

Rethinking Annual Dose Limits: A Biologically Based Critique of Radiation Protection Standards

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Abstract

Annual dose limits provide a practical basis for radiation protection, but a calendar year is not necessarily a biologically meaningful interval. Cellular repair, adaptive responses, and dose-rate effects may alter outcomes when the same total dose is delivered in different patterns. Conversely, rapid repair of measurable damage does not establish the absence of delayed effects or justify higher permissible doses. We propose research into temporally resolved exposure metrics that could complement cumulative dose accounting. Any regulatory change would require evidence linking exposure patterns to relevant health outcomes.

Keywords

Adaptive response, ALARA principle, Annual dose limits, Dose rate, Linear no-threshold model, Radiation protection

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Commentary

The linear no-threshold (LNT) model remains a central assumption in radiation protection, although extrapolating risk at low doses involves uncertainty.¹⁻³ Observations from high-background areas such as Ramsar and experiments in deep underground laboratories have prompted debate about adaptive responses and biological effects of background radiation.⁴⁻⁹ These findings do not, by themselves, establish a safe exposure threshold or quantify occupational cancer risk. A more focused question concerns the time interval over which exposure is assessed.

Annual effective-dose limits facilitate monitoring, compliance, and long-term record-keeping. Yet two workers with identical annual doses could receive them through substantially different exposure patterns. Radiation quality, dose to individual organs, dose rate, and spacing of exposures can affect biological responses. Cells repair many DNA lesions over

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hours or days, although repair may be incomplete or erroneous, and some outcomes can emerge much later. Accordingly, short-term recovery of a cellular endpoint cannot be equated with elimination of lifetime stochastic risk.

Annual limits also do not assume that damage remains physically unrepaired for twelve months: cumulative dose is a protection quantity used to manage risk. Dose-rate effects are already considered in radiation protection, and a rolling or annual total still helps constrain exposures accumulated over a working life. Our concern is narrower: an annual total alone may not describe biologically relevant differences between exposure schedules. It should be examined alongside measurements of temporal exposure patterns.

The same distinction applies to optimization. As low as reasonably achievable (ALARA) calls for balancing dose reduction against practical and societal considerations; it does not require reducing every exposure regardless of cost or clinical benefit.^{10,11} Evidence of adaptive responses or cellular changes under unusually low-background laboratory conditions is insufficient to abandon optimization or infer that additional occupational exposure is beneficial.^{8,9}

Future studies could combine time-stamped personal dosimetry with organ-dose estimates, radiation quality, dose-rate profiles, and prespecified biological endpoints. Longitudinal occupational studies would then need to test whether temporal metrics improve prediction of clinically relevant outcomes beyond cumulative dose, while accounting for confounding and measurement uncertainty. Daily or weekly constraints could be evaluated as complementary safeguards, but choosing numerical limits from cellular repair times alone would be premature.

Annual dose accounting remains useful. A biologically informed framework would retain its practical strengths while testing whether exposure timing adds meaningful predictive information. Until such evidence is available, this proposal supports research and refinement of monitoring, not relaxation of existing limits.

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Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Joseph J. Bevelacqua is President of Bevelacqua Resources, a radiation safety consulting firm. The other authors declare no competing interests.

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