

TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

BASIC SAFETY PUBLICATION

PUBLICATION FONDAMENTALE DE SÉCURITÉ

**Effects of current on human beings and livestock –
Part 1: General aspects**

**Effets du courant sur l'homme et les animaux domestiques –
Partie 1: Aspects généraux**

UNCLASSIFIED



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**EFFECTS OF CURRENT ON HUMAN BEINGS
AND LIVESTOCK –****Part 1: General aspects****FOREWORD**

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60479-1, which is a technical specification, has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

This fourth edition cancels and replaces the third edition, published as a technical report in 1994, and constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- Dependence of the total body impedance Z_T for 50th percentile rank of a population of living human beings for large, average and small surface areas of a contact in dry, water-wet and saltwater-wet conditions at touch voltage $U_T = 25$ V to 200 V a.c. 50/60 Hz.
- Oscillograms of touch voltages U_T and touch currents I_T for a.c., current path hand-to-hand, large surface areas of contact in dry condition taken from measurements given in Figure 16 with the relevant explanations in the main text.
- Fibrillation data for dogs, pigs and sheep obtained from experiments and for persons calculated from statistics of electrical accidents with transversal direction of current flow, hand-to-hand and touch voltages $U_T = 220$ V to 380 V a.c. with body impedances Z_T (5%) given in Figure 19 with the relevant explanations in the main text.
- Change of Curve B in Figure 20 from 10 mA to 5 mA: conventional time/current zones of effects of a.c. current (15 Hz to 100 Hz) on persons with the relevant explanations in the main text.
- Let-go currents for 60 Hz sinusoidal current given in Figure 23 with the relevant explanations in the main text.
- new structure to the body of the standard.

This technical specification has the status of a basic safety publication in accordance with IEC Guide 104.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
64/1427/DTS	64/1463/RVC

Full information on the voting for the approval of this technical specification 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 2.

IEC 60479 consists of the following parts under the general title *Effects of current on human beings and livestock*

Part 1: General aspects

Part 2: Special aspects:

Chapter 4: Effects of alternating current with frequencies above 100 Hz

Chapter 5: Effects of special waveforms of current

Chapter 6: Effects of unidirectional single impulse currents of short duration

Part 3: Effects of currents passing through the bodies of livestock

Part 4: Effects of lightning strokes on human beings and livestock

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of October 2006 and June 2013 have been included in this copy.

Withdrawn

INTRODUCTION

This technical specification provides basic guidance on the effects of shock current on human beings and livestock, for use in the establishment of electrical safety requirements.

In order to avoid errors in the interpretation of this specification, it must be emphasized that the data given herein is mainly based on experiments with animals as well as on information available from clinical observations. Only a few experiments with shock currents of short duration have been carried out on living human beings.

On the evidence available, mostly from animal research, the values are so conservative that the standard applies to persons of normal physiological conditions including children, irrespective of age and weight.

There are, however, other aspects to be taken into account, such as probability of faults, probability of contact with live or faulty parts, ratio between touch voltage and fault voltage, experience gained, technical feasibilities, and economics. These parameters have to be considered carefully when fixing safety requirements, for example, operating characteristics of protective devices for electrical installations.

The form of the specification as has been adopted summarizes results so far achieved which are being used by technical committee 64 as a basis for fixing requirements for protection against shock. These results are considered important enough to justify an IEC publication which may serve as a guide to other IEC committees and countries having need of such information.

This technical specification applies to the threshold of ventricular fibrillation which is the main cause of deaths by electric current. The analysis of results of recent research work on cardiac physiology and on the fibrillation threshold, taken together, has made it possible to better appreciate the influence of the main physical parameters and, especially, of the duration of the current flow.

IEC 60479-1 contains information about body impedance and body current thresholds for various physiological effects. This information can be combined to derive estimates of a.c. and d.c. touch voltage thresholds for certain body current pathways, contact moisture conditions, and skin contact areas. Information about touch voltage thresholds for physiological effects is contained in the IEC 61201.

This specification refers specifically to the effects of electric current. When an assessment of the harmful effects of any event on human beings and livestock is being made, other non-electric phenomena, including falls, heat, fire, or others should be taken into account. These matters are beyond the scope of this specification, but may be extremely serious in their own right.

Recent research work has also been conducted on the other physical accident parameters, especially the waveform and frequency of the current and the impedance of the human body. This fourth revision of IEC 60479-1 should be viewed as the logical development and evolution of the third edition.

Clause 2 of IEC 60479-1 (third edition) on the impedance of the human body contained little information on the dependence of the impedance on the surface area of contact and then only for dry conditions.

Therefore measurements were carried out on 10 persons using medium and small surface areas of contact in dry, water-wet and saltwater-wet conditions, current path hand to hand, at a touch voltage of 25 V a.c. 50 Hz. The impedance values for a percentile rank of 5 %, 50 % and 95 % have been calculated from these measurements.

Due to unpleasant sensations and the possibility of inherent danger, measurements using large surface areas of contact (order of magnitude 10 000 mm²) in dry, water-wet and saltwater-wet conditions and with medium and small surface areas of contact (order of magnitude 1 000 mm² and 100 mm²) in dry condition at touch voltages from 25 V up to and including 200 V a.c. have only been carried out on one person. By the use of deviation factors it was nevertheless possible to derive values of the total body impedance Z_T for a percentile rank of 5 %, 50 % and 95 % of a population of persons. With the same one person measurements were also made with still smaller surface areas of contact (10 mm² and 1 mm²) and between fingertips.

For the calculation of total body impedance Z_T for a percentile rank of 5 %, 50 % and 95 % of a population of persons for large surface areas of contact for touch voltages above 200 V up to 700 V and higher up to the asymptotic values the method to adapt values of Z_T measured on corpses to those of persons used for the second edition of IEC 60479-1 was improved by taking account of the different temperature of the corpses during measurements and the temperature of 37 °C for persons.

The present state of knowledge of a.c. impedance Z_T of the human body for large, medium and small surface areas of contact in dry, water-wet and salt-water-wet conditions and of the d.c.-resistance R_T of the human body for large areas of contact in dry conditions are presented.

It should be mentioned that the thresholds as order of magnitude are valid for all persons (men, women and children) independent of their state of health. Often concerns are expressed in that respect but if the background of such objections is examined it is found that such objections represent just opinions without experimental evidence. Some measurements indicate that the thresholds of perception and let-go for women are lower than for men. This may also be the case for children.

Furthermore in Clause 5 a heart-current factor F for the current path foot to foot has been introduced. This is important for electrical risks caused by step voltages.

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

1 Scope

For a given current path through the human body, the danger to persons depends mainly on the magnitude and duration of the current flow. However, the time/current zones specified in the following clauses are, in many cases, not directly applicable in practice for designing measures of protection against electrical shock. The necessary criterion is the admissible limit of touch voltage (i.e. the product of the current through the body called touch current and the body impedance) as a function of time. The relationship between current and voltage is not linear because the impedance of the human body varies with the touch voltage, and data on this relationship is therefore required. The different parts of the human body (such as the skin, blood, muscles, other tissues and joints) present to the electric current a certain impedance composed of resistive and capacitive components.

The values of body impedance depend on a number of factors and, in particular, on current path, on touch voltage, duration of current flow, frequency, degree of moisture of the skin, surface area of contact, pressure exerted and temperature.

