Selective Investigation of As-Found Design, Construction, Maintenance and Aging in Nuclear Power Plants

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INTRODUCTION

In the past several years sampling has been presented to the nuclear industry as an efficient, cost-effective means of investigating potential problems related to the licensing basis, design modifications, maintenance programs, etc., or developing information needed as input into nuclear plant life extension (NUPLEX) and probabilistic risk assessments (PRA). Some recent implementations include the Braidwood Construction Assessment Program (BCAP), the Diablo Canyon Project's Independent Design Verification Program (IDVP), the Comanche Peak Response Team's (CPRT) Design Adequacy and Quality of Construction Programs, and the Nuclear Construction Issues Group (NCIG) "Sampling Plan for Visual Inspection of Welds," (NCIG,1987).

Compared to a 100 percent review or reinspection, a sampling investigation (selective investigation) has the following advantages:

- o Economy due to review, inspection, or testing of only part of the whole
- o Quantified level of assurance and quality
- o Results applicable to "hidden" or inaccessible attributes.

Most selective investigation techniques used in the nuclear industry are really modified versions of routine acceptance sampling, the mainstay of the manufacturing industry. Generally, acceptance sampling is used to audit manufacturing processes in order to ensure conformance to requirements. The repetitive nature of a manufacturing process characterizes homogeneity in a population of product. In a qualitative sense, greater assurance is obtained when a homogenous population is accepted based on a sample than when a non-homogenous population is accepted based on a sample, even though the resulting statistical assurances may be identical (e.g., 95/95).

For a typical nuclear industry application (e.g., NCIG-02), the sample acceptance criterion is modified to include engineering evaluations of discrepant items when the acceptance number is exceeded. If the discrepancies are determined by an engineering evaluation to meet licensing commitments, even in the discrepant condition, <u>and</u> no generic problems are identified, the population is accepted, as the saying goes, "with reasonable assurance."

Although an engineering evaluation may indicate the seriousness of an individual discrepancy, information regarding the design or construction process is generally lost with this type of investigation. The fact that engineering acceptance of a deviation is tailor-made to suit the specific as-found condition also means that the population can no longer be viewed as homogenous. In large populations, in which a sample has identified discrepancies, there is a significant likelihood that other discrepancies exist in the unsampled population and that some may be more serious than what has been observed. The use of a duel acceptance criteria signals a major departure from routine acceptance sampling, and the ramifications have not been completely appreciated by the nuclear industry.

This paper presents a rational alternative to the typical selective investigation technique of modified acceptance sampling for addressing design and hardware issues at nuclear facilities.

MARGIN REDUCTION MODEL

The selective investigation methodology advanced in this paper is, itself, a modified acceptance approach with two screening levels. However, a major emphasis is placed upon the implications indicated by the sample outcome. The first screening level is based on conformance of sampled items to design documents (or in the case of design adequacy conformance, to adequate analytical models, assumptions and calculations). The screening procedure is straight forward and requires little or no engineering evaluation. If the sample is found deviation free, no further investigation is required, since there is a strong indication that the process of design, construction, or maintenance was adequate for the entire population, or that aging effects have not significantly degraded the capacity of items within the population. If the as-found sample deviates from the design documents (or design deviations exist) by virtue of errors, poor maintenance, or general aging, the second level of screening is used to determine implications to the remaining population.

Design and/or construction errors, improper modifications or maintenance practices, and general life-cycle aging processes are detrimental to functional integrity of hardware by either reducing capacity or increasing load effects (usage) on an item. In either case, the safety margin is reduced. Safety margin is capacity minus usage, where "capacity" is defined by the application (e.g., for licensing commitments, it is generally code-allowable limits; for PRA or NUPLEX it may be actual functional limits).

