

# Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation — Guide

ICS 13.230; 33.060.20

## National foreword

This Published Document is the official English language version of CLC/TR 50427:2004. It is envisaged that PD CLC/TR 50427:2004 will eventually replace BS 6656:2002 but for a transitional period both documents will be current in order for users of the standards to familiarize themselves with the contents of the new document.

The UK participation in its preparation was entrusted by Technical Committee GEL/31, Electrical apparatus for explosive atmospheres, to Subcommittee GEL/31/-/602, Radio-frequency radiation-induced ignition and detonation, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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TECHNICAL REPORT

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December 2004

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English version

**Assessment of inadvertent ignition of flammable atmospheres  
by radio-frequency radiation –  
Guide**

Evaluation des risques d'inflammation  
des atmosphères inflammables  
par des rayonnements de  
radiofréquence –  
Guide

Leitfaden zur Verhinderung  
der unbeabsichtigten Zündung  
explosionsfähiger Atmosphären  
durch hochfrequente Strahlung

This Technical Report was approved by CENELEC on 2004-08-28.

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**CENELEC**

European Committee for Electrotechnical Standardization  
Comité Européen de Normalisation Electrotechnique  
Europäisches Komitee für Elektrotechnische Normung

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## **Foreword**

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## Introduction

Electromagnetic waves produced by radio-frequency (RF) transmitters (e.g. radio, television and radar) will induce electric currents and voltages in any conducting structure on which they impinge. The magnitude of the induced current and voltages depends upon the shape and size of the structure relative to the wavelength of the transmitted signal and on the strength of the electromagnetic field. When parts of the structure normally in contact are caused to break or separate momentarily (e.g. during maintenance or as a result of vibration) a spark may occur if the induced voltage and current is sufficiently large. If this happens in a location where a potentially flammable atmosphere may be present a hazardous situation can occur. However, the possibility of ignition will depend on many factors including whether the spark can deliver sufficient energy to ignite a particular flammable atmosphere.

This European Technical Report provides a systematic approach to assist transmitter operators, plant managers and all others concerned with a logical method for the assessment and elimination of RF induced ignition hazards.

The assessment procedures recommended in this European Technical Report are based on measurements of the powers and energy that can be extracted from typical structures, including cranes, and measurements of the minimum powers and energy that are required to ignite various flammable atmosphere gas groups.

The assessment procedures for probability of ignition recommended in this European Technical Report are based on the assumption that worst case conditions apply at all times. The critical features are the coincidence of the structure in resonance and the presence of the gas/air mixture in the optimum proportions for RF spark ignition. Deviation from these optimum conditions will result in significantly higher powers being required for ignition.

NOTE 1 Several studies have been performed which indicate that the power could be twice as great for an assumed risk as detailed in reference [1], if due allowance is taken for probabilistic effects. In order to achieve a probability of ignition comparable with other risks, it would be necessary for effective extractable power calculated to be twice the values determined according to this European Technical Report. The probabilistic elements could be taken into consideration following further research work and practical experience.

NOTE 2 If allowances for probabilities are to be applied then expert advice should be sought.

## 1 Scope

This European Technical Report provides guidance on assessing the potential ignition hazard from the inadvertent extraction of energy from electromagnetic fields, propagated from communication, radar or other transmitting antennas to plant where a potentially flammable atmosphere may be present. The frequency range covered by this European Technical Report is 9 kHz to 60 GHz. This European Technical Report does not apply to similar hazards arising from electromagnetic fields generated by other means, such as electric storms, electricity generating installations or other radiating electrical equipment, nor does it apply to any hazard arising within telecommunication or other electronic equipment.

NOTE 1 The methods of assessment from 9 GHz to 60 GHz are based on extrapolation of data for frequencies below 9 GHz.

NOTE 2 The ignition of dust is not covered in this European Technical Report. This European Technical Report also provides advice on how to mitigate the hazard in cases where the assessment indicates that a hazard may exist. This European Technical Report does not cover the hazards associated with the use of electro-explosive devices (EED) (see CLC/TR 50426), or the biological hazards of exposure to RF fields.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

| <u>Publication</u> | <u>Year</u> | <u>Title</u>                                                                                                          |
|--------------------|-------------|-----------------------------------------------------------------------------------------------------------------------|
| EN 60079-0         |             | <i>Electrical apparatus for explosive gas atmospheres — Part 0: General requirements (IEC 60079-0)</i>                |
| EN 50020           |             | <i>Electrical apparatus for potentially explosive atmospheres — Intrinsic safety “i”</i>                              |
| EN 60079-10        |             | <i>Electrical apparatus for explosive gas atmospheres — Part 10: Classification of hazardous areas (IEC 60079-10)</i> |

## 3 Terms and definitions

For the purposes of this European Technical Report the following terms and definitions apply.

### 3.1

#### **circuit factor, $Q_k$**

performance parameter for a structure acting as a receiving antenna (see [2])

NOTE Assuming the structure to be tuned to the transmission frequency  $f_t$ ,  $Q_k$  is the ratio of  $f_t$  to  $\Delta f$ , where  $\Delta f$  is the difference between those frequencies, one above and one below  $f_t$ , at which the structure resonates when it is re-tuned so that the open circuit voltage at  $f_t$  has fallen by 3 dB.  $Q_k$  is closely related to the Q factor of a tuned circuit.

### 3.2

#### **extractable power, $P_{\max}$**

power dissipated in a resistive load connected across a discontinuity in a structure acting as a receiving antenna

NOTE The extractable power reaches its maximum when the structure is tuned to the frequency of the transmitter (under these conditions the impedance of the structure presents a resistive value only, with no reactive components), and the load resistance is a value equal to that of the structure.

### 3.3

#### **modulus match power, $P_{\text{mm}}$**

maximum value of extractable power that can be achieved with a resistive load at a frequency to which the structure is not tuned (see [2])

**3.4****structure efficiency**

ratio of the extractable power that the structure can deliver to a matched load and the maximum extractable power delivered by a lossless short dipole in free space immersed in the same field

**3.5****thermal initiation time**

time during which energy deposited by the spark accumulates in a small volume of gas around it without significant thermal dissipation

NOTE For times shorter than the thermal initiation time the total energy deposited by the spark will determine whether or not ignition occurs. For increasingly longer times, the power or rate at which energy is deposited becomes the determining factor for ignition.

**3.6****vulnerable zone**

region surrounding a transmitter in which a potential hazard could arise within a hazardous area of a plant

**3.7****far field**

region, distant from the transmitter, in which the field strength is inversely proportional to distance in the absence of ground reflection

NOTE The inner limit of the far field is generally regarded as the distance  $d$  from the transmitter defined as follows. For frequencies up to and including 30 MHz,  $d = 8H^2/\lambda$ , where  $H$  is the height of the top of the antenna above ground and  $\lambda$  is the wavelength. At frequencies above 30 MHz,  $d = 2W^2/\lambda$ , where  $W$  is the width of the antenna.

**3.8****near field**

region close to the transmitter which lies within the far field region

NOTE In the near field region the dependence of the field strength on distance is complex and mutual coupling effects can also affect the value of extractable power.

**3.9****flammable atmosphere**

gas/air or vapour/air mixture capable of being ignited which can occur in a hazardous area

NOTE See EN 60079-10 for further information.

**3.10****equivalent isotropically radiated power (EIRP)**

product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain)

**3.11****effective field strength**

value of electric field strength due to a single transmitter which is derived from the transmitter characteristics, modulation factors (see 6.5) and distance, and is used for the calculation of extractable power

**3.12****antenna gain**

gain produced by an antenna concentrating radiation in a particular direction

NOTE 1 The gain of an antenna is always related to a specified reference antenna.

NOTE 2 The gain,  $G$ , of an antenna in a particular direction is given by the equation:  $G = (1)$  where  $R$  is the power in Watts,  $W$ , that should be radiated from the reference antenna;  $A$  is the power in Watts,  $W$ , that should be radiated from the given antenna to give the same field strength at a fixed distance in that direction.

$$G = \frac{R}{A} \quad (1)$$

where

$R$  is the power in Watts,  $W$ , that should be radiated from the reference antenna;

$A$  is the power in Watts,  $W$ , that should be radiated from the given antenna to give the same field strength at a fixed distance in that direction.

NOTE 3 The gain, which is often expressed in logarithmic form, is stated in decibels.

### 3.13

#### **hazard**

potential source of danger to life, limb or health, or of discomfort to a person or persons, or of damage to property

### 3.14

#### **safe distance**

distance outside which it is considered that there is no potential hazard

## 4 Symbols and abbreviations

### 4.1 Modulation codes

|       |                                                                                                                              |
|-------|------------------------------------------------------------------------------------------------------------------------------|
| AM    | Amplitude-modulated speech or music transmission. Carrier power quoted.                                                      |
| MCW   | Amplitude-modulated tone transmission. Carrier power quoted.                                                                 |
| TV    | Amplitude-modulated video transmission. Peak power quoted.                                                                   |
| R ( ) | Pulse-modulated radar transmission. Peak power quoted. The number in brackets indicates the pulse duration in s where known. |
| FM    | Frequency modulation.                                                                                                        |
| FSK   | Frequency shift keying.                                                                                                      |
| GFSK  | Gaussian frequency shift key modulation.                                                                                     |
| SSB   | Single sideband transmission. Peak envelope power quoted.                                                                    |
| CW    | Continuous wave.                                                                                                             |
| MSK   | Minimum shift keying.                                                                                                        |
| GMSK  | Gaussian minimum shift keying.                                                                                               |
| CDMA  | Code division multiple access.                                                                                               |
| PCM   | Pulse code modulation.                                                                                                       |
| PSK   | Phase shift keying.                                                                                                          |
| PM    | Phase modulation.                                                                                                            |
| DQPSK | Differential quadrature phase shift keying.                                                                                  |

## 4.2 Polarization codes

V Vertical polarization.

