Battelle
Pacific Northwest Laboratories

Internal Distribution
WL Robison
BW Wachholz

Date July 9, 1979

To North Marshall Islands Advisory Group

409836

From R. O. Gilbert R.O. Gilbert

R

Subject An Approach for Assessing the Validity of the $3\bar{x}$ Rule for Estimating the Maximum Individual Dose. Should the Method be Used for the Enewetak Dose Assessment?

I have been thinking about LLL's proposed procedure of using $3\bar{x}$ as an estimate of the "maximum individual" dose, where $\bar{x}$ is the estimated maximum annual dose as computed using average values for the diet and food concentrations. LLL argues that $3\bar{x}$ may be equal to the 95th percentile or so of the dose distribution over individuals, so that the probability of an individual receiving an annual dose greater than $3\bar{x}$ is very small. The validity of this approach is open to question, of course, since we don't know what the actual distribution of doses will be for any given year following the return of the Enewetak people to the Enewetak Atoll, if that return should take place.

Personally, I would feel more confident about the $3\bar{x}$ approach if LLL could demonstrate via computer simulations that this factor of 3 is reasonable. These simulations could be based on the diet information from Michael Pritchard's recent survey of the Enewetak people, and upon the soil and plant/soil ratio data now available.

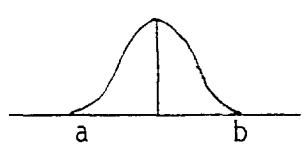
The basic idea would be to generate the projected dose by specifying distributions for each of the input parameters of the model, e.g., Bennett's model for Sr-90 in bone. The model itself would be assumed to be correct. If the resulting variability of the generated dose distribution was such that, say, 20 or 30 percent of the distribution was greater than $3\bar{x}$, then we might consider using $4\bar{x}$ or some other factor that did reach out into the 99 percentile or so. On the other hand, if the value $3\bar{x}$ was greater than 99 percent of the distribution under worst case conditions, I would feel more comfortable with the factor 3. Of course, the simulation results would prove nothing since we don't have a very good handle on the distributions of the various parameters involved. But, by going through the simulation process and generating the dose

distribution for various distributions of the input parameters, we could see the sensitivity of the dose distribution to these input distributions. If it turned out that the input distributions had to be extremely and unrealistically variable before the value $3\bar{x}$ rule broke down, this would be at least somewhat encouraging.

My initial ideas on how to set up the simulation study are as follows (I use Bennett's model to illustrate, but the same general scheme could be used on the other models LLL is using):

1. Restrict attention initially to a population of 36 adult women living on Enjebi under famine conditions, where all coconut and other "natural" foods were obtained on Enjebi. That is, choose what LLL currently considers to be the worst possible case.

2. Use the actual diets obtained for the 36 adult females interviewed by Pritchard. For each such female we have an estimate of the grams of food eaten per day for each type of food. We make the assumption that these survey results are representative of the entire population of Enewetak adult females. There are two options at this point. We could use the exact same dietary intakes obtained in the interview, i.e., treat them as constants, or we could assume that the survey result for a given food is the mean of a statistical distribution with some variance (after all, there is certainly error involved in estimating daily intakes of food). I prefer the latter approach, but then we must decide what statistical distribution to use and the parameters of that distribution. Initially one might assume a normal distribution with mean equal to the reported survey result and a standard deviation approximated by (b-a)/6, where a and b are imposed lower and upper limits on the distribution (g/day intake for a given food is on the abscissa).



The value of a and b might be initially taken, e.g., to be plus and minus 50 percent of the survey result. With more thought on this, LLL might be able to come up with more likely values for a and b.

3. Using the above ideas it might be possible then, to generate a "reasonable" dietary intake for each of the 36 females. This scheme could be repeated day after day for as long a time period as desired (easily done on the computer). Note that we have added variability by using different dietary intakes for individuals and a range of possible daily intakes for each food item.

4. So far we have considered only variation in dietary intake. Now we must consider the concentration of Sr-90 in each days diet. Consider a given food, say coconut. While we do not have much data on coconuts, it is reasonable to assume the distribution of concentrations in coconuts over the island would be lognormal if the soil concentrations in which those coconuts grew is lognormal. We could imagine that coconuts are gathered from different trees and hence that each days intake of coconut is a sample from a lognormal distribution. The parameters μ and σ (mean and standard deviation of the logarithms of the data) of that distribution can be estimated from the parameters of the soil distribution and the ratio data. Using the estimated parameters $\hat{\mu}$ and $\hat{\sigma}$, the computer could generate a pCi/g concentration intake from ingesting coconut for each day. The Sr-90 daily intake for each food could be so generated. The parameters of the lognormal distribution for each food would be different if the food to soil ratios varied for each food (which they do).

