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Uncertainty Quantification of The Fission Product Release During Severe Accidents in Nordic BWRs

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Abstract – *Source term evaluation constitutes an important element in the assessment of efficiency of a Severe Accident Management (SAM) strategy. It is crucial to identify phenomena and parameters that present major contributions to the uncertainty in the magnitude and timing of the releases and quantify the uncertainty. In this work source term evaluation and uncertainty quantification were performed using MELCOR for two accident scenarios, large break LOCA and station blackout, that leads to containment failure due to ex-vessel phenomena (such as debris bed coolability and steam explosion) at RPV melt-through. Preliminary screening was performed using best-estimate and bounding assessment, where parameters were varied one-at-a-time. Dakota was used to perform Morris sensitivity analysis, followed by uncertainty quantification of the cesium and iodine release fractions using point-estimate values of phenomenological uncertain parameters that were identified to affect the accident progression, release paths and magnitude of release. It was observed from the sensitivity indices that during LOCA, melt candling, fission product diffusion in the fuel and bubble characteristic models are phenomenologically important. Whereas, aerosol dynamics, vapor diffusivity, hygroscopic aerosol and bubble characteristic models were phenomenologically important during SBO accident. The melt debris release characteristics was shown to affect fission product release in both accident scenarios. For the uncertainty quantification, parameters were sampled using Monte-Carlo sampling method. 95th percentiles for cesium and iodine releases were computed with empirical CDFs and Wilks' methods. The results of the study provide valuable insights into the impact of MELCOR models, modelling parameters, and sensitivity coefficients on code predictions.*

Keywords: Source term, MELCOR, LOCA/SBO phenomenon, sensitivity analysis

I. Introduction

Source term is the timing, fraction and speciation of the fission products (FPs) released to the containment during a severe accident (SA) in a nuclear reactor. An effective severe accident management (SAM) strategy entails analysis of source term. Estimation of the consequences of SA relies on the magnitude of the FP released. The International Atomic Energy Agency (IAEA) recommends [1] employing best estimate analyses, typically using integral plant response codes like MAAP [2] and MELCOR [3, 4], for developing SAM strategies. These codes and models can help to address complex and interconnected phenomena and scenarios and respective epistemic and aleatory uncertainties.

The thermal hydraulic conditions in the reactor pressure vessel (RPV) and primary cooling circuit play a crucial role in core degradation and relocation to the lower plenum (LP). This leads to in-vessel debris bed formation, debris remelting, and melt pool formation in the LP, exerting thermo-mechanical loads on the lower head and structures such as instrumentation guide tubes (IGTs) and control rod guide tubes (CRGTs), eventually resulting in RPV failure. The phenomena and timing of events during the in-vessel phase set the initial and boundary conditions for the ex-vessel stages of the accident progression. The characteristics of melt release are particularly vital for ex-vessel phenomena, such as direct containment heating (DCH), fuel coolant interactions (FCI), hydrogen generation and combustion, ex-vessel debris bed formation, and coolability.

The Risk Oriented Accident Analysis Methodology (ROAAM), initially proposed by Theofanous [5] and later developed as ROAAM+ framework, is applied to assess the effectiveness of SAM in preventing containment failure in Nordic BWRs [6]. ROAAM+ incorporates deterministic and probabilistic analyses to evaluate the impact of uncertainties in phenomena and scenarios.

While previous ROAAM+ analyses have systematically assessed uncertainty in containment failure probability, it remains uncertain whether the same factors are major contributors to uncertainty in the source term. The scenarios represented in Probabilistic Safety Assessment Level 1 and Level 2 (PSA L1 and L2) may affect the phenomena of fission product release, retention in the RPV, containment, and eventual release to the environment. Therefore, research into the significance of scenario and modelling parameters on fission product releases during various severe accident scenarios is warranted. This paper expands on the work performed earlier regarding sensitivity analysis in Nordic BWRs [7].

