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Mechanical safety of cathode ray tubes

Sécurité mécanique des tubes cathodiques

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- **IEC web site***
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For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV).

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications IEC 60027: *Letter symbols to be used in electrical technology*, IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets* and IEC 60617: *Graphical symbols for diagrams.*

* See web site address on title page.

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International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http://www.iec.ch

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CONTENTS

Clause Page

Page

INTERNATIONAL ELECTROTECHNICAL COMMISSION

MECHANICAL SAFETY OF CATHODE RAY TUBES

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61965 has been prepared by IEC technical committee 39: Electronic tubes.

The text of this standard is based on the following documents:

FDIS	Report on voting
39/252/FDIS	39/255/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A and B are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition; or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

This International Standard sets forth test methods and limits for cathode ray tubes (CRTs). Hitherto, the only IEC standard for the mechanical safety of CRTs has been contained within clause 18 of the equipment standard IEC 60065. Whereas that standard has been accepted and used by many countries, many others have not been able to implement its requirements because of differing local needs. This new standard aims to provide the basis for wider acceptance and use, and reflects the current IEC policy of producing separate component standards to which equipment standards can refer.

Many years of experience had been built up in the use of both the IEC 60065 test and the other commonly used national alternatives. During the development of this new standard, extensive test programmes and ballistic and statistical calculations were carried out to verify that the requirements of the standard give protection for users of CRTs when the tubes are mounted in the equipment for which they are intended. This was also done to ensure that the new standard maintains the stringent requirements of both IEC 60065 and the alternative tests in common use. These tests and calculations also confirmed

a) the acceptability of one standard ball for the mechanical strength test, and

b) the need for the implosion test where it is not always possible to induce rapid devacuation using the ball impact test.

As the impact tests in this standard are overstress tests, only the effect of rapid devacuation is evaluated and not subsequent relaxation of mechanical stresses in the CRT from the implosion protection system.

MECHANICAL SAFETY OF CATHODE RAY TUBES

1 Scope

This International Standard is applicable to cathode ray tubes and cathode ray tube assemblies (hereinafter referred to as CRTs) which are intended for use as components in apparatus and which have integral protection with respect to the effects of implosion.

These requirements apply to CRTs intended for use in apparatus including electrical and electronic measuring and testing equipment, information technology equipment, medical equipment, telephone equipment, television equipment and other similar electronic apparatus.

This standard is intended to apply only to those CRTs in which the face of the CRT forms part of the enclosure for the apparatus. The test methods do not apply to CRTs which are protected by separate safety screens.

A CRT covered by this standard is intended to be installed in an enclosure designed both to protect the rear of the CRT against mechanical or other damage under normal conditions of operation and to protect the user against particles expelled in a backwards direction from the CRT face in the event of implosion.

This standard contains requirements for CRTs of 76 mm diagonal and larger that incorporate implosion protection systems providing protection against the hazards of particles expelled forwards beyond the face. There is no intended protection against particles expelled in other directions.

Compliance is tested by subjecting CRTs to the test procedures and criteria which are given in clauses 8 (large CRTs) and 9 (small CRTs) of this standard. The definitions of large and small CRTs are given in clause 3.

NOTE This set of requirements replaces the current requirements for the mechanical safety of cathode ray tubes (CRTs) as described in IEC 60065 (clause 18), which will be modified accordingly.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60065:1998, *Audio, video and similar electronic apparatus – Safety requirements*

IEC 60068-1:1988, *Environmental testing – Part 1: General and guidance*
Amendment 1 (1992)

IEC 60216-1, *Guide for the determination of thermal endurance properties of electrical insulating materials. Part 1: General guidelines for ageing procedures and evaluation of test results*

3 Definitions

For the purposes of this document the following definitions apply.

3.1
bonded frame
system employing a preformed metal frame that covers the periphery of the CRT rim area. The space or void between the CRT rim and the metal frame is filled with resin or equivalent

3.2
CRT diagonal
nominal diagonal of the glass envelope at its maximum dimension (for example, mould-match line) excluding any hardware

3.3
CRT envelope
structure consisting of a face or faceplate, funnel and neck assembly

3.4
devacuation
equalization of the pressure in a CRT relative to the ambient pressure

3.5
fracture
one or more cracks in the faceplate or funnel causing a rapid or slow devacuation of the CRT envelope

3.6
glass particle
piece of glass that exceeds 0,025 g in weight

3.7
implosion
devacuation due to the rapid and sudden inward collapse of a CRT envelope, usually accompanied by a loud report

3.8
laminated CRT
system that provides a separate external safety panel bonded to the face of the CRT

3.9
prestressed banded CRT
system that employs a metal tension band (located over the CRT rim area) that is tightened by thermal shrinking, or other means, to a tensile load. The system may also include a metal rim band located between the tension band and the CRT rim. The tension band or the rim band or both may have an interlayer of tape, resin or the equivalent placed between the mating parts

3.10
shaling
condition where the glassware splits into thin layers

3.11
test cabinet
enclosure which is used to accommodate the CRT during tests

3.12
useful phosphor screen
a) colour CRT: the visible phosphored area of the CRT as viewed from the front
b) monochrome CRT: specified maximum useful phosphored area of the CRT

3.13
large CRT
CRT with diagonal dimension exceeding 160 mm

3.14
small CRT
rectangular CRT with a minor face dimension of at least 50 mm, a minimum diagonal dimension of 76 mm and a maximum diagonal dimension of 160 mm; a round CRT of a minimum diameter of 76 mm and a maximum diameter of 160 mm

3.15
common quality management system
quality management system described in documentation which is identical with systems used in two or more plants and under one central control and management

4 General requirements

4.1 Corrosion protection

If corrosion of a metal part will contribute to a failure to meet the requirements of this standard, then the part shall be adequately protected against corrosion.

4.2 Mechanical damage

To improve repeatability and reproducibility of test results, it should be verified that samples submitted for test have no external visible scratching on the surface of the face plates.

4.3 Handling

Safety precautions should be addressed when handling test samples prior to, and after testing.

5 Environmental conditioning

5.1 Standard atmospheric conditions for testing

Unless otherwise specified, all tests and measurements shall be made under standard atmospheric conditions for testing as given in 5.3 of IEC 60068-1:

– temperature: 15 °C to 35 °C;
– relative humidity: 25 % to 75 %;
– air pressure: 86 kPa to 106 kPa

5.2 Preconditioning

Before CRTs are subjected to thermal conditioning or to testing they will be allowed to stabilize at standard atmospheric conditions for testing (see 5.1) for a minimum period of 16 h.

5.3 Thermal conditioning

Details of thermal conditioning are given in tables 1 to 6. After thermal conditioning has been completed, the CRTs will be allowed to stabilize at standard atmospheric conditions for testing (see 5.1) for a minimum period of 24 h.

6 Sampling

6.1 Sampling plans

Details are given in tables 1 to 6.

6.2 Sample numbers

The numbers of CRTs and the test programmes for prestressed banded CRTs are given in tables 1 and 2, for bonded frame CRTs in tables 3 and 4 and for laminated CRTs in tables 5 and 6.

NOTE In addition to the quantities specified in the tables, additional samples shall be made available for use in case of retest to satisfy the intent of the requirement.

6.3 Compliance

All CRTs in a test group shall comply with the test requirements for that group, except that, if only one CRT from all the test groups does not comply with the requirements, acceptability may be determined by subjecting a second test group to the set of tests during which unacceptable results occurred. The construction is acceptable if all CRTs in the second test group comply with the requirements.

7 Test preparation and set-up

7.1 Scratch patterns

As the form and depth of the scratch patterns may affect the force which is needed to obtain implosion or devacuation of the CRT, it is recommended that the scratches be made using a diamond- or carbide-tipped stylus, a glass cutter with a wheel of hardened steel or other similar tools.

7.2 Barriers

Barriers as specified in the test procedures, each made of 10 mm to 20 mm thick material, $250\,^{0}_{-3}$ mm high and (2,00 ± 0,01) m long, shall be placed on the floor in front of the test cabinet at the specified locations, measured horizontally from the vertical plane of the centre of the front surface of the CRT to the near surface of the barrier closest to the tube face. The tolerance on the position of the barrier shall be ±10 mm, unless otherwise stated. The barriers may be less than 2 m long provided that they extend to the walls of the test room (see figures 2 and 5). A non-skid surface such as a blanket or rug may be placed on the floor.

NOTE A particle travelling past the plane of the front surface of the barrier shall be considered to have passed the barrier.

7.3 Mounting

The CRT shall be mounted in a test cabinet of rigid construction and of suitable dimensions that does not permit a gap or opening wider than 6 mm around the CRT (see figure 1). The mounting of the CRT in front of, or behind, the front panel of the test cabinet shall be in accordance with the CRT manufacturer's specifications or intended application. When mounting specifications are not available, the preferred mounting method shall be behind the front panel unless design features do not allow this condition.

A hole of suitable area shall be provided at the top of the cabinet to allow access to the funnel. This hole shall be covered during the impact test.

An opening having an area of not less than one-quarter of the area of the face of the CRT or 0,02 m^2, whichever is the smaller, shall also be provided in the bottom or rear of the cabinet for air intake in the event of an implosion.

The cabinet shall be firmly supported so as to prevent movement during the test.

7.4 Mounting position

The centre of the CRT shall be (1,00 ± 0,05) m above the floor.