H Horizontal polarization.

V/H Either vertical or horizontal polarization, or both simultaneously.

## 5 General considerations

### 5.1 Radio-frequency hazard

For a radio-frequency hazard assessment, detailed consideration should be taken of the conditions that have to be satisfied simultaneously for a hazard to exist. These are as follows:

NOTE 1 The simultaneous occurrence of these four conditions is unlikely.

NOTE 2 See [3] for further information.

a) electromagnetic radiation of sufficient intensity;

NOTE 3 An electromagnetic field of sufficient intensity may be generated by a fixed/mobile or portable transmitter, the magnitude of the field depending upon the transmitted power, the antenna gain and the proximity to the site under consideration.

NOTE 4 Intense electromagnetic fields are also generated by the intentional radio frequency sources in industrial, scientific and medical (ISM) equipment. Field strengths in the order of 10 V/m may be present in the near vicinity of the equipment.

Typical characteristics of industrial equipment are:

|                            |   |                              |
|----------------------------|---|------------------------------|
| 2,5 GHz to 10 kW           | } | industrial microwaves        |
| 915 MHz to 100 kW          |   |                              |
| 27 MHz to (10 to 50) kW    | } | welding or drying techniques |
| 13,56 MHz to (10 to 50) kW |   |                              |

b) presence of a structure capable of behaving as a receiving antenna. Only structures in a hazardous area (as defined in EN 60079-10) should be considered (see Clause 7 and Clause 8);

c) existence of a mechanism whereby the received energy or power can be delivered as a spark;

d) presence of a flammable atmosphere (see Clause 8).

All conducting structures behave as receiving antennas, but the magnitude of induced current and voltage depends upon the method of construction and the configuration. Experience gained in practical measurements on structures has shown that for frequencies up to and including 30 MHz, the loop configuration is the most efficient receiving system (see [4]). At higher frequencies all structures are large compared with a wavelength and their behaviour is conveniently treated by the use of long dipole theory. The behaviour of these structures is described in Clause 7.

The generation of a spark is dependent upon the appearance of a small discontinuity in a receiving structure, for example when parts of a structure normally in contact are caused to separate, either during maintenance or at any time by flexing, mechanical vibration or similar actions.

The spark energy required to ignite a flammable atmosphere depends upon the nature and composition of the flammable atmosphere. In making the assessment, it is assumed that the composition is at its optimum for ignition to take place. This in itself provides a margin of safety under most circumstances, since the energy required for ignition of a particular atmosphere generally increases rapidly as its composition moves away from the optimum.

## 5.2 Philosophy of systematic method of approach

This European Technical Report is based on a series of graded assessments, each requiring a progressively more detailed analysis.

The initial assessment procedure is designed to eliminate from further consideration those locations where it is highly unlikely that a hazard exists. It is based on “realistic worst case” estimates of the radius of the zone around different classes of transmitter within which a hazard might result from the presence of a structure in a hazardous area.

If the initial assessments indicate that a hazard might exist, the full assessment procedure given in 10.4 should be followed. This provides a method of computing the maximum power available in any spark produced, based on more detailed information about the actual transmitter and plant and their relative location. This calculated power should then be compared with the minimum power required to ignite the particular flammable atmosphere concerned (see Table 2, Table 3 and Figure 4).

When this procedure is followed, it will quickly become apparent whether the available information is adequate for an assessment to be made with a high degree of confidence or whether additional information is required from practical measurements on site. If doubt exists, then expert opinion should be sought (see Annex A).

The assessment procedures in this European Technical Report determine whether ignition is possible under worst case conditions. No account is taken of any effects that could influence the probability of ignition. An inherent safety factor exists for many circumstances.

The assessment procedures recommended in Clause 10 apply generally to most circumstances. For cranes, mobile transmitters and oil rigs the special considerations described in Clause 12 should be taken into account.

## 5.3 Responsibility for making the hazard assessment

The radio-frequency (RF) environment is becoming increasingly severe, with the proliferation of transmitting sources, increased transmitter powers and the exploitation of new techniques.

NOTE 1 Legislation, (for example in the UK see [5]), requires that employers safeguard both their employees and others who may be placed at risk by their activities. Hence, both operators of RF transmitters and users of plant in which a flammable atmosphere may be present have a responsibility to ensure safe operation.

NOTE 2 Particular locations such as mines and quarries may exist where additional responsibilities are placed on the owners and managers.

Operators of a proposed plant in which a flammable atmosphere may be present should send details to the transmitter operators and request information about relevant transmitters in the locality of the site. If a potential hazard is indicated, the plant operator should then use the assessment procedures given in this European Technical Report, in consultation with the transmitter operators concerned.

Similarly, the operator of a proposed new (or altered) transmitter should contact all operators of plant with potentially flammable atmospheres within the vulnerable zone for their transmitter, and use the procedure given in this European Technical Report to assess the potential hazard at each location.

Where both plant and transmitter already exist but an assessment is required, the plant operator should be held responsible for ensuring that an assessment is made. If for some reason relevant information cannot be made available to the body responsible for the assessment, the responsibility for having an assessment carried out should be assumed by the body unable to release the necessary information.

NOTE 3 As an aid to those who need to make a hazard assessment but do not have the necessary technical resources, a list of sources of information and specialist organizations capable of providing consultation or test facilities is given in Annex A.

## 6 Transmitters and transmitter output parameters

### 6.1 Types of transmitter

This clause provides information on various types of transmitter and transmitting systems. This information is necessarily rather brief for certain types of radar and other military equipment but basic details are given and further information may be sought from the specialist organizations listed in Annex A. Typical types of antenna are shown in Figure B.1.

### 6.2 Frequency range

The main frequency range covered in this guide is 9 kHz to 60 GHz. The types of transmitter considered include the following:

- a) radio and television broadcast transmitters in specific bands in the range 0,15 MHz to 1 000 MHz;
- b) fixed and mobile transmitters for communication purposes, private, commercial and amateur, in specific bands above 0,4 MHz and for military use above 0,15 MHz;
- c) radar, in specific bands at 220 MHz, 600 MHz and above 1 GHz;
- d) navigational equipment, non-directional beacons, etc., from 9 kHz upwards.

### 6.3 Transmitter output power

Transmitter output power from several watts up to megawatts may be encountered depending on the frequency range and the application. The method of specifying the power varies, which is significant for hazard assessment when highly directional antennas are in use and when considering different modulation systems. In general, values are specified in the technical documentation for either the carrier or the peak power output from the transmitter together with the antenna gain, although the product of the two is often quoted in the technical documentation to give the equivalent isotropically radiated power (EIRP).

### 6.4 Antenna gain

The reference antenna is often an isotropic antenna that radiates uniformly in all directions. Although this is a purely hypothetical concept it is nevertheless very useful for reference purposes. When the gain of an antenna relative to an isotropic reference antenna is stated in decibels it is denoted by dBi. In practice, the gain of an antenna is often expressed relative to a half-wave dipole which itself has a gain of 1,64 (or 2 dB) relative to an isotropic antenna. In special circumstances other reference antennas may be used, for example a short monopole. It is therefore important that the reference antenna is correctly specified. The maximum gains for typical antennas are listed in Table B.1, Table B.2 and Table B.3.

### 6.5 Modulation factors

#### 6.5.1 General

Most transmissions are modulated in order to convey information or to enable them to carry out specific tasks (for example, radar). The characteristics of the principal modulating systems are described in 6.5.2 to 6.5.5. A modulation factor,  $m$ , is necessary for calculating the effective field strength  $E$  in 10.4.3. Modulation factors are listed in Table 8 for different types of modulation.

NOTE Radio-frequency transmission may be unmodulated in which case the radiated power is constant and the power quoted in the technical documentation should be used. Such transmissions are sometimes referred to as continuous wave (CW).

## 6.5.2 Frequency modulation (FM)

For frequency modulation the frequency of the transmission is varied to carry the information but the output power remains constant as with CW transmissions. Frequency shift keying (FSK) and gaussian frequency shift keying (GFSK), minimum shift keying (MSK) and gaussian minimum shift keying (GMSK) are forms of frequency modulation. Phase shift keying (PSK) and phase modulation (PM) are treated similarly in that no allowance for modulation is necessary since the output power is not affected by the modulation.

## 6.5.3 Amplitude modulation (AM)

### 6.5.3.1 General

The amplitude of the transmission is varied to carry the information. This information may consist of speech or music or a coded transmission or it may be a television picture waveform.

### 6.5.3.2 Speech and music

When speech and music are transmitted, the power quoted in the technical documentation is that of the unmodulated or carrier transmission but the instantaneous field strength at the modulation peaks may be up to two times greater when the speech or music is at its loudest volume. Since the duration of the modulation peaks may exceed the thermal initiation time of the gas, it is necessary to make some allowance for the power increase (modulation) when making an assessment. As a result of experience gained with amplitude modulated broadcast transmitters, a modulation factor,  $m$ , of 1,4 should be used for calculations of effective field strengths for RF ignition effects (see [6] and [7]).