II. Approach

II.A. Nordic BWR MELCOR Model

Analysis of the FP release was performed using MELCOR 2.2.18019. Oskarshamn 3 (O3) is the reference reactor design modelled in MELCOR [8] and the subject of current study. O3 has a nominal operating power of 3900 MW, operating pressure of 70 bar, 700 SVEA-96 Optima2 fuel elements [9] and 169 B4C control rods. The core is modelled as having five radial rings with eight axial levels, with a sixth downcomer ring, RPV and containment are represented with 27 control volumes (CVs), connected with 45 flow paths (FLs) and 73 heat structures (HSs). The RPV is modelled with 19 axial levels, with 66 IGTs uniformly distributed among radial rings. Containment is subdivided into CVs for wetwell (WW), upper drywell (UDW), lower drywell (LDW), blowdown (BD) pipes and overflow pipes from LDW to UDW. Leakage to the environment is modelled directly from the drywell (DW).

Two SA scenarios are considered in this work, as classified under release category 4 (RC4) [10] - SA initiated by a transient or loss of coolant accident (LOCA). RC4A is initiated by large-break LOCA and RC4B is initiated by a station blackout (SBO). In RC4A a large break occurs in the main steam lines, and subsequently LDW is flooded. Containment spray systems and water injection are unavailable during the entire transient. RC4B starts with depressurization of reactor coolant system (RCS). Automatic depressurization system, LDW flooding from WW, safety relief are initiated according to standard control logic. In both scenarios containment fails due to FCI phenomena or basemat melt-through. The two scenarios were further split into two subcases based on the mode of debris ejection from the RPV. The ejection mode, controlled by the IDEJ switch (which controls the physics in the COR package) in MELCOR. When IDEJ0 is selected solid debris along with molten debris can be ejected from the vessel (solid debris ejection ON), and the mode with only the molten debris ejection is IDEJ1 (solid debris ejection OFF). Thus, four splinter scenarios were considered in total, LOCA-IDEJ0, LOCA-IDEJ1, SBO-IDEJ0 and SBO-IDEJ1.

II.B. Uncertainties of Interest

A total of 50 MELCOR parameters were shortlisted that contribute to FP release from fuel, core degradation and relocation, RPV lower head failure, FP and aerosol dynamics, spray and pool scrubbing and filters trapping. Details of the selection criteria for these parameters is presented in an earlier study [10]. Uncertainties in modeling both in-vessel and ex-vessel phenomena can significantly influence the source term, potentially affecting the probability of containment failure. For instance, uncertainty in the conditions of melt release from the vessel can lead to a fivefold change in the conditional probability of an unacceptable release. The in-vessel phase involving core degradation can result in the release of highly volatile fission products, while the ex-vessel phase, particularly the Molten Core Concrete Interaction (MCCI), contributes to the generation of aerosols.

During the initial stages of the accident, the pressure suppression pool plays a vital role in scrubbing aerosols, but onset of boiling in the pool can lead to resuspension and subsequent release of fission products. The MELCOR parameters governing the dynamics and behavior of fission products and aerosols also hold substantial importance in determining the characteristics of the source term. These parameters have a significant impact on the overall assessment of the potential environmental consequences of severe accidents in nuclear power plants.

II.C. Problem Setting

An earlier paper looked at narrowing down the selected 50 MELCOR parameters to the most influential parameters [7]. Cesium (class 16 and class 17 in MELCOR RN package) and iodine (class 2) release fractions are selected to be figures-of-merit (FOMs).

Table I MELCOR parameters selected for SA/UA.