The impedance values indicated in this technical specification result from a close examination of the experimental results available from measurements carried out principally on corpses and on some living persons.

Knowledge of the effects of alternating current is primarily based on the findings related to the effects of current at frequencies of 50 Hz or 60 Hz which are the most common in electrical installations. The values given are, however, deemed applicable over the frequency range from 15 Hz to 100 Hz, threshold values at the limits of this range being higher than those at 50 Hz or 60 Hz. Principally the risk of ventricular fibrillation is considered to be the main mechanism of death of fatal electrical accidents.

Accidents with direct current are much less frequent than would be expected from the number of d.c. applications, and fatal electrical accidents occur only under very unfavourable conditions, for example, in mines. This is partly due to the fact that with direct current, the let-go of parts gripped is less difficult and that for shock durations longer than the period of the cardiac cycle, the threshold of ventricular fibrillation is considerably higher than for alternating current.

NOTE The IEC 60479 series contains information about body impedance and body current thresholds for various physiological effects. This information can be combined to derive estimates of a.c. and d.c. touch voltage thresholds for certain body current pathways, contact moisture conditions, and skin contact areas. Information about touch voltage thresholds for physiological effects is contained in IEC 61201.

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.

IEC 61201:1992, *Extra-low voltage (ELV) – Limit values*

Guide 104:1997, *The preparation of safety publications and the use of basic safety publications and group safety publications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 General definitions

3.1.1

longitudinal current

current flowing lengthwise through the trunk of the human body such as from hand to feet

3.1.2

transverse current

current flowing across the trunk of the human body such as from hand to hand

3.1.3

internal impedance of the human body

Z_i

impedance between two electrodes in contact with two parts of the human body, neglecting skin impedances

3.1.4

impedance of the skin

Z_s

impedance between an electrode on the skin and the conductive tissues underneath

3.1.5

total impedance of the human body

Z_T

vectorial sum of the internal impedance and the impedances of the skin (see Figure 1)

3.1.6

initial resistance of the human body

R_0

resistance limiting the peak value of the current at the moment when the touch voltage occurs

3.1.7

dry condition

condition of the skin of a surface area of contact with regard to humidity of a living person being at rest under normal indoor environmental conditions

3.1.8**water-wet condition**

condition of the skin of a surface area of contact being exposed for 1min to water of public water supplies (average resistivity $\rho = 3\,500\,\Omega\text{cm}$, pH = 7 to 9)

3.1.9**saltwater-wet condition**

condition of the skin of a surface area of contact being exposed for 1 min to a 3 % solution of NaCl in water (average resistivity $\rho = 30\,\Omega\text{cm}$, pH = 7 to 9)

NOTE It is assumed that saltwater-wet condition simulates the condition of the skin of a sweating person or a person after immersion in seawater. Further investigations are necessary.

3.1.10**deviation factor**

F_D

total body impedance Z_T for a given percentile rank of a population divided by the total body impedance Z_T for a percentile rank of 50 % of a population at a given touch voltage

$$F_D(X\%, U_T) = \frac{Z_T(X\%, U_T)}{Z_T(50\%, U_T)}$$

3.2 Effects of sinusoidal alternating current in the range 15 Hz to 100 Hz**3.2.1****threshold of perception**

minimum value of touch current which causes any sensation for the person through which it is flowing

3.2.2**threshold of reaction**

minimum value of touch current which causes involuntary muscular contraction

3.2.3**threshold of let-go**

maximum value of touch current at which a person holding electrodes can let go of the electrodes

3.2.4**threshold of ventricular fibrillation**

minimum value of touch current through the body which causes ventricular fibrillation

3.2.5**heart-current factor**

F

relates the electric field strength (current density) in the heart for a given current path to the electric field strength (current density) in the heart for a touch current of equal magnitude flowing from left hand to feet

NOTE In the heart, the current density is proportional to the electric field strength.

3.2.6**vulnerable period**

comparatively small part of the cardiac cycle during which the heart fibres are in an inhomogeneous state of excitability and ventricular fibrillation occurs if they are excited by an electric current of sufficient magnitude

NOTE The vulnerable period corresponds to the first part of the T-wave in the electrocardiogram which is approximately 10 % of the cardiac cycle (see Figures 17 and 18).

3.3 Effects of direct current

3.3.1

total body resistance

R_T

sum of the internal resistance of the human body and the resistances of the skin

3.3.2

d.c./a.c. equivalence factor

k

ratio of direct current to its equivalent r.m.s. value of alternating current having the same probability of inducing ventricular fibrillation

NOTE As an example for shock durations longer than the period of one cardiac cycle and 50 % probability for ventricular fibrillation, the equivalence factor for 10 s is approximately:

$$k = \frac{I_{\text{d.c.-fibrillation}}}{I_{\text{a.c.-fibrillation (r.m.s.)}}} = \frac{300 \text{ mA}}{80 \text{ mA}} = 3,75 \text{ (see Figures 20 and 22)}$$

3.3.3

upward current

direct touch current through the human body for which the feet represent the positive polarity

3.3.4

downward current

direct touch current through the human body for which the feet represent the negative polarity

4 Electrical impedance of the human body

The values of body impedance depend on a number of factors and, in particular, on current path, on touch voltage, duration of current flow, frequency, degree of moisture of the skin, surface area of contact, pressure exerted and temperature.

A schematic diagram for the impedance of the human body is shown in Figure 1.

4.1 Internal impedance of the human body (Z_i)

The internal impedance of the human body can be considered as mostly resistive. Its value depends primarily on the current path and, to a lesser extent, on the surface area of contact.

NOTE 1 Measurements indicate that a small capacitive component exists (dashed lines in Figure 1).

Figure 2 shows the internal impedance of the human body for its different parts expressed as percentages of that related to the path hand to foot.

For current paths hand to hand or hand to feet, the impedances are mainly located in the limbs (arms and legs). If the impedance of the trunk of the body is neglected, a simplified circuit diagram can be established which is shown in Figure 3.

NOTE 2 In order to simplify the circuit diagram, it is assumed that the impedance of arms and legs have the same values.

4.2 Impedance of the skin (Z_s)

The impedance of the skin can be considered as a network of resistances and capacitances. Its structure is made up of a semi-insulating layer and small conductive elements (pores). The skin impedance falls when the current is increased. Sometimes current marks are observed (see 4.7).

The value of the impedance of the skin depends on voltage, frequency, duration of the current flow, surface area of contact, pressure of contact, the degree of moisture of the skin, temperature and type of the skin.

For lower touch voltages the value of the impedance of the skin varies widely, even for one person, with surface area of contact and condition (dry, wet, perspiration), temperature, rapid respiration, etc. For higher touch voltages the skin impedance decreases considerably and becomes negligible when the skin breaks down.

As regards the influence of frequency, the impedance of the skin decreases when the frequency increases.

4.3 Total impedance of the human body (Z_T)

The total impedance of the human body consists of resistive and capacitive components.

For lower touch voltages, there are considerable variations in the impedance of the skin Z_s and the total impedance of the human body Z_T similarly varies widely. For higher touch voltages, the total impedance depends less and less on the impedance of the skin and its value approaches that of the internal impedance Z_i . See Figures 4 to 9.

As regards the influence of frequency, taking into account the frequency dependence of the skin impedance, the total impedance of the human body is higher for direct current and decreases when the frequency increases.