For each of the 36 females the following data would hence be generated (assume only 2 foods in the diet for ease of illustration), where

	Food 1			Food 2		
Day	grams/day	pCi/g	pCi/day	grams/day	pCi/g	pCi/day
1	G_{11}	C_{11}	$G_{11}C_{11}$	G_{21}	C_{21}	$G_{21}C_{21}$
2	G_{12}	C_{12}	$G_{12}C_{12}$	G_{22}	C_{22}	$G_{22}C_{22}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
365	$G_{1,365}$	$C_{1,365}$	$G_{1,365}C_{1,365}$	$G_{2,365}$	$C_{2,365}$	$G_{2,365}C_{2,365}$

g_{ij} is the grams of food i ingested on day j by this particular female, and c_{ij} is the pCi/g in that ingested food. The g's and c's have been generated as described above. By summing the pCi/day intakes of Sr-90 over all foods over the entire year, we get the daily dietary intake for the year (D_n) needed in Bennett's bone model. His model for adults is

$$B_n = (c + g)D_n + e^{-\lambda}(B_{n-1} - cD_{n-1})$$

where B_n = concentration of Sr-90 in bone for year n (n = 1,2,...),
D_n = dietary intake of Sr-90 for year n,
and c, g and λ are parameters as defined by Bennett.

Thus, going through the above scheme we can generate a value for D_n to use in this model for a given individual. What about the parameters c, g and λ? Bennett obtained estimates for these based on a multiple regression analysis. We might generate values for c, g and λ in the same way as we did for dietary intakes. For example, consider c. Let the value of c used in Bennett's model be drawn from a normal distribution with a mean equal to the value published by Bennett and a standard deviation approximated by (b-a)/6, where a and b might be plus and minus, say 20 percent on either side of Bennett's value. Again, the correct percentage to use is open to question. This same approach could be used to obtain computer generated values for g and λ.

At this point we have generated values for D_n, d, g, and λ so that B_n can be computed for a given female individual. We also have an estimate of the amount of calcium (Ca) in her bones since the diet survey also gives estimated body weights. We could also generate a value of Ca to use from a normal distribution to take into account measurement error. Hence, for this individual we can calculate B_n/Ca, i.e., the estimated concentration of Sr-90 per gram of calcium in her bones. This is then multiplied by 4.5 to obtain $D_{o,n}$, the estimated dose rate (mrem/yr) to a small tissue-filled cavity in bone (Spiers approach). Also, $D_{s,n} = 0.434\ D_{o,n}$ and $D_{m,n} = 0.315\ D_{o,n}$.

The above scheme would be followed for each of the 36 females resulting in an estimated dose $D_{o,n}$ for each. Hence, a distribution (histogram) of doses to these 36 individuals could be generated. We could compute $\bar{x}$ and $3\bar{x}$ for this distribution and see if $3\bar{x}$ is in fact a reasonable estimate of the maximum individual dose.

Rather than end the investigation at this point, I would recommend that the entire scheme be repeated, say 1000 times. Each time a distribution of doses would be obtained, but these distributions would vary because new values for diet, food concentrations, calcium, c, g, and λ would be generated each time. For each of these 1000 distributions we could compute $\bar{x}$ and $3\bar{x}$. If, in all 1000 cases, $3\bar{x}$ was greater than 95 or 99 percent of the distribution, then we might begin to have some confidence in the $3\bar{x}$ approach.

It's clear, of course, that the results of this type of exercise will not settle the issue of whether $3\bar{x}$ is or is not a good technique. In fact, it might only serve to muddy the water and cause confusion. On the other hand, if the $3\bar{x}$ rule worked well even under the most extreme and worst cases possible, it could be very encouraging.

The above scheme is very sketchy and needs to be gone over and revised by someone who is more familiar than I with the evaluation of dose models. Chet Richmond or Chet Francis might be able to suggest someone from Oak Ridge who could assist and advise LLL in such a project (Dr. Charles T. Garter, ORNL, would, in my view, be qualified.)

I will be on vacation in Michigan from July 17-30 and hence won't be available during that time to discuss this memo. I wanted to get it in the mail before I left so that if other members of the Advisory Group agreed with me that the matter was worth pursuing, it could get underway during July.