8 Testing of large CRTs

8.1 Mechanical strength (ball impact test)

8.1.1 Test procedure

A solid smooth steel ball of (40 ± 1) mm diameter and mass of (260 ± 15) g, including the hook, and a minimum C scale Rockwell hardness of 60, shall be suspended by suitable means such as a fine wire or chain with a mass not exceeding 10 % of the mass of the ball and the hook. It shall be allowed to fall freely as a pendulum from a calculated height and strike the face of the CRT with an energy of (5,5 ± 0,1) J. The CRT shall be placed so that the face is vertical and in the same vertical plane as the point of support of the pendulum. A single impact shall be applied to any point on the CRT face at a distance of 40 mm or greater from the edge of the useful phosphor screen.

NOTE The test laboratory should consider all their test set-up uncertainties to ensure this 40 mm minimum position of the point of impact.

The barrier shall be placed 1,5 m from the plane of the centre of the face of the CRT (see figure 2).

8.1.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s of the initial impact meets the following requirements:

a) there shall be no glass particle (a single piece of glass having a mass greater than 0,025 g) past the 1,5 m barrier;

b) the total mass of all pieces of glass past the 1,5 m barrier shall not exceed 0,1 g.

8.2 Implosion test (missile)

8.2.1 Test procedure

The face of the CRT at the top and bottom shall be scratched (3 ± 1) mm from the screen or phosphor edge into the viewing area. The scratches shall be horizontal lines (100 ± 5) mm long.

The impact object shall be a steel missile (see example in figure 3) with a mass of (2,3 ± 0,1) kg, a minimum C scale Rockwell hardness of 60 and having one end rounded on a radius of (25 ± 0,5) mm.

The CRT shall be subjected to a single impact, intending to cause rapid devacuation using the minimum energy within the range. The impact object shall be swung through an arc of a pendulum to obtain an impact of not less than 7,0 J and not more than 14,0 J to cause rapid devacuation of the samples in the test group.

The impact area shall be the area bounded by two concentric circles where the radius of one circle is one-sixth of the height of the useful phosphor screen and the second circle radius is one-half of the height of the useful phosphor screen less 50 mm (see figure 4). In figure 4, if R_2 is less than R_1 then the impact shall be applied to the circle specified in R_1.

NOTE Previous testing experience on a particular CRT design (obtained from the CRT manufacturer or the test laboratory) should be considered when selecting the energy level within the range and the impact location.

The impact object travel shall be restricted so that the rounded end of the missile penetrates the CRT face equal to, or less than 25 mm (see figure 5).

Barriers shall be placed 1,0 m and 1,5 m from the vertical plane of the centre of the face of the CRT (see figure 5).

If no CRTs devacuate as a result of this test then the alternative implosion test (missile) described in 8.2.3 shall be carried out.

8.2.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s of the initial impact meets the following requirements:

a) there shall be no single piece of glass having a mass greater than 15 g between the 1,0 m and 1,5 m barriers;

b) the total mass of all pieces of glass between the 1,0 m and 1,5 m barriers shall not exceed 45 g;

c) there shall be no single piece of glass having a mass greater than 1,5 g beyond the 1,5 m barrier.

8.2.3 Alternative implosion test (missile)

This alternative test shall be used as an additional test when the test in 8.2.1 has devacuated no CRTs, or may be used as an alternative to the test in 8.2.1 when it can be shown that the 8.2.1 test is unlikely to devacuate at least one CRT of the sample group.

8.2.3.1 Test procedure

As in 8.2.1, except that the impact object will be a steel missile (see example in figure 10) with a mass of (1,4 ± 0,1) kg, a minimum C scale Rockwell hardness of 60 and one end rounded on a radius of (15 ± 0,5) mm.

8.2.3.2 Glass throw criteria

As in 8.2.2. If no CRTs devacuate as a result of the test in 8.2.3.1, then the glass throw requirements of 8.2.2 are deemed to have been satisfied.

8.3 Implosion test (thermal shock)

8.3.1 Test procedure

The CRT shall be mounted in the test cabinet which is described in 7.3 and 7.4. The barrier shall be placed at (150 ± 2) mm from the vertical plane of the centre of the face of the CRT. An area shall be scratched on the faceplate sidewall or face of the CRT using one of the patterns illustrated in figure 6.

A thermal shock shall be applied using one of the following methods.

a) Liquid nitrogen

   The scratched area shall be cooled using liquid nitrogen until a fracture occurs. A dam of modelling clay or equivalent may be used to contain the liquid nitrogen.

b) Hot rod

   The end of an ordinary flint glass rod, of suitable diameter (for example, 10 mm) shall be heated until it is red hot and nearly fluid. The heated end of the rod shall be pressed firmly on the scratched area of the CRT. If devacuation of the CRT does not occur within 10 s then the rod shall be withdrawn and cold water poured slowly on the scratched area. If a devacuation cannot be induced by repeated applications of the hot rod then the test shall be carried out using liquid nitrogen (see 8.3.1a)).

8.3.2 Glass throw criteria

A CRT is in compliance if, within 5 s of the initial fracture, no glass particle is expelled through the plane of the face beyond the 150 mm barrier.

8.4 High-energy impact test

CRTs which have a laminated implosion protection system shall be subjected to the following high-energy impact test.

8.4.1 Test procedure

A (25 ± 1) mm diameter steel pin (see figure 8) shall be inserted through the hole at the top of the test cabinet and placed on the CRT envelope (3 ± 1) mm behind the seal of the faceplate and funnel. If the hardware extends back from the seal more than 3 mm so as to interfere with the placement of the pin, then the pin shall be placed as close as possible to the hardware without touching it. A weight (see figure 9a), having a mass of (4,5 ± 0,1) kg, shall be caused to fall from a height so as to impact the pin at the end of its fall.

The height of the test mass shall be adjusted to limit the amount of energy to the minimum required to produce fracturing of the glassware, but not less than 7 J.

If fracturing of the glass does not occur, the impact energy shall be increased in 7 J increments to a maximum of 63 J using a new test sample each time until all the CRTs in the test group have suffered rapid devacuation.

The impact energy shall not be so large as to cause the pin to punch a hole with little or no cracking or shaling of the glassware. If this condition does occur then a lower impact energy shall be selected so as to result in fracturing (7 J steps not necessary).

NOTE Previous testing experience on a particular CRT design (obtained from the CRT manufacturer or the test laboratory) should be considered when selecting the energy level within the range.

The implosion pin shall be restricted so that its travel on impact shall be a maximum of 6 mm. The pin travel restriction assembly shall be positioned so that its impact energy shall not be transferred to the test cabinet. Figures 7, 8 and 9 give examples of equipment that may be used.

Barriers shall be placed 1,0 m and 1,5 m from the plane of the centre of the face of the CRT.

8.4.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s of the initial impact meets the following requirements:

a) there shall be no single piece of glass having a mass greater than 15 g between the 1,0 m and 1,5 m barriers;

b) the total mass of all pieces of glass between the 1,0 m and 1,5 m barriers shall not exceed 45 g;

c) there shall be no single piece of glass having a mass greater than 1,5 g beyond the 1,5 m barrier.

9 Testing of small CRTs

9.1 Mechanical strength (ball impact test)

9.1.1 Test procedure

A solid smooth steel ball of (40 ± 1) mm diameter and mass of (260 ± 15) g, including the hook, and a minimum C scale Rockwell hardness of 60, shall be suspended by suitable means such as a fine wire or chain with a mass not exceeding 10 % of the mass of the ball and hook. It shall be allowed to fall freely as a pendulum from a calculated height and strike the face of the CRT with an energy of (2,0 ± 0,1) J. The CRT shall be placed so that the face is vertical and in the same vertical plane as the point of support of the pendulum. A single impact shall be applied to any point on the CRT face at a distance of 25 mm or greater from the edge of the useful screen.

NOTE The test laboratory should consider all their test set-up uncertainties to ensure this 25 mm minimum position of the point of impact.

The barrier shall be placed 0,6 m from the plane of the centre of the face of the CRT (see figure 2).

9.1.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s of the initial impact meets the following requirements:

a) there shall be no glass particle (a single piece of glass having a mass greater than 0,025 g) past the 0,6 m barrier;

b) the total mass of all pieces of glass past the 0,6 m barrier shall not exceed 0,1 g.

9.2 Implosion test (high ball)

If implosion or rapid devacuation does not occur when the CRT is tested as specified in 9.1 then a CRT having other than a laminated implosion protection system shall be subjected to the following test.

9.2.1 Test procedure

The face of the CRT shall be scratched at the top and bottom edges (3 ± 1) mm from the screen phosphor edge into the viewing area. The length of the scratches shall be 45 % to 55 % of the longest dimension/width of the face of the CRT.

Using a (40 ± 1) mm diameter steel ball having a mass of (260 ± 15) g and a minimum C scale Rockwell hardness of 60, a CRT having other than a laminated implosion screen shall be subject to additional impact tests during which the impact energy shall be increased in 0,7 J increments until fracturing occurs. A new sample shall be used for each test until all CRTs in the test group have been tested, with implosion or rapid devacuation occurring.

Barriers shall be placed 0,6 m and 1,2 m from the plane of the centre of the face of the CRT (see figure 2).

