$$E[N(t)] = N_0 p(t) \tag{10.13}$$

while the variance about this number is

$$V[N(t)] = N_0 p(t)[1 - p(t)] \tag{10.14}$$

The specific death rate, k_d, is

$$k_d = \frac{1}{-E[N(t)]} \cdot \frac{d}{dt} E[N(t)] \tag{10.15a}$$

and if $p(t)$ is not a function of $N(t)$, then

$$k_d = -\frac{d}{dt} \ln p(t) \tag{10.15b}$$

The functional form for $p(t)$ depends on the organism and environment. The simplest form is to assume a first-order death model in which k_d is a constant and has units of reciprocal time:

$$p(t) = e^{-k_d t} \tag{10.16}$$

In the microbiological literature, the term *decimal reduction time* (D) is often used. It is the time for the number of viable cells to decrease tenfold. For example, with k_d as a constant, D is

$$E[N(t)] = N_0 e^{-k_d t} \tag{10.17a}$$

$$0.1 = e^{-k_d D} \tag{10.17b}$$

$$D = \frac{2.303}{k_d} \tag{10.17c}$$

A plot of ln $N(t)/N_0$ versus time is called a *survival curve* (see Fig. 10.12). Such a curve is implicitly deterministic; the deterministic and probabilistic approaches give essentially the same result as long as $N(t)$ is >> 1 (about 10 to 100). Extrapolation of a survival curve to one organism or less is not proper.

Most real populations are not homogeneous. Often a subgroup is more resistant to the sterilization agent. Also, organisms growing in clumps tend to be more resistant to death. These factors are important in processing (see Fig. 10.13 for the effects on survival curves). For example, consider a tragic error in the early development of a polio vaccine. The virus is inactivated ("killed"). The required processing time was estimated from linear extrapolation (on a semilog plot) of a survival curve. The original data for the plot did not extend to sufficiently low numbers to detect the presence of a resistant subpopulation. Consequently, some patients were inoculated with live rather than killed virus.

10.4.2 Sterilization of Liquids

The kinetics of death apply to the sterilization of liquids. Values for k_d can be determined for inactivation by chemical, thermal, or radioactive agents. Thermal inactivation is very