### 6.5.3.3 Coded transmissions

A version of amplitude modulation used for Morse and other coded transmissions is known as modulated continuous wave (MCW). For modulated continuous wave, whereby the carrier is fully modulated by a continuous tone, a modulation factor,  $m$ , of 2 should be used.

### 6.5.3.4 Television transmissions (TV)

For television transmissions the peak power is usually quoted in the technical documentation but in this case no allowance for modulation is necessary, because the mean power is approximately equal to the peak power.

## 6.5.4 Single sideband (SSB) operation

For single sideband (SSB) operation the peak envelope power is usually quoted in the technical documentation and a value of 0,7 for the modulation factor,  $m$ , should be used.

## 6.5.5 Pulsed radar

Pulsed radar consists of pulses transmitted at frequent intervals. The transmissions are characterized by a peak power  $P_o$ , a mean power  $P_m$ , a pulse duration  $t$  (in s) and a pulse repetition rate of  $n$  pulses per second. These are related by the equation:

$$P_o = \frac{P_m}{nt} \quad (2)$$

where

$nt$  is the duty cycle.

The peak power,  $P_o$ , should be used for assessment purposes and no additional allowance for modulation should be considered (see [8] and [9]).

## 7 Structures and spark-making mechanisms

### 7.1 Structures

Voltage and current may be induced in a metal object in an electromagnetic field; when two such conducting objects are in intermittent contact an RF discharge may result. The source of RF power for ignition by discharge is, in effect, an antenna situated in the incident electromagnetic field. The antenna configuration may be formed by any metallic object or assembly of objects, such as pipelines, storage tanks bridged by walkways, tanker loading facilities and vent stacks. However, not all the metallic objects on a site are capable of delivering significant energy into a discharge and some classification of structures can be achieved in order to identify possible hazard situations.

For analogy with simple antenna types, structures may be divided into loop types or vertical (monopole) types for consideration at frequencies up to and including 30 MHz and may be easily identified in a survey of the plant. At higher frequencies, sections or small parts of the structure, whose physical dimensions are comparable with a wavelength of the transmitter frequencies, may behave as efficient antennas. There is no requirement to identify these since due allowance for their characteristics is made in the assessment procedure (see Clause 10) where it is assumed that their behaviour is not significantly different from that of a long dipole (see [10]).

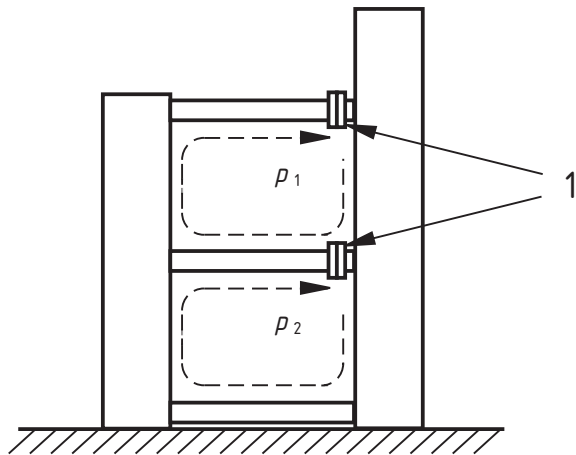
### 7.2 Loop-type structures

At frequencies up to and including 30 MHz, structures which form loops (see Figure 1) are more efficient as receiving antennas than other types of structure (see [2], [4], [11] and [12]). When the internal loop perimeter is about one half-wavelength, the structure is self-resonant and its efficiency is at a maximum. Loop structures having a smaller loop perimeter than the optimum can, however, be brought into resonance by the presence of stray capacitance across the discontinuity. The efficiency decreases rapidly when the ratio of the loop perimeter to the wavelength is below 0,5 and remains approximately constant for values of this ratio greater than 0,5.

At any potential discontinuity in the structure, it is possible to calculate the maximum extractable power,  $P_{\max}$  (see 3.2) provided that information is available regarding the following:

- a) the structure perimeter;
- b) the frequency of the transmission;
- c) the incident field strength at the structure location.

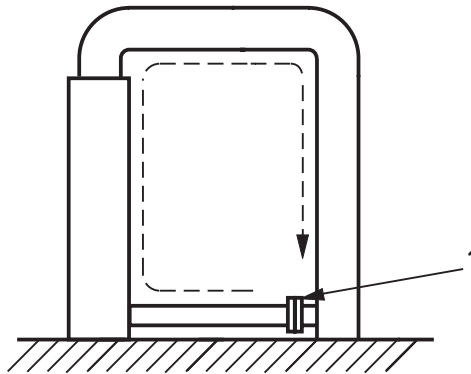
NOTE Cranes form particularly efficient loop-type structures and are thus treated as a special case (see 12.1).



**Key**

- 1 Possible discontinuities
- $p$  Internal perimeter of the loop

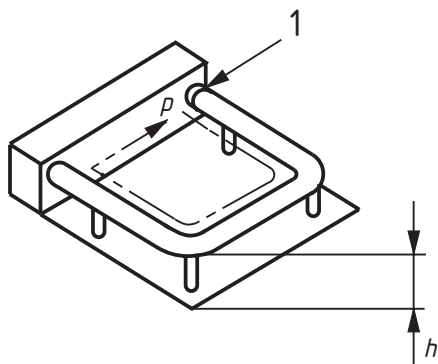
**a) Loop formed by columns and pipes**



**Key**

- 1 Possible discontinuity
- $p$  Internal perimeter of the loop

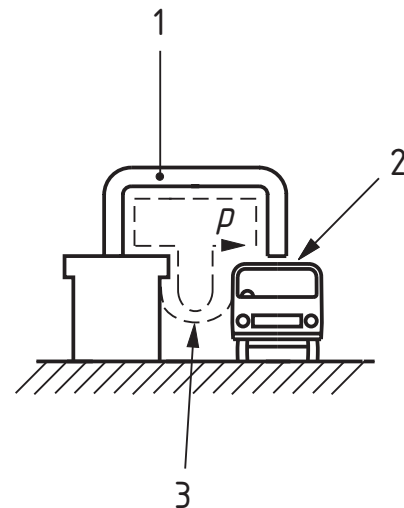
**b) Loop formed by columns and pipes**



**Key**

- 1 Possible discontinuity
- $p$  Internal perimeter of the loop
- $h$  Height of the structure

**c) Horizontal loop**

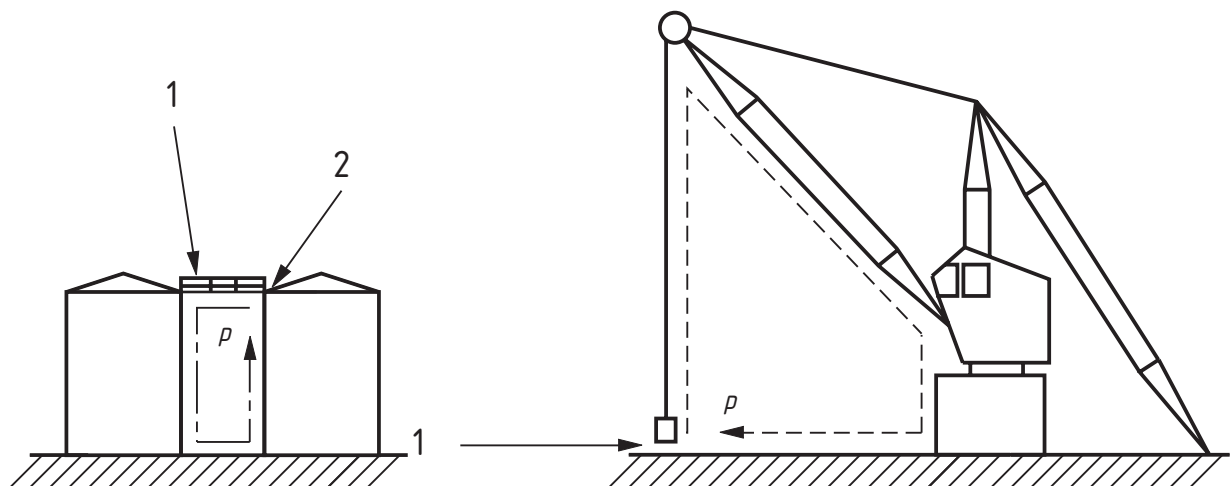


**Key**

- 1 Loading arm
- 2 Discontinuity
- 3 Antistatic bonds
- $p$  Internal perimeter of the loop

**d) Tanker loading facility**

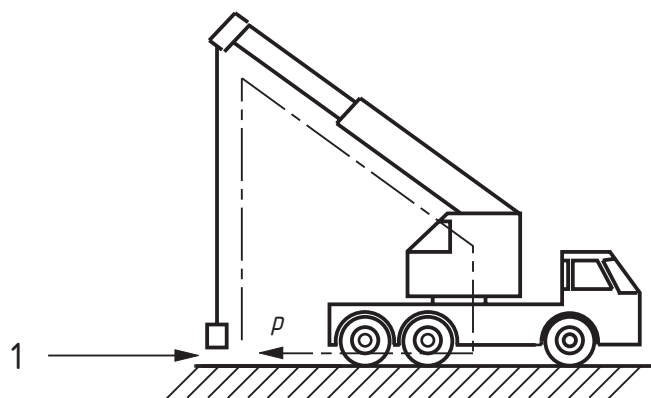
**Figure 1 — Typical loop-type structures**

**Key**

- 1 Walkway
- 2 Possible discontinuity
- p Internal perimeter of the loop

**e) Storage tanks****Key**

- 1 Discontinuity
- p Internal perimeter of the loop

**f) Fixed crane****Key**

- 1 Discontinuity
- p internal perimeter of the loop

**g) Mobile crane****Figure 1 — Typical loop-type structures (concluded)****7.3 Vertical structures**

Many vertical structures may be observed in a plant or area where flammable material is used. Probably the most easily identifiable vertical structure is the vent or flare stack, although any free-standing structure such as a fractionating column comes into the same category.