Margin is often expressed as a ratio to capacity in order to construct a useful probabilistic distribution for a population. Deviations of the type described above will reduce the margin ratio in accordance with the following equation:

$$MRR = (M_D - M_{AB})/M_D = \{CRR + (1-MR_D)\ UIR\}/MR_D$$

where

MRR = margin reduction ratio (i.e., $MRR < 1.0$ is safe; $MRR \geq 1.0$ is unsafe)

M_D = design margin, $C_D - U_D$

M_{AB} = as-built margin, $C_{AB} - U_{AB}$

CRR = capacity reduction ratio, $(C_D - C_{AB})/C_D$

MR_D = design margin ratio, M_D/C_D

UIR = usage increase ratio, $(U_{AB} - U_D)/U_D$

C_D = design capacity

C_{AB} = as-built capacity

U_D = design usage

U_{AB} = as-built usage

The margin reduction ratio for a given item in a population is uncertain until it is inspected or reviewed and evaluated. Indeed, a frequency distribution of MRR within a population may be inferred from the evaluation of the sample. Most often the shape of the distribution will be similar to that shown in Fig. 1.

Licensing

In order to verify the existence of an adequate licensing basis in cases where the adequacy of QA/QC documentation has been questioned, the two level screen is applied to a sample of hardware or design calculations for reinspection/ reevaluation. If the first screen fails, the as-built margin distribution is determined from the sample, as in Fig. 1. The upper end of the margin reduction distribution for the population is predicted probabilistically based on the sample results. If the expected number of items in the population likely to violate licensing requirements (e.g., exceed allowable stresses) is more than some predetermined number, it is concluded that an adverse condition exists and corrective action is necessary in order to establish the adequacy of the licensing basis.

In what must be considered one of the most extensive uses of the selective investigation methodology in a licensing case, the Comanche Peak Response Team (CPRT), a third-party investigative team established by Texas Utilities Electric Company, conducted selective investigations of some 40 specific issues related to design, construction, QA/QC and testing adequacy in addition to a self-initiated selective investigation of the quality of construction of some 30 hardware populations covering over 300 installation attributes.

In one example, the selective investigation methodology was applied to the issue of inadequate QC-inspection procedures for certain types of skewed welds in ASME Section NF pipe supports (USNRC,1988a). The CPRT randomly selected 60 supports and found 12 had undersized skewed welds according to the corrected measuring technique. The first screen failed. However, none of the 12 welds were found to be overstressed, and a statistical study of actual stress margins in the population was conducted based on the data collected in the sample. The expected number of supports with overstressed skewed welds was determined to be one in a thousand, which was less than the predetermined number of one in the entire population of 130 supports. As an added measure of confidence the proportion of the population with skewed-weld stresses above yield was estimated to be 10^{-7}. Therefore, despite the lack of adequate QC-inspection procedures, it was concluded that the combination of conservative design margins and good craftsmanship negated the concern that deficiencies existed due to the original inspection inadequacies.

PRA and NUPLEX

Past PRA and seismic margin studies have prompted concerns regarding the influence of design and construction errors on risk assessments (Kennedy, et. al. 1984). More recently NUPLEX efforts have begun to grapple with ways of evaluating and addressing aging effects of components and hardware on plant performance beyond the expiration of the arbitrary 40-year license (USNRC,1988b). In the future, selective investigations will be used to address these issues, since as-found margins determined from hardware samples prior to performing a PRA or NUPLEX study will be one of the most cost-efficient means available for evaluating the implications of errors and aging on the safety of plants. The as-found margin distribution for a population of hardware items may be used either to demonstrate that the rate and magnitude of deviations from as-designed conditions are acceptably low and do not significantly influence the risk of an accident, or to provide information regarding the increased risk due to aging effects or errors. This type of evaluation is useful in determining the benefit of existing maintenance and repair programs as well, or simply establishing the physical baseline condition from which life extension decisions can be made.

For seismic PRA or margin studies, only the capacity reduction and usage increase ratios are of concern. Hardware component local capacities are generally stated in terms of a lognormal probability model which is governed by three parameters: the median capacity, $\hat{A}$;the random logarithmic standard deviation, β_r; and the uncertainty logarithmic standard deviation, β_u (Ellingwood, 1988). The relationship between as-found and as-designed local capacities, including capacity reductions and usage increases due to aging effects or construction errors, can be written:

$$A' = \left[\frac{1}{1\text{-UIR}}\right] (1\text{-CRR})\ A$$

where A = the local capacity, disregarding errors and aging
A' = the as-found local capacity

The first two terms of the above equation, which incorporate the previously defined ratios, UIR and CRR, have distributions that range from 0.0 to 1.0, with discrete probability masses at 1.0 (see Fig. 2). These distributions are estimated based on the sample of hardware and/or calculations obtained during the selective investigation. Although A may be assumed lognormally distributed, the distribution of A′ cannot be assumed lognormally distributed since the first two terms are mixed distributions. The distribution of A′, however, can easily be determined numerically by a Monte Carlo simulation.