4.4 Factors affecting initial resistance of the human body (R_0)

At the moment when the touch voltage occurs, capacitances in the human body are not charged. Therefore skin impedances Z_{s1} and Z_{s2} are negligible and the initial resistance R_0 is approximately equal to the internal impedance of the human body Z_i (see Figure 1). The initial resistance R_0 depends mainly on the current path and to a lesser extent on the surface area of contact.

The initial resistance R_0 limits the current peaks of short impulses (e.g. shocks from electric fence controllers).

4.5 Values of the total impedance of the human body (Z_T)

The dependence of the total body impedance Z_T for the 50th percentile rank of a population of living human beings for large, medium and small surface areas of contact (order of magnitude 10 000 mm², 1 000 mm² and 100 mm² respectively) in dry, water-wet and saltwater-wet conditions at touch voltages $U_T = 25$ V a.c. to 200 V a.c. is shown in Figures 7, 8 and 9.

4.5.1 Sinusoidal alternating current 50/60 Hz for large surface areas of contact

The values of the total body impedances in Tables 1, 2 and 3 are valid for living human beings and a current path hand to hand for large surface areas of contact (order of magnitude 10 000 mm²) in dry (Table 1), water-wet (Table 2) and saltwater-wet (Table 3) conditions.

The range of the total body impedances for touch voltages up to 700 V for large surface areas of contact in dry, water-wet and saltwater-wet conditions for a percentile rank of 50 % of the population is presented in Figure 4.

The values for Tables 1, 2 and 3 represent the best knowledge on the total body impedances Z_T for living adults. On the knowledge at present available the total body impedance Z_T for children is expected to be somewhat higher but of the same order of magnitude.

Table 1 – Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in dry conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1 750	3 250	6 100
50	1 375	2 500	4 600
75	1 125	2 000	3 600
100	990	1 725	3 125
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 For living persons the values of Z_T correspond to a duration of current flow of about 0,1 s. For longer durations Z_T values may decrease (about 10 % to 20 %) and after complete rupture of the skin Z_T approaches the internal body impedance Z_i .

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 25 Ω .

Table 2 – Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in water-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1175	2 175	4 100
50	1100	2 000	3 675
75	1025	1 825	3 275
100	975	1 675	2 950
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value =internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 For living persons the values of Z_T correspond to a duration of current flow of about 0,1 s. For longer durations Z_T values may decrease (about 10 % to 20 %) and after complete rupture of the skin Z_T approaches the internal body impedance Z_i .

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 25 Ω .

Table 3 – Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in saltwater-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	960	1 300	1 755
50	940	1 275	1 720
75	920	1 250	1 685
100	880	1 225	1 655
125	850	1 200	1 620
150	830	1 180	1 590
175	810	1 155	1 560
200	790	1 135	1 530
225	770	1 115	1 505
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 Due to low skin impedances in this case it may be assumed that Z_T depends little on the duration of current flow; Z_T approaches the internal body impedance Z_i .

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 5 Ω .

The values indicated in Tables 1 to 3 have been derived from measurements carried out on corpses and on living persons (adults, males and females) as described in Annex A.

At voltages higher than approximately 125 V for water-wet conditions and 400 V for saltwater-wet conditions the values for the total body impedance are the same as for dry conditions (see Figure 4).

4.5.2 Sinusoidal alternating current 50/60 Hz for medium and small surface areas of contact

The value of the internal body impedances Z_i and of the initial body resistance R_0 (see 4.6) depend only to a small extent on the surface areas of contact.

However, when the surface area of contact is very small, in the order of a few square millimetres, the values are increased.

After the skin has broken down (for touch voltages over approx. 100 V and after longer durations of current flow), the total body impedance Z_T approaches values of the internal body impedance Z_i and depends only to a small extent on the surface area of contact and its condition of dampness.

The measurements of the dependence of the total body impedance Z_T on the surface area of contact for a.c. 50 Hz in dry, water-wet and saltwater-wet conditions which have been carried out on living persons at touch voltages of $U_T = 25$ V to 200 V are described in Annex A.

NOTE No data on Z_T for surface areas in water-wet and saltwater-wet conditions of persons or corpses is available for touch voltages above 200 V.

The dependence of the total body impedance Z_T for a current path hand to hand on the surface area of contact (from 1 mm² up to approximately 8 000 mm²) in dry condition for a touch voltage range of 25 V to 200 V, a.c. 50 Hz, measured on one person is shown in Figure 5. For touch voltages below 100 V and small surface areas of contact in the order of a few mm², deviations in the measurements can easily reach about + 50 % of the average, depending on temperature, pressure, location within the palm of the hand, etc.

The dependence of the total body impedance Z_T between the tips of the right forefinger and the left forefinger (surface area of contact approximately 250 mm²) on the touch voltage for a.c. 50/60 Hz for a voltage range from 25 V to 200 V is shown in Figure 6.

From Figure 6 one can calculate that the partial impedance of one forefinger at a touch voltage of 200 V is on the order of 1 000 Ω .

The measurements of the total body impedance Z_T shown in Figures 5 and 6 have been carried out on one living person only.

For a percentile rank of 5 %, 50 % and 95 % of a population of living human beings on the knowledge at present available the following presentation is given for the total body impedance Z_T for large, medium and small surface areas of contact (order of magnitude 10 000 mm², 1 000 mm² and 100 mm² respectively) in dry, water-wet and saltwater-wet conditions:

- for large surface areas of contact, the values have been presented in Tables 1, 2 and 3 for dry, water-wet and saltwater-wet conditions for touch voltages $U_T = 25$ V to 1 000 V, a.c. 50/60 Hz;
- for medium surface areas of contact, the values are presented in the following Tables 4, 5 and 6 for dry, water-wet and saltwater-wet conditions for touch voltages $U_T = 25$ V to 200 V a.c. 50/60 Hz;
- for small surface areas of contact, the values are presented in the following Tables 7, 8 and 9 for dry, water-wet and saltwater-wet conditions for touch voltages $U_T = 25$ V to 200 V a.c. 50/60 Hz.

Table 4 – Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in dry conditions at touch voltages $U_T = 25$ V to 200 V a.c. 50/60 Hz (values rounded to 25 Ω)

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	11 125	20 600	38 725
50	7 150	13 000	23 925
75	4 625	8 200	14 750
100	3 000	5 200	9 150
125	2 350	4 000	6 875
150	1 800	3 000	5 050
175	1 550	2 500	4 125
200	1 375	2 200	3 525

Table 5 – Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in water-wet conditions at touch voltages $U_T = 25 \text{ V}$ to $200 \text{ V a.c. 50/60 Hz}$ (values rounded to 25Ω)

Touch voltage V	Values for the total body impedances $Z_T (\Omega)$ that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	5 050	9 350	17 575
50	4 100	7 450	13 700
75	3 400	6 000	10 800
100	2 800	4 850	8 525
125	2 350	4 000	6 875
150	1 800	3 000	5 050
175	1 550	2 500	4 125
200	1 375	2 200	3 525

Table 6 – Total body impedances Z_T for a current path hand to hand for medium surface areas of contact in saltwater-wet conditions at touch voltages $U_T = 25 \text{ V}$ to $200 \text{ V a.c. 50/60 Hz}$ (values rounded to 5Ω)

Touch voltage V	Values for the total body impedances $Z_T (\Omega)$ that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	1 795	2 425	3 275
50	1 765	2 390	3 225
75	1 740	2 350	3 175
100	1 715	2 315	3 125
125	1 685	2 280	3 075
150	1 660	2 245	3 030
175	1 525	2 210	2 985
200	1 350	2 175	2 935

