4. Permissible Body Current Limit

The magnitude and duration of the current conducted through a human body at 50 or 60 Hz should be less than those that cause ventricular fibrillation.

4.1 Duration Formula. The duration for which a 50-60 Hz current can be tolerated by most people is related to its magnitude by Eq 3. Based on the results of Dalziel's studies, it is assumed that 99.5% of all persons can safely withstand, without ventricular fibrillation, the passage of a current in magnitude and duration determined by the following formula:

$$I_B = k/\sqrt{t_s} \qquad \text{(Eq4)}$$

where, in addition to the terms previously defined, for Eq 3,

$$k = \sqrt{S_B}$$

Dalziel found that the shock energy that can be survived by 99.5% of persons weighing approximately 50 kg (110 lbs) results in a value of S_B of 0.0135. Thus, $k_{50} = 0.116$ and the formula for the allowable body current becomes

$$I_B = 0.116/\sqrt{t_s} \text{ for 50 kg body weight} \qquad \text{(Eq 5)}$$

Note that the above equation results in values of 116 mA for 1 s and 367 mA for 0.1 s.

Since Eq 4 is based on tests limited to a 0.03-3.0 s range, it obviously is not valid for very short or long times, and some values of current can be tolerated indefinitely [B20], [B24].

In a perspective of the past 40 years of researching I_B, in 1936 Ferris *et al.* [B49] suggested 100 mA as the fibrillation threshold if shock durations are not specified. The value 100 mA was derived from extensive experience at Columbia University, on animals having body and heart weights comparable to man, for a maximum shock duration of 3 s. Some of the more recent experiments suggest the existence of two distinct thresholds: one where the exposure time is shorter than one heartbeat period and another one for the current exposure longer than one heartbeat. For a 50 kg (110 lbs) adult, Biegelmeier proposes the threshold values at 500 and 50 mA, respectively [B6], [B7]. Other recent works on this subject are by Lee and Kouwenhoven [B27], [B65], [B68].

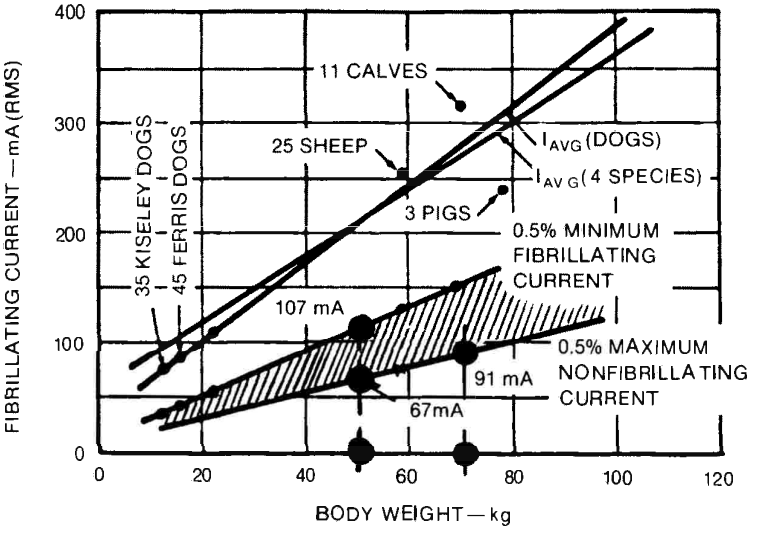
4.2 Alternative Assumptions. Fibrillation current is actually a function of individual body weight, as illustrated in Fig 4. This shows the relationship between the critical current and body weight for several species of animals (calves, dogs, sheep, pigs), and a 0.5% common threshold region for mammals.

In the 1961 edition of this guide, constants S_B and k in Eqs 3 and 4, given as 0.0272 and 0.165, respectively, had been assumed valid for 99.5% of all men weighing approximately 70.3 kg (155 lbs). Dalziel's more recent studies (in 1968), on which Eq 4 is based, lead to the alternate value of $k = 0.157$ and $S_B = 0.0246$ as being applicable to persons weighing 70 kg (155 lbs) [B22], [B24]. Thus,

$$I_B = 0.157/\sqrt{t_s} \quad \text{for 70 kg body weight} \qquad \text{(Eq 6)}$$

The maximum 3 s nonfibrillating current of 91 mA at the 70 kg base is still below the threshold of fibrillation of 107 mA at 50 kg (110 lbs), as shown in Fig 4.

Fig 4
Fibrillating Current Versus Body Weight for Various Animals Based on a Three-Second Shock



VALUE OF CONSTANT k FOR EFFECTIVE RMS VALUES OF I_B ($k = I_B \sqrt{t_s}$):

$k_{70} = 0.091 \sqrt{3} = 0.157$
$k_{50} = 0.067 \sqrt{3} = 0.116$
$k_{50} = 0.107 \sqrt{3} = 0.185$
FIBRILLATION

Users of this guide may select $k = 0.157$ provided that the average population weight can be expected to be at least 70 kg.[10]

Equation 4 indicates that much higher currents can be allowed where fast operating protective devices can be relied upon to limit fault duration. A judgment decision is needed as to whether to use the clearing time of regular high-speed relays, or that of the back-up protection, as the basis for calculation.

4.3 Note on Reclosing. Reclosure after a ground fault is common in modern operating practice. In such circumstances, a person might be subjected to the first shock, which would not permanently injure him, but would upset and disturb him temporarily. Next, a single fast automatic reclosure could result in a second shock, initiated within less than 0.5 s from the start of the first. It is this second shock, occurring after a relatively short interval of time before the person has recovered, that might cause a serious accident. With manual reclosure, the possibility of exposure to a second shock is reduced since the reclosing time interval may be substantially greater.

The cumulative effect of two or more closely spaced shocks has not been thoroughly evaluated, but a reasonable allowance can be made by using the sum of individual shock durations as the time of a single exposure. This is discussed in more detail in 13.4.

[10] Typically, these conditions can be met in places that are not accessible to the public, such as in switchyards protected by fences or walls, etc. Depending on specific circumstances, an assessment should be made if a 50 kg criterion (Eq 5) ought to be used for areas outside the fence.