No	Model	Parameter name	Range [10]	Units	Distribution	Scenario
1	Fission product release from fuel	SC710641	241000 - 381400	J/kg-mole	Uniform	LOCA/SBO
2		SC710651	0.000006 - 0.00001	M	Uniform	SBO
3	Core degradation and relocation	TUO2ZRO2	2450 - 2800	K	Uniform	LOCA
4		FCELRA	0.1 - 0.25		Uniform	LOCA
5		HFRZSS	1000 - 2500	W/m2-K	Uniform	LOCA
6		SC11312	2100 - 2500	K	Uniform	LOCA/SBO
7	RPV lower head failure	TPFAIL	1273 - 1600	K	Uniform	SBO
8		HDBPN	100 - 1000	W/m2-K	Uniform	LOCA/SBO
9	Fission product and aerosol dynamics	GAMMA	1 - 3		Uniform	LOCA/SBO
10		STICK	0.5 - 1		Uniform	LOCA
11		RHONOM	1000 - 4900	kg/m3	Uniform	SBO
12		TURBDS	0.00075 - 0.00125	m2/s3	Uniform	LOCA/SBO
13		SC7111I1	4.2347 - 5.7293	A	Uniform	LOCA
14		SC7111I2	467.5 - 632.5	K	Uniform	LOCA/SBO
15		SC7111CS1	3.0745 - 4.1595	A	Uniform	SBO
16		SC7111CS2	82.45 - 111.55	K	Uniform	LOCA
17		SC7170CS	3.3575 - 4.5425	kg/kg H2O	Uniform	SBO
18		SC7170CSI3	0.374 - 0.506	kg/kg H2O	Uniform	SBO
19		SC7170CSI4	1.9125 - 2.5875	kg/kg H2O	Uniform	LOCA
20		SC7170CSM	0.5695 - 0.7705	kg/kg H2O	Uniform	LOCA/SBO
21	Spray and pool scrubbing, and filters trapping	SC71521	0.005 - 0.008	m	Uniform	LOCA
22		SC71531	6.6946 - 9.0574	cm/s	Uniform	LOCA
23		SC71551	1.523 - 2.0606		Uniform	LOCA
24		SC71555	0.9681 - 1.3098		Uniform	SBO
25		SC71542	0.0025593 - 0.0034626	I-s/cm2	Uniform	LOCA/SBO
26		SC3210	1 - 1.15		Uniform	LOCA

Following the best estimate and bounding analysis, 26 influential parameters were screened, 19 of which were found to be significant in LOCA and 15 of which were significant in SBO. The list of these 26 parameters is provided in *Table I*. Morris one-at-a-time (OAT) global sensitivity method [11] was used to arrive at indices that quantify the significance of a particular parameter. Morris method is a screening method that can be applied to models with non-monotonic and discontinuous interactions. The method is based on elementary effects of changing one parameter, computed for each factor (k) and trajectory (R), made of $k+1$ points in the parameter input space. Every factor takes a discrete number of levels (p), and for reasonable coverage of input space, large p requires large R, resulting in $(k+1)*R$ simulations. In our study $p=6$ and $R=20$ were considered, resulting in 400 simulations each for LOCA-IDEJ0 and LOCA-IDEJ1, and 320 simulations each for SBO-IDEJ0 and SBO-IDEJ1. Dakota package [12] supports sensitivity studies by Morris method and was adopted to create sample inputs, and generate Morris sensitivity indices.

II.D. Uncertainty Analysis

Uncertainty quantification (UQ) involves evaluating how input uncertainties affect model responses. These uncertainties can be categorized as aleatory uncertainties, inherent variabilities in nature that cannot be eliminated, or epistemic uncertainties, which arise from a lack of knowledge and can potentially be reduced. When dealing with aleatory uncertainties, where sufficient data is usually available, probabilistic methods are commonly employed to compute response distribution statistics based on input probability distribution specifications. On the other hand, epistemic uncertainties often involve limited data, making the application of probability theory questionable and prompting the use of non-probabilistic methods e.g. based on interval specifications (Dempster-Shafer evidence theory) [12]. In the Dempster-Shafer theory of evidence, uncertain input variables are represented as sets of intervals. Each interval is assigned a basic probability assignment (BPA) by the user, expressing the likelihood of the uncertain input falling within that interval. Subsequently, the intervals and their associated BPAs are processed through the simulation to derive cumulative distribution functions for belief (representing the lower bound on probability estimate) and plausibility (aligning with upper bound of probability estimate) [12].

