Attachment 4

MSPI - How To Really Do The Calculation

Calculation of URI

Calculation of system URI due to changes in component unreliability is as follows:

$$URI = CDFp \sum_{j=1}^{m} \left[\frac{FVURcj}{URpcj}\right]_{max} (URBcj - URBLcj) \qquad \text{Eq 1.}$$

Where the summation is over the number of monitored components (m) in the system, and:

CDF_p is the plant-specific internal events, at power, core damage frequency,

FV_{URc} is the component-specific Fussell-Vesely value for unreliability,

UR_{Pc} is the plant-specific PRA value of component unreliability,

UR_{Bc} is the Bayesian corrected component unreliability for the previous 12 quarters,

and

UR_{BLc} is the historical industry baseline calculated from unreliability mean values for each monitored component in the system.

It is convenient to simplify this form of the equation by substitution of the Birnbaum importance:

$$B = CDF\left[\frac{FV}{UR}\right].$$

Splitting equation 1 into two summations, resulting in:

$$URI = \sum_{j=1}^{m} Bj * URBcj - \sum_{j=1}^{m} Bj * URBLcj.$$

Thus URI can be evaluated in two parts

$$URI = URIBc - URIBL, \qquad \text{Eq 2.}$$

each represented by a summation.

The second summation is the baseline value, which does not depend on the performance history of the components and can be defined as

$$URIBL = \sum_{j=1}^{m} Bj * URBLcj. \qquad \text{Eq 3.}$$

This leaves the first summation, which does depend on the performance history, to be evaluated.

$$URIBc = \sum_{j=1}^{m} Bj * URBcj. \qquad \text{Eq 4.}$$

Before continuing with the evaluation of this term it is important to recognize that even though the summation is written as a sum over all monitored components, the term UR_{Bcj} is the same value for all components within the same component group, e.g. those components for which data is combined. Thus this summation may be written as a summation over the number of groups $\underline{g}$ and then the individual components $\underline{c}$ within a group.

$$URIBc = \sum_{i=1}^{g} \sum_{j=1}^{c} Bij * URBcij \qquad \text{Eq 5.}$$

But as stated before, for all components in group $\underline{i}$:

$$URBci1 = URBci2 = URBci3.... = URBci \qquad \text{Eq 6.}$$

And the summation may be rewritten as:

$$URIBc = \sum_{i=1}^{g} * URBci \sum_{j=1}^{c} Bij \qquad \text{Eq 7.}$$

If we then define the quantity ***Wi*** as the sum of the Birnbaum importances for all components in group $\underline{i}$:

$$Wi = \sum_{j=1}^{c} Bij \qquad \text{Eq 8.}$$

Equation 7 may then be written as:

$$URIBc = \sum_{i=1}^{g} * URBci * Wi \qquad \text{Eq 9.}$$

This form of the equation illustrates that the quantity URI_{Bc} can be thought of as the product of two group related quantities, the group unreliability and a group importance value.

We can now proceed to calculate the quantity UR_{Bc}. For simplicity the subscript ***i*** will be omitted from the following section.

Calculation of UR_{Bc}

Component unreliability is calculated by:

$$URBc = PD + \lambda Tm. \qquad \text{Eq 10.}$$

Where:

P_D is the component failure on demand probability calculated based on data collected during the previous 12 quarters,

λ is the component failure rate (per hour) for failure to run calculated based on data collected during the previous 12 quarters,

and

T_m is the risk-significant mission time for the component based on plant specific PRA model assumptions.

NOTE:

For valves only the P_D term applies

For pumps $P_D + \lambda T_m$ applies

For diesels $P_{D\,start} + P_{D\,load\,run} + \lambda T_m$ applies

This example will be calculated using the form in equation 10.

The first term on the right side of equation 10 is calculated as follows.[1]

$$PD = \frac{(Nd + a)}{(a + b + D)}. \qquad \text{Eq 11.}$$

where in this expression:

N_d is the total number of failures on demand during the previous 12 quarters,

D is the total number of demands during the previous 12 quarters. The number of demands is the actual ESF demands plus estimated test and estimated operational/alignment demands. It is also permissible to use the actual number of test and operational demands. An update to the estimated demands is required if a change to the basis for the estimated demands results in a >25% change in the estimate.

The values a and b are parameters of the industry prior, derived from industry experience.

In the calculation of equation 11the numbers of demands and failures is the sum of all demands and failures for similar components within each system. Do not sum across units for a multi-unit plant. For example, for a plant with two trains of Emergency Diesel Generators, the demands and failures for both trains would be added together for one evaluation of P_D which would be used for both trains of EDGs.

