during signal transmission. Optical radiation is also used in analyzers and for liquid level indication. The rapid development of powerful LEDs (power LEDs) is significantly changing the current lighting technology. Optical systems are also increasingly used in explosion hazardous areas. In terms of explosion protection,

there are a number of advantages; on the one hand electrical sparking is not possible, and the electrical isolation realized by optical transmission media is often advantageous.

However, on the usage of sources of optical radiation in hazardous areas it must be noted that radiation in the optical spectral range can produce a source of ignition, particularly if focused [1–6]. Here there are primarily three different mechanisms that need to be considered. The radiation can be absorbed by the potentially explosive gas mixture and cause ignition of the mixture either due to a local temperature rise or due to photochemical processes. On the other hand, the second possible means of ignition due to the absorption of the radiation by solid surfaces or particles may arise in the case of continuous wave radiation (cw-radiation) in the near infrared, and in the visible spectral range. This route is regarded as the most probable of the possible variants. Finally, pulsed, focused laser radiation can also, as the third possibility, result in the formation of a plasma or cause a reaction at the absorber surface, and therefore cause ignition. →

**Research results**

Optical radiation is described as a possible source of ignition in the European Directive 94/9/EC (ATEX Directive).

General protection principles for electromagnetic waves in the frequency range of  $3 \cdot 10^{11}$  Hz to  $3 \cdot 10^{15}$  Hz (optical spectral range) are also given in the standard EN 1127-1 [2]. However, as originally there was only limited information available on quantitative limits, several research projects were undertaken to obtain safe operational limits for systems using optical radiation. Several studies have addressed the ignition of inflammable gas/air mixtures by optical radiation. The most likely ignition hazard is light incident on an absorbing surface resulting in a local temperature rise, or a reaction in the absorber material that can cause a surrounding explosive atmosphere to ignite. As part of two European research projects, limiting values were determined for continuous radiation [8, 9, 13]. A typical experimental setup consisted of optical fibres of varying diameter that were coated on one end (target for the simulation of the soiling of the end of fibre) with a suitable absorber material that absorbed the optical radiation in the fibre as completely as possible. The end of the fibre was arranged in a test vessel filled with an explosive mixture (Figure 1).

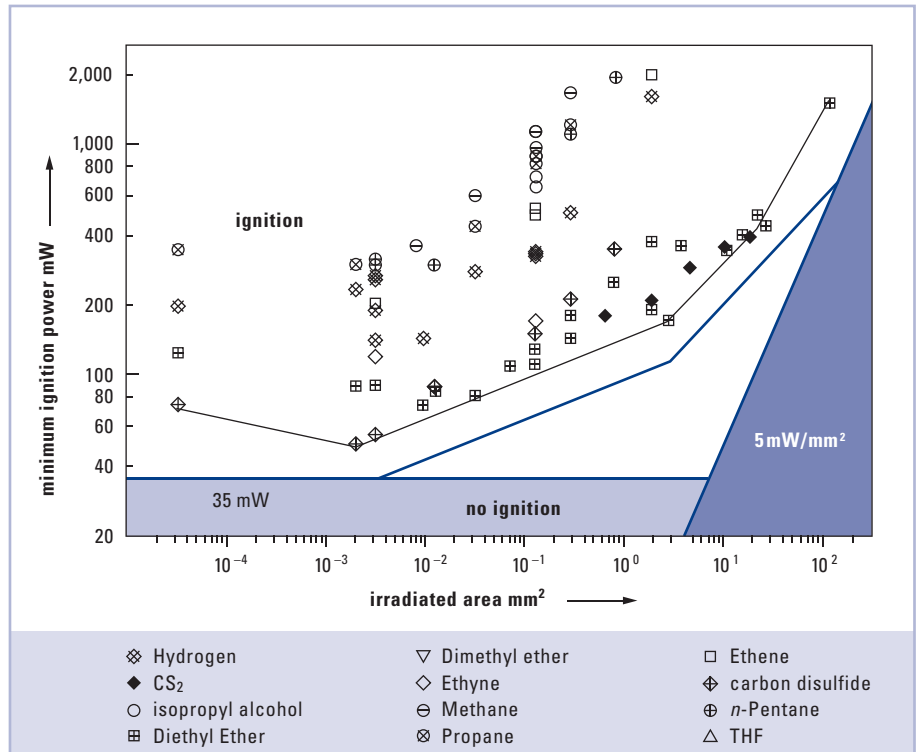


Figure 2: Minimum radiant ignition power with inert absorber target material ( $\alpha_{1064 \text{ nm}} = 83 \%$ ,  $\alpha_{805 \text{ nm}} = 93 \%$ ) and cw-radiation of 1064 nm (except the limiting value of CS<sub>2</sub>-mixture)