Sampling-based uncertainty propagation

The adequacy of coverage in the uncertainty space of model input parameters is influenced by several factors, including the number of samples, the chosen probability distributions, and the selected sampling approach. Taking these factors into account is essential for addressing uncertainties and obtaining reliable results during the propagation process. Wilks' non-parametric method is a frequently employed approach in computational applications within the nuclear industry to establish tolerance limits with a certain confidence level for input parameters with unknown distributions [13]. One of the key benefits of using Wilks' method is that the required sample size remains independent of the number of input parameters, allowing for efficient handling of multiple input parameters simultaneously. *Table II* provides minimum sample size for Wilks' upper bounds and intervals.

Table II Minimum sample size required for tolerance/confidence Wilks' tolerance limits and bounds for ranks from 1 to 5.

r	95%/95%		99%/99%	
	Bound	Interval	Bound	Interval
1	59	93	459	662
2	93	153	662	1001
3	124	208	838	1307
4	153	260	1001	1596
5	181	311	1157	1874

For each SA scenario 150 cases (N) are sampled using Monte Carlo (MC) random sampling method in Dakota. In each case MELCOR simulations run for 72 h of the accident. Following a procedure similar to the deterministic-realistic hybrid methodology [14] the uncertainty ranges are calculated. 95th percentiles from the empirical cumulative distribution functions can be obtained for each of the FOMs. A subset of these trials can be sampled for Wilks' 95%/95% estimates. For 1st, 2nd and 3rd order, 59, 93 and 124 trials are necessary. The 59th, 92nd and 122nd value in the set of ordered output gives the conservative 95%/95% value. Out of N trials, 59, 93 and 124 samples are randomly selected, and Wilks' values are calculated. Correspondingly, for the parametric method the distribution of these randomly selected sets can be identified by a goodness-of-fit test. If the samples follow a normal distribution, the population mean (μ_p) and population standard deviation (σ_p) under a confidence level (say 95%), can be estimated as,

$$\mu_p \leq \left[\mu_s + t_\alpha(n-1) * \frac{\sigma_s}{\sqrt{n}}\right] \qquad (1)$$

$$\sigma_p^2 \leq \frac{(n-1) * \sigma_s^2}{\chi^2_{1-\alpha}(n-1)} \qquad (2)$$

where μ_s is the sample mean, σ_s is the sample standard deviation, $t_\alpha(n-1)$ is the Student t variable at $(1-\alpha)$ confidence level under $(n-1)$ degrees of freedom and $\chi^2_{1-\alpha}(n-1)$ is the χ^2 variable at $(1-\alpha)$ confidence level under $(n-1)$ degrees of freedom. The 95%/95% coverage ($Y_{95/95}$) can then be expressed as,

$$Y_{95/95} = \mu_{p,95\%} + 1.645 * \sigma_{p,95\%} \qquad (3)$$

To determine the goodness-of-fit (GoF) for a distribution, Pearson χ^2 test, Kolmogorov-Smirnov test and Anderson-Darling test are performed, which tests the hypothesis that the given distribution can be defined by a normal distribution. If the distribution does not follow a normal distribution, the test is performed by fitting Weibull and Extreme Value distributions. In the latter two cases, the 95%/95% confidence interval can be determined by means of probability box methods, log-likelihood ratio test, Wald test and Lagrange multiplier test. An alternative is using bootstrap method to obtain approximate confidence intervals for 95% limits. The idea is to repeatedly sample random 59, 93 and 124 samples from the original N trials and perform the GoF test and determine the 95th percentiles.

III. Results

III.A. Sensitivity Indices

The Morris sensitivity indices for the 4 splinter cases for cesium release fraction and iodine release fractions are presented in *Figure III*, *Figure IV*, *Figure V* and *Figure VI*. No incomplete simulations were found in SBO, whereas 9 numerical simulation code crashes were observed in LOCA. For the crashed cases the results were extrapolated to 72 h. The boxplots of the total CS and I2 release fractions are shown in *Figure I* and *Figure II* respectively. It is to be noted that the cesium isotope releases in LOCA are above the acceptability limit of 0.1 % of the inventory[1]. The impact of the method by which debris is expelled from the vessel is evident in the distribution of release fractions. Solely expelling molten liquid into the chamber results in greater releases. In scenarios involving LOCA, significantly higher quantities of CS are discharged in comparison to a SBO situation. However, this pattern does not hold true for I2 release, where comparable or even greater release occurs during SBO compared to LOCA. This suggests that the seemingly more severe accident (LOCA) with immediate failure of the primacy coolant system might paradoxically not be as dangerous in terms of I2 release.