9.2.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s of the initial impact meets the following requirements:

a) there shall be no single piece of glass having a mass greater than 15 g between the 0,6 m and 1,2 m barriers;
b) the total mass of all pieces of glass between the 0,6 m and 1,2 m barriers shall not exceed 45 g;
c) there shall be no single piece of glass having a mass greater than 1,5 g beyond the 1,2 m barrier.

9.3 Implosion test (thermal shock)

9.3.1 Test procedure

As 8.3.1.

9.3.2 Glass throw criteria

As 8.3.2.

9.4 High-energy impact test

CRTs which have a laminated implosion protection system shall be subjected to the following high-energy impact test.

9.4.1 Test procedure

A (9,5 ± 0,5) mm diameter steel pin shall be inserted through the hole in the top of the test cabinet and placed directly on the envelope seal line. A weight (see figure 9b) having a mass of (0,45 ± 0,02) kg, shall be caused to fall freely from a height so as to impact the pin at the end of its fall.

The height of the test mass shall be adjusted to limit the amount of energy to the minimum amount required to produce fracturing of the glassware, but not less than 2,7 J.

If fracturing of the glass does not occur, the impact energy shall be increased in 0,7 J increments, using a new test sample each time, until all CRTs in the test group have been tested with rapid devacuation.

The impact energy shall not be so large as to cause the pin to punch a hole with little or no cracking or shaling of the glassware. If this condition does occur then a lower impact energy shall be selected so as to result in fracturing (0,7 J steps not necessary).

NOTE Previous testing experience on a particular CRT design (obtained from the CRT manufacturer or the test laboratory) should be considered when selecting the energy level within the range.

The impact pin shall be restricted so that its travel on impact shall be a maximum of 6 mm. The pin travel restriction assembly shall be positioned so that impact energy shall not be transferred to the test cabinet. Figures 7, 8 and 9 give examples of equipment that may be used.

Barriers shall be placed 0,6 m and 1,2 m from the plane of the centre of the face of the CRT.

9.4.2 Glass throw criteria

A CRT is in compliance if the expulsion of glass within 5 s after the initial impact meets the following requirements:

a) there shall be no single piece of glass having a mass greater than 15 g between the 0,6 m and 1,2 m barriers;

b) the total mass of all pieces of glass between the 0,6 m and 1,2 m barriers shall not exceed 45 g;

c) there shall be no single piece of glass having a mass greater than 1,5 g beyond the 1,2 m barrier.

10 Marking

Along with the CRT manufacturer's name, trade name or identifying code, and a type number, each CRT which meets the requirements of this standard shall be marked with the following statement, or wording with a similar meaning. The marking shall be of a permanent and legible type and in the appropriate language.

WARNING. This cathode ray tube employs integral implosion protection. For continued safety it must be replaced with a cathode ray tube of the same or equivalent type number.

11 Normative requirements for the use of tables 1 and 2 (prestressed banded CRTs)

Sampling and testing for new construction (sampling plan I), new construction with known tape or resin (sampling plan II), tension band only (sampling plan III) and alternative construction (sampling plan IV) will be used when any of the following new construction features or variations in construction apply. Unique constructions may require a special investigation.

11.1 Sampling plan I: New construction

Applicable to first-time testing for a CRT manufacturer or a change in construction of a previously tested CRT that employs any of the following nominal design changes:

11.1.1 Size

New CRT diagonal size range (see table 7).

11.1.2 Deflection angle

New deflection angle range for a particular CRT size range (see table 7).

11.1.3 Glassware shape

Glassware in a particular CRT size and deflection angle range, having the following shape variations, is considered a new glassware shape.

a) front panel outside curvature – a change in height measurement from the Z point to the centre of the face panel of more than ±10 % from a previously tested CRT for a manufacturer;

b) aspect ratio – any change in the height-to-width ratio of the front panel from a previously tested CRT for a manufacturer;

c) glassware thickness – a change in glassware thickness of more than ±20 % at any point, other than the neck, from a previously tested CRT for a manufacturer;

d) corner radius – any change in external or internal panel corner radius (plan view) of more than ±10 %.

11.1.4 Glassware supplier

New glassware supplier not previously used by the CRT manufacturer. Subsidiaries of present glassware suppliers who use the same chemistry, mould designs, processes and quality control arrangements, under a common quality management system, are not considered to be new suppliers.

11.1.5 Resin

New resin in the prestressed banded system. A resin is considered new if it is of a different generic type, for example, epoxy, polyester or other material.

11.1.6 Tape

New tape employed in the tension band system. A tape is considered new if one or more of the following circumstances apply:

a) tape width – the tape width under the tension band is reduced by more than 20 %;

b) change in generic type of adhesive, for example, acrylic, silicone, natural rubber, etc;

c) adhesion – more than 20 % decrease in adhesion strength;

d) single-sided adhesive – tape that is changed from a double-sided adhesive to a single-sided adhesive;

e) any combination that differs from that used in previously tested CRTs;

f) change in backing generic type, for example, polyester cloth, etc.;

g) change in backing thickness of more than ±20 %.

11.2 Sampling plan II: New construction with known resin or tape

Applicable to first-time testing for a CRT manufacturer or a change in construction of a previously tested CRT that employs any of the following nominal design changes:

11.2.1 Tape and resin

A new CRT construction as defined in 11.1.1 to 11.1.4 with a tape or resin which has been previously tested and found acceptable for a CRT manufacturer in the same or a larger CRT size.

11.3 Sampling plan III: Tension band and alternative tension band

Applicable to any of the following changes in tension band or hardware:

11.3.1 Tension band only

CRTs using this construction employ only a tension band. There is no material between the tension band and the CRT envelope. This sampling plan applies to new constructions as well as a construction change where tape or resin is deleted from the system.

11.3.2 Band-end securement

For tension band only construction, where there are significant changes in the band-end securement method, such as a change from spot weld to crimp type.

11.3.3 Band tension

A change in nominal band tension or minimum glassware recovery value of greater than –5 % to +15 % from a previously tested CRT, employing a particular size range, deflection angle range and glassware shape.

11.3.4 Band-tension system

Change in the band-tensioning system such as a change from machine tightened to shrink band, or others.

11.3.5 Hardware

Change in the hardware system such as addition or deletion of rim bands, reinforcing bars or other structural materials between the tension band and the CRT envelope.

11.3.6 Band width

Reduction of nominal tension band width by more than 10 %.

11.3.7 Band material

Change in metallurgical composition.

11.3.8 Band position

Change in the nominal location of the band (forward or backward) by more than 3 mm from its original position as measured from the front of the band to the Z point on the panel.

11.3.9 Band-surface coating

Addition or change in the surface coating of the tension band when welding is the method of band end securement. CRTs need not be tested if the tensile strength of the new welded band is equal to, or greater than, the original.

11.4 Sampling plan IV: Alternative construction

Applicable to any tension band construction such as tension band only, tension band with tape, rim band, etc. Alternative construction consists of variation in construction in any of the following:

11.4.1 Size

New size within a diagonal size range previously tested for the CRT manufacturer.

11.4.2 Deflection angle

New deflection angle within a range previously tested for a CRT manufacturer.

11.4.3 Glassware supplier

Glassware supplier previously used by the CRT manufacturer in another size range.

11.4.4 Glassware thickness

Glassware whose minimum thickness varies from the glassware originally tested by more than ±10 % and less than, or equal to, ±20 % at any point other than the neck, is considered an alternative construction.

11.4.5 Resin

Resin used in the prestressed banded system is considered an alternative construction if the tensile strength of the cured resin is less than 80 % of the original resin. Addition of tested resin to a CRT construction previously tested using a tension band only (without resin) will be accepted without testing.

11.4.6 Tape

Addition of tested tape to a CRT construction previously tested using a tension band only (without tape) will be accepted without testing.

12 Normative requirements for the use of tables 3 and 4 (bonded frame CRTs)

Sampling and testing for new construction (sampling plan I) and alternative construction (sampling plan II) will be used when any of the following new construction features or variations in construction apply. Unique constructions may require a special investigation.

12.1 Sampling plan I: New construction

Applicable to first-time testing for a CRT manufacturer or change in construction of a previously tested CRT that employs any of the following nominal design variations:

12.1.1 Size

New CRT diagonal size range (see table 7).

12.1.2 Deflection angle

New deflection angle range for a particular CRT size range (see table 7).

12.1.3 Glassware shape

Glassware in a particular CRT size and deflection angle range, having the following shape variations, is considered a new glassware shape:

a) front panel curvature and corner radius – a change in height measurement from the Z point to the centre of the face panel of more than ±10 % from a previously tested CRT for a CRT manufacturer;

b) aspect ratio – any change in the nominal height-to-width ratio of the front panel from a previously tested CRT for a CRT manufacturer;

c) glassware thickness – a change in glassware thickness of more than ±20 % at any point, other than the neck, from a previously tested CRT for a CRT manufacturer.

12.1.4 Glassware supplier

New glassware supplier not previously used by the CRT manufacturer. Subsidiaries of present glassware suppliers who use the same chemistry, mould designs, processes and quality control arrangements, under a common quality management system, are not considered to be new suppliers.

12.1.5 Resin

New resin used in a CRT employing a particular size range, deflection angle range and glassware shape.

12.1.6 Resin thickness

A change in resin thickness of more than ±25 %.

12.1.7 Frame thickness

A change in the thickness of the material used to form the frame of more than ±10 %.