However, even for structures that are situated on a concrete base, the base affords a low impedance path to earth at radio frequencies, and the power that can be extracted at this point is extremely low (see [4]). Free-standing vertical structures are therefore not classified among the more efficient types of structures acting as receiving antennas and generally may be omitted from consideration except where part of a vertical structure forms one side of a loop. The structure should then be assessed on the basis of the internal perimeter of the loop.

## 7.4 Spark-making mechanisms

Although a high RF potential may exist between two parts of a structure, the nature of the gap and the spark-making mechanism is highly relevant to the RF ignition of gases or vapours present around the discontinuity. Radio-frequency discharges occur most easily if two parts initially in contact are drawn apart, i.e. if a break-spark occurs. The breakdown of gaps that are not in intermittent contact requires considerably higher voltages than those necessary to produce ignitions from break-sparks, and therefore discharges across a fixed gap are not considered to be a significant problem (see [13]).

The types of construction or operation that are likely to result in an intermittent contact across a discontinuity are to be encountered in, for example, road tanker loading facilities, where rubbing contact can occur between the loading arm and the tanker; very often the loop circuit is completed by anti-static bonds from the tanker or the base of the loading system. Similarly, when flanges are parted or valves are removed during maintenance procedures, an intermittent contact may be obtained thereby providing a discontinuity in the loop. Such a condition is worthy of consideration, particularly if the loop formed by the pipework is of the optimum dimension for resonance. Discharges are also more easily obtained if one of the conducting members forms a sharp point, as for example at the ends of the strands of a wire hawser.

## 8 Ignition of flammable atmospheres

### 8.1 Flammable atmospheres

Spark ignition in a flammable atmosphere occurs when the power or energy in the spark exceeds a certain threshold value, which depends both on the nature and the concentration of the flammable gas or vapour. Table C.1 shows flammable gases and vapours grouped according to their ease of ignition. The threshold power or energy of an RF spark for the different groups has been determined using a representative gas for each group as given in Table 1.

**Table 1 — Representative gases for gas groups**

| Gas group                                                                                                 | Representative gas |
|-----------------------------------------------------------------------------------------------------------|--------------------|
| I <sup>a</sup>                                                                                            | Methane            |
| IIA                                                                                                       | Propane            |
| IIB                                                                                                       | Ethylene           |
| IIC                                                                                                       | Hydrogen           |
| <sup>a</sup> Group I refers to fire damp in mines (mainly methane) which can occur freely at the surface. |                    |

In making the hazard assessment, no distinction is made between the different zones (0, 1 and 2) of a hazardous area as defined in EN 60079-10. In assessing the potential hazard, therefore, significant structures as described in Clause 7 should be identified in hazardous areas, together with the gas group of the associated flammable gas or vapour.

### 8.2 Ignition by radio-frequency discharges

The nature of an RF discharge and the way the energy in the spark is transferred to the gas around it are complex phenomena. However, the ability of a spark to ignite a flammable atmosphere may be characterized by the power or energy that can be extracted by a spark across a discontinuity in a structure (see [14]). The threshold values of power or energy are worst-case values, and generally higher values than those quoted in the technical documentation are necessary to cause ignition.

For any particular flammable atmosphere, there is a thermal initiation time, during which thermal dissipation of the energy deposited by the spark is negligible (see [8]). For times shorter than half the thermal initiation time, the significant quantity determining ignition is the energy of the spark. For longer times, ignition is determined by the power of the discharge. These two cases may be brought together by considering the power averaged over the thermal initiation time. Thus, if the discharge is caused by a pulsed transmission, the pulse duration of which is shorter than half the thermal initiation time and for which the interval between pulses is longer than the thermal initiation time, the peak power required for ignition is greater than the average power by the ratio of the thermal initiation time to the pulse duration. For methane the thermal initiation time is approximately 200  $\mu\text{s}$ , for ethylene it is approximately 80  $\mu\text{s}$  and for hydrogen approximately 20  $\mu\text{s}$ .

### 8.3 Criteria for ignition

NOTE The criteria for ignition of flammable atmospheres used in this European Technical Report are based on the results of considerable research (see [3] and [11]).

#### 8.3.1 Effectively continuous transmissions

The threshold values of RF power  $P_{\text{th}}$  which if exceeded will cause ignition are given in Table 2, for continuous transmissions and for pulsed transmissions whose pulse duration exceeds the thermal initiation time (see [15] and [6]).

**Table 2 — Radio-frequency power thresholds**

| Gas group | Threshold power, $P_{\text{th}}$<br>W                                    | Thermal initiation time (averaging period) |
|-----------|--------------------------------------------------------------------------|--------------------------------------------|
|           |                                                                          | $\mu\text{s}$                              |
| I         | 6 for long narrow structures, e.g. cranes,<br>8 for all other structures | 200                                        |
| IIA       | 6                                                                        | 100                                        |
| IIB       | 3,5                                                                      | 80                                         |
| IIC       | 2                                                                        | 20                                         |

NOTE The thermal ignition time for Group IIB comes from VDE 0848-5.

#### 8.3.2 Radar transmissions

For pulsed radar and other transmissions where the pulses are short compared with the thermal initiation time (and are separated by a period longer than the thermal initiation time), the energy in a single pulse is the preferred criterion and the threshold energy values  $Z_{\text{th}}$  are as given in Table 3 (see [9]).

Offshore radars for navigational purposes should be installed such that the radiation from the rotating antennas does not directly impinge on structures where flammable gases may be present.

**Table 3 — Radio-frequency energy thresholds**

| Gas group | Threshold energy $Z_{\text{th}}$ |
|-----------|----------------------------------|
|           | $\mu\text{J}$                    |
| I         | 1 500                            |
| IIA       | 950                              |
| IIB       | 250                              |
| IIC       | 50                               |

NOTE 1 Most pulsed radar transmissions have pulse durations that are short compared to thermal initiation times. However, longer pulse transmissions may be encountered and if the pulse duration exceeds half the thermal initiation time, expert guidance should be sought unless use of the thresholds in Table 2 indicates no hazard.

NOTE 2 The threshold figures have been derived from practical experiments in the field using dipole-like structures, and due allowance has been made for the internal circuit losses. These values are higher than those that may be obtained using a resonant cavity, but the latter scenario is considered unrealistic in the context of petrochemical structures.

## 9 Practical measurements and tests

### 9.1 Measurement of electromagnetic fields

The test equipment and method of measurement of electromagnetic field strengths are given in Annex D. However, for measurement of field strengths in the context of the spark ignition hazard, consideration should be given to the following factors that could have a significant bearing on assessment of the potential hazard.

- a) Measurements of field strengths should be made at a point where the measured value is representative of the field that is incident upon the structure. Measurements should be made either at the site of the structure before it is erected or at some point on open ground at approximately the same distance from the transmitter and in a similar direction in order to avoid errors due to the directional properties of the transmitter.

NOTE 1 The presence of the structure can affect the field in its immediate vicinity due to re-radiation.

NOTE 2 Where measurements are to be made close to the transmitter, i.e. in the near field, specialist advice should be sought (see Annex A).

NOTE 3 Although higher field strengths may be expected when the ground is wet, the effect of variations in ground conditions has been shown to be unimportant and no correction to measured field strengths is required even where the ground appears dry or is concreted.

- b) For horizontally-polarized transmissions at frequencies up to and including 30 MHz, measurements should be made at a height similar to that of the mean height of the structures concerned.
- c) The possibility of infrequent transmission, for example from mobile transmitters and ships, should be considered and arrangements made to ensure, where possible, that all relevant transmitters are operating.
- d) Where a test transmitter has been set up to simulate a proposed transmitter, the measured field strength should be corrected by factors which allow for i) the difference in power and ii) the difference in distance, if necessary, as recommended in E.3.

**WARNING** Precautions should be taken to prevent the exposure of persons to intense RF radiation.

### 9.2 Measurement of extractable power

The power that can be extracted at a discontinuity in a structure irradiated by RF electromagnetic waves may be determined by direct measurement using one of the following methods:

- a) **frequency selective measurements of current and voltage.** The extractable power at a particular transmission frequency should be calculated from values of voltage and current measured at the discontinuity in the structure, as recommended in E.2a).
- b) **broad-band power measurement.** Measurements of the total power (from all transmitters) that may be delivered to a fixed resistive load should be made using an instrument developed specifically for RF ignition hazard assessments as recommended in E.2b).

NOTE 1 See also [16].

NOTE 2 This method affords a simple means of assessment at frequencies up to 10 MHz and enables the measured aggregate extractable power at a discontinuity in a structure to be obtained very quickly.

### 9.3 Test transmissions

Where test transmissions are to be used, a temporary low-power transmitter should be located at an alternative site that lies in the same direction as the proposed site of the transmitting antenna.

NOTE 1 The output power of the test transmitter may need to be about 50 W to 100 W in order to provide sufficient signal at the plant. No provision for modulating the test transmission is necessary.

Annex E provides information on the use of test transmissions and on the scaling factors that should be used to modify the measured values of field strength or extractable power.