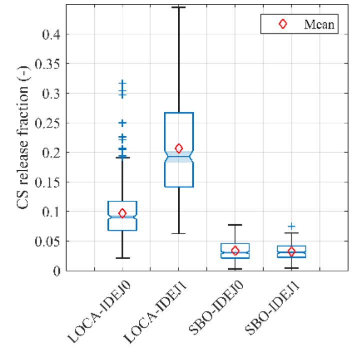

Figure I Boxplot for the distribution of the CS release fractions for the 4 splinter scenarios.

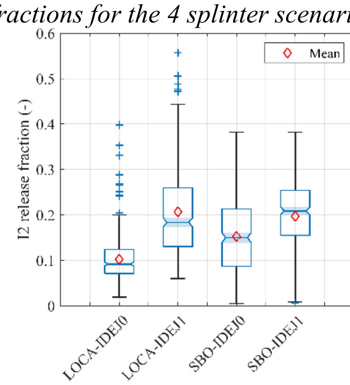

Figure II Boxplot for the distribution of the I2 release fractions for the 4 splinter scenarios.

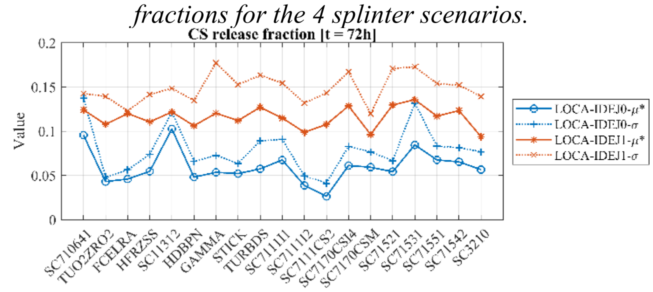

Figure III Morris sensitivity coefficients for CS release fraction during LOCA.

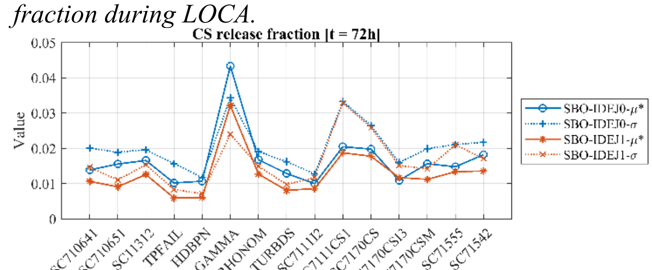

Figure IV Morris sensitivity coefficients for CS release fraction during SBO.

[1] According to the Swedish Radiation Safety Authority, acceptance criteria for mitigating systems after a SA is judged to be fulfilled if radioactive release after a severe accident is limited to below 0.1 % of inventory of cesium isotopes 134Cs and 137Cs in an 1800 MW core [15].

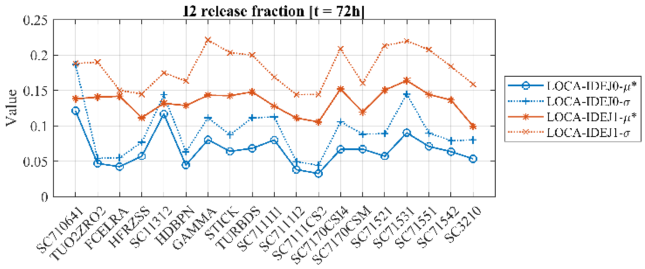

Figure V Morris sensitivity coefficients for I2 release fraction during LOCA.