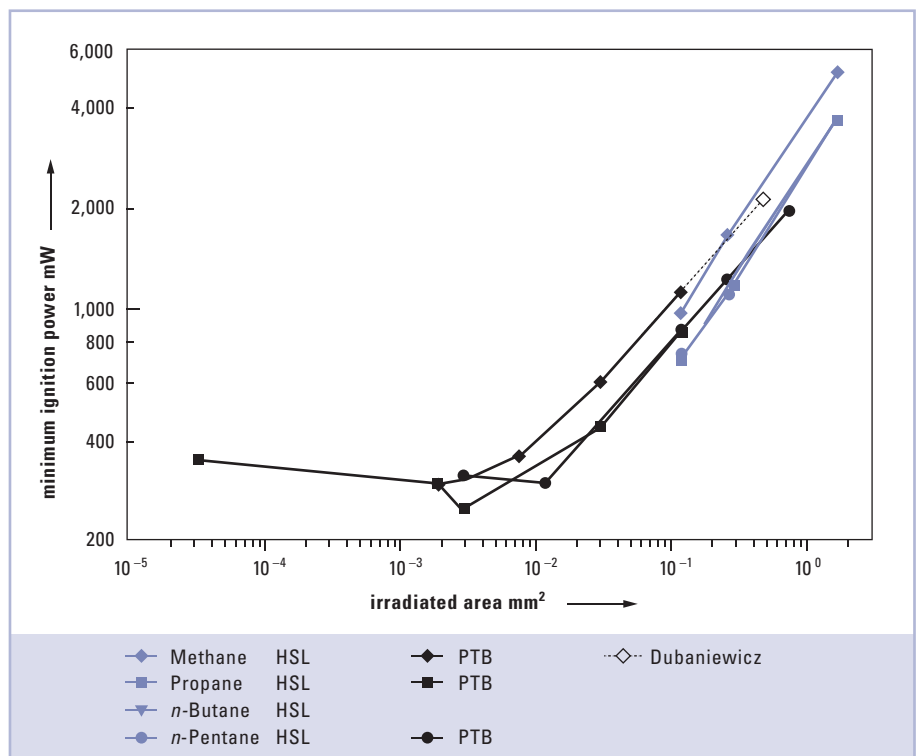


Figure 3: Minimum radiant ignition power with inert absorber target ( $\alpha_{1064 \text{ nm}} = 83 \%$ ,  $\alpha_{805 \text{ nm}} = 93 \%$ ) and cw-radiation (PTB: 1064 nm, Health and Safety Laboratories; HSL: 805 nm) for some n-alkenes

For inert and combustible target materials, a limit of 50 mW was found for all inflammable gas/air mixtures (with the exception of CS<sub>2</sub>) with continuous radiation (Figure 2 and 3). In an additional series of special tests with a carbon disulphide/air mixture, the ignition limiting value was at around 20 mW. Values of around 10 mW/mm<sup>2</sup> were determined for the minimum irradiance capable of causing ignition.

Unfortunately, the results obtained for continuous radiation with the different inflammable gases did not produce any clear structure to the explosion groups or the temperature classes as are normally used for explosion protection equipment. However it was found that for flammable gases and vapours in explosion group IIA combined with temperature classes T1, T2 or T3, it was not possible to find powers capable of causing ignition below 200 mW. As this combination covers the overwhelming majority of inflammable gases and vapours, the limit stated is of significant practical importance.