NOTE 2 In most European countries, Regulating Authority approval is required for such test transmissions.

### 9.4 Incendivity tests

Incendivity tests should be carried out to determine whether the power extractable from the structure is sufficient to cause ignition of a flammable gas or vapour surrounding the discontinuity. At frequencies below 1,5 MHz these tests should be carried out with a spark test apparatus as described in EN 50020 and E.4. For operations in hazardous areas, the apparatus should be surrounded by an enclosure continuously purged with inert gas or other equally effective measures to prevent the external ignition of a flammable concentration of gas or vapour and the production of an external potentially explosive atmosphere by the gases used for the test.

The most easily ignitable concentration of the flammable gas or vapour should be used, for example 8,3 % by volume of methane in air, and 21 % by volume of hydrogen in air, as shown in Table 4.

**Table 4 — Representative gases for gas groups and the most easily ignited mixture  
(% volume with air)**

| Gas group | Representative gas   | Most easily ignited mixture<br>(% volume with air) <sup>a</sup> |
|-----------|----------------------|-----------------------------------------------------------------|
| I         | methane <sup>b</sup> | 8,3 ± 0,3                                                       |
| IIA       | propane              | 5,25 ± 0,25                                                     |
| IIB       | ethylene             | 7,8 ± 0,5                                                       |
| IIC       | hydrogen             | 21 ± 2                                                          |

<sup>a</sup> These gas/air proportions should be varied in order to achieve maximum sensitivity.  
<sup>b</sup> Group I refers to fire damp in mines (mainly methane) which can occur freely at the surface.

NOTE 1 Rusty steel rotating disks have been found to provide lower ignition thresholds than cadmium disks (see [17]).

At higher frequencies, further modifications of the spark test apparatus should be made as recommended in E.4.

NOTE 2 See also [8] and [9].

**WARNING** It is essential that all practical on-site tests be carried out with the full co-operation and under the guidance of safety and operations personnel. The test programme should be devised and discussed with all personnel intimately concerned with the safe operation of the areas where tests are to be made. For example, some tests may involve the parting of flanges, removal of valves, etc., and it is necessary to make adequate provision for the support of incomplete structures and safety of the personnel carrying out the tests. Also, where measurements are to be made in a hazardous area care should be taken that the instruments proposed to be used for measurement purposes are cleared for use in the test area, and that the appropriate permits to work are obtained.

## 10 Methods of assessment for determining potential RF ignition hazards on a plant containing hazardous areas

### 10.1 General

This clause describes the methods of assessment that can be used to ascertain whether or not a potential RF ignition hazard exists on a plant containing hazardous areas.

Subclauses 10.2, 10.3 and 10.4 describe the theoretical assessments that should be performed in order to determine whether it is necessary to carry out the practical on-site tests that are described in 10.5.

**NOTE** Except where transmitters or their feeders are located in hazardous areas, (continuous) transmitters with a maximum peak output power of less than 2 W, or (pulsed) radar transmitters with a peak energy in the pulse of less than 50  $\mu$ J need not be considered in the assessments, as no hazard exists.

Flow charts are given in Figure 2 and Figure 3 in order to clarify the assessment methods. The “assessment flow chart” (see Figure 2) lists the steps in the theoretical assessment methods and the second “on-site test flow chart” (see Figure 3) outlines the procedures that are recommended for practical tests. The flow charts have been designed so that safe situations become apparent as soon as possible and the initial assessments involve the minimum effort.

An explanation of the flow charts and assessment procedures is given in a) and b) below:

- a) **Explanation of flow charts and assessment procedures.** The flow charts are designed to provide a step by step guide to the assessment procedure of this clause, the actions required at each stage being clearly indicated in the boxes. The number(s) in the blocks refer to the subclause(s) in this clause which are relevant to the action or decision required. The assessment flow chart shows the procedures for assessment of the risk to a particular plant or for the assessment of the risk from a particular transmitter. These paths are followed until either no hazard is indicated or the full assessment is reached, at which point they merge into a single procedure. If a hazard is indicated by the full assessment, the on-site test flow chart (see Figure 3) indicates the sequential procedure to be followed by the following cases:
  - 1) for existing plant and transmitters;
  - 2) for existing plant and a proposed transmitter;
  - 3) for an existing transmitter and a proposed plant. The appropriate path should be selected and followed through until no hazard is indicated.
- b) **Future plant or transmitter modifications.** Even when an assessment of the type described in 10.5 indicates that there is no RF ignition hazard at the time the assessment is undertaken, the assessment should be repeated whenever a modification to the plants or transmitters is considered.

### 10.2 Basis of the theoretical assessments

#### 10.2.1 General

There are three types of theoretical assessments. These should be carried out in the following situations:

- a) the initial assessment recommended in 10.3.1 should be made when potential risks from a particular transmitter are being ascertained;
- b) the initial assessment recommended in 10.3.2 should be made when the risks to a particular existing or planned plant are being ascertained;
- c) the full assessment procedure given in 10.4 should be carried out if one of the initial assessments indicates a potential hazard.

The initial assessment methods compare the basic parameters of the situation (the transmitter details, the distance between the transmitter and the plant, and the flammable vapours and gases that might be found on the plant) with tables of distances that define the potentially vulnerable zone. The full assessment method involves evaluating the hazard for the particular existing or planned structures on the plant that is under consideration and should be used when the initial assessment indicated a potential hazard.

### 10.2.2 Initial assessment

Available knowledge on the behaviour of structures as receiving antennas and the incendivity of RF discharges as outlined in Clause 7, Clause 8, and 10.4.4 has been used to construct Figure 4, which illustrates the relationship between the safe threshold field strength and frequency of transmission for single unmodulated transmissions. The sets of curves at frequencies below 10 MHz are for loop-type structures with various perimeters.

NOTE 1 Figure 4 is provided for information only.

Table 5, Table 6 and Table 7 define the size of the potentially vulnerable zone around a transmitter under worst case conditions for the three gas groups and should be used in the initial assessment methods as recommended in 10.3.1 and 10.3.2.

NOTE 2 Table 5 has been derived using the following assumptions:

- a) the loop perimeter taken at frequencies up to and including 30 MHz is 85 m;
- b) where a range of frequencies is stated in column 3, the frequency which gives the largest vulnerable zone has been selected.

NOTE 3 For Table 6 and Table 7, a 40 m loop has been considered.

NOTE 4 The distances given in Table 5, Table 6 and Table 7 have been calculated on the basis of safe threshold field strength data of the type given in Figure 4, together with a multiple transmission factor which has been derived for these tables only and takes into account the presence of a number of different transmitters on a given site.

At low frequency (l.f.) and medium frequency (m.f.) the multiple transmission factor takes account of the frequency differences between transmissions (see 10.4.5.2). The effective total radiated power is assumed to be twice that of the most powerful m.f. transmitter; this factor is derived from experimental data obtained at a typical transmitter site. At high frequency (h.f.) the effective power is assumed to be four times that of the most powerful transmitter. This factor is considered adequate for up to six separate co-sited transmitters, each having the same power, because h.f. transmissions are normally radiated from directional antennas which point in different directions and thus would not sum arithmetically.

NOTE 5 In calculating the radii of vulnerable zones, the powers for single transmitters listed in column 4 of Table 5 were multiplied by the multiple transmission factors given in column 6.

Table 5 gives radii of vulnerable zones for the most common transmissions found in Europe, assuming a loop perimeter of 85 m, which is the largest value found in surveys of large petrochemical and gas handling plant; for horizontal loops a height of 15 m has been taken. The list is not exhaustive but it is considered that the majority of transmissions which are likely to be encountered have been included. For every category, the most powerful transmission has been listed and in the case of m.f. broadcast transmissions, a range of commonly used transmitter powers and antenna gains has been stated. Table 6 has been formulated on the basis of the presence of a loop-type structure with a maximum perimeter of 40 m and for a horizontal loop height of 5 m. Table 7 gives the maximum size of vulnerable zones with both small and large structures.

### 10.2.3 Full assessment

Where the initial assessment indicates a potential hazard, the full assessment procedure recommended in 10.4 should be followed.

