Transient equilibrium

In nuclear physics, **transient equilibrium** is a situation in which equilibrium is reached by a parent-daughter radioactive isotope pair where the half-life of the daughter is shorter than the half-life of the parent. Contrary to secular equilibrium, the half-life of the daughter is not negligible compared to parent's half-life. An example of this is a molybdenum-99 generator producing technetium-99 for nuclear medicine diagnostic procedures. Such a generator is sometimes called a *cow* because the daughter product, in this case technetium-99, is milked at regular intervals.\(^1\) Transient equilibrium occurs after four half-lives, on average.

**Activity in transient equilibrium**

The activity of the daughter is given by the Bateman equation:

\[
A_d = ([A_P(0) \frac{\lambda_d}{\lambda_d - \lambda_P} \times (e^{-\lambda_P t} - e^{-\lambda_d t})] \times BR) + A_d(0)e^{-\lambda_d t},
\]

where \(A_P\) and \(A_d\) are the activity of the parent and daughter, respectively. \(T_P\) and \(T_d\) are the half-lives of the parent and daughter, respectively, and BR is the branching ratio.

In transient equilibrium, the Bateman equation cannot be simplified by assuming the daughter's half-life is negligible compared to the parent's half-life. The ratio of daughter-to-parent activity is given by:

\[
\frac{A_d}{A_P} = \frac{T_P}{T_P - T_d} \times BR.
\]

**Time of maximum daughter activity**

In transient equilibrium, the daughter activity increases and eventually reaches a maximum value that can exceed the parent activity. The time of maximum activity is given by:

\[
t_{max} = \frac{1.44 \times T_P T_d}{T_P - T_d} \times ln(T_P/T_d).
\]

where \(T_P\) and \(T_d\) are the half-lives of the parent and daughter, respectively. In the case of \(^{99m}\text{Tc}\) - \(^{99}\text{Mo}\) generator, the time of maximum activity (\(t_{max}\)) is approximately 24 hours which makes it convenient for medical use.

**References**

\(^1\) [transient equilibrium](http://web.ead.anl.gov/marssim/acrogloss/dsp_wordpopup.cfm?word_id=504)
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