is high enough to energize a relay directly. However, the USA has recently [1] adopted a maximum ground-fault current of 5 mA. This places strict performance requirements on the core material for the differential transformer.

THE HUMAN ELECTRICAL CIRCUIT

Just how much electrical energy a person can safely tolerate has been the subject of intensive investigation by many authors [2–5]. It is generally agreed that strength of current and length of exposure times are of significant influence. For a review, the reader is referred to the publications listed in the references.

The equivalent electrical circuits of the human body can be considered as consisting of several series and parallel resistances, varying greatly among individuals and test conditions. Osypka [2] measured the "wet body" resistances, which are the lowest and, therefore, allow the greatest current to flow. Wet body resistances at 50 Hz were found to be 1,300 ohms for the hand-body-hand current path, 975 ohms for one hand-body-feet, and 650 ohms for hands-body-feet. At 110 volts, this would result in currents of 85, 113, and 170 mA, respectively.

How the human body reacts to current flowing through it for various exposure times can be described by Fig. 2. Region I identifies exposures causing no permanently damaging effects; region II exposures can cause light burns with muscle and heart damage; while exposures in region III will cause heart fibrillations resulting in death, and in the case of high voltage, severe burning.

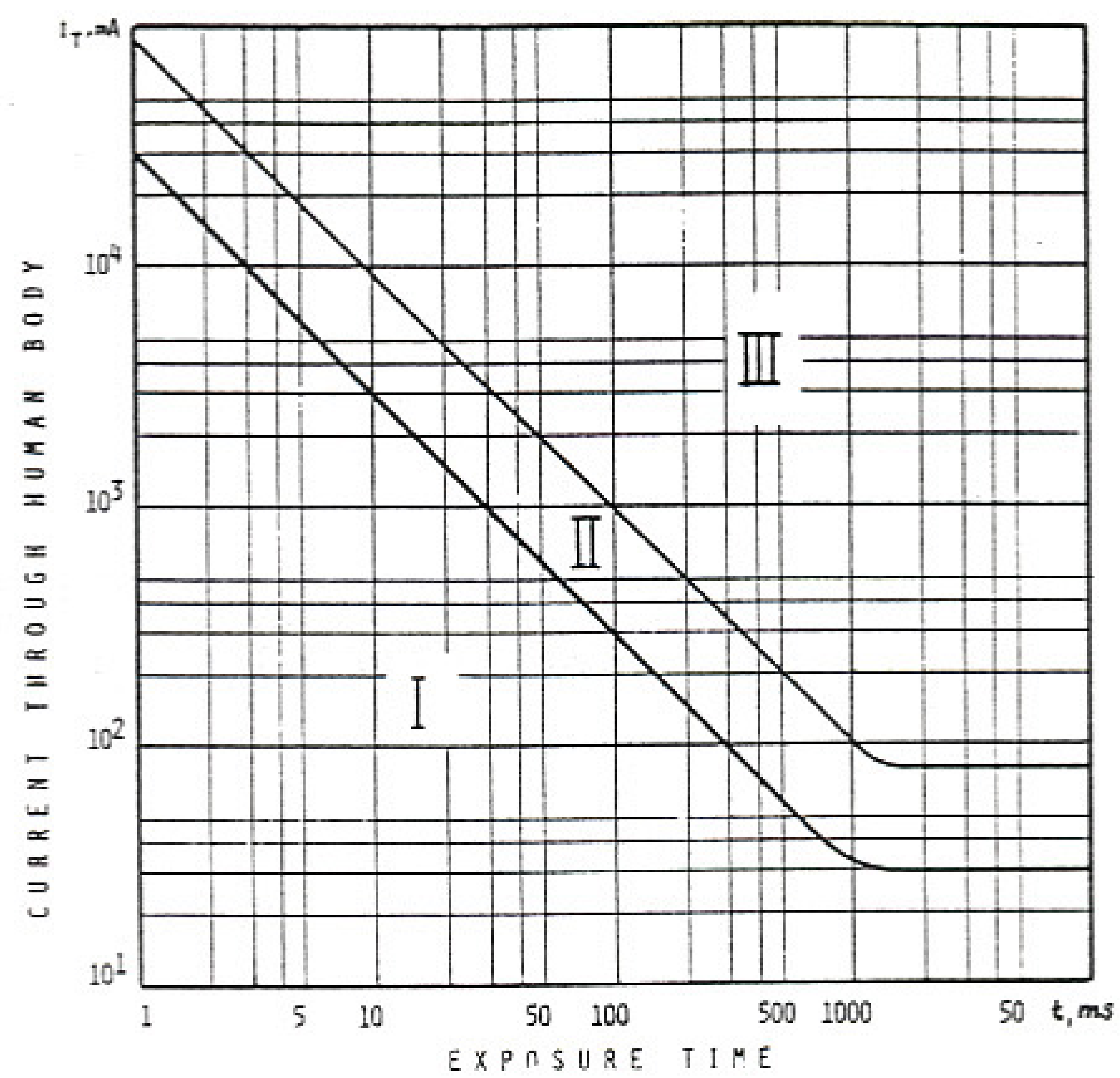

Fig. 2. Hazard current I_T versus exposure time (after Osypka), I. no damage to human organs, II. damage to human organs, III. heart fibrillations, death, burns.