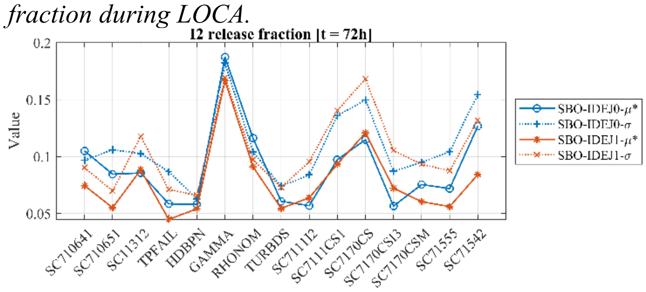

Figure VI Morris sensitivity coefficients for I2 release fraction during SBO.

In Morris method, μ_j^* represents the influence of input on output, and σ_j represents non-linearity and/or interaction between inputs. The figures above show the magnitude of the Morris indices at the end of 72 h since initiating event. Parameters SC11312 (breach temperature of crust or blockage for the release of molten material) of the candling model and FCELRA (radiative exchange factor from one cell boundary to adjacent cell) of the intercell radiation model are the most significant for CS release during LOCA-IDEJ0 and LOCA-IDEJ1 respectively. Parameters SC710641 (activation energy for the fuel type) of the CORSOR-Booth diffusion model in the fuel and FCELRA of the intercell radiation model are the most significant for I2 release during LOCA-IDEJ0 and LOCA-IDEJ1 respectively. Parameter GAMMA (aerosol agglomeration shape factor) of the aerosol dynamics model is the most significant for CS and I2 releases during SBO-IDEJ0 and SBO-IDEJ1.

However, the most important parameters can change over the course of the accident progression. Such changes provide important insights for assessment of effectiveness of the mitigation strategy in reducing the releases of CS and I2 into the environment. By analyzing the indices at different times for each of the splinter cases, one can identify what model drives the FP release at each stage. *Table III* and *Table IV* provide the driving parameters during different time periods of the accident for CS and I2 releases respectively.

Table III Significant parameters over the course of 72 h of the accidents for CS release.

LOCA-IDEJ0		
0 – ~4 h SC71542	~4 – 10 h SC71531	~10 – 72 h SC11312
LOCA-IDEJ1		
0 – ~6 h SC71542	~6 – 15 h SC11312	~15 – 72 h FCELRA
SBO-IDEJ0		
0 – ~2.75 h SC71555	~2.75 – 12 h GAMMA	~12 – 72 h GAMMA
SBO-IDEJ1		
0 – ~2.75 h SC71555	~2.75 – 15 h GAMMA	~15 – 72 h GAMMA

Table IV Significant parameters over the course of 72 h of the accidents for I2 release.

LOCA-IDEJ0		
0 – ~2.5 h SC71542	~2.5 – 8 h GAMMA	~8 – 72 h SC11312
LOCA-IDEJ1		
0 – ~6 h SC71542	~6 – 15 h SC11312	~15 – 72 h FCELRA
SBO-IDEJ0		
0 – ~2.75 h SC71555	~2.75 – 12 h GAMMA	~12 – 72 h GAMMA
SBO-IDEJ1		
0 – ~2.75 h SC71555	~2.75 – 10 h GAMMA	~10 – 72 h GAMMA

For cesium release, parameter SC71542 of the SPARC-90 bubble swarm velocity model is the most significant parameter in the initial hours of LOCA in both solid debris ejection mode on and off. Subsequently, parameter SC71531 of the SPARC-90 bubble rise velocity model affects most the release in case of LOCA-IDEJ0, whereas parameter SC11312 is dominating in LOCA-IDEJ1. During the initial period of SBO, parameter SC71555 of the SPARC-90 particle impaction model drives the CS release mechanism in both modes of IDE0 and IDEJ1. For iodine release, parameter SC71542 is the most significant parameter in the initial hours of LOCA in both solid debris ejection mode on and off. Subsequently, parameter GAMMA drives the release in case of LOCA-IDEJ0, whereas parameter SC11312, is dominating. During the initial period of SBO, parameter SC71555 drives the I2 release mechanism in both modes of IDE0 and IDEJ1. Further analysis is underway to understand the interrelation between the phenomena involved.

III.B. Uncertainty Analysis

Table V provides the values of maximum, minimum, mean, standard deviation and the 95th percentiles for the distributions with 150 runs for each scenario.