12.2 Sampling plan II: Alternative construction

Consists of variation in construction in any of the following nominal design changes:

12.2.1 Size

New size within a diagonal size range previously tested for a CRT manufacturer.

12.2.2 Deflection angle

New deflection angle within a range previously tested for a CRT manufacturer.

12.2.3 Glassware supplier

Glassware supplier previously used by the CRT manufacturer in another size range.

12.2.4 Glassware thickness

Glassware whose thickness varies from the glassware originally tested by more than ±10 % and less than, or equal to, ±20 % at any point other than the neck, is considered an alternative construction.

12.2.5 Resin

New resin for a size within a size range previously tested for that particular resin.

12.2.6 Resin thickness

A change in resin thickness of more than ±10 % but less than, or equal to, ±25 %.

13 Normative requirements for the use of tables 5 and 6 (laminated CRTs)

Sampling and testing for new construction (sampling plan I) and alternative construction (sampling plan II) will be used when any of the following new construction features or variations in construction apply. Unique constructions may require a special investigation.

13.1 Sampling plan I: New construction

Applicable to first-time testing for a CRT manufacturer or a change in construction of a previously tested CRT that employs any of the following nominal design variations:

13.1.1 Bonding material

New bonding material used or proportion of resin to hardener changed by more than ±20 %.

13.1.2 Bonding material thickness

A change in bonding material thickness of more than ±25 %.

13.1.3 Front panel thickness

A decrease in front panel glass thickness of more than 25 %.

13.2 Sampling plan II: Alternative construction

Applicable to a variation in construction in any of the following nominal design changes:

13.2.1 Bonding material

Bonding material previously tested for a CRT manufacturer but used in a different size range (see table 7).

13.2.2 Bonding material thickness

A change in bonding material thickness of more than ±10 % and less than, or equal to, ±25 %.

13.2.3 Front panel thickness

A decrease in front panel glass thickness in the range of 10 % to 25 %.

Table 1 – Sampling and test programme for prestressed banded CRTs exceeding 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning				Impact and implosion test groups		
		Number of CRTs	Circulating air chamber			Number of CRTs to be tested as described in		
			Temp °C[b]	RH %	Time h	8.1 (ball)[c]	8.3 (thermal)	8.2 (missile)
						Group A	Group B	Group C
I	New construction	5	–	–	–	2	1	2
		4	150[d]	–	48[d]	2	1	1
		4	50	90 - 95	48	2	1	1
		4	[e]	–	[e]	2	1	1
II	New construction with previously tested tape or resin	12	–	–	–	6	2	4
III	Tension band only and alternative tension band	9	–	–	–	4	2	3
IV	Alternative construction	6	–	–	–	3	1	2

[a] See clause 11 for details of the requirements regarding changes in design features.

[b] The tolerance of the oven temperature shall be ±2 °C.

[c] CRTs not visibly damaged in this test may also be subjected to the tests described in 8.2 and 8.3. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

[d] Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

[e] CRTs shall be thermally cycled between –40 °C and +70 °C at the rate of two cycles per day for a total of five cycles and held at each temperature extreme for 4 h.

Table 2 – Sampling and test programme for prestressed banded CRTs from 76 mm to 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning				Impact and implosion test groups		
		Number of CRTs[f]	Circulating air chamber			Number of CRTs to be tested as described in		
			Temp °C[b]	RH %	Time h	9.1 (ball)[c]	9.3 (thermal)	9.2 (high ball)[f]
						Group A	Group B	Group C
I	New construction	5	–	–	–	2	1	2
		4	150[d]	–	48[d]	2	1	1
		4	50	90 - 95	48	2	1	1
		4	[e]	–	[e]	2	1	1
II	New construction with previously tested tape or resin	12	–	–	–	6	2	4
III	Tension band only and alternative tension band	9	–	–	–	4	2	3
IV	Alternative construction	6	–	–	–	3	1	2

[a] See clause 11 for details of the requirements regarding changes in design features.

[b] The tolerance of the oven temperature shall be ±2 °C.

[c] CRTs not visibly damaged in this test may also be subjected to the tests described in 9.2 and 9.3. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

[d] Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

[e] CRTs shall be thermally cycled between –40 °C and +70 °C at the rate of two cycles per day for a total of five cycles and held at each temperature extreme for 4 h.

[f] Test 9.2 is only applied if implosion or rapid devacuation does not occur in ball test 9.1.

Table 3 – Sampling and test programme for bonded frame CRTs exceeding 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning				Impact and implosion test groups		
		Number of CRTs	Circulating air chamber			Number of CRTs to be tested as described in		
			Temp °C[b]	RH %	Time h	8.1 (ball)[c]	8.3 (thermal)	8.2 (missile)
						Group A	Group B	Group C
I	New construction	5	–	–	–	2	1	2
		4	150[d]	–	48[d]	2	1	1
		4	50	90 - 95	48	2	1	1
		4	e	–	e	2	1	1
II	Alternative construction	6	–	–	–	3	1	2

a See clause 12 for details of the requirements regarding changes in design features.

b The tolerance of the oven temperature shall be ±2 °C.

c CRTs not visibly damaged in this test may also be subjected to the tests described in 8.2 and 8.3. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

d Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

e CRTs shall be thermally cycled between –40 °C and +70 °C at the rate of two cycles per day for a total of five cycles and held at each temperature extreme for 4 h.

Table 4 – Sampling and test programme for bonded frame CRTs from 76 mm to 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning				Impact and implosion test groups		
		Number of CRTs[f]	Circulating air chamber			Number of CRTs to be tested as described in		
			Temp °C[b]	RH %	Time h	9.1 (ball)[c]	9.3 (thermal)	9.2 (high ball)[f]
						Group A	Group B	Group C
I	New construction	5	–	–	–	2	1	2
		4	150[d]	–	48[d]	2	1	1
		4	50	90 - 95	48	2	1	1
		4	e	–	e	2	1	1
II	Alternative construction	6	–	–	–	3	1	2

a See clause 12 for details of the requirements regarding changes in design features.

b The tolerance of the oven temperature shall be ±2 °C.

c CRTs not visibly damaged in this test may also be subjected to the tests described in 9.2 and 9.3. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

d Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

e CRTs shall be thermally cycled between –40 °C and +70 °C at the rate of two cycles per day for a total of five cycles and held at each temperature extreme for 4 h.

f Test 9.2 is only applied if implosion or rapid devacuation does not occur in ball test 9.1.

Table 5 – Sampling and test programme for laminated CRTs exceeding 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning			Impact and implosion test groups		
		Number of CRTs	Circulating air chamber		Number of CRTs to be tested as described in		
			Temp °C[b]	Time h	8.1 (ball)[c]	8.3 (thermal)	8.4 (high energy)
					Group A	Group B	Group C
I	New construction	5	–	–	2	1	2
		5	150[d]	48[d]	2	1	2
II	Alternative construction	5	–	–	2	1	2

[a] See clause 13 for details of the requirements regarding changes in design features.

[b] The tolerance of the oven temperature shall be ±2 °C.

[c] CRTs not visibly damaged in this test may also be subjected to the tests described in 8.3 and 8.4. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

[d] Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

Table 6 – Sampling and test programme for laminated CRTs from 76 mm to 160 mm diagonal

Sampling plan	CRT design[a]	Thermal conditioning			Impact and implosion test groups		
		Number of CRTs	Circulating air chamber		Number of CRTs to be tested as described in		
			Temp °C[b]	Time h	9.1 (ball)[c]	9.3 (thermal)	9.4 (high energy)
					Group A	Group B	Group C
I	New construction	4	–	–	2	1	1
		4	150[d]	48[d]	2	1	1
II	Alternative construction	3	–	–	1	1	1

[a] See clause 13 for details of the requirements regarding changes in design features.

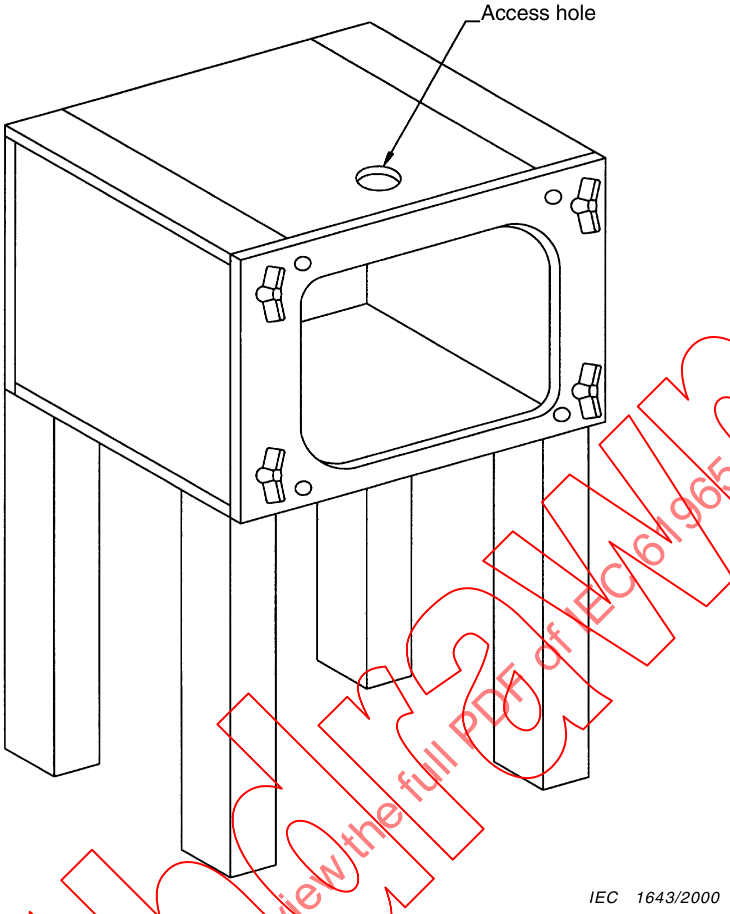
[b] The tolerance of the oven temperature shall be ±2 °C.

