August 17, 2001

MEMORANDUM TO: William H. Bateman, Chief
                   Materials and Chemical Engineering Branch
                   Division of Engineering
                   Office of Nuclear Reactor Regulation

FROM: Mark A. Cunningham, Chief   /RA/ by Alan Rubin for:
                   Probabilistic Risk Analysis Branch
                   Division of Risk Analysis and Applications
                   Office of Nuclear Regulatory Research

SUBJECT: STATISTICAL ANALYSIS OF CRDM SAMPLING (REVISED)

        Attached to this memo is a note which explains how the results of inspecting a sample of

control rod drive mechanisms (CRDMs) for cracks can be used to draw inferences about the

CRDMs in the population which are not inspected. The note is a revision of the analysis

attached to my memo dated July 27, 2001. The revision reflects the latest industry evaluation of

the affected plants' operating experience.

Attachment: As stated

cc: A. Hiser, NRR
      J. Zimmerman, NRR

Inferences from CRDM Sampling
(Revised 8/14/01)

This note explains how the results of inspecting a sample of plants or CRDMs can be used to draw inferences about the plants or CRDMs in the population which are not inspected. It is assumed that all items in the population have the same probability of having a crack indication by inspection and that the inspection results are statistically independent. All inferences are made at the 95 percent confidence level.

Denote the population size by N and the sample size of inspected items by n. Then $m = N - n$ is the number of items in the population which are not inspected. Denote the probability that inspection indicates a crack by p. If the unit of inspection is the plant, then p is the probability that none of the CRDMs in the plant indicates a crack.

Assume that none of the n items inspected indicates a crack. Then the 95 percent upper confidence bound on p is

$$p_{.95} = 1 - (.05)^{1/n} \qquad (1)$$

Let $q\,(m)$ be the probability that *none* of the m uninspected items would have a crack indication under inspection. Then $q(m) = (1 - p)^m$ and the 95 percent *lower* confidence bound on $q(m)$ is

$$q_{.95}\,(m) = (.05)^{m/n} \qquad (2)$$

Example 1: Suppose that $n = 5$ of the 12 plants with less than 5 EFPY are inspected and that no crack indications are found. Then, with 95 percent confidence, $p < 0.45$ and $q(7) > 0.015$. In other words, all that can be claimed for the $m = 7$ uninspected plants is that the probability of their not indicating any cracks could be as small as 0.015. The reason that this lower bound is so small is that the probability that any one of the 7 uninspected plants would indicate a crack could be as large as 0.45, coupled with the requirement that *none* of the 7 uninspected plants can have a crack indication.

Example 2: Suppose that all 12 plants with less than 5 EFPY are inspected and that no crack indications are found. Then, with 95 percent confidence, $p < 0.22$. From Eq. (2), the probability that none of the 8 uninspected plants between 5 and 10 EFPY would indicate any cracks could be as small as 0.14.

Example 3: Suppose that the unit of inspection in Examples 1 and 2 is the CRDM rather than the plant. Because there are 69 CRDMs in a plant, the values of n and m are each multiplied by 69. However, their ratio is unchanged. Hence, from Eq. (2), the lower bound for $q_{.95}\,(m)$ is also unchanged. Therefore, the results of Examples 1 and 2 remain the same.

Example 4: This is the same as Example 1, except that one of the 5 inspected plants is assumed to indicate a crack. Then the 95 percent upper confidence bound on p increases from 0.45 to 0.66. The corresponding lower bound for the 7 uninspected plants decreases to 0.00055.

Example 5: This is the same as Example 2, except that one of the 12 inspected plants is assumed to indicate a crack. Then the 95 percent upper confidence bound on p increases from 0.22 to 0.34. The corresponding lower bound for the 8 uninspected plants between 5 and 10 EFPY decreases to 0.036.

Another approach is to incorporate the data from the inspections already made. A total of 15 CRDMs in 4 plants were found to have crack indications. These plants contain a total of (4)(69) = 276 CRDMs. Based on this data and on tables for Poisson confidence bounds, an upper 95 percent confidence bound on p is (23.1)/(276) = 0.084. Hence the probability that none of the 69 CRDMs in an uninspected plant would indicate a crack could be as small as $(1 - .084)^{69}$ = 0.0024.

Example 6: Suppose that 5 additional plants are inspected and no crack indications are found. Assuming independence and combining with the previous data yields a total of 15 indications in (9)(69) = 621 CRDMs. Based on this data set, an upper 95 percent confidence bound on p is (23.1)/(621) = 0.037.   Hence the lower bound on the probability that none of the 69 CRDMs in an uninspected plant would indicate a crack increases from 0.0024 to $(1 - .037)^{69}$ = 0.073.

Example 7: This is the same as Example 6, except that 12 additional plants are inspected. The combined data set consists of 15 indications in (16)(69) = 1104 CRDMs. The upper bound on p decreases from 0.037 to 0.021. The lower bound on the probability that none of the 69 CRDMs in an uninspected plant would indicate a crack increases from 0.073 to $(1 - .021)^{69}$ = 0.23.