Table V Summary of the UA results.

	Size	min	max	***μ***	***σ***	95th %
CS release						
LOCA-IDEJ0	150	0.0287	0.2115	0.0875	0.0286	0.1372
LOCA-IDEJ1	150	0.0768	0.3948	0.2032	0.0781	0.342
SBO-IDEJ0	150	0.0037	0.0869	0.0311	0.0147	0.0567
SBO-IDEJ1	150	0.0053	0.0706	0.0303	0.0124	0.0523
I2 release						
LOCA-IDEJ0	150	0.028	0.2018	0.092	0.0338	0.1588
LOCA-IDEJ1	150	0.082	0.4977	0.2008	0.093	0.3945
SBO-IDEJ0	150	0.0064	0.3896	0.147	0.0663	0.2623
SBO-IDEJ1	150	0.0149	0.3606	0.1918	0.0681	0.2942

Non-parametric method results

Considering each FOM independently, the Wilks' non-parametric estimates for the first 3 orders of one sided 95/95 is calculated. These are then repeatedly calculated for 500 different, random selections of samples for each order and the maximum, minimum, mean and standard deviation of the resulting distributions are presented in *Table VI*.

Table VI Wilks' non-parametric 95/95 estimates.

		CS release				I2 release			
	Size	min	max	***μ***	***σ***	min	max	***μ***	***σ***
LOCA-IDEJ0	59	0.1333	0.2115	0.1755	0.0298	0.1353	0.2018	0.1882	0.0145
	93	0.1347	0.1629	0.1555	0.009	0.147	0.1857	0.179	0.0082
	124	0.1372	0.1593	0.1528	0.0081	0.1607	0.1857	0.179	0.0082
LOCA-IDEJ1	59	0.3325	0.3948	0.3885	0.0102	0.3746	0.4977	0.4703	0.0289
	93	0.3387	0.389	0.3867	0.0051	0.3945	0.4468	0.443	0.0078
	124	0.3582	0.389	0.3867	0.0051	0.4048	0.4468	0.443	0.0078
SBO-IDEJ0	59	0.0556	0.0869	0.0754	0.0101	0.2390	0.3896	0.3262	0.0531
	93	0.0557	0.0705	0.067	0.0042	0.2515	0.278	0.2747	0.0041
	124	0.0589	0.0705	0.067	0.0042	0.2623	0.278	0.2747	0.0041
SBO-IDEJ1	59	0.0471	0.0706	0.0625	0.0069	0.2802	0.3606	0.3298	0.0271
	93	0.0518	0.0579	0.0573	0.0011	0.29	0.3062	0.3032	0.0036
	124	0.0526	0.0579	0.0573	0.0011	0.2944	0.3062	0.3032	0.0036

Parametric method results

Based on the goodness-of-fit tests, the 95/95 estimates for a normal distribution are calculated for 500 bootstraps of each statistical order using the Equation (3) mentioned earlier. The boxplots of the resulting distribution in CS and I2 release fractions during LOCA and SBO are shown in *Figure VII, Figure VIII, Figure IX* and *Figure X* respectively. The 95th percentiles are calculated only for those instances which passe the respective tests. In addition, estimations by Weibull and EV distributions are also shown in the figures[2].

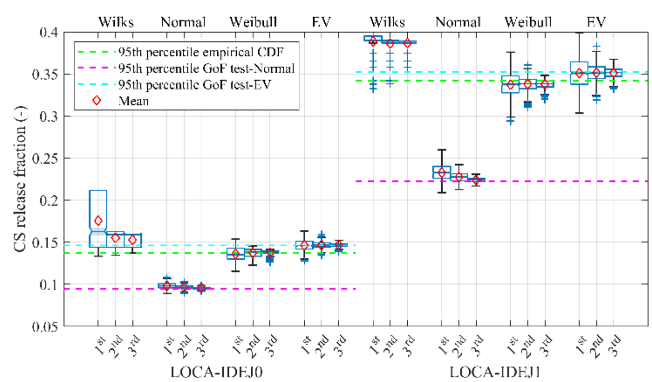

Figure VII Boxplots for the 95/95 estimates by goodness-of-fit tests for CS release during LOCA.