[c] CRTs not visibly damaged in this test may also be subjected to the tests described in 9.3 and 9.4. If a CRT yields unacceptable results in either of these tests, the results shall be considered inconclusive and disregarded. A new CRT shall be tested in its place, as previous testing might have weakened the CRT.

[d] Other Arrhenius based time/temperature combinations (according to the principles of IEC 60216-1) may be used (for example, 140 °C for 96 h, 130 °C for 168 h, 120 °C for 336 h or 110 °C for 672 h).

Table 7 – CRT size and deflection angle ranges

CRT diagonal size range mm		Diagonal deflection angle degrees	
Laminated construction	**Prestressed banded and bonded frame construction**	**Laminated construction**	**Prestressed banded and bonded frame construction**
76 - 160	76 - 160	40 - up	40 - 69
161 - 320	161 - 255		70 - 99
321 - 520	256 - 350		100 - 112
521 - 690	351 - 460		113 - up
691 - 850	461 - 540		
	541 - 640		
	641 - 740		
	741 - 890		
	891 - 1 200		



NOTE 1 A cabinet is typically 20 mm thick and made of plywood or metal of similar strength. The front panel shall be made of plywood, typically 20 mm thick.

NOTE 2 An opening having an area of not less than one-quarter of the area of the face of the CRT or 0,02 m^2, whichever is the smaller, shall be provided in the bottom or rear of the cabinet for air intake in the event of an implosion.

Figure 1 – Example of a test cabinet

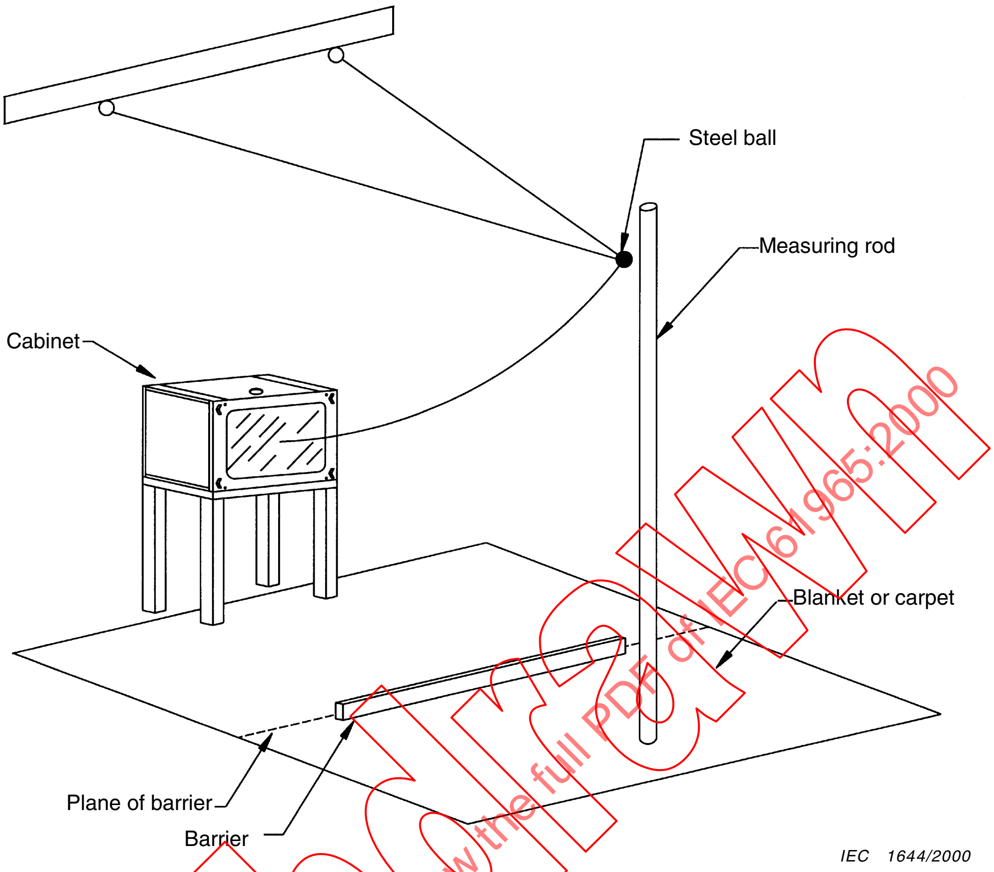
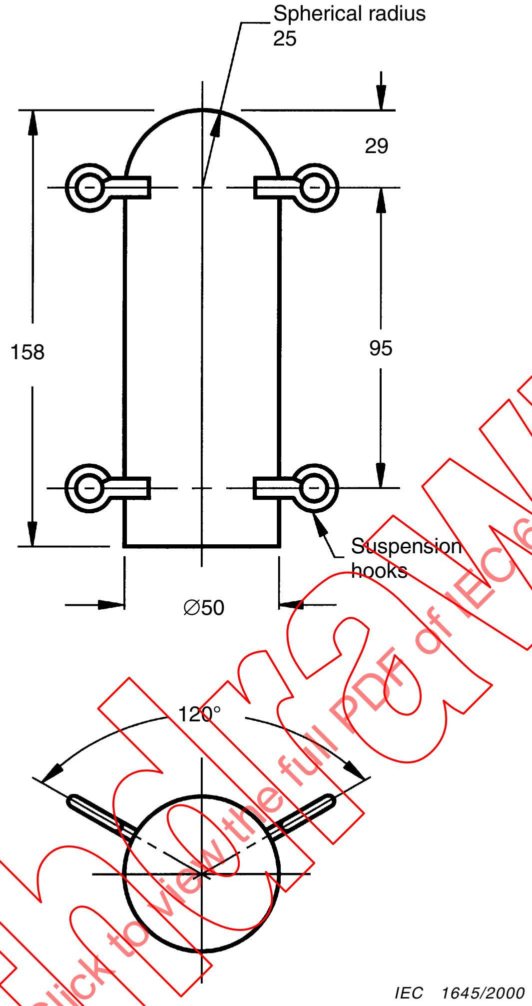
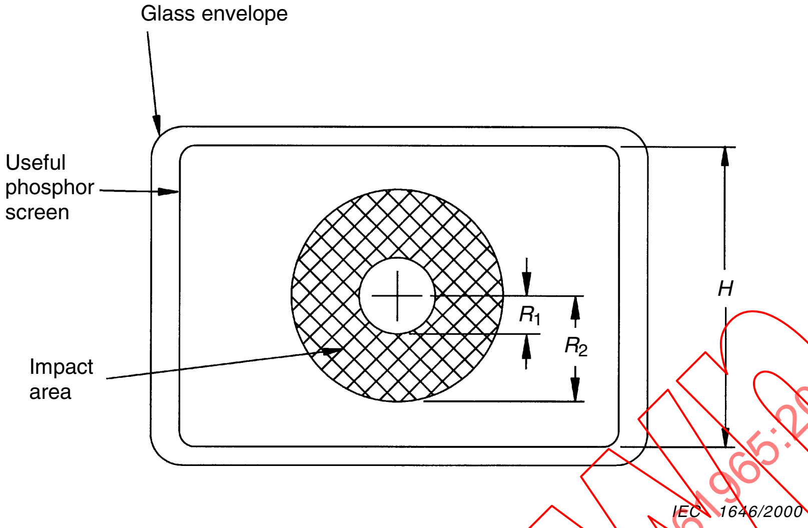


Figure 2 – Example of a ball impact test



NOTE All linear dimensions are in millimetres.

Figure 3 – Example of a 2,3 kg steel missile



Key

H height of the useful phosphor screen.

R_1 *H*/6.

R_2 *H*/2 – 50 mm.

