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Application of non-parametric statistical methods in CAREM

Present the basis that the methodology insures independence (or treatment of any dependencies) of parameters and the continuity of the random variables using the approach (Audit Issues [AI] 51 and 63)

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Order statistics for LOCA methodology

- **Coverage Approach:**

– a tolerance region A/Q is built which covers a proportion Q of the **joint distribution** of the output variables with confidence A: proposed by Guba(2003)

– coverage A/Q of 3 parameter case is equivalent to find tolerance intervals for each output with level $\sqrt[3]{A}/\sqrt[3]{Q}$

e,g. A=Q=0.95 and k=3 => intervals 98.3/98.3 for each parameter

– this requires more cases compared to single parameter case with the same A/Q

TS

Order statistics for LOCA methodology

- **Testing Approach:**

– a tolerance region A/Q is built which covers a proportion Q of the single output variable of a reactor meeting all the criteria with confidence A: proposed by Wallis(2003, 2005-1, 2005-2, 2006).

TS

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Order statistics for LOCA methodology

- **CAREM use Testing Approach:**

TS

Audit Issues to be dissussed

- Issue 51
- Issue 63

Issue - 51

The guidance in RG 1.157, Section 4 establishes acceptable controls for the estimation of uncertainties. The following issues are related to the distribution-free statistics method described in Section 4.3.2 of the topical report:

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Issue – 51:a

It appears that the method described in Section 4.3.2 is similar to the formulation of Guba, Makai and Pál based on order statistics (Reliability Engineering and System Safety, Vol. 80, Issue 3, pp.217-232, June 2003). Confirm or provide a reference for the method used in the topical report.

Response – 51:a

The method of section 4.3.2 follows the following 2 articles;

Ref.1: G. B. Wallis, W. T. Nutt, "Reply to "Comments on 'Evaluation of nuclear safety from the outputs of computer codes in the presence of uncertainties', by W.T. Nutt and G.B. Wallis," by Y. Orechwa", Reliability Engineering and System Safety 87 (2005) 137–145.

Ref.2: H. Glaser, "BEMUSE Phase VI Report, Status report on the area, classification of the methods, conclusions and recommendations", NEA/CSNI/R(2011)4, 28-Mar-2011; (https://www.oecd-nea.org/nsd/docs/2011/csni-r2011-4.pdf). Especially, section 7.6 and section 7.7 are guide of CAREM.

Response – 51:a continued

Following statements are found in Ref.1;

"Using the testing approach one can determine whether or not computer code outputs simultaneously satisfy a set of physical criteria with 95% confidence that the criteria are satisfied with 95% probability, using only 59 runs. This conclusion is independent of the number of criteria and of any inter-dependencies between the outputs from the code."

Response – 51:a continued

Following statements are found in section 7.6 of Ref.2;

"When the upper tolerance limit approaches regulatory acceptance criteria, e.g. 1200°C PCT, the number of code runs may be increased to 150 or 200 calculations instead of the 59 code runs needed, using Wilks' formula at the first order for the estimation of a α = 95% one-sided tolerance limit with a confidence level β of 95%. This would be advisable for two reasons:

Response – 51:a continued

Firstly, for uncertainty analysis, it is possible to use Wilks' formula for example at the order 3 (124 runs) up to 5 (181 runs) for percentile α and confidence β unchanged, which may reduce the effect of conservatism of tolerance limits from a small number of code runs, i.e. the dispersion of the estimated tolerance limit in conservative direction tending to substantially overestimate the 95%-quantile one is originally interested in.

On the other hand, the underestimation of the 95% percentile with 5% probability decreases when the order of Wilks' formula is increased.

Response – 51:a continued

Secondly the results of sensitivity analysis will become more reliable, particularly for less important parameters, because the variances of the estimators of the sensitivity measures will decrease and spurious (artificial) correlations between independent input parameters will appear less frequently when sample sizes increase.

Response – 51:a continued

TS

Issue – 51:b

Section 4.3.2 states that the third highest result of 124 random calculations provides the 95/95 limit.

In case the method in the topical report uses order statistics (see part (a) of this issue), it is unclear whether the approach employed in the topical report is the single parameter uncertainty evaluation with the third estimator grade or the multiple parameter uncertainty evaluation with three parameters.

Both approaches require 124 random calculations.

Clarify the method used in CAREM.

Response – 51:b

TS

Issue – 51:c

In case the distribution-free statistics method is based on the single parameter uncertainty evaluation for the PCT, the approach used to determine the limiting values of local cladding oxidation and hydrogen generation is not clear.

It is not possible to determine whether the limiting values of local cladding oxidation and hydrogen generation are those that correspond to the calculations resulting in the limiting PCT or are derived from separate 124 random calculations for each of those two parameters.

Explain and justify the approach used.

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Response – 51:c

TS

Issue – 51:d

In case the distribution-free statistics method is based on the multiple parameter uncertainty evaluation with three parameters, such a method assumes that the parameters are continuous and independent.

During LBLOCA calculations bursting of cladding may be predicted to occur resulting in a discontinuous increase in the cladding temperature.

In addition, the local and the core-wide cladding oxidation and hydrogen generation values are dependent on the corresponding cladding temperature.

Clarify whether the methodology described in the topical report is limited to pre-burst conditions or justify the applicability of the assumption of the continuity of the parameters in the event of cladding burst.

Issue – 51:d

Further, justify the assumption of the independence of the three parameters (e.g., PCT, cladding oxidation and hydrogen generation).

Response – 51:d continued

TS

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Issue – 63

The guidance in RG 1.157, Section 4 establishes acceptable controls for the estimation of calculational uncertainty.

Section 5.2.2 of the topical report discusses the use of simple random sampling approach to perform 124 calculations using the distributions of the uncertainty parameters listed in Table 5-1.

Describe the model or method that is utilized to perform the random selection of samples and provide justification that the sampling process is unbiased.

Response – 63

Following reference is a guide for CAREM.

H. Glaser, "BEMUSE Phase VI Report, Status report on the area, classification of the methods, conclusions and recommendations", NEA/CSNI/R(2011)4, 28-Mar-2011; (https://www.oecd-nea.org/nsd/docs/2011/csni-r2011-4.pdf),

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Response – 63 continued

Following statements are found in section 7.2;

"It is also important to note that the model outcome sample values $Y_1 \ldots . Y_N$ from which the tolerance intervals/limits are determined must constitute a random sample of the model outcome Y in the statistical sense, i.e. they must be realizations of stochastically independent and identically distributed random variables $Y_1 \ldots . Y_N$.

This is ensured if the underlying input parameter sample is generated according to the simple random sampling (SRS) principle.

Response – 63 continued

Other types of parameter selection procedures like Latin Hypercube Sampling or Importance Sampling, etc. may therefore not be appropriate for tolerance intervals or tolerance limits".

Also it (in section 7.7) strongly recommends the simple random sampling technique to get a random sample.

There is no concern about the bias with the simple random sampling process in the reference.

Response – 63 continued

To get the random sample, open source computer program, LHS, is used:

G. D. Wyss, K. H. Jorgensen, "A User's Guide to LHS: Sandia's Latin Hypercube Sampling Software", SAND98-0210, February 1998.

Simple random sampling is performed using the option "random sampling" in the LHS code that will cause LHS to perform pure Monte Carlo sampling to generate random sample.

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Thank you for your attention