The ignition hazard due to pulsed radiation was investigated using two independent methods [7]. Here pulses with a pulse length in the nanosecond and microsecond range were generated using a Nd:YAG laser. Inert and combustible targets were attached to the end of optical fibres and exposed in explosive mixtures. For the second test method, small particles were exposed in the laser's focused beam path. The latter method yielded the lowest ignition values. In both cases, ignition was not caused by a hot surface, but primarily

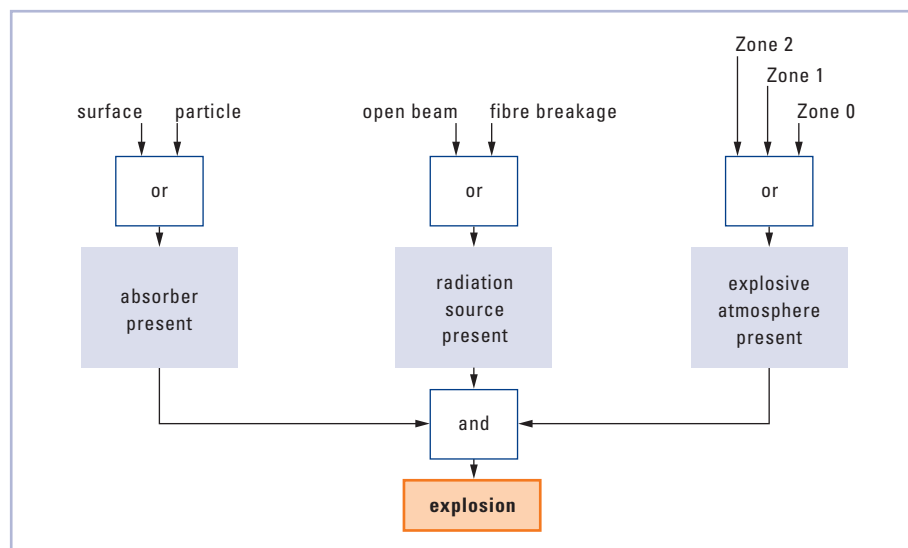


Figure 4: Ignition hazard assessment according to EN 60079-28

by a plasma or combustion process generated in the target material. The ›optical minimum ignition energies‹ measured for hydrogen, propane, diethyl ether, pentane and carbon disulphide with air were higher than the minimum electrical ignition energies (spark ignition) by a factor of roughly 2 to 9.

The data obtained from the research projects were used as the basis for the protection concept ›inherently safe optical radiation‹. As these data were determined under ›worst case‹ conditions in the laboratory, they already include a safety factor compared to practical situations.

### Safety concepts for optical radiation, standardization

Based on the new research results, around 10 years ago Working Group IEC TC31 WG8 was founded by the IEC under German chairmanship; this working group was tasked with the preparation of a standard for devices that operate with optical radiation. The group worked closely with a working group from the ISA in the USA and proposed three possible protection concepts for optical devices:

- › inherently safe optical radiation ›op is‹
- › protected optical radiation ›op pr‹
- › optical systems with interlock ›op sh‹



The standard prepared was published in 2006 as IEC 60079-28 and, using the parallel voting procedure, also adopted as European Standard EN 60079-28 [1], as well as, VDE document VDE 0170-28:2007.

However, it is important that an ignition risk assessment is performed before the application of protective measures, similar, for example, to usual practice for non-electrical equipment in the context of the ATEX Directive (Figure 4). The prerequisites for the production of an explosion by optical radiation are then:

- potentially explosive mixture
- source of radiation of sufficient intensity/duration
- an appropriate target particle or corresponding surface (unless the breakdown conditions are also achieved without the presence of a solid body)

A concrete ignition hazard is only to be assumed if these three prerequisites are met.

Even in the case of unconfined radiation that exceeds the value for inherent safety (Table 1), ignition will not necessarily occur, because additional conditions (unlike for electrical spark ignition) are necessary to initiate an ignition process.

An assessment of the specific case or the specific equipment must be performed taking into account all the conditions necessary for ignition, as well as, also taking into account the related risk level (IEC: Equipment Protection Level ›EPL‹, category in accordance with the Directive 94/9/EC). The concept of ›inherently safe optical radiation‹ is described in the most detail in EN 60079-28. Inherently safe optical radiation refers to visible radiation or infrared radiation that in normal or defined fault conditions cannot provide sufficient energy to ignite a specific explosive atmosphere. The safety approach with this concept is to limit the irradiance. The limiting values are based on the research projects mentioned and include an additional safety factor. Table 1 contains an extract from the standard mentioned above. The values stated apply for continuous wave radiation (cw-mode).

