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Insights from the Preliminary Uncertainty Analysis for ICARE2 Late Core Degradation Models : TMI2 and FPT4S Cases

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Abstract

Using a coupled system of the severe accident analysis code ICARE2 and the statistical uncertainty quantification code SUNSET, a preliminary uncertainty analysis has been performed (1) to verify an applicability of the most recent ICARE2 301 version to TMI2 late phase and PHEBUS experiment FPT4S and (2) to provide a framework for final uncertainty analysis. The results show that the ICARE2 301 version is well suited to the FPT4S case through the wide-ranges of uncertainty parameters while the code results in crashes of a few calculations for the TMI2 case. Based on this study, some additional tasks are recommended: (1) identify and resolve the crashes of calculations due to any combination of uncertainty parameters (TMI2 only), (2) increase the number of uncertainty samples (TMI2 and FPT4S) to get more reliable results for uncertainties, (3) consider a longer transient time to identify the impact of some uncertainty parameters on the final results (TMI2 only), and (4) utilize more refined uncertainty ranges and distribution types, in the final stage of the uncertainty analysis.

1. INTRODUCTION

The main objectives of this work are to identify the applicability of the ICARE2 301 version to the uncertainty analysis for TMI2 late phase and PHEBUS experiment FPT4S, and to construct a set of framework for final uncertainty analysis. The ICARE2 code input data is presented in the form of independent block data with a kind of tree structure, each of them defining various types of quantities [1]. These quantities may be either scalar values, tabulated parameters and structures. Moreover, the code is linked to the SIGAL analyzer which is a set of general libraries and tools providing many facilities like a management of all main information [2,3], pre- and post-processing and its uncertainty analysis is currently made by coupling with a statistical code, SUNSET [4,5]. Because of these features of ICARE2, its uncertainty analysis is normally performed by taking the following procedures,

Step 1: Select key uncertain parameters which might impact greatly on the subsequent accident progression and response parameters to identify their impacts. Twenty eight and twenty three uncertain parameters have been selected for TMI2 and FPT4S, respectively and they are classified into major three categories: boundary conditions, material properties, and physical parameters which are mainly related to the debris bed and molten pool dynamics. Nine response parameters are considered for the TMI2 late phase analysis and twenty response parameters are selected for the FPT4S analysis.

Step 2: Assign bounding values to each uncertain parameter and related probability distribution, by considering the existing data source and expert judgment if needed. In this work, all probability distributions are assumed to be uniform, characterizing the largest uncertainty for given uncertainty bound.

Step 3: Prepare all procedures for modification of uncertain input values and for extraction of the response values. This step corresponds to the introduction of uncertainties into ICARE2 and this is currently made by coupling with SUNSET. Based on this framework for uncertainty analysis, all the procedures are written utilizing the SIGAL analyzer language.

Step 4: Identify the applicability of the current ICARE2-SUNSET to the uncertainty analysis with a limited set of uncertainty samples. This is to investigate any combination of uncertain samples causing a crash in the calculations of ICARE2. A crash in the calculation might come largely from the improper modification procedure and/or inappropriate modeling of ICARE2.

Step 5: If all problems are resolved in the previous step, the remaining step is to perform the final uncertainty and sensitivity analysis with a full set of uncertainty samples, in order to derive statistical parameters for each of response parameters (e.g., mean, median, variance), confidence intervals, and sensitivity measures to rank the input parameters according to the importance of their contribution to the whole response uncertainty.

For the purpose of this work, the preliminary uncertainty analysis is limited only to performing the above steps (1) to (4) because the last step will be made in the further work. TABLE 1 shows all uncertainty inputs applied in this study and the response parameters are given in TABLE 2.

2. THE FRAMEWORK FOR UNCERTAINTY ANALYSIS

In order to perform the uncertainty analysis under ICARE2-SUNSET framework, it is necessary to prepare two types of uncertainty input structures. One is to specify the uncertainty inputs to be modified and response parameters to be extracted in the ICARE2 input data [6] and another is to prepare SUNSET specific input data [7].

2.1 Specification of SUNSET Uncertainty Inputs

The statistical code, SUNSET, provides the user with a global and modular approach to the uncertainty and sensitivity analysis of the results of a calculation code. For this purpose, SUNSET input data specifies the following three conditions to be utilized in the uncertainty analysis:

(1) Specification of types for statistical analysis: Some options for statistical sampling are specified in the first part of SUNSET input data, including information on sampling type, link to the executable code, random number generator, two statistical tolerance limits utilized in Wilks' formula (i.e., fractile, confidence level), and confidence threshold for the statistical tests.
(2) Specification of uncertainty inputs: The information for the uncertainty inputs is specified by including parameter index, parameter name corresponding to the modification procedure described in ICARE2 input data, probability distribution to be applied and related parameter values.
(3) Specification of response parameters: The information for the response parameters are specified by including parameter name corresponding to the extraction procedure described in ICARE2 input data and response data type, some options for statistical analysis.