Table 7 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in dry conditions at touch voltages $U_T = 25 \text{ V}$ to $200 \text{ V a.c. 50/60 Hz}$ (values rounded to 25Ω)

Touch voltage V	Values for the total body impedances $Z_T (\Omega)$ that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	91 250	169 000	317 725
50	74 800	136 000	250 250
75	42 550	74 000	133 200
100	23 000	40 000	70 400
125	12 875	22 000	37 850
150	7 200	12 000	20 225
175	4 000	6 500	10 725
200	3 500	5 400	8 650

Table 8 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in water-wet conditions at touch voltages $U_T = 25 \text{ V}$ to 200 V a.c. 50/60 Hz (values rounded to 25Ω)

Touch voltage V	Values for the total body impedances $Z_T (\Omega)$ that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	39 700	73 500	138 175
50	29 800	54 200	99 725
75	22 600	40 000	72 000
100	17 250	30 000	52 800
125	12 875	22 000	37 850
150	7 200	12 000	20 225
175	4 000	6 500	10 725
200	3 500	5 400	8 650

Table 9 – Total body impedances Z_T for a current path hand to hand for small surface areas of contact in saltwater-wet conditions at touch voltages $U_T = 25 \text{ V}$ to 200 V a.c. 50/60 Hz (values rounded to 5Ω)

Touch voltage V	Values for the total body impedances $Z_T (\Omega)$ that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	5 400	7 300	9 855
50	5 105	6 900	9 315
75	4 845	6 550	8 840
100	4 590	6 200	8 370
125	4 330	5 850	7 900
150	4 000	5 550	7 490
175	3 700	5 250	7 085
200	3 400	5 000	6 750

4.5.3 Sinusoidal alternating current with frequencies up to 20 kHz

The values of the total body impedance for 50/60 Hz decrease at higher frequencies due to the influence of the capacitances of the skin and approach, for frequencies above 5 kHz, the internal body impedance Z_i .

The measurements of the total body impedance with frequencies up to 20 kHz at touch voltages of 10 V and 25 V are described in Annex B.

Figure 10 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large surface areas of contact for a touch voltage of 10 V and frequencies from 25 Hz to 20 kHz.

Figure 11 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large surface areas of contact for a touch voltage of 25 V and frequencies from 25 Hz to 2 kHz. From the results, curves have been derived giving the dependence of the total body impedance Z_T of a population for the 50th percentile rank for touch voltages from 10 V to 1 000 V and a frequency range from 50 Hz to 2 kHz for a current path hand to hand or hand to foot for large surface areas of contact in dry condition. The curves are shown in Figure 12.

NOTE No measurements have been carried out in water-wet and saltwater-wet conditions.

4.5.4 Direct current

The total body resistance R_T for direct current is higher than the total body impedance Z_T for alternating current for touch voltages up to approximately 200 V due to the blocking effect of the capacitances of the human skin.

The measurements of the total body impedance which have been carried out with direct current for large surface areas of contact in dry condition are described in Annex C.

NOTE No measurements have been carried out in water-wet and saltwater-wet conditions.

The values for the total body resistance R_T for direct current determined in the way described in Annex C are presented in Table 10 (see Figure 13, continuous lines).

For large surface areas of contact in water-wet and saltwater-wet conditions the total body resistance R_T may be determined with sufficient accuracy from Tables 2 and 3, while neglecting small differences of Z_T between a.c. and d.c. which may exist in the voltage range below 100 V. For all other cases, the tables for a.c. can be used for a conservative estimate.

Table 10 – Total body resistances R_T for a current path hand to hand, d.c., for large surface areas of contact in dry conditions

Touch voltage V	Values for the total body resistance R_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	2 100	3 875	7 275
50	1 600	2 900	5 325
75	1 275	2 275	4 100
100	1 100	1 900	3 350
125	975	1 675	2 875
150	875	1 475	2 475
175	825	1 350	2 225
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value	575	775	1 050

NOTE 1 Some measurements indicate that the total body resistance R_T for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 For living persons, the values of R_T correspond to a duration of current flow of about 0,1 s. For longer durations R_T values may decrease (about 10 % to 20 %) and after complete rupture of the skin R_T approaches the initial body resistance R_0 .

NOTE 3 Values of R_T are rounded to 25 Ω.

4.6 Value of the initial resistance of the human body (R_0)

The value of the initial resistance of the human body R_0 for a current path hand to hand or hand to foot and large surface areas of contact can be taken as equal to 500 Ω for a percentile rank of 5 % for a.c. and for d.c. The values for 50 % and 95 % of the population can be taken as equal to 750 Ω and 1 000 Ω respectively (similar to Table 1). The values depend only little on the surface areas of contact and on conditions of the skin.

NOTE The values for initial resistance R_0 are somewhat lower than the asymptotic values for the total body impedance Z_T for a.c. 50/60 Hz and the total body resistance R_T for d.c., because when contact is made the capacitances of the skin and the internal capacitance of the body are uncharged.

5 Effects of sinusoidal alternating current in the range of 15 Hz to 100 Hz

This clause describes the effects of sinusoidal alternating current passing through the human body within the frequency range 15 Hz to 100 Hz.

NOTE Unless otherwise specified, the current values defined hereinafter are r.m.s. values.

Examples of touch currents and their effects are shown in Figure 20.

5.1 Threshold of perception

The threshold depends on several parameters, such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature), and also on the physiological characteristics of the individual.

5.2 Threshold of reaction

The threshold depends on several parameters, such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature), and also on the physiological characteristics of the individual.

A value of 0,5 mA independent of time, is assumed in this technical specification for the threshold of reaction when touching a conductive surface.

5.3 Immobilization

Immobilisation in this document means the effect of electric current such that the body of the influenced human being (or part of the body) cannot move voluntarily.

The effect on muscles may result from current flowing through the affected muscles or through associated nerves or the associated part of the brain.

The values of current which cause immobilisation depend on the volume of the muscles affected, the type of nerve and the parts of the brain affected by the current.

5.4 Threshold of let-go

The threshold of let-go depends on several parameters, such as the contact area, the shape and size of the electrodes and also on the physiological characteristics of the individual.

A value of about 10 mA is assumed for adult males in this technical specification.

In this document a value of about 5 mA covers the entire population (for additional information, see Figure 23).

5.5 Threshold of ventricular fibrillation

The threshold of ventricular fibrillation depends on physiological parameters (anatomy of the body, state of cardiac function, etc.) as well as on electrical parameters (duration and pathway of current flow, current characteristic, etc.). A description of heart activity is given in Figures 17 and 18.

With sinusoidal a.c. (50 Hz or 60 Hz), there is a considerable decrease in the threshold of fibrillation if the current flow is prolonged beyond one cardiac cycle. This effect results from the increase in inhomogeneity of the excitatory state of the heart due to the current induced extra-systoles.

For shock durations below 0,1 s, fibrillation may occur for current magnitudes above 500 mA, and is likely to occur for current magnitudes in the order of several amperes, only if the shock falls within the vulnerable period. For shocks of such intensities and durations longer than one cardiac cycle reversible cardiac arrest may be caused.

For duration of current flow longer than one heart period Figure 19 shows a comparison between the thresholds of ventricular fibrillation from animal experiments and for human beings calculated from statistics of electrical accidents.