[2] The 95th percentile estimates for the initial 150 trials are shown as horizontal line Note that since the distributions of CS and I2 release fractions did not pass the test for Weibull fit, the estimate is not shown. However, for CS release during LOCA-IDEJ1, SBO-IDEJ0, SBO-IDEJ1 and I2 release during LOCA-IDEJ1 do not pass the test for normal fit, nevertheless the 95th percentile is estimated for reference purposes.

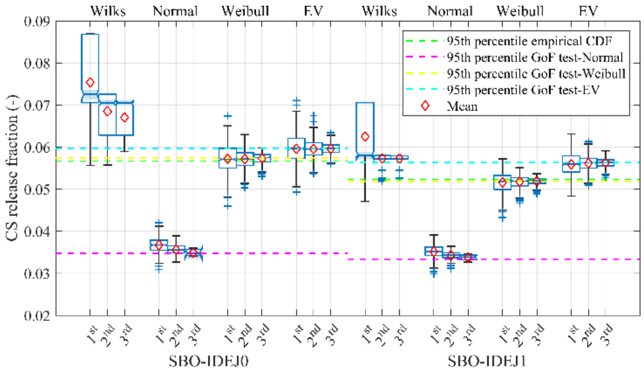

Figure VIII Boxplots for the 95/95 estimates by goodness-of-fit tests for CS release during SBO.

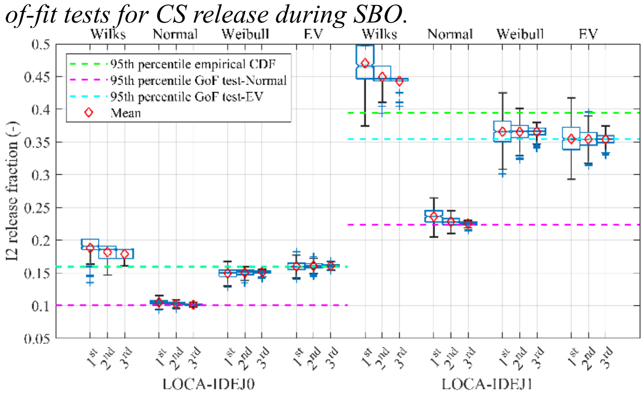

Figure IX Boxplots for the 95/95 estimates by goodness-of-fit tests for I2 release during LOCA.

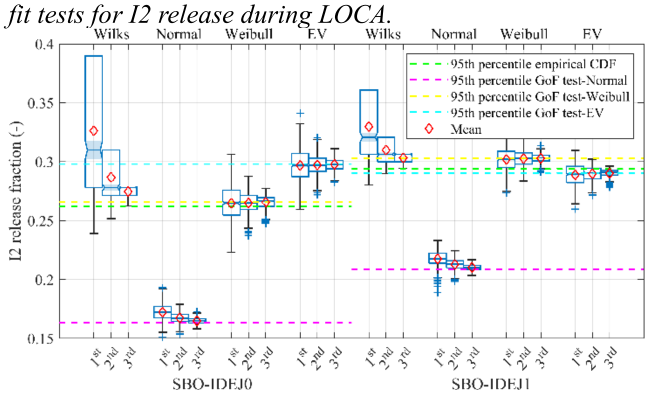

Figure X Boxplots for the 95/95 estimates by goodness-of-fit tests for I2 release during SBO.

IV. Conclusions

The results obtained from the CS and I2 releases are conservative, where a significant number of trials exceed the threshold for acceptable release. Due to the computational complexity of analyzing the results using MELCOR simulations, the current study adopted a bootstrap approach to determine the 95/95 confidence bounds. The non-parametric Wilks' method is notably conservative for the initial three statistical orders. In contrast, the parametric goodness-of-fit test, yields less conservative estimates. When considering Weibull and EV distributions, the analysis demonstrates that the choice of distribution significantly impacts the calculated 95/95 confidence bounds.

Acknowledgments

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