Based on the above conditions, the results of a code calculation are obtained in the forms of ICARE2 code outputs for each calculation, their statistical values (e.g., mean and standard deviation, etc.), and sensitivity coefficients by a type of regression model (e.g., normalized regression coefficients, standard regression coefficients, partial rank correlation coefficients, etc.).

2.2 Specification of ICARE2 Uncertainty Input

In addition to the preparation of SUNSET input data, the ICARE2 input data must also be modified to perform the uncertainty analysis. This can be made by specifying some information about the uncertainty inputs and response parameters in the last part of the ICARE2 input data. This data part consists of a type of ICARE2 data base structure and usually put in the last part of the input data to modify the existing parameter values. These data structures are placed in the last part of ICARE2 input.

2.3 Uncertain Parameter Modification

As mentioned before, the uncertainty inputs are modified by a type of modification procedures which manages a particular parameter and to put it at the right place in the ICARE2 data base. This kind of procedure which is written in the SIGAL analyzer language, has no particular result and modifies only the existing values to the new values specified by SUNSET during the uncertainty calculation. The following rules are applied in to preparation of a modification procedure:

(1) If information for material properties under consideration is not explicitly specified in ICARE2 input deck, put the information in the right positions.
(2) All uncertainty inputs are treated as an independent parameter, except for,
    - Solidus temperatures for UO2 & ZRO2 are treated as the same uncertainty parameter for FPT4S
    - Liquidus temperatures UO2 & ZRO2 are treated as the same uncertainty parameter for FPT4S
    - Emissivities are treated as the same uncertainty parameter for FPT4S & TMI2
(3) Uncertainty bounds are given by three data types, depending on each feature of uncertain inputs. The last two types are mostly applied to material properties which are functions of temperature and the temperature behavior of material properties is one of the parameters for uncertainty studies.
    - Raw data: Reference (nominal) values given in ICARE2 are replaced by new data values. Its mathematical expressionis given as follows, $X_{ref} \leftarrow X_{new}$.

- Multiplier (M.F) : Reference values given in ICARE2 are replaced by a product of constant value. In the uncertainty analysis the random number K is generated in the range of $K > 0$. Its mathematical expressionis given as follows, $X_{new} \leftarrow K \cdot X_{ref}$, $K > 0$.
- Weighted multiplier(W.M) : Reference values given in ICARE2 are replaced by a weighted average of lower and upper bound values. In the uncertainty analysis the random number a is generated in the range of $0 \leq a \leq 1.0$. Its mathematical expressionis given as follows,

  $X_{new} \leftarrow a \cdot X_{ref}^{upper} + (1 - a) \cdot X_{ref}^{lower}$, $0 \leq a \leq 1.0$.

2.4 Response Data Extraction

The response parameters are obtained by a type of extraction procedure which gets some information from the ICARE2 data base or builds information combining data issued from the data base. There are two types of response parameters, i.e., scalar responses and time-dependent responses. For a time-dependent response, the time-dependent response values are transformed to have the same sampling time for all the calculations of the response. By this approach, the time-dependent uncertainty bands and time-dependent sensitivity measures are calculated. The scalar type of response always results in only one value for each calculation and the final outputs are treated by data histogram. The following rules are applied in preparation of the extraction procedures:

(1) While some response values are directly obtained from the global parameters defined in the ICARE2 data base, other values are evaluated by utilizing the data base information.

(2) Three storage types are utilized to store the extracted uncertainty values, depending on each feature of the response parameters:
- SCALAR type: This type of response parameter is characterized by having only one point value for each uncertainty sample vector and through whole transient time.
- VECTOR type: This type of response parameter is characterized by having time-dependent response values for each uncertainty sample vector and through whole transient time.
- MATRIX type: This type of response parameter is basically the same as the VECTOR type, except that several response parameters are treated in a common procedure.

3. IMPLEMENTATION AND RESULTS

The primary concern of this study is to verify the applicability of the ICARE2 301 version to the uncertainty analysis of TMI2 late phase accident scenarios and PHEBUS experiment FPT4S and to provide a framework for real uncertainty analysis. This section summarizes the results of their implementations.