In adapting the results from animal experiments to human beings, an empirical curve c_1 (see Figure 20) was conventionally established for a current path left hand to both feet, below which fibrillation is unlikely to occur. The high level for short durations of exposure between 10 ms and 100 ms was chosen as a descending line from 500 mA to 400 mA. On the basis of information on electrical accidents, the lower level for durations longer than 1 s was chosen as a descending line from 50 mA at 1 s to 40 mA for durations longer than 3 s. Both levels were connected by smooth curves.

By statistical evaluation of animal experiments, curve c_2 and curve c_3 (see Figure 20) have been established defining a probability of fibrillation of about 5 % and 50 % respectively. Curves c_1 , c_2 and c_3 apply for current path left hand to both feet.

5.6 Other effects related to electric shocks

Other electrical effects such as muscular contractions, rise in blood pressure, disturbances of formation and conduction of cardiac impulses (including atrial fibrillation and transient rhythm disturbances) may occur. Such effects are not generally lethal.

With currents of several amperes lasting more than seconds, deep-seated burns, and other internal injuries, may occur. Surface burns may also be seen.

High voltage accidents may not result in ventricular fibrillation, instead giving other forms of cardiac arrest. This is shown in accident statistics and confirmed by animal experiments. However there is at present insufficient data to differentiate the likelihood of these conditions.

Ventricular fibrillation is fatal because it denies blood flow which transports required oxygen. Electrical accidents that do not involve ventricular fibrillation can also be fatal. Other effects may affect respiration and might prevent the person from shouting for help. These related mechanisms include functional disturbance of respiratory control, paralysis of respiratory muscles, damage to the neural activation pathways for these muscles, and damage to the respiratory control mechanism within the brainstem. These effects, if permanent, lead inevitably to death. If a person is to recover from a reversible respiratory effect, prompt artificial respiration is mandatory. Nonetheless, the person may still die. If current flows through critical parts such as the spinal cord or the respiratory control centre, death can occur. These effects are under consideration and thresholds are not yet defined.

High transmembrane electric fields can damage cells, especially long slender cells, such as skeletal muscle cells. This is not a thermal effect. This has been observed for example with high-magnitude, short-duration body currents (such as from momentary contact with high-voltage power distribution lines). A high electric field across cell membranes can induce the formation of pores in the membranes. The effect is called electroporation. The pores may be stable and ultimately seal over, or may enlarge, become unstable, and subsequently cause rupture of the cell membranes. Tissue then becomes irreversibly damaged. Necrosis of the tissue can occur, often requiring amputation of injured limbs. Electroporation is not limited to any particular current magnitude or to any particular current pathway or duration of flow.

Related non-electrical injuries, such as traumatic injury, should be considered.

5.7 Effects of current on the skin

Figure 14 shows the dependence of changes of the human skin on current density, i_T (mA/mm²) and duration of current flow.

As a guideline the following values can be given:

- below 10 mA/mm², in general no changes to the skin are observed. For longer durations of current flow (several seconds) the skin below the electrode may be of greyish-white colour with a coarse surface (zone 0);
- between 10 mA/mm² and 20 mA/mm², a reddening of the skin occurs with a wave like swelling of whitish colour along the edges of the electrode (zone 1);
- between 20 mA/mm² and 50 mA/mm², a brownish colour develops below the electrode extending into the skin. For longer durations of current flow (several tens of seconds) full current marks (blisters) are to be observed around the electrode (zone 2);
- above 50 mA/mm², carbonization of the skin can occur (zone 3);
- with large contact areas current densities may be low enough not to cause any alterations of the skin in spite of fatal current magnitudes.

5.8 Description of time/current zones (see Figure 20)

Table 11 – Time/current zones for a.c. 15 Hz to 100 Hz for hand to feet pathway – Summary of zones of Figure 20

Zones	Boundaries	Physiological effects
AC-1	Up to 0,5 mA curve a	Perception possible but usually no 'startled' reaction
AC-2	0,5 mA up to curve b	Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects
AC-3	Curve b and above	Strong involuntary muscular contractions. Difficulty in breathing. Reversible disturbances of heart function. Immobilization may occur. Effects increasing with current magnitude. Usually no organic damage to be expected
AC-4 ¹⁾	Above curve c_1	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time
	c_1 - c_2	AC-4.1 Probability of ventricular fibrillation increasing up to about 5 %
	c_2 - c_3	AC-4.2 Probability of ventricular fibrillation up to about 50 %
	Beyond curve c_3	AC-4.3 Probability of ventricular fibrillation above 50 %
¹⁾ For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.		

5.9 Application of heart-current factor (F)

The heart-current factor permits the calculation of currents I_h through paths other than left hand to feet which represent the same danger of ventricular fibrillation as that corresponding to I_{ref} left hand to feet shown in Figure 20:

$$I_h = \frac{I_{ref}}{F}$$

where

I_{ref} is the body current for the path left hand to feet given in Figure 20;

I_h is the body current for paths given in Table 12;

F is the heart-current factor given in Table 12.

NOTE The heart-current factor is to be considered as only a rough estimation of the relative danger of the various current paths with regard to ventricular fibrillation.

For different current paths, the following heart-current factors are given in Table 12.

Table 12 – Heart-current factor F for different current paths

Current path	Heart-current factor F
Left hand to left foot, right foot or both feet	1,0
Both hands to both feet	1,0
Left hand to right hand	0,4
Right hand to left foot, right foot or to both feet	0,8
Back to right hand	0,3
Back to left hand	0,7
Chest to right hand	1,3
Chest to left hand	1,5
Seat to left hand, right hand or to both hands	0,7
Left foot to right foot	0,04

EXAMPLE A current of 225 mA hand to hand has the same likelihood of producing ventricular fibrillation as a current of 90 mA left hand to both feet.

6 Effects of direct current

This clause describes the effects of direct current passing through the human body.

NOTE 1 The term "direct current" means ripple-free direct current. However, as regards fibrillation effects, the data given in this clause are considered to be conservative for direct currents having a sinusoidal ripple content of not more than 10 % r.m.s.

NOTE 2 The influence of ripple is dealt with in chapter 5 of IEC 60479-2.

NOTE 3 For durations of current flow below 10 ms see chapter 6 of IEC 60479-2.

An example of a touch current and its effects are shown in Figure 21.

6.1 Threshold of perception and threshold of reaction

These thresholds depend on several parameters, such as the contact area, the conditions of contact (dryness, wetness, pressure, temperature), the duration of current flow and on the physiological characteristics of the individual. Unlike a.c., only making and breaking of current is felt and no other sensation is noticed during the current flow at the level of the threshold of perception. Under conditions comparable to those applied in studies with a.c., the threshold of reaction was found to be about 2 mA.

6.2 Threshold of immobilization and threshold of let-go

Unlike a.c. there is no definable threshold of immobilization or let-go for d.c. Only making and breaking of current lead to painful and cramp-like contractions of the muscles.

6.3 Threshold of ventricular fibrillation

As described for a.c. (see 5.5), the threshold of ventricular fibrillation induced by d.c. depends on physiological as well as on electrical parameters.

Information derived from electrical accidents seems to indicate that the danger of ventricular fibrillation generally exists for longitudinal currents. For transverse currents, experiments on animals have, however, shown that at higher current intensities ventricular fibrillation may also occur.