Figure 4 – Missile impact area on a typical CRT

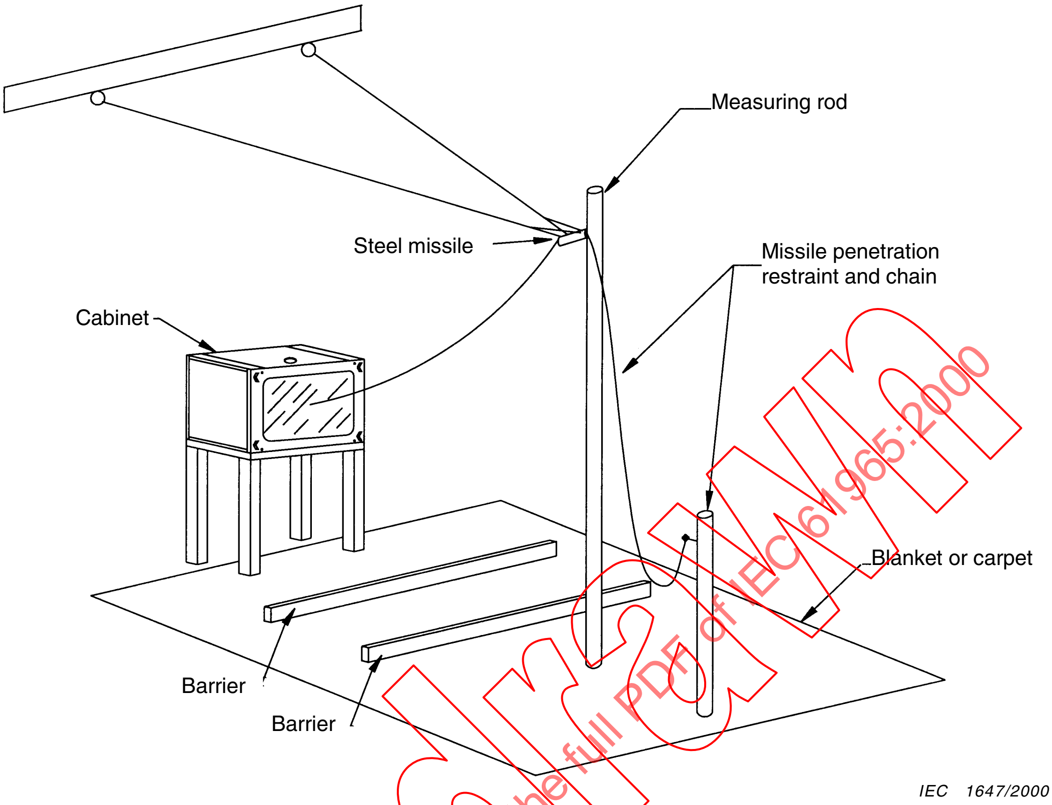
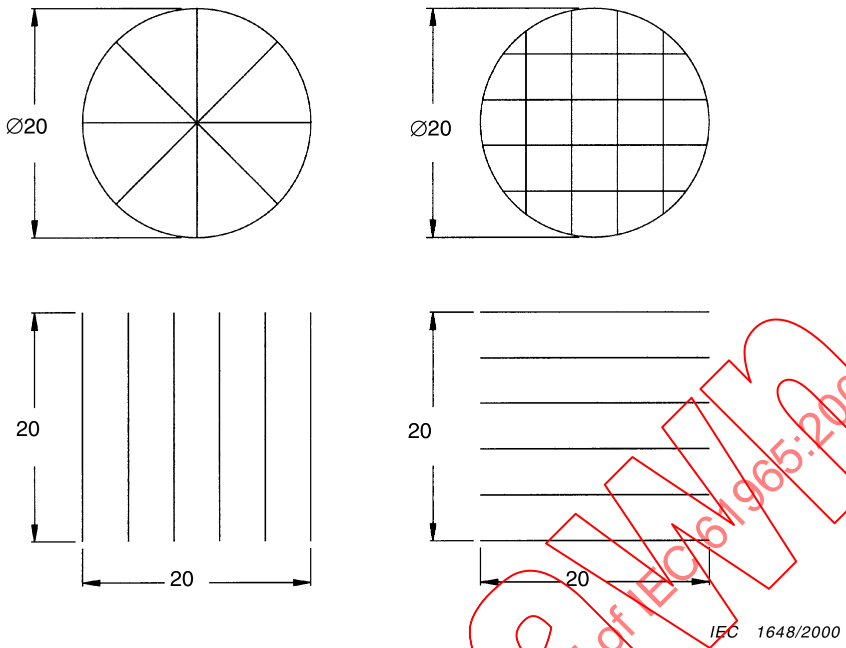
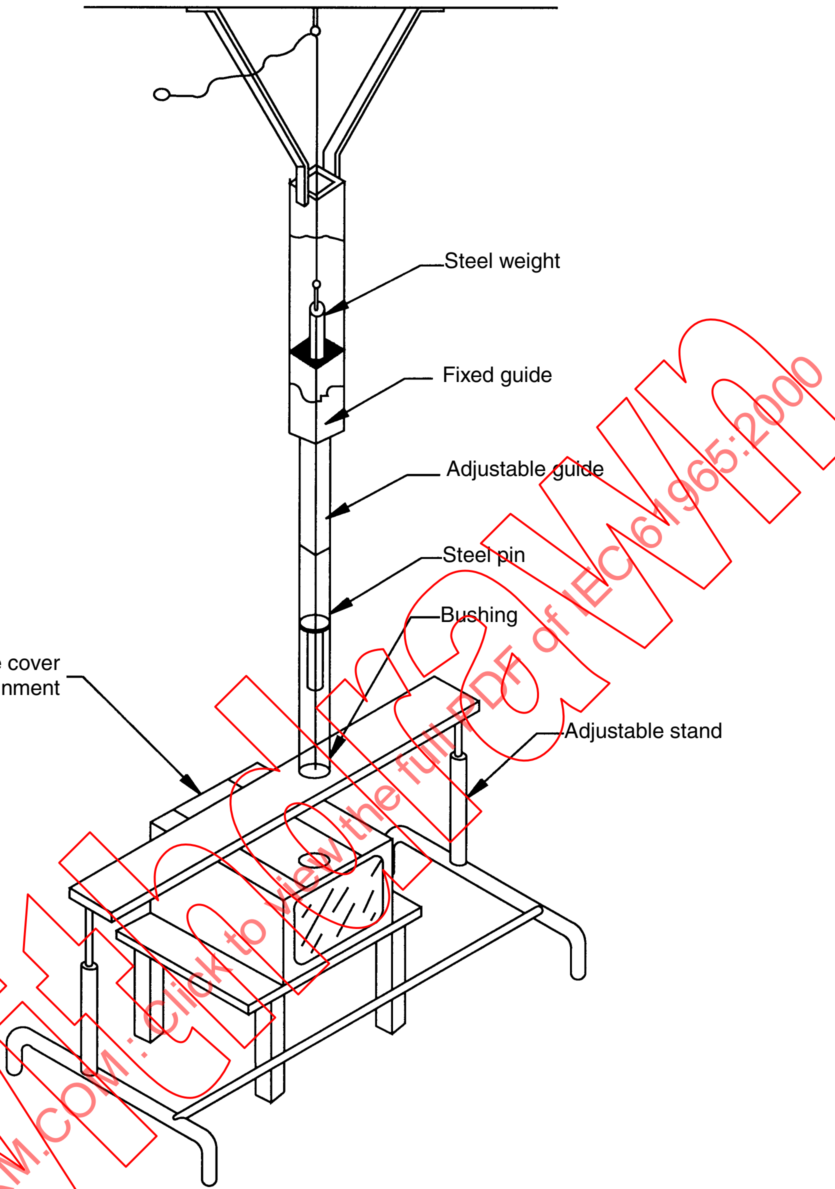


Figure 5 – Example of a missile impact test



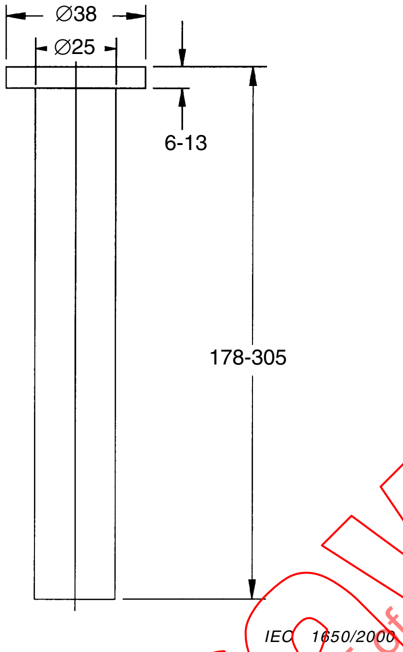
NOTE All linear dimensions are in millimetres.

Figure 6 – Options for scratch patterns for implosions by the thermal shock method



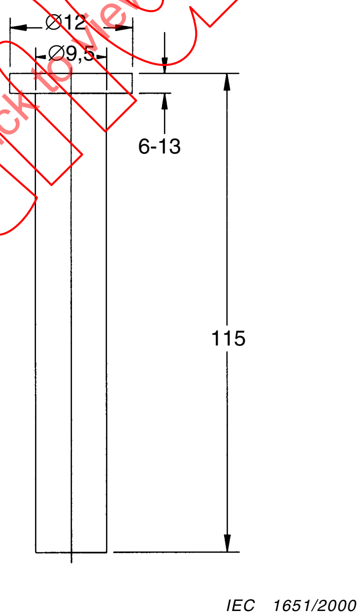
NOTE Adjust height of adjustable stand in such a way that, when the weight hits the pin, the amount of penetration of the pin into the CRT will be a maximum of 6 mm.

Figure 7 – Example of high-energy impact test set-up



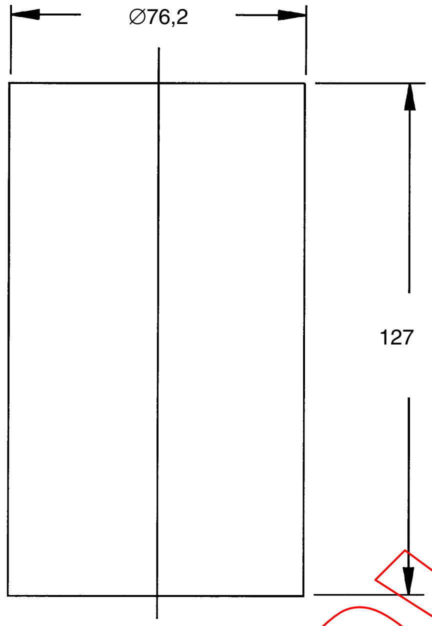
NOTE All linear dimensions are in millimetres.

