M E M O R A N D U M

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SUBJECT: ARITHMETIC VS. GEOMETRIC MEANS FOR EXPOSURE DATA

Presented below is the justification for the recommendation that arithmetic means, rather than geometric means, be used to represent the central tendency of a set of pesticide exposure data, especially when dealing with those collected from the same study. This mean statistic is one of the several that are being considered in the revision of the Branch's guidance document for preparing human pesticide exposure assessment documents.

Strictly speaking, the term *central tendency* is not something that can be found in most standard textbooks in statistics. Neither is there much discussion on geometric mean or lognormal distribution in these textbooks. Insofar as the means of many samples tend to be proportional to the range or to the standard deviation of the respective samples, replacement of each measurement by its logarithm in these samples tends to normalize the distribution. This is because such a transformation usually results in the variances being more nearly equal. It is thus not surprising to see that many environmental data tend to follow a lognormal, rather than a normal, distribution. After all, we rarely are able to collect a large enough sample in which the observations would behave more or less homogeneously in every aspect except the test response, as would in a controlled experiment. Parkhurst (1998) already presented the arguments that *geometric means of environmental concentration data are biased low and that they do not represent components of mass balances properly*. In the justification given below, the focus is on measurements directly or indirectly pertaining to pesticide exposure. For ease of discussion, here the average of a set of measurements is said to be taken *geometrically* if it is the geometric mean; that is, if the average is taken as the antilog of the mean logarithm of the measurements.

When a group of workers are monitored on a given day for dermal or inhalation exposure to a pesticide, there are only a couple of reasons why the exposure measurements should be averaged. One argument for calculating the average of these measurements is that eventually this single value, not the range that encompassing it, should be used to compare to the NOEL (no observed effect level) which is also a single value. In determining a NOEL from an animal study, its average is almost always taken arithmetically. For instance, in dietary feeding studies, the intakes of the test material by the animals, which are typically based on *mean* food consumption and *mean* rate of change in body weight (e.g., Wilson and Hayes, 1994), are averaged arithmetically, not geometrically. Therefore, it would be conceptually unsound or inconsistent to compare the geometric mean of the human exposure measurements to an average animal (though supposedly human-equivalent) NOEL that was taken arithmetically. Otherwise, to do so it would assume that the worker exposure at one level (the level in question) follows a lognormal distribution, but that at another level (at the NOEL) it follows a (different) normal distribution.

Another reason why the exposure measurements should be averaged is that we always advocate the use of their central tendency as an estimate of the fair exposure received by an individual over a season or a lifetime period. Although some assessors do not agree that the exposure of one worker can be equated with that of another worker, there are enough assessors who feel that the exposures received by other workers in the same group on that same day can be used to mirror or to approximate the exposures that a particular worker would experience in other days. Supporting this latter argument is the basic assumption that the exposure variation seen among the workers in the same study group was due primarily to variables extrinsic, rather than intrinsic, to the workers. For example, a few workers received a higher exposure on a given day primarily because they *happened* to use a less effective piece of application equipment, to harvest crops in a section of the field that was sprayed more heavily, or to have just a bad day. If the exposures of the workers in the same study group should be averaged to provide an estimate for the mean exposure of a particular worker, then that central tendency should be represented by the arithmetic mean and not by the geometric mean calculated from the data. The following numerical illustration readily supports this assertion.

Suppose there are these 10 lognormal-like exposures (E) measured (in µg): 2, 3, 4, 5, 5, 6, 6, 7, 8, 80, with a geometric mean of 6.3 and an arithmetic mean of 12.6. We further suppose that the worker would apply the pesticide for only 10 days in a (30-day) season and that his (her) seasonal average daily dose (SADD) is of interest. The argument here is that if the above 10 observations were good enough to be used as surrogate, then we should calculate the SADD under the premise that similar, if not the exact, observations would reoccur on any 10 workdays on which a worker would perform the same task. Therefore, the SADD prior to amortization would be 12.6 µg = $(E_1 + E_2 + \ldots + E_{10})/10 = (2 + 2 + \ldots + 80)/10$, which is simply the *arithmetic* mean of the 10 observations noted earlier. Thus far, there does not seem to be any incidence in which a SADD was based on an average (of the daily exposures) taken geometrically.

Reentry exposures for field workers are sometimes necessarily extrapolated from available dislodgeable foliar residues (DFR). The extrapolation is accomplished by means of a dermal transfer factor. This transfer factor is defined simply as the ratio (or sometimes some other relation, such as linear regression) of *dermal exposure* (µg/hr) to *DFR* (µg/cm^2), both measured more or less at the same time in some previous studies. For reasons as stated above, it is apparent that an arithmetic (rather than a geometric) mean should also be used as the average for a set of dermal transfer factors derived from exposures of workers monitored in the same study.

References

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cc: Chuck Andrews