3.1 Conditions for Implementation

Three main groups of uncertainty sources are utilized in this study, i.e., initial and boundary conditions, material properties, and physical model parameters which describe mostly the debris bed dynamics. Then all computations necessary for uncertainties analysis should be made taking into account probability distribution for each input parameter. There are several methods to generate random sets of input parameters. In this study the random sampling method to generate random sets of input parameters is used for simplicity. Analysis of uncertainties for deterministic models like this study may be difficult because of the large amount of input parameters when the quantitative assessment of their influence is unknown. In this study, thus, all input parameters are assumed to be independent. Furthermore, the uncertainty of each parameter may be estimated by the corresponding probability distribution in a given range of its variation. Because real distributions are unknown for the time being all distributions are assumed to be uniform. On the other hand, the uncertainty samples for ICARE2 calculations are automatically specified in SUNSET, based on two tolerance limits of Wilks' formula (i.e., fractile and confidence level). In this study two tolerance limits (i.e., a bilateral α-fractile at the β-confidence level), α=0.9 and β=0.95, are applied as statistical values, respectively, determining the uncertainty sample number. According to these values, 46 uncertainty samples are automatically generated by SUNSET.

3.2 Statistical Outputs for the Responses

Under the above conditions, this study has shown that the ICARE2 301 version is well suited to the FPT4S case through the wide-ranges of uncertainty parameters (no crash) while the code results in an abnormal stop for just five calculations of the TMI2 case. Accordingly, the statistical analysis has been made for whole outputs in the FPT4S case (i.e., 46 response values), but the analysis has been limited to slightly reduced outputs in the TMI2 case (i.e., 41 response values).

The results are shown in TABLE 3.1 and TABLE 3.2, respectively. All these values are obtained at the specified final transient time of calculations, i.e., 6000 sec. for TMI2 and 18000 sec. for FPT4S.

3.3 Sensitivity Coefficients

On the other hand, a regression approach provides some information for quantitative sensitivity measures. In this study the normalized regression coefficients obtained from the first order linear regression model were utilized, which are derived from SUNSET. These measures represent the relative contribution in percentage of uncertainties of each parameter to uncertainties of a given response. Thus, these coefficients can be used as an initial appreciation of the sensitivity of the response to the parameter under consideration. They can be used as far as the use of such a regression model is justified. TABLE 4.1 and TABLE 4.2 show the normalized regression coefficients for TMI2 (at 6000 sec.) and FPT4S (at 18000 sec.), respectively. From these coefficients, it is possible to extract key uncertainty parameters to the given response which needs to be studied in more detail or an experiment to reduce their uncertainties. For example, the five largest contributors to the mass of the molten material (MASSMM) for TMI2 case are classified by PARDST (14.1%), CONZRO (8.8%), UO2SOL (8.1%), TMCLAD (7.7%), MNPORO (7.0%). In this case, a percentage sum of the five largest contributors takes charge of about 45.7 % of the overall parameters. Of course, key uncertainty contributors might be different with the response. It is identified that the present results for sensitivity coefficients are consistent with the results obtained using the one-at-a-time sensitivity analysis based on point values.

4. CONCLUSION AND RECOMMENDATIONS

Using a coupled code system of ICARE2 and SUNSET, a preliminary uncertainty analysis has been performed (1) to verify the applicability of the most recent ICARE2 301 version to TMI2 late phase and PHEBUS experiment FPT4S and (2) to provide a framework for final uncertainty analysis. The results show that the ICARE2 301 version is well operated for the FPT4S case through the wide-ranges of uncertainty parameters while the code results in crashes in a few calculations for the TMI2 case. Especially, it is identified that the major uncertainty contributors on each response are consistent with the results obtained by one-at-a-time sensitivity analysis based on point values. For the TMI2 case, a deeper investigation should be made to resolve the calculational problem, which cause the crashes. This can be made by investigating the physically unreasonable combination of uncertainty samples or the use of bounding values exceeding the range of any parameter considered in the ICARE2 code.

Based on this study, the following recommendations have been made for the final uncertainty analysis :

(1) Primarily, it is necessary to identify and resolve the sources of abnormal calculations for some combinations of uncertainty parameters for the TMI2 case (i.e., Crash case).
(2) Second, it is necessary to check a correlation matrix between input parameters to make sure that all parameters are independent, in case any dependency between uncertain parameters are not specified.
(3) Third, it is possible to get more reliable results for uncertainties by using a larger number of uncertainty samples (e.g., two tolerance limits $\alpha = \beta$ =0.95 in Wilks' formula providing 93 samples). It may be required to utilize LHS (Latin Hypercube sampling) to provide more credible results under a limited number of uncertainty samples.
(4) Fourth, it is required to specify more refined uncertainty ranges and distributions. For example, there is no data for surface tension of liquid material and thus its uncertainty range is assumed. Additionally, all distributions are assumed to be uniform. If existing, real distributions should be used in the final analysis.
(5) Fifth, it is necessary to consider a longer transient time to identify the impact of uncertainty parameters on the final results (e.g., baffle thermal failure for TMI2 case).
(6) Sixth, it is more informative to extract time evolutionary results for time-dependent response parameters.