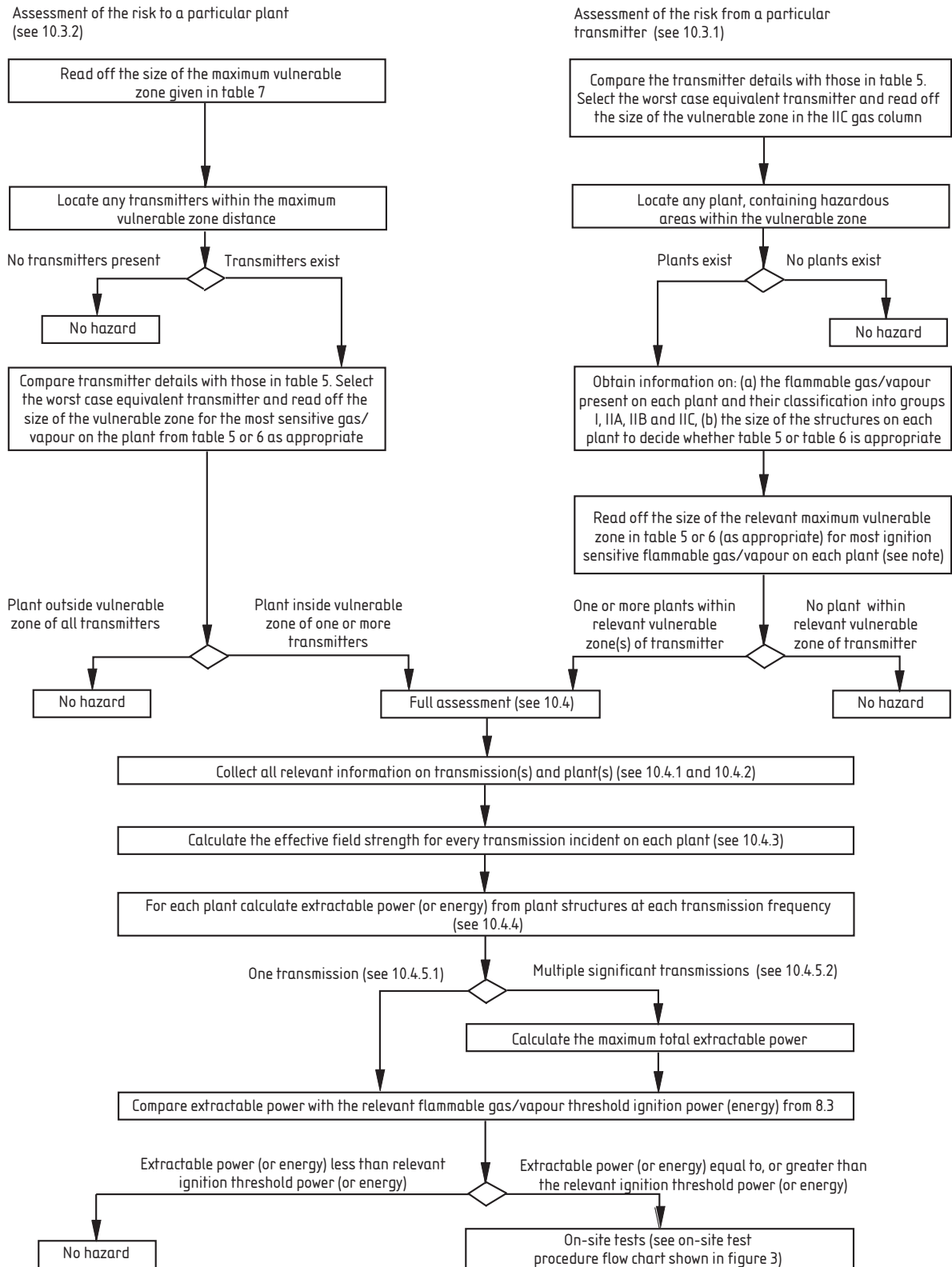
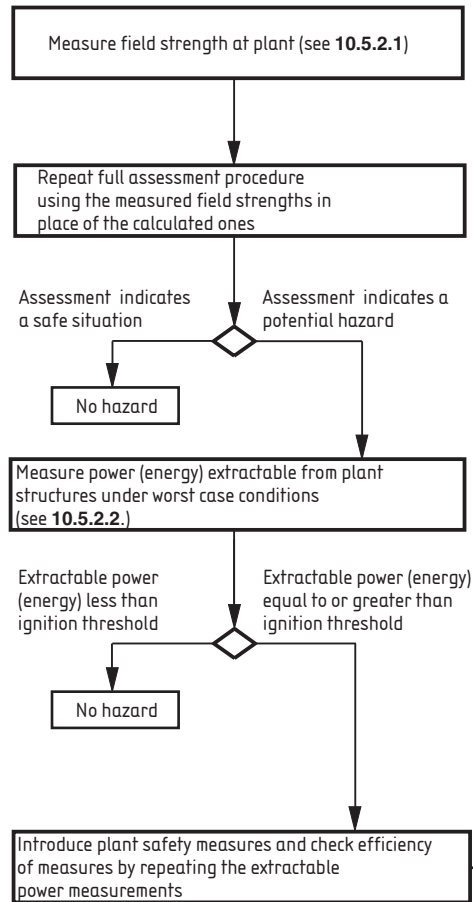
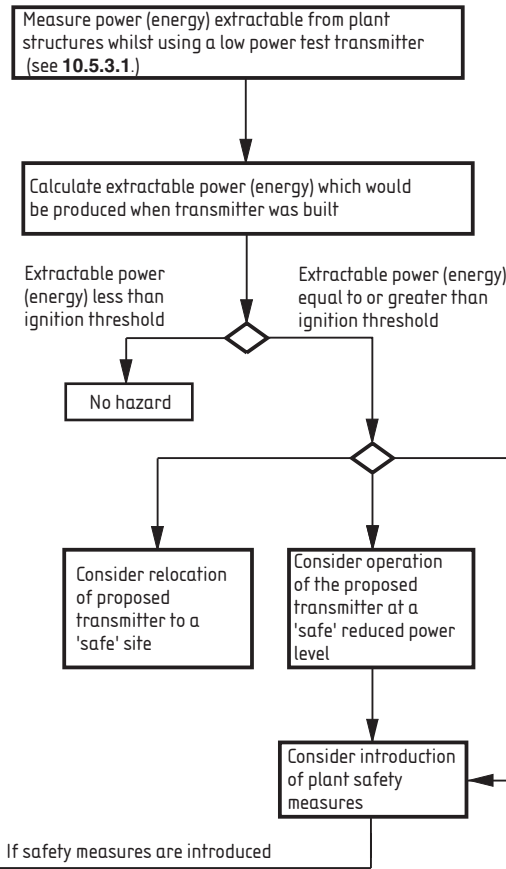


Figure 2 — Assessment procedure flow chart

Case 1  
Tests when the plant and transmitter(s) are both in existence (see 10.5.2)



Case 2  
Tests when the plant is in existence and there is a proposal for a transmitter (see 10.5.3)



Case 3  
Tests when the transmitter(s) is in existence and there is a proposal for a plant (see 10.5.4.)

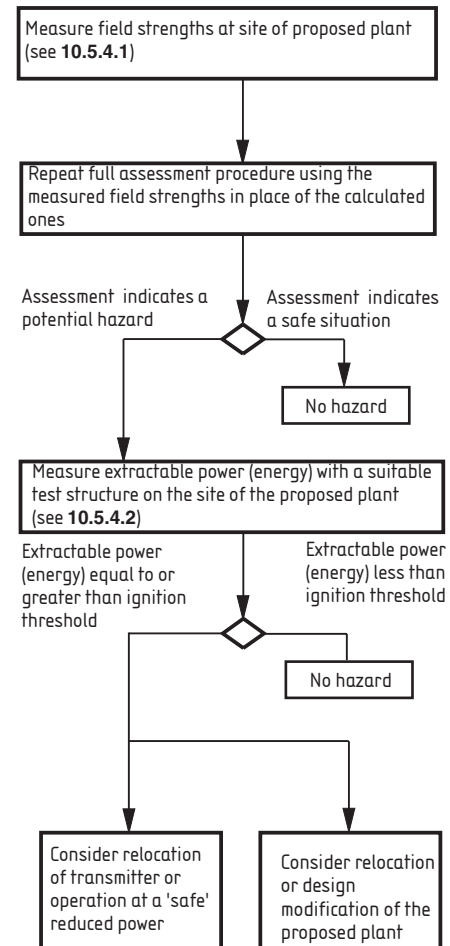


Figure 3 — On-site test procedure flow chart [see 10.5 and 10.1b)]