As an alternative to Table 1, safe power figures can be taken from Figure 2 for intermediate values for the surface areas on which combustible solid absorbers can be excluded (exception: materials in group IIC T6).

The standard also includes limits for inherently safe pulsed radiation. The conditions for experimental ignition tests in specific cases are also defined. However, these tests are very complex and time-consuming.

Optical equipment with the inherently safe optical radiation ›op is‹ protection concept must have protection in relation to the power/energy limit based on the category/safety level to prevent excessively high radiant intensities in hazardous areas.

It may be taken into account that optical sources such as laser diodes or Light Emitting Diodes (LEDs) fail if they are overloaded by excessive power in fault conditions.

The failure characteristic of certain optical sources can be used for the necessary power limiting in case of a fault (test on 10 samples).

Explosion group	I	IIA	IIA	IIIB	IIC	
Temperature class		T3	T4	T4	T4	T6
Surface temperature (°C)	<150	<200	<135	<135	<135	<85
Power (mW)	150	150	35	35	35	15
Irradiance (mW/mm <sup>2</sup> ) (surface area not exceeding 400 mm <sup>2</sup> )	20*	20*	5	5	5	5
* For irradiated areas greater than 30 mm <sup>2</sup> , where combustible materials may intercept the beam, the 5 mW/mm <sup>2</sup> irradiation limit applies						

Table 1: Safe optical power and irradiance for hazardous areas categorized by apparatus group and temperature class



Protected optical radiation ›op pr‹ exists if optical radiation is confined in an optical medium and it can be assumed that radiation will not escape from the enclosing medium into the hazardous area, and the reliability of the confining medium is suitable for the respective zone/category.

In relation to the resistance of the enclosing medium (e.g. optical fibre), methods for increased safety ›e‹ for electrical cables can be applied (e.g. protected installation and protected against mechanical stress). If the optical couplers, radiation sources or the unprotected radiation are only used outside the hazardous area, no further protective measures are required. This situation also applies if the optical radiation sources, couplers etc. are arranged in a protected enclosure that complies with the type of protection flameproof enclosures ›d‹ or pressurized enclosures ›p‹.

For applications in zone 2/category 3G (see Table 2), the optical fibre is assumed to protect against the release of the optical radiation into the atmosphere. For foreseeable malfunctions it can be protected by using additional armouring, conduit, cable trays or raceway.

The optical systems with interlock on the breakage of the optical fibre ›op sh‹ protection concept can be used for non-inherently safe radiation, if the source is cut off, if the protection by the confinement fails, and the radiation becomes unconfined for a short time. The shut down time must be shorter than the ignition delay time.

The interlock cut off must be reliable as is appropriate for the risk level of the optical system (zone, EPL, category). To investigate the functional properties of such equipment, e.g., methods can be used as described in IEC/EN 61508 [14] and IEC/EN 61511 [15].

Where it can be demonstrated by the ignition hazard assessment (Figure 4) that the conditions for ignition are attained readily after the breakage of the optical fibre, the shut down times for the purpose of eye protection are allowed to be used (see IEC 60825-2:2000 [16]).

Not every protection concept described is suitable for every risk level. The basic principles (Table 2) are given in EN 60079-28:

### Application of EN 60079-28 in practice

In the test laboratory at the Physikalisch-Technische Bundesanstalt (PTB), a measuring facility was set up that enables the radiant power from almost monochromatic continuous sources of radiation to be measured under computer control. Specially designed, programmable current sources are used to control semiconductor laser diodes and LEDs. As a further variable on the optical radiant power that can be delivered, it must be possible to vary the enclosure temperature for the sources of radiation. →