As the above equation indicates, design and construction errors and aging effects will lower the high confidence, low probability of failure (HCLPF) value of fragility in seismic margin studies and increase the risk estimated by seismic PRAs. However, to date, no one has actually incorporated selective investigation data into such studies.

Special Issues

In addition to licensing, PRA, and NUPLEX issues, there is always a continuous stream of NRC IE Bulletins and Information Notices requesting investigation or requiring action to address special hardware issues (e.g., nonconforming materials (Bulletin 88-05), minimum edge distance for expansion anchors (IN 88-25), etc.). Although the resolution of some of these issues may be handled in a generic manner, involving an industry-wide response (e.g., NUMARC response to 88-05), in other cases resolution requires plant-specific investigation. The issue of edge distance and expansion anchors, for example, has been rolled into the seismic qualification of equipment in operating nuclear power plants (USI A-46) program and will be dealt with during SQUG walkdowns of equipment installations at specific plants. These plant-specific walkdowns of equipment anchorages may well be amenable to the proposed selective investigation methodology as a means of determining whether a significant problem exists in a population, and, in some cases, provide justification for not performing a 100 percent walkdown if significant implications are not indicated.

Conclusions

Recognizing that it is not only important to know the seriousness of the errors or aging effects that are found during the selective investigation, but that it is probably more important to realistically predict the seriousness of the ones remaining in the uninspected/unreviewed population, it is concluded that any sampling-based investigation methodology adopted by the nuclear industry include a rational basis for determining the implications of the as-found conditions in nuclear facilities, giving due consideration to the variability of such conditions.

References

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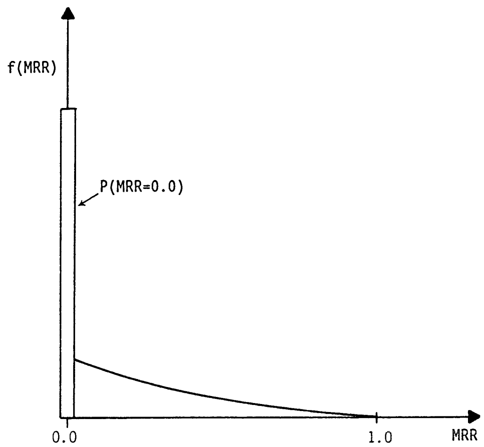

Figure 1 Distribution of MRR

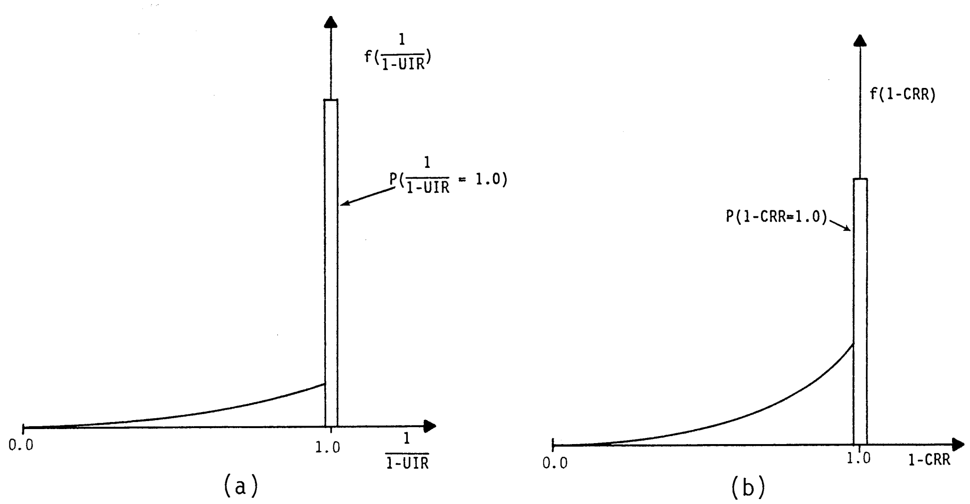

Figure 2 Distributions of $\frac{1}{1-UIR}$ and 1-CRR