Experiments on animals as well as information derived from electrical accidents show that the threshold of fibrillation for a downward current is about twice as high as for an upward current.

For shock durations longer than the cardiac cycle, the threshold of fibrillation for d.c. is several times higher than for a.c. For shock durations shorter than 200 ms, the threshold of fibrillation is approximately the same as for a.c. measured in r.m.s. values.

Curves derived from animal experiments have been constructed that apply to longitudinal, upward (feet positive) current. Curves c_2 and c_3 in Figure 22 show the calculated combinations of current magnitude and duration at which the probabilities of ventricular fibrillation of the animals are about 5 % and 50 % respectively when the current path is longitudinal through the body (i.e. left foreleg to both hind legs). Curve c_1 shows current and duration combinations below which the likelihood of ventricular fibrillation is estimated to be very low for the same longitudinal pathway of current through the body based on the animal studies. Later studies show that the ventricular fibrillation threshold for humans is higher than the current magnitude as compared to the animals for each duration. For example, the left hand to feet threshold current for a healthy human might be in the order of 200 mA for long durations of current. However, not all human hearts are healthy, and some maladies can affect the ventricular fibrillation threshold. Some people with unhealthy heart conditions have ventricular fibrillation thresholds below normal, but the amount of the reduction is not precisely known. Therefore, it is recommended that the c_1 line shown in the figure that is based on animal studies, be used to describe the ventricular fibrillation threshold for humans as a conservative estimate. There are no known electrical accidents that show an electrocution below the c_1 curve. This indicates that the c_1 curve is probably conservative for all humans. For longitudinal downward current (feet negative), the curves have to be shifted to a higher current magnitude by a factor of approximately 2.

6.4 Other effects of current

Above approximately 100 mA, a sensation of warmth may be felt in the extremities during current-flow. Within the contact area, painful sensations are felt.

Transverse currents up to 300 mA flowing through the human body for several minutes might, increasing with time and current, cause reversible cardiac dysrhythmias, current marks, burns, dizziness and sometimes unconsciousness. Above 300 mA, unconsciousness frequently occurs.

With currents of several amperes lasting longer than seconds, deep-seated burns or other injuries, and even death, are likely to occur.

Effects such as electroporation (see 5.6) can result from contact with d.c. circuits as well as a.c. circuits.

Related non-electrical injuries, such as traumatic injury, should be considered.

6.5 Description of time/current zones (see Figure 22)

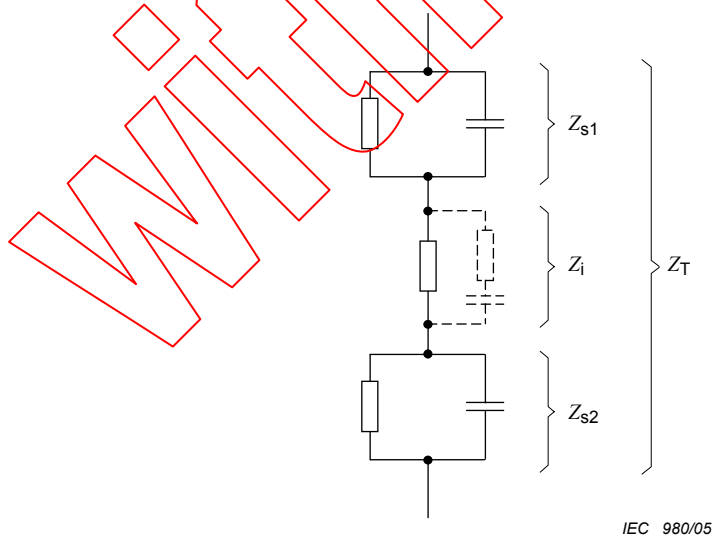
**Table 13 – Time/current zones for d.c. for hand to feet pathway –
Summary of zones of Figure 22**

Zones	Boundaries	Physiological effects
DC-1	Up to 2 mA curve a	Slight pricking sensation possible when making, breaking or rapidly altering current flow
DC-2	2 mA up to curve b	Involuntary muscular contractions likely especially when making, breaking or rapidly altering current flow but usually no harmful electrical physiological effects
DC-3	Curve b and above	Strong involuntary muscular reactions and reversible disturbances of formation and conduction of impulses in the heart may occur, increasing with current magnitude and time. Usually no organic damage to be expected
DC-4 ¹⁾	Above curve c_1 c_1 - c_2 c_2 - c_3 Beyond curve c_3	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time DC-4.1 Probability of ventricular fibrillation increasing up to about 5 % DC-4.2 Probability of ventricular fibrillation up to about 50 % DC-4.3 Probability of ventricular fibrillation above 50 %

¹⁾ For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation this figure relates to the effects of current which flows in the path left hand to feet and for upward current. For other current paths the heart current factor has to be considered.

6.6 Heart factor

The heart factor F applies to d.c. the same as for a.c. (see 5.8).



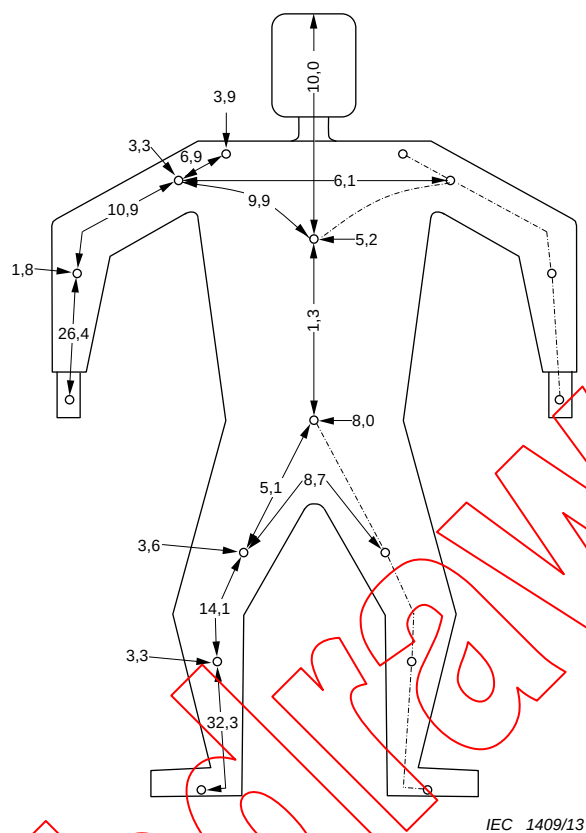
Key

Z_i internal impedance

Z_{s1} , Z_{s2} impedance of the skin

Z_T total impedance

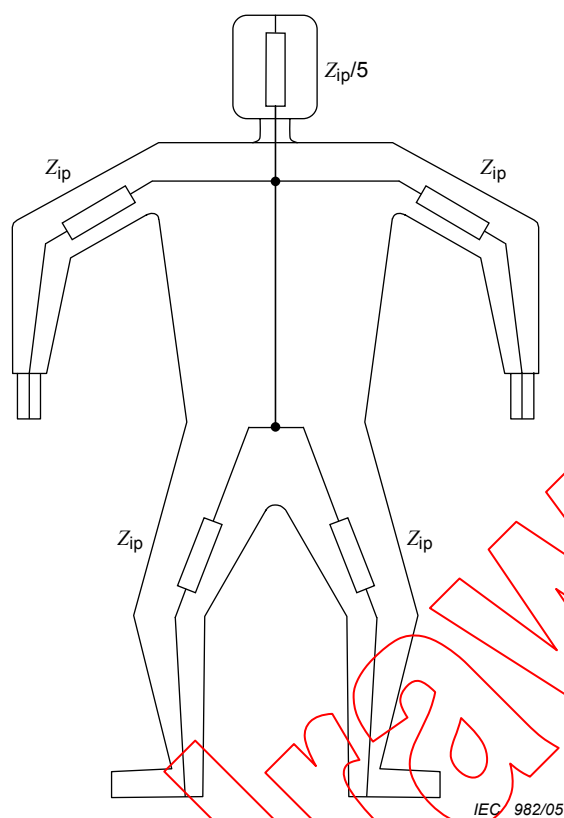
Figure 1 – Impedances of the human body



The numbers indicate the percentage of the internal impedance of the human body for the part of the body concerned, in relation to the path hand to foot.