Figure 8a – Example of steel pin for CRTs exceeding 160 mm face diagonal used in high-energy impact test



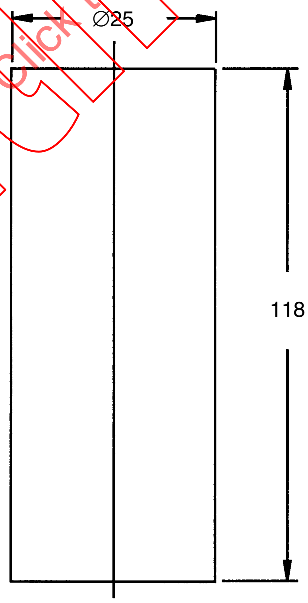
NOTE All linear dimensions are in millimetres.

Figure 8b – Example of steel pin for CRTs from 76 mm to 160 mm diagonal used in high-energy impact test



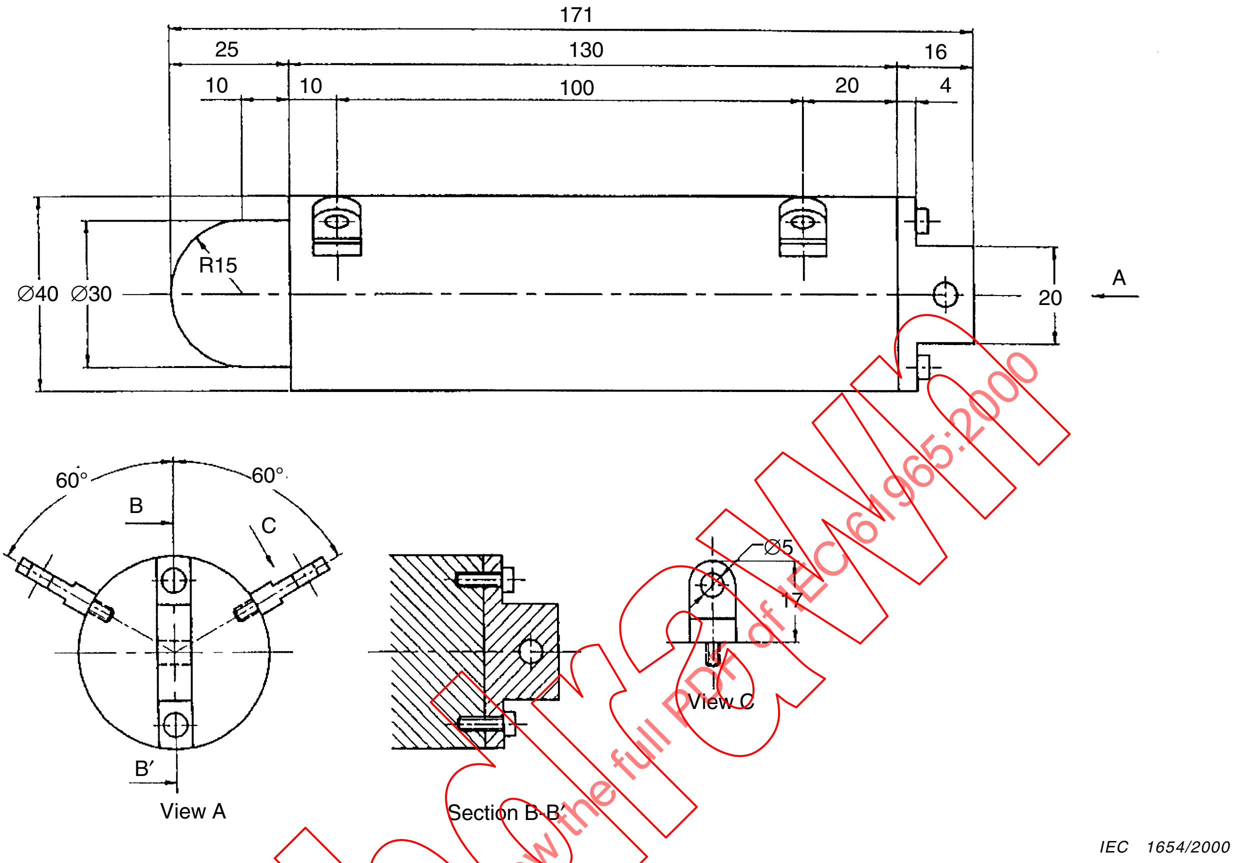
NOTE All linear dimensions are in millimetres.

Figure 9a – Example of 4,5 kg weight used in high-energy impact test on CRTs exceeding 160 mm diagonal



NOTE All linear dimensions are in millimetres.

Figure 9b – Example of 0,45 kg weight used in high-energy impact test on CRTs from 76 mm to 160 mm face diagonal



NOTE 1 All linear dimensions are in millimetres.

NOTE 2 Weight: approx. 1,4 kg.

NOTE 3 Rockwell hardness: >60.

NOTE 4 Surface: Chromium coating.

Figure 10 – Example of 1,4 kg steel missile

Annex A
(informative)

Background to the development of this standard

At its meeting in Eindhoven on 8-9 November 1994, IEC TC 39 noted that a confusing and costly situation had developed worldwide concerning the certification of the mechanical strength of cathode ray tubes (CRTs). The current clause 18 of IEC 60065 was still being used in most countries and had proved to be satisfactory to them. The binational standard UL 1418/CSA-C22.2 No. 228-92 was also being used for certification, mainly in the North American continent. The committee decided to propose a New Work Item 39/231/NP to develop a new standard which would ultimately replace the existing standards. After the voting stage it was clear that sufficient support existed and Working Group 2 was established comprising experts from Canada, Italy, Japan, Korea, The Netherlands, United Kingdom, United States of America and Germany.

IEC 60065 is an equipment standard under the responsibility of IEC TC 92. TC 39 undertook the task of creating a new standard intended to replace clause 18 of IEC 60065, in line with the IEC policy that component requirements should be published in component standards, in the development of which due notice should be given to the component user requirements (Administrative Circular No. 71/1988).

At its first meeting, TC 39/WG 2 noted that, in fact, clause 18 of IEC 60065 and the binational UL/CSA standard were the two documents which required harmonization. The two standards are similar in approach to testing. They both contain conditioning regimes and tests to prove the mechanical strength and the effects to the user of the implosion or rapid devacuation of the CRT. Both standards address only CRTs which have integral implosion protection systems.

Over 30 years' experience has been built up in the use of both standards. In that time, CRT technology has moved forward in the area of implosion protection systems and with the evolution of larger CRTs. Experience has also shown that certain areas of interpretation need to be addressed.

This standard contains the following main clauses:

- environmental conditioning instructions for use prior to testing;
- test methods and requirements which demonstrate that the CRT is mechanically strong enough to withstand impact damage which could be encountered in normal use so that the viewer is adequately protected against injury;
- test methods and requirements which demonstrate that, in the event of an implosion or rapid devacuation of the CRT, the implosion occurs in a controlled manner;
- detailed sampling tables which specify the numbers of CRTs to be tested to certify new designs and changes in design or construction;
- dedicated test methods and requirements for small CRTs (76 mm to 160 mm diagonal) and large CRTs (exceeding 160 mm diagonal).

During the development of the new standard, the TC 39 WG 2 members carried out extensive testing programmes and calculations to demonstrate that the proposed new test methods ensure protection for the users of the CRTs which are covered by the standard, and that the stringent requirements of either of the existing standards are not degraded. The conclusions of these findings are summarized as follows:

A.1 Mechanical strength test

a) The ball impact test attempts to simulate the situation where the CRT can be struck by any likely domestic object. The shape and energy of such objects will vary enormously and the choice of a **single** device size and energy for this test is in order to ensure standardization i.e., an easily reproducible and repeatable test with the minimum of variability.

b) The 40 mm/5,5 J ball test was selected as it was already in use in IEC 60065 and was optional in the binational standard. Testing showed it to be generally equivalent to the use of the 51 mm/7 J ball when combined with the use of a single barrier at 1,5 m.

c) From ballistic and statistical calculations the kinetic energy of a 0,025 g particle (the maximum size permitted by this standard) is of the order of 1×10^{-4} J and the maximum particle speed is around 4 m/s (9 m.p.h.). This energy level is negligible with respect to its ability to cause flesh damage as human skin exhibits visco-elastic properties (people performing normal activities frequently encounter airborne particles of greater mass and higher velocity than this).

A.2 Implosion test

Due to the introduction of larger CRTs having thicker face plates and to the use of laminated screens, it is not possible, in some cases, to induce rapid devacuation using the ball impact test. In order to evaluate the effectiveness of the implosion protection system, a test with a larger impact object (missile or high-energy) is used to induce rapid devacuation.

A.3 Small CRTs (76 mm to 160 mm diagonal)

Research has shown that small CRTs may require implosion protection systems. Scaled-down tests have been developed for these sizes.