Table 5 — Radii of vulnerable zones

| 1          | 2                              | 3                   | 4                 | 5                            | 6                                         | 7                             | 7a       | 8                              | 9                                        | 10        | 11        |
|------------|--------------------------------|---------------------|-------------------|------------------------------|-------------------------------------------|-------------------------------|----------|--------------------------------|------------------------------------------|-----------|-----------|
| Serial no. | Type of transmission           | Frequency           | Transmitter power | Modulation code <sup>a</sup> | Multiple transmission factor <sup>b</sup> | Antenna gain <sup>c</sup> dBi | EIRP dBW | Polarization code <sup>d</sup> | Radii of vulnerable zones m <sup>e</sup> |           |           |
|            |                                |                     |                   |                              |                                           |                               |          |                                | Groups I/IIA                             | Group IIB | Group IIC |
| 1          | Navigational (Omega)           | 10 kHz to 14 kHz    | 100 kW            | 1 sec pulse                  | 1                                         | - 5                           | 45       | V                              | NH                                       | NH        | NH        |
| 2          | v.l.f. communications          | 14 kHz to 20 kHz    | 650 kW            | FSK                          | 1                                         | - 5                           | 53       | V                              | NH                                       | NH        | NH        |
| 3          | l.f. communications            | 20 kHz to 70 kHz    | 300 kW            | FSK                          | 1                                         | 0                             | 55       | V                              | NH                                       | NH        | 840       |
| 4          | l.f. communications            | 90 kHz to 110 kHz   | 135 kW            | FSK                          | 1                                         | 0                             | 51       | V                              | NH                                       | 600       | 800       |
| 5          | l.f. communications            | 110 kHz to 150 kHz  | 325 kW            | FSK                          | 1                                         | 1                             | 56       | V                              | 1 000                                    | 1 400     | 1 750     |
| 6          | l.f. broadcast (long wave)     | 150 kHz to 283 kHz  | 2 000 kW          | AM                           | 1                                         | 8 <sup>f</sup>                | 71       | V                              | 12 500                                   | 16 200    | 21 400    |
| 7          | l.f. broadcast                 | 150 kHz to 283 kHz  | 500 kW            | AM                           | 2                                         | 4                             | 61       | V                              | 4 300                                    | 5 500     | 7 200     |
| 8          | l.f. broadcast                 | 150 kHz to 283 kHz  | 50 kW             | AM                           | 2                                         | 3                             | 50       | V                              | 1 100                                    | 1 500     | 2 100     |
| 9          | Radio beacons                  | 285 kHz to 525 kHz  | 1 kW              | MCW                          | 2                                         | 2                             | 32       | V                              | 450                                      | 600       | 800       |
| 10         | m.f. ship communication (land) | 415 kHz to 525 kHz  | 5 kW              | MCW                          | 2                                         | 4                             | 41       | V                              | 1 300                                    | 1 700     | 2 200     |
| 11         | m.f. ship communication (sea)  | 415 kHz to 525 kHz  | 800 W             | MCW                          | 2                                         | 0                             | 29       | V                              | 320                                      | 420       | 560       |
| 12         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 500 kW            | AM                           | 2                                         | 8                             | 65       | V                              | 17 900                                   | 21 200    | 29 200    |
| 13         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 1 000 kW          | AM                           | 1                                         | 8                             | 68       | V                              | 17 900                                   | 21 200    | 29 200    |
| 14         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 150 kW            | AM                           | 2                                         | 8                             | 60       | V                              | 11 500                                   | 14 200    | 17 500    |
| 15         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 50 kW             | AM                           | 2                                         | 8                             | 55       | V                              | 7 300                                    | 9 200     | 11 500    |
| 16         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 20 kW             | AM                           | 2                                         | 8                             | 51       | V                              | 4 600                                    | 5 800     | 7 300     |
| 17         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 10 kW             | AM                           | 2                                         | 5                             | 45       | V                              | 2 600                                    | 3 300     | 4 300     |
| 18         | m.f. broadcast                 | 0,53 MHz to 1,6 MHz | 1 kW              | AM                           | 2                                         | 5                             | 35       | V                              | 860                                      | 1 200     | 1 500     |
| 19         | h.f. broadcast <sup>g</sup>    | 3,95 MHz to 4MHz    | 500 kW            | AM                           | 4                                         | 16 (Elev 18°)                 | 73       | H                              | 1 900                                    | 2 100     | 2 350     |
| 20         | h.f. broadcast <sup>h</sup>    | 5,9 MHz to 26,1 MHz | 500 kW            | AM                           | 4                                         | 21 (Elev 9°)                  | 78       | H                              | 2 600                                    | 3 000     | 3 500     |

Table 5 — Radii of vulnerable zones (continued)

| 1          | 2                                                                  | 3                    | 4                           | 5                            | 6                                         | 7                                  | 7a       | 8                              | 9                                        | 10            | 11            |
|------------|--------------------------------------------------------------------|----------------------|-----------------------------|------------------------------|-------------------------------------------|------------------------------------|----------|--------------------------------|------------------------------------------|---------------|---------------|
| Serial no. | Type of transmission                                               | Frequency            | Transmitter power           | Modulation code <sup>a</sup> | Multiple transmission factor <sup>b</sup> | Antenna gain <sup>c</sup> dBi      | EIRP dBW | Polarization code <sup>d</sup> | Radii of vulnerable zones m <sup>e</sup> |               |               |
|            |                                                                    |                      |                             |                              |                                           |                                    |          |                                | Groups I/IIA                             | Group IIB     | Group IIC     |
| 21         | m.f./h.f. communications: vertically-polarized transmitter on land | 1,6 MHz to 25 MHz    | 30 kW<br>30 kW <sup>i</sup> | FSK/ SSB<br>FSK/SSB          | 4<br>4                                    | 12<br>12                           | 57       | V<br>V                         | 8 700<br>190                             | 10 900<br>230 | 13 700<br>260 |
| 22         | h.f. communications: horizontally-polarized transmitter on land    | 4 MHz to 25 MHz      | 30 kW<br>30 kW <sup>i</sup> | SSB<br>SSB                   | 4<br>4                                    | 18 <sup>j</sup><br>18 <sup>j</sup> | 63       | H                              | 630<br>260                               | 720<br>290    | 830<br>330    |
| 23         | marine m.f./h.f.                                                   | 1,6 MHz to 4,4 MHz   | 400 W                       | SSB                          | 2                                         | 5                                  | 31       | V                              | 260                                      | 340           | 450           |
| 24         | marine h.f.                                                        | 6,2 MHz to 26 MHz    | 1,5 kW                      | SSB                          | 2                                         | 5                                  | 37       | V                              | 130                                      | 170           | 230           |
| 25         | h.f. communications: civil aircraft <sup>l</sup>                   | 2,8 MHz to 23 MHz    | 400 W                       | SSB                          | 2                                         | 2                                  | 28       | V/H                            | 100                                      | 140           | 180           |
| 26         | h.f. communication band                                            | 27 MHz to 30 MHz     | 950 W                       | FM                           | 2                                         | 3                                  | 33       | V                              | 19                                       | 24            | 30            |
| 27         | Amateur radio (fixed and portable)                                 | 1,8 MHz to 2 MHz     | 400 W                       | CW/SSB                       | 2                                         | 5 (Elev 30°)                       | 31       | H                              | 135                                      | 150           | 175           |
| 28         | Amateur radio (fixed and portable)                                 | 1,8 MHz to 2 MHz     | 400 W                       | CW/SSB <sup>k</sup>          | 2                                         | - 8                                | 18       | V                              | 75                                       | 95            | 127           |
| 29         | Amateur radio (fixed and portable) <sup>i</sup>                    | 3,5 MHz to 29,7 MHz  | 400 W                       | CW/SSB <sup>k</sup>          | 2                                         | 5 (Elev 30°)<br>10 (Elev 30°)      | 31<br>36 | H                              | 100<br>130                               | 100<br>140    | 120<br>160    |
| 30         | Amateur radio (fixed and portable) <sup>i</sup>                    | 3,5 MHz to 29,7 MHz  | 400 W                       | CW/SSB                       | 2                                         | 5                                  | 31       | V                              | 170                                      | 220           | 300           |
| 31         | Amateur radio (fixed and portable)                                 | 50 MHz               | 400 W                       | CW/SSB                       | 2                                         | 9                                  | 35       | V/H                            | 27                                       | 35            | 46            |
| 32         | Amateur radio (fixed and portable)                                 | 70 MHz               | 150 W                       | CW/SSB                       | 2                                         | 9                                  | 31       | V                              | 14                                       | 18            | 24            |
| 33         | Amateur radio (fixed and portable)                                 | 144 MHz              | 400 W                       | CW/SSB                       | 2                                         | 18                                 | 44       | V/H                            | 36                                       | 47,5          | 63            |
| 34         | Amateur radio (fixed and portable)                                 | 430 MHz              | 400 W                       | CW/SSB                       | 2                                         | 19                                 | 45       | V/H                            | 4,5                                      | 19            | 25            |
| 35         | Amateur radio (fixed and portable)                                 | 1,24 GHz             | 200 W                       | CW/SSB                       | 2                                         | 24                                 | 47       | V/H                            | 6,5                                      | 8,5           | 11            |
| 36         | Amateur radio (fixed and portable)                                 | 2,31 GHz             | 50 W                        | CW/SSB                       | 2                                         | 28                                 | 45       | V/H                            | NH                                       | NH            | 4             |
| 37         | Amateur radio (fixed and portable)                                 | 3,4 GHz to 3,475 GHz | 20 W                        | CW/SSB                       | 2                                         | 25                                 | 38       | V/H                            | NH                                       | NH            | 1,5           |