NOTE In order to calculate the total body impedance Z_T for a given current path, the internal partial impedances Z_{ip} for all parts of the body of the current path have to be added as well as the impedances of the skin of the surface areas of contact. The numbers outside the body show internal portions of the impedance to be added to the total, when the current enters at that point.

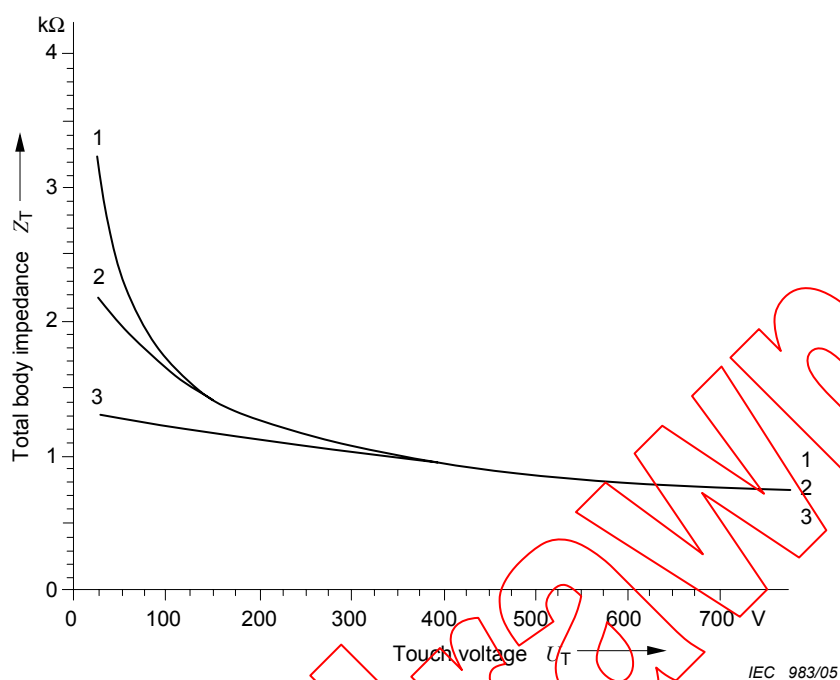
Figure 2 – Internal partial impedances Z_{ip} of the human body

**Key**

Z_{ip} internal partial impedance of one extremity (arm or leg)

NOTE The internal impedance from one hand to both feet is approximately 75 %, the impedance from both hands to both feet 50 % and the impedance from both hands to the trunk of the body 25 % of the impedance hand to hand or hand to foot.

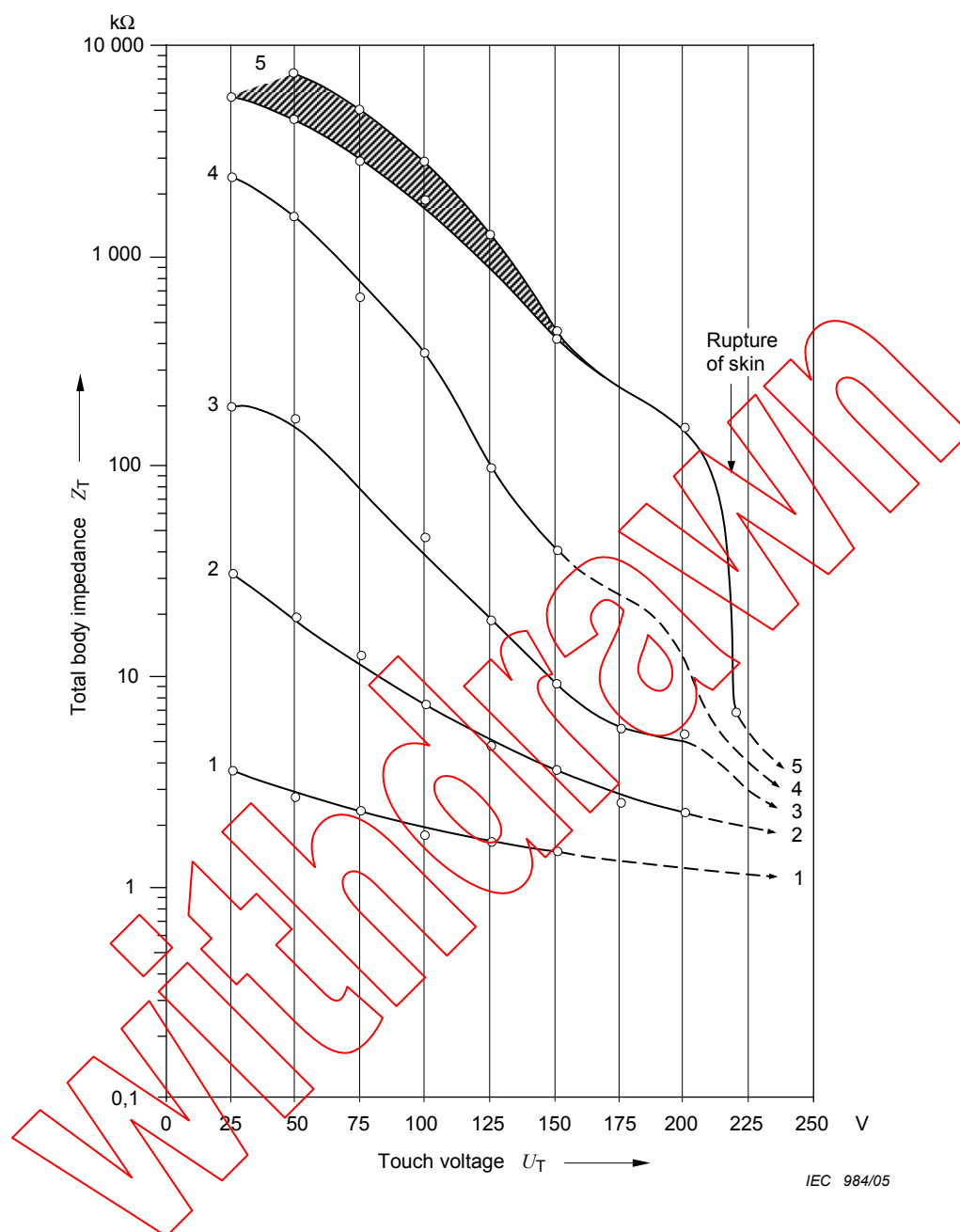
Figure 3 – Simplified schematic diagram for the internal impedances of the human body



Key

- 1 dry conditions (Table 1)
- 2 water-wet conditions (Table 2)
- 3 saltwater-wet conditions (Table 3)