A.4 Evaluation time

As the impact tests in this standard are overstress tests, evaluation of test results includes only the effect of rapid devacuation and not subsequent relaxation of mechanical stresses in the CRT from the implosion protection system. Five seconds is deemed satisfactory to evaluate the result of rapid devacuation and exclude results of stress relaxation.

Annex B
(informative)

Velocity and potential force of glass particles expelled from a CRT subjected to a ball impact – Ballistic and statistical calculations

B.1 Introduction

An assignment was given to determine the potential force of glass particles passing over the test set-up barriers after being expelled from a tested CRT subjected to a ball impact test. The test set-up barriers are placed at a distance of 0,9 m in the UL/CSA standard and 1,5 m in this standard. The equivalent instantaneous force of a glass particle with a specified mass of 25 mg at a given distance then needs to be determined. This can then also be compared to IEC 60065, clause 18, in which a particle of 10 g is allowed to reach the barrier at 1,5 m.

A glass particle will be expelled at a vertical height of 1,0 m and would have the minimum velocity to pass over a 0,25 m barrier placed at 0,9 m in one solution and at 1,5 m in the other (figure B.1). If possible, air resistance should be factored into the equation. In addition, any available information on medical studies determining the force required to lacerate human skin is to be acquired.

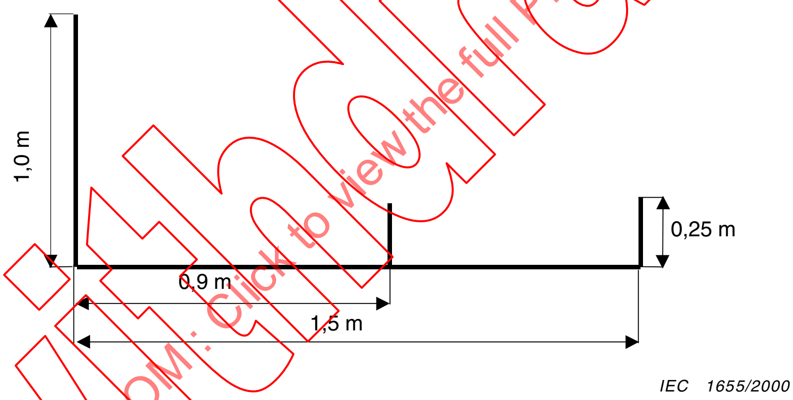


Figure B.1 – Height of the barriers and distances from the CRT face

The objective of this annex is to investigate the velocity and potential force of glass particles expelled from an imploding CRT. In this annex, the analysis of a glass particle with, and without, air friction influences is described. Finally conclusions are drawn.

B.2 Analysis without friction

B.2.1 Introduction

After a glass particle is expelled from the CRT screen, the primary forces acting on the particle are the gravitational force and the air friction. In this clause the trajectory of a glass particle is determined as it is expelled from a CRT screen with a certain velocity and angle. First, the analysis without air friction influences is described because this enables the equations of motion to be solved analytically. Furthermore, due to the shape of the particles, the air resistance is probably very small. The trajectory of the glass particle then has a parabolic shape. This is shown in figure B.2.

In the UL/CSA test set-up a barrier with a height h is placed at a distance l_2 from the screen. In the IEC test set-up, the barrier is placed at a distance l_1. The values for the set-up parameters are given in table B.1. The implosion protection system of CRTs assures that glass particles with a mass of 25 mg will not exceed the respective distances.

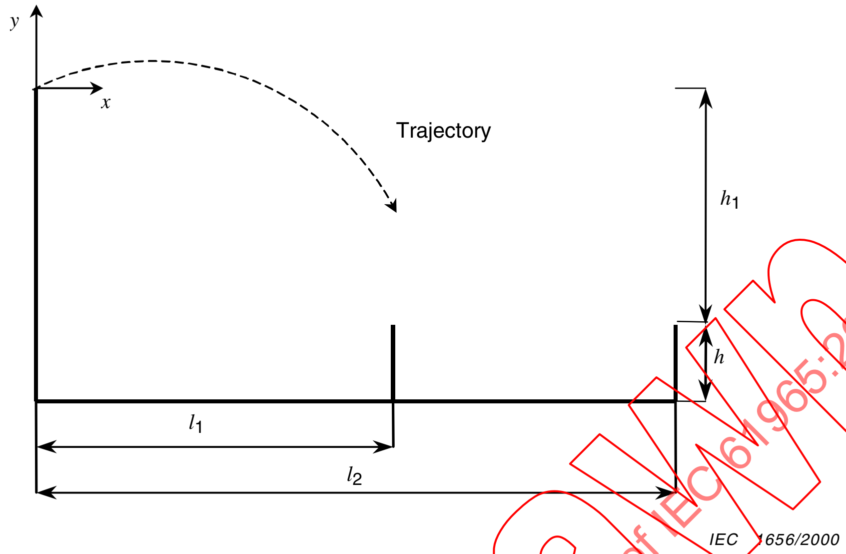


Figure B.2 – Example of the parabolic trajectory of a glass particle and the definition of the distances

Table B.1 – Values of the distances

Distances	Values m
h	0,25
h_1	0,75
l_1	1,5
l_2	0,9

B.2.2 Equations of motion

Figure B.3 shows the definition of a glass particle that is propelled from the CRT with an initial velocity v_0 under an angle β. The only force acting on the particle is the gravitational force. Newton's law can then be used to determine the force equilibrium in x- and y-direction:

$$ma_x = 0$$

$$ma_y = 0$$

where

m is the mass of the glass particle in kg;

a_x is the acceleration of the particle in x-direction in m/s²;

a_y is the acceleration of the particle in y-direction in m/s²;

g is the gravitational acceleration of 9,81 m/s².

These relations can be integrated twice with the initial conditions as shown in figure B.3. This results in the following displacement equations:

$$x = v_0 \cos \beta \times t$$

$$y = v_0 \sin \beta \times t - \frac{1}{2} g t^2$$

where

x is the displacement in x-direction;

y is the displacement in y-direction;

v_0 is the initial velocity;

β is the initial angle at which the particle is expelled;

t is the time.

NOTE The time derivative of the displacement is the velocity and the time derivative of the velocity is the acceleration.

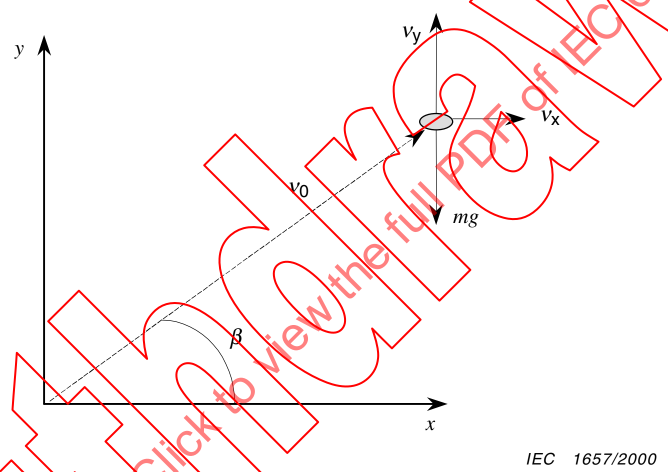


Figure B.3 – Definition of the initial angle and initial velocity and the forces acting on a particle

B.2.3 Minimum velocity to reach a prescribed distance

The unknowns in the equations of motion are the initial velocity v_0 and the time t. The initial angle β needs to be prescribed. Therefore, the required initial velocity depends on the value for β. The known values are $x = l_1$ or l_2 and $y = h$ (table B.2 and figure B.1).

There are two equations with two unknowns. To solve the equations a relation for t can be determined from the first equation and substituted in the second equation:

$$x = v_0 \cos\beta \times t \rightarrow t = \frac{x}{v_0 \cos\beta}$$

$$y = v_0 \sin \beta \times \frac{x}{v_0 \cos \beta} - \frac{1}{2} g \left(\frac{x}{v_0 \cos \beta} \right)^2$$

This can be rewritten to obtain the following relation:

$$v_0 = \sqrt{\frac{gx^2}{2x \sin\beta \cos\beta - 2y \cos^2 \beta}}$$

Figure B.4 shows the initial velocity that is required to pass over the barriers at $x = l_1$ (solid line) or $x = l_2$ (dashed line) as a function of the initial angle β. The curves can be interpreted as follows:

- if the initial angle β is 0° then glass particles with a velocity higher than 3,8 m/s will pass over both barriers;
- if the initial angle β is 0° then glass particles with a velocity lower than 2,3 m/s will remain within the barrier of 0,9 m;
- if the initial angle β is 0° then glass particles with a velocity higher than 2,3 m/s and lower than 3,8 m/s will fall outside the barrier at 0,9 m and inside the barrier of 1,5 m.

It can be seen that the function has an upper and a lower boundary. The barriers can not be passed for any value of the initial velocity if the values for β are beyond these limits.

The limit to the velocity is defined by the boundary values of β. The velocity goes to infinity if the denominator in the root equation has a value of zero. This happens when

$$\beta = \tan^{-1}\left(\frac{y}{x}\right)$$

Table B.2 shows the upper and lower boundary values of the initial angle.

Table B.2 – Upper and lower boundary values of the initial angle

Barrier	β_{low}	β_{up}
l_1	–26,7°	90°
l_2	–39,8°	90°

An upper boundary β_{up} is reached when the angle is so great that an infinite value for the velocity is needed to reach a distance of l_1.