**Table 5 — Radii of vulnerable zones (continued)**

| 1          | 2                                                            | 3                     | 4                 | 5                            | 6                                         | 7                             | 7a       | 8                              | 9                                        | 10        | 11        |
|------------|--------------------------------------------------------------|-----------------------|-------------------|------------------------------|-------------------------------------------|-------------------------------|----------|--------------------------------|------------------------------------------|-----------|-----------|
| Serial no. | Type of transmission                                         | Frequency             | Transmitter power | Modulation code <sup>a</sup> | Multiple transmission factor <sup>b</sup> | Antenna gain <sup>c</sup> dBi | EIRP dBW | Polarization code <sup>d</sup> | Radii of vulnerable zones m <sup>e</sup> |           |           |
|            |                                                              |                       |                   |                              |                                           |                               |          |                                | Groups I/IIA                             | Group IIB | Group IIC |
| 38         | Amateur radio (fixed and portable)                           | 5,65 GHz to 5,85 GHz  | 20 W              | CW/SSB                       | 2                                         | 28                            | 41       | V/H                            | NH                                       | NH        | NH        |
| 39         | Amateur radio (fixed and portable)                           | 10 GHz to 10,5 GHz    | 50 W              | CW/SSB                       | 2                                         | 40                            | 57       | V/H                            | NH                                       | NH        | NH        |
| 40         | Amateur radio (fixed and portable)                           | 24 GHz to 24,25 GHz   | 10 W              | CW/SSB                       | 2                                         | 38                            | 48       | V/H                            | NH                                       | NH        | NH        |
| 41         | Amateur radio (mobile)                                       | 1,8 MHz to 2 MHz      | 100 W             | CW/SSB                       | 2                                         | - 15                          | 5        | V                              | 1,7                                      | 2         | 3         |
| 42         | Amateur radio (mobile)                                       | 3,5 MHz to 7,3 MHz    | 100 W             | CW/SSB                       | 2                                         | - 10                          | 10       | V                              | 15                                       | 20        | 26        |
| 43         | Amateur radio (mobile)                                       | 14 MHz to 29,7 MHz    | 100 W             | CW/SSB                       | 2                                         | 5                             | 25       | V                              | 18                                       | 22        | 29        |
| 44         | Amateur radio (mobile)                                       | 50 MHz                | 100 W             | CW/SSB                       | 2                                         | 2                             | 22       | V                              | 6                                        | 8         | 10        |
| 45         | Amateur radio (mobile)                                       | 70 MHz                | 100 W             | CW/SSB                       | 2                                         | 2                             | 22       | V                              | 5                                        | 6,5       | 8,5       |
| 46         | Amateur radio (mobile)                                       | 144 MHz               | 100 W             | CW/SSB                       | 2                                         | 5                             | 25       | V                              | 4                                        | 5,3       | 7         |
| 47         | Amateur radio (mobile)                                       | 430 MHz               | 50 W              | CW/SSB                       | 2                                         | 8                             | 25       | V                              | 1,5                                      | 2         | 2,5       |
| 48         | Amateur radio (mobile)                                       | 1,24 GHz to 1,325 GHz | 10 W              | CW/SSB                       | 2                                         | 8                             | 18       | V                              | 0,2                                      | 0,3       | 0,4       |
| 49         | CB radio                                                     | 27 MHz                | 4 W               | FM                           | 2                                         | 2                             | 8        | V                              | NH                                       | NH        | NH        |
| 50         | FM Radio broadcast (band II)                                 | 87 MHz to 108 MHz     | 30 kW             | FM                           | —                                         | 10                            | 55       | V/H                            | NH <sup>m</sup>                          |           |           |
| 51         | v.h.f. TV broadcast (band I)                                 | 47 MHz to 68 MHz      | 250 kW            | TV                           | 1                                         | 6                             | 60       | V/H                            | NH <sup>m</sup>                          |           |           |
| 52         | v.h.f. TV broadcast (band III)                               | 174 MHz to 230 MHz    | 65 kW             | TV                           | 1                                         | 12                            | 60       | V/H                            | NH <sup>m</sup>                          |           |           |
| 53         | TV broadcast (bands IV and V)                                | 470 MHz to 854 MHz    | 50 kW             | TV                           | —                                         | 15                            | 62       | V/H                            | NH <sup>m</sup>                          |           |           |
| 54         | v.h.f. and u.h.f. land, fixed and mobile and maritime mobile | 68 MHz to 470 MHz     | 25 W              | AM/FM                        | 4                                         | 2                             | 16       | V                              | 3,5                                      | 4,5       | 6         |
| 55         | v.h.f. and u.h.f. base stations                              | 98 MHz to 400 MHz     | 125 W             | AM                           | 4                                         | 5                             | 26       | V                              | 12,5                                     | 16        | 21,5      |
| 56         | TETRA (mobile)                                               | 380 MHz to 520 MHz    | 30 W              |                              | 2 <sup>n</sup>                            | 0                             | 15       | V/H                            | 0,5                                      | 0,7       | 0,9       |
| 57         | TETRA base station                                           | 380 MHz to 520 MHz    | 40 W              |                              | 1                                         | 5                             | 21       | V/H                            | 0,7                                      | 1         | 1,3       |
| 58         | u.h.f. radio link                                            | 146 MHz to 174 MHz    | 25 W              | AM/FM                        | 2                                         | 12                            | 26       | V/H                            | 6,5                                      | 8         | 11        |
| 59         | u.h.f. fixed and mobile                                      | 862 MHz to 960 MHz    | 25 W              | MSK                          | 4                                         | 8                             | 22       | V/H                            | 0,7                                      | 1         | 1,3       |

Table 5 — Radii of vulnerable zones (continued)

| 1<br>Serial<br>no. | 2<br>Type of transmission             | 3<br>Frequency        | 4<br>Transmitter<br>power | 5<br>Modulation<br>code <sup>a</sup> | 6<br>Multiple<br>transmission factor <sup>b</sup> | 7<br>Antenna gain <sup>c</sup><br>dBi | 7a<br>EIRP<br>dBW | 8<br>Polarization<br>code <sup>d</sup> | 9<br>Radii of vulnerable zones<br>m <sup>e</sup> |              |              |
|--------------------|---------------------------------------|-----------------------|---------------------------|--------------------------------------|---------------------------------------------------|---------------------------------------|-------------------|----------------------------------------|--------------------------------------------------|--------------|--------------|
|                    |                                       |                       |                           |                                      |                                                   |                                       |                   |                                        | Groups<br>I/IIA                                  | Group<br>IIB | Group<br>IIC |
| 60                 | Radio telephone TACS base station     | 900 MHz               | 10 W                      | FM                                   | 8 <sup>o</sup>                                    | 12                                    | 22                | V/H                                    | 1                                                | 1,3          | 1,7          |
| 61                 | Radio telephone TACS, mobile          | 900 MHz               | 10 W                      | FM                                   | 2                                                 | 2                                     | 12                | V/H                                    | 0,2                                              | 0,2          | 0,3          |
| 62                 | Radio telephone GSM 900 (mobile)      | 900 MHz               | 2 W                       | GMSK                                 | 2                                                 | 0                                     | 3                 | V/H                                    | NH                                               | NH           | NH           |
| 63                 | Radio telephone GSM 900 (mobile)      | 900 MHz               | 20 W                      | GMSK                                 | 1                                                 | 0                                     | 13                | V/H                                    | 0,1                                              | 0,1          | 0,3          |
| 64                 | Radio telephone GSM 900 base station  | 900 MHz               | 10 W                      | GMSK                                 | 16 <sup>p</sup>                                   | 14                                    | 24                | V/H                                    | 1,7                                              | 2,3          | 3            |
| 65                 | Radio telephone DCS 1800 (mobile)     | 1,7 GHz to 1,9 GHz    | 1 W                       | GMSK                                 | 2                                                 | 0                                     | 0                 | V/H                                    | NH                                               | NH           | NH           |
| 66                 | Radio telephone DCS 1800 base station | 1,7 GHz to 1,9 GHz    | 6,5 W                     | GMSK                                 | 12 <sup>q</sup>                                   | 18                                    | 26                | V/H                                    | 1                                                | 1,3          | 1,8          |
| 67                 | Radio telephone DCS 1800 base station | 1,7 GHz to 1,9 GHz    | 8 W                       | GMSK                                 | 16 <sup>r</sup>                                   | 18                                    | 27                | V/H                                    | 1,3                                              | 1,7          | 2,3          |
| 68                 | Radio telephone DCS 1800 (mobile)     | 1,7 GHz to 1,9 GHz    | 0,25 W                    | GMSK                                 | 2                                                 | 0                                     | - 6               | V/H                                    | NH                                               | NH           | NH           |
| 69                 | Radio telephone CT2                   | 864 MHz to 868 MHz    | 0,01 W                    | PCM                                  | 1                                                 | 0                                     | - 20              | V/H                                    | NH                                               | NH           | NH           |
| 70                 | Radio telephone (mobile) DECT         | 1,88 GHz to 1,9 GHz   | 0,25 W                    | GFSK                                 | 1                                                 | 0                                     | - 6               | V/H                                    | NH                                               | NH           | NH           |
| 71                 | Radio telephone DECT base station     | 1,88 GHz to 1,9 GHz   | 0,25 W                    | GFSK                                 | 1                                                 | 22                                    | 16                | V/H                                    | NH                                               | NH           | NH           |
| 72                 | UMTS (mobile)                         | 1,88 GHz to 2,2 GHz   | 1 W                       | CDMA                                 | 2                                                 | 0                                     | 0                 | V/H                                    | NH                                               | NH           | NH           |
| 73                 | UMTS base station                     | 1,88 GHz to 2,2 GHz   | 20 W                      | CDMA                                 | 3                                                 | 18                                    | 31                | V/H                                    | 0,8                                              | 1,1          | 1,4          |
| 74                 | u.h.f. radio link                     | 450 MHz to 470 MHz    | 50 W                      | FM                                   | 2                                                 | 20                                    | 37                | V/H                                    | 4,5                                              | 7            | 9,5          |
| 75                 | u.h.f. radio link                     | 1,4 GHz to 1,9 GHz    | 4 W                       | FSK/FM                               | 1                                                 | 36                                    | 42                | V/H                                    | NH                                               | NH           | NH           |
| 76                 | u.h.f. radio LAN                      | 2,44 GHz to 2,475 GHz | 1 W                       | FSK                                  | 1                                                 | 0                                     | 0                 | V/H                                    | NH                                               | NH           | NH           |
| 77                 | s.h.f. radio link                     | 3,4 GHz               | 20 W                      | FM                                   | 1                                                 | 46                                    | 59                | V/H                                    | NH                                               | NH           | NH           |
| 78                 | s.h.f. radio link                     | 7,1 GHz to 7,9 GHz    | 3 W                       | FSK/FM                               | 1                                                 | 50                                    | 55                | V/H                                    | NH                                               | NH           | NH           |
| 79                 | s.h.f. radio link                     | 12,5 GHz to 15 GHz    | 3 W                       | FSK/FM                               | 1                                                 | 50                                    | 55                | V/H                                    | 1,1                                              | 1,4          | 1,9          |
| 80                 | s.h.f. radio link                     | 21,2 GHz to 23 GHz    | 0,16W                     | FSK/FM                               | 1                                                 | 50                                    | 42                | V/H                                    | NH                                               | NH           | NH           |