THE SAFE TRIP CURRENT

Another danger of small-current exposures lasting several seconds or longer and falling into region I exists. At these exposures the victim may not be able to "let go" of the conductor. This will cause immediate sweat formation decreasing the body resistance and thus increasing the current flow toward the trip current of the GFI. GFI's with 30 mA trip current will, therefore, eventually actuate preventing bodily harm, even though the person may suffer severe discomfort for a short time.

"Let go" current distributions for the three most likely current paths through the body are plotted (after Osypka) in Fig. 3. It is clear from Fig. 3 that the 5 mA trip current adopted in the USA will protect more than 99 percent of the population from this type of electrical shock. The current is low enough to eliminate completely all discomfort associated with electrical contact. Investigations have shown that operation at this small

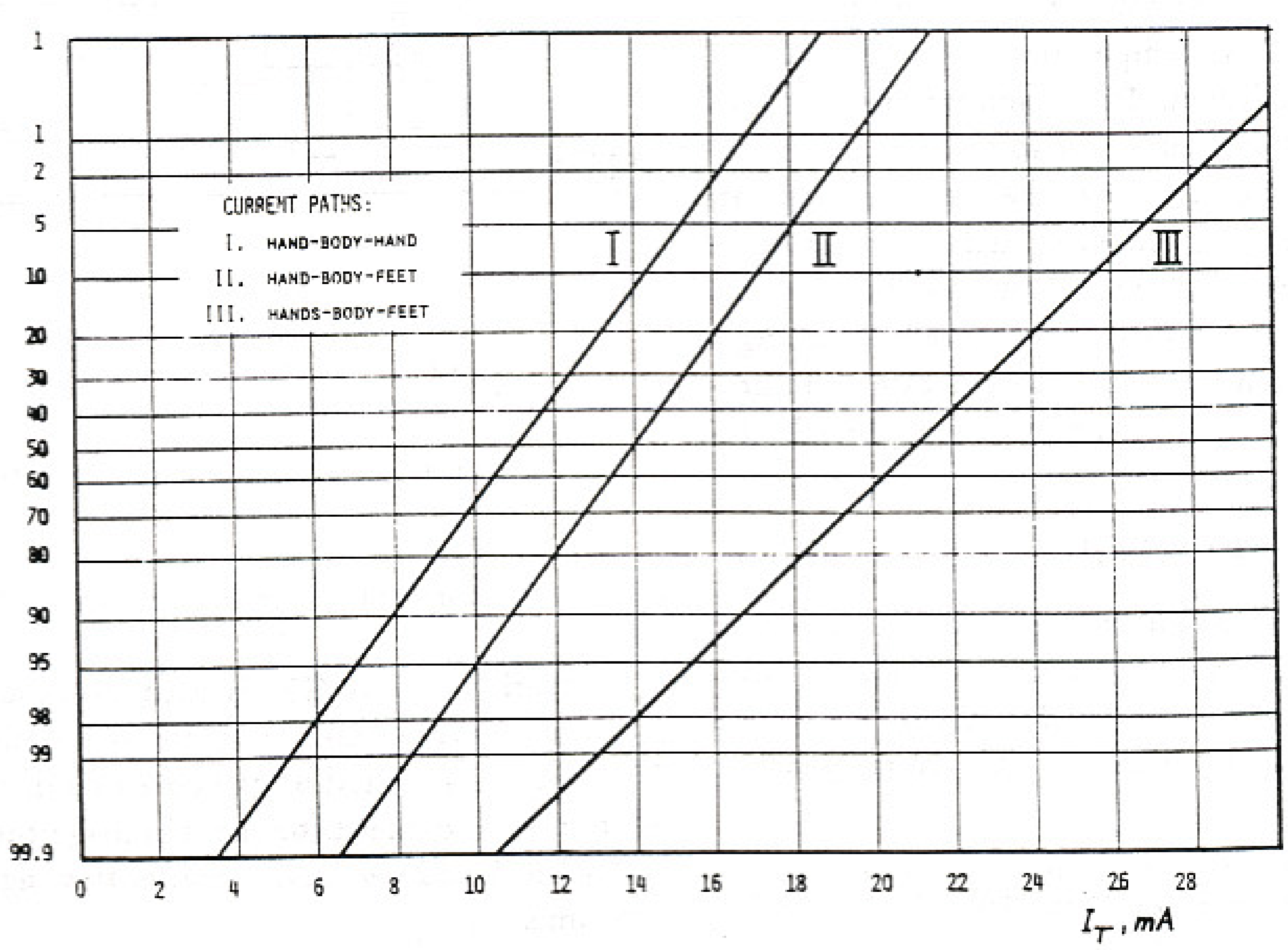

Fig. 3. "Let go" current distribution for humans (after Osypka).