Figure 4 – Total body impedances Z_T (50 %) for a current path hand to hand, for large surface areas of contact in dry, water-wet and saltwater-wet conditions for a percentile rank of 50 % of the population for touch voltages $U_T = 25$ V to 700 V, a.c. 50/60 Hz



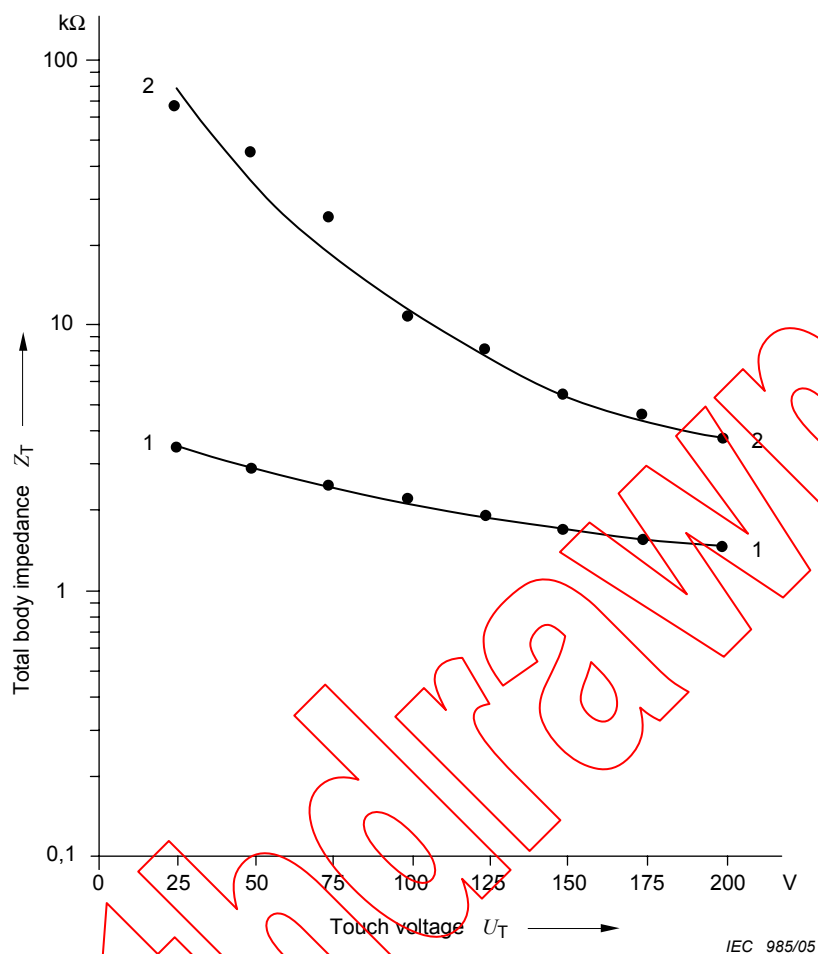
Key

(For further details, see Annex D)

- | | | |
|---|-------------------------|----------------------|
| 1 | Surface area of contact | 8200 mm ² |
| 2 | Surface area of contact | 1250 mm ² |
| 3 | Surface area of contact | 100 mm ² |
| 4 | Surface area of contact | 10 mm ² |
| 5 | Surface area of contact | 1 mm ² |

(Breakdown of the skin at 220 V)

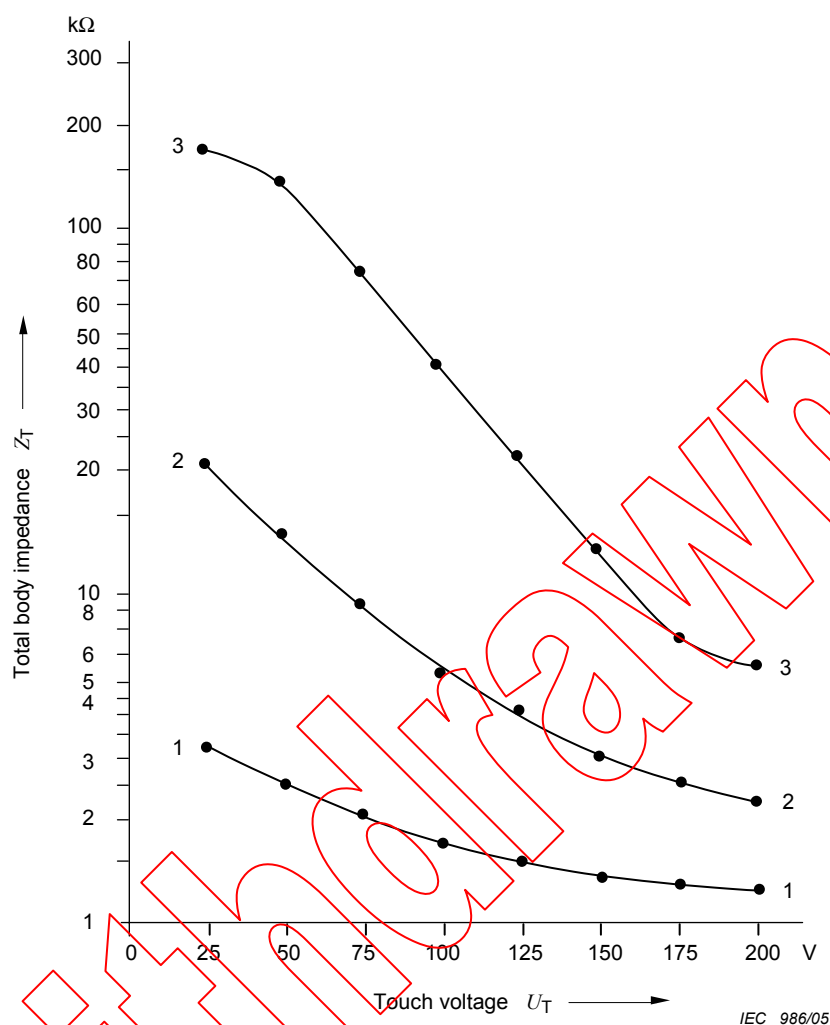
Figure 5 – Dependence of the total impedance Z_T of one living person on the surface area of contact in dry condition and at touch voltage (50 Hz)



Key

- 1 large surface areas of contact (approximately 8 000 mm²), current path hand to hand
- 2 surface areas of fingertips (approx. 250 mm²), current path from the tips of the right to left forefinger

Figure 6 – Dependence of the total body impedance Z_T on the touch voltage U_T for a current path from the tips of the right to the left forefinger compared with large surface areas of contact from the right to the left hand in dry conditions measured on one living person, touch voltage range $U_T = 25$ V to 200 V, a.c. 50 Hz, duration of current flow max. 25 ms



Key

- 1 large surface areas of contact, electrodes type A (order of magnitude 10 000 mm²), according to Table 1
- 2 middle sized surface areas of contact, electrodes type B (order of magnitude 1000 mm²), according to Table 5
- 3 small surface areas of contact, electrodes type C (order of magnitude 100 mm²), according to Table 8

Figure 7 – Dependence of the total body impedance Z_T for the 50th percentile rank of a population of living human beings for large, medium and small surface areas of contact (order of magnitude 10 000 mm², 1 000 mm² and 100 mm² respectively) in dry conditions at touch voltages U_T = 25 V to 200 V a.c. 50/60 Hz