In the second term on the right side of equation 10, λ is calculated as follows.

$$\lambda = \frac{(Nr + \alpha)}{(Tr + \beta)} \qquad \text{Eq 12.}$$

where:

N_r is the total number of failures to run during the previous 12 quarters,

T_r is the total number of run hours during the previous 12 quarters (actual ESF run hours plus estimated test and estimated operational/alignment run hours.

[1] Atwood, Corwin L., Constrained noninformative priors in risk assessment, *Reliability Engineering and System Safety*, 53 (1996; 37-46)

α and β are parameters of the industry prior, derived from industry experience.

In the calculation of equation 12 the numbers of demands and run hours is the sum of all run hours and failures for similar components within each system.

Substituting equations 11 and 12 into equation10:

$$URBc = \frac{(Nd+a)}{(a+b+D)} + \frac{(Nr+\alpha)}{(Tr+\beta)}Tm. \qquad \text{Eq 13.}$$

This can be rearranged as

$$URBc = \frac{a}{(a+b+D)} + \frac{\alpha}{(Tr+\beta)}Tm + \frac{Nd}{(a+b+D)} + \frac{Nr}{(Tr+\beta)}Tm. \qquad \text{Eq 14.}$$

In this form, the first two terms can be thought of as the zero failure value of UR_{Bc}. This can be noted as UR_Z. Note that this value is a function of the number of demands in a component group, the run time of the component group and the mission time.

$$URZ = \frac{a}{(a+b+D)} + \frac{\alpha}{(Tr+\beta)}Tm. \qquad \text{Eq 15.}$$

The last two terms can be thought of as the contribution due to demand or runtime failures that have occurred during the monitoring period. Thus equation 14 becomes

$$URBc = URZ + \frac{Nd}{(a+b+D)} + \frac{Nr}{(Tr+\beta)}Tm. \qquad \text{Eq 16.}$$

Substituting equation 16 into equation 9 results in the following expression for URI_{Bc}:

$$URIBc = \sum_{i=1}^{g} Wi * \left(URZ + \frac{Nd}{(a+b+D)} + \frac{Nr}{(Tr+\beta)}Tm \right)_i \qquad \text{Eq 17.}$$

If this concept is extended further it can be seen that the URI can be written as a sum of the baseline value, the zero failure values for each group and a series of coefficients times the number of failures. First, the notation is simplified further through the following definitions.

The zero failure value for component group ***i*** is:

$$XZi = Wi * URZ \qquad \text{Eq 18.}$$

The demand failure coefficient for component group ***i*** is:

$$XDi = \frac{Wi}{(a+b+D)_i} \qquad \text{Eq 19.}$$

The run failure coefficient for component group ***i*** is:

$$X_{Ri} = \frac{W_i}{(T_r + \beta)_i} T_{mi} \qquad \text{Eq 20.}$$

Note that equations 19 and 20 represent the ΔURI value per failure in group ***i***.

Thus we can now write equation 17 as follows:

$$URI_{Bc} = \sum_{i=1}^{g} \left(X_{Zi} + N_{di} * X_{Di} + N_{ri} * X_{Ri} \right) \qquad \text{Eq 21.}$$

And finally substituting into equation 2.

$$URI = \sum_{i=1}^{g} \left(X_{Zi} + N_{di} * X_{Di} + N_{ri} * X_{Ri} \right) - URI_{BL} \qquad \text{Eq 22.}$$

The expression for MSPI is then:

$$MSPI = \sum_{i=1}^{g} \left(X_{Zi} + N_{di} * X_{Di} + N_{ri} * X_{Ri} \right) - URI_{BL} + UAI \qquad \text{Eq 23.}$$

If this result is less than 1.0e-06 or greater than 1.0e-05, then there is no further computation necessary. If, however, the result is between these two values, then the risk limit has to be applied. This is accomplished in the following manner.

From the set of X_{Di} and X_{Ri} for all component groups, identify the maximum value for all values where the corresponding number of failures is **NOT** zero. This can be notated as X_{MAX}. This is the contribution to MSPI from the highest worth single failure.

The value of the limited MSPI is then given by:

$$MSPI_{\text{limit}} = MSPI - X_{MAX} + MINIMUM(X_{MAX}, 5.0e-07) \qquad \text{Eq 24.}$$

This expression starts with the original value, subtracts the contribution from the highest worth single failure and adds back the smaller of the this value or 5.0e-07, the risk cap. If the value of the highest worth failure is less than 5.0e-07, then

$$MSPI_{\text{limit}} = MSPI. \qquad \text{Eq 25.}$$