Protection concept(s)	Level of risk		
	Zone 0 Category 1G EPL G <sub>a</sub>	Zone 1 Category 2G EPL G <sub>b</sub>	Zone 2 Category 3G EPL G <sub>c</sub>
Inherently safe optical radiation ›op is‹			
Safe with two faults	yes	yes	yes
Safe with one fault	no	yes	yes
Safe in normal operation	no	no	yes
Protected fibre optical media with ignition capable beam ›op pr‹			
With additional mechanical protection	no	yes	yes
Without additional mechanical protection	no	no	yes
Protected fibre optical media with ignition capable beam interlocked with fibre ›op sh‹ breakage			
With additional mechanical protection	yes	yes	yes
Without additional mechanical protection	no	yes	yes
Non (unconfined, ignition capable beam)	no	no	no

Table 2: Application of protection concepts for optic systems

The measurement setup includes a collimator. This component has the task of focusing the divergent radiation from semiconductor laser diodes into a defined parallel beam to be able to measure all the optical radiant power emitted in a free space application using a detector.

An integrating sphere is used to advantage at the PTB for testing LEDs; this sphere makes it possible to measure all the radiation from sources with large divergence due to the integration of the radiation (Figure 7). Semiconductor sensors are very suitable for the measurement of monochromatic sources. Various types of sensors are available so that, depending on the spectral characteristic (visible range/infrared range) of the source to be measured, the optical radiation can be correctly evaluated for safety purposes.

The measuring facility described enables the optical radiation to be measured as a function of the electrical parameters at a defined ambient temperature for the most common optical sources.

Wideband sources, e.g. halogen lamps, xenon lamps and white high power LEDs (Figure 6) are increasingly used as part of explosion protected electrical equipment, particularly for lighting (Figure 5) and indication.

To determine the radiant power and the irradiance, thermopile measuring sensors (Figure 8) are used; these operate based on the Seebeck effect.

This is a calorimetric measuring principle. By using apertures or special probe attachments with a defined area, it is possible to determine the radiant intensity from the measurement of the optical radiant power.

This evaluation criterion is used particularly for large radiated areas ( $> 4 \text{ mm}^2$ ), as are to be found in lighting technology (see Figure 2).

In some application cases, the safety related assessment is somewhat more complex in practice. If pulsed radiation is used for data transmission (e.g. via optical fibre), the pulse duration and the pulse sequence are often undefined, at least in safety terms.

Here the range of situations to be considered for safety stretches from continuous on through undefined pulse packets to any short single pulses. In these cases, a restrictive assessment with the assumption of continuous radiation (cw-mode) provides assistance; the cw-power used is the same as the maximum pulse power produced. If this value is above the limit for inherently safe optical radiation, use can be made of the following rules:

For sequences of optical pulses, the criteria for a single pulse apply to each individual pulse (energy criterion). At repetition rates above 100 Hz, the mean power must not exceed the limits for the continuous radiation. At repetition rates below 100 Hz a higher mean power can be applied, provided this has been demonstrated by appropriate ignition tests in accordance with chapter 6 of EN 60079-28. It is also the case here that the repetition rates for the pulses must be protected using safety features as a function of the risk level (ATEX-category, EPL). As a result, for category 3G or EPL Gc the operating data can be used, while for category 2G/EPL Gb the repetition rates must remain unchanged even in the event of one failure, and for category 1G/EPL Ga in the event of two independent failures.



Figure 5: Explosion protected hand lamp type 6140 of R. STAHL



Figure 6: High Power LED (Philips Lumileds Lighting Company)



Figure 7: Integrating sphere (Company Laser 2000)



Figure 8: Thermopile measuring sensor with analysing unit (Company Laser 2000)



## Conclusion and outlook

Equipment that utilizes optical radiation is today increasingly used in many sectors of industry. E.g., optical fibre technology is often used due to its high data transmission speed as well as its immunity to external interference during signal transmission. The continuing development of powerful LEDs (»power LEDs«) is now having an impact on lighting technology. Optical systems already have a fixed place in explosion hazardous areas. The new standard EN 60079-28 for the explosion protection of optical equipment was written based on several European research projects and other scientific findings. Based on a prior ignition hazard assessment, the standard describes three possible protection concepts for optical equipment, inherently safe optical radiation »op is«, protected optical radiation »op pr« and optical systems with interlock »op sh«. The safety-related evaluation of the optical systems can be undertaken using suitable measuring instrumentation. Dust explosion protection is not covered in the current standard; this may be included along with other improvements in the second edition of IEC/EN 60079-28, on which work is currently starting.

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