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TABLE 1 Uncertainty Parameters for TMI2 & FPT4S

Category	Uncertainty Parameters	Uncertainty Ranges	Parameter Name	Application		Data Type		
				TMI2	FPT4S	Raw	M.F[1]	W.M[2]
I.C & B.C	total power	[0.9, 1.0]	TPOWER		√		√	
	steam mass flow	[0.91, 1.09]	QSTEAM		√		√	
	hydrogen mass flow	[0.96, 1.04]	QHYDRO		√		√	
	initial porosity	[0.4, 0.6]	DBPORO		√	√		
	particles size distribution	[2.0, 5.0]e-3	PSZDST		√	√		
	auto-protection factor	[0.9, 1.1]	SHIELD		√	√		
Material Property	melting temp UO2 (solid)	[2760, 2840	UO2SOL	√	√	√		
	melting temp UO2 (liquid)	[2760, 2840]	UO2LIQ	√	√	√		
	melting temp ZrO2 (solid)	[2885, 2915]	ZROSOL	√	√	√		
	melting temp ZrO2 (liquid)	[2885, 2915]	ZROLIQ	√	√	√		
	solid emissivity UO2	Data Table	EMSUO2	√	√			√
	liquid emissivity UO2	Data Table		√	√			√
	solid emissivity ZrO2	Data Table	EMSZRO	√	√			√
	liquid emissivity ZrO2	Data Table		√	√			√
	liquid viscosity UO2	[0.67, 1.33]	VISUO2	√	√		√	
	liquid viscosity ZrO2	[3.0, 4.0]e-3	VISZRO	√	√			√
	liquid viscosity Zr	[3.0, 4.0]e-3	VISZRR	√				√
	liquid viscosity SS	[4.5, 6.0]e-3	VISSTL	√				√
	liquid surface tension UO2	[0.8, 1.2]	SUFUO2	√	√		√	
	liquid surface tension ZrO2	[0.8, 1.2]	SUFZRO	√	√		√	
	liquid surface tension Zr	[0.8, 1.2]	SUFZRR	√			√	
	liquid surface tension SS	[0.8, 1.2]	SUFSTL	√			√	
	contact angle UO2	[0.0, 180]	CONUO2	√	√	√		
	contact angle ZrO2	[0.0, 180]	CONZRO	√	√	√		
	contact angle Zr	[0.0, 180]	CONZRR	√		√		
	contact angle SS	[0.0, 180]	CONSTL	√		√		
Physical Models: *Debris Formation*	thickness of clad failure	[0.9, 1.1]	THCLAD	√			√	
	max. temp. of clad failure	[1.4, 2.6]e+3	TMCLAD	√		√		
	size distribution of particles	[2.0, 5.0]e-3	PARDST	√		√		
	fraction of frozen corium	[0.0, 1.0]	-[3]	√		√		
Debris bed Properties	radiative contribution (Imura-Yagi)	[0.8, 1.2]	RADCON	√	√	√		
	shape factor (Imura-Yagi)	[0.8, 1.0]	FSHAPE	√	√	√		
	multiplying factor (Carman-Cozeny)	[1.0, 1.42]	MFACTR	√	√	√		
	relative permeability (Carman-Cozeny)	[2.0, 4.0]	RLPERM	√	√	√		
	multiplying factor (Gunn)	[0.21, 1.05]	CONVHT	√	√	√		
Molten Pool	effective conductivity (Mayinger)	[0.1, 10.0]	-	√	√	√		
	boundary layer thickness	[0.76, 1.0]	-	√		√		
	height of upper zone	[0.0, 0.5]	-	√		√		
	temperature of upper zone	[2.5, 3.0]e+3	-	√		√		
Crust Formation	unstable crust temperature	[0.0, 1.0]	TCRUST	√	√	√		
	mushy region conductivity	[0.0, 1.0]	-	√	√	√		
Cavity Radiation	minimum porosity	[0.0, 0.1]	MNPORO -	√	√	√		

Note: MF [1]: Multiplier, WM [2]: Weighted Multiplier , - [3]: not considered in this study

TABLE 2 Response Parameters for TMI2 & FPT4S

Category	Response Parameters	Parameter Name	Application		Data Storage Type		
			TMI2	FPT4S	Scalar	Vector	Matrix
Molten Pool	total mass of molten material	MASSMM	√	√		√	
	height of molten pool	-[1]	√	√		√	
	radius of molten pool	-	√	√		√	
	bottom elevation of molten pool	-	√	√		√	
	top crust thickness	-	√	√		√	
	bottom crust thickness	BTCRST	√	√		√	
	side wall crust thickness	SDCRST	√	√		√	

	time of molten pool appearance oxide composition of molten pool	TIMEPL COMMPL	√ √		√	 √	
Debris bed Others	total hydrogen production total mass of debris formed oxide composition of debris formed upper plenum temperature time of baffle thermal failure	MASSH2 MASSDB COMPDB TEMPUP TIMBFL	√ √ √ √ √		 √	√ √ √ √	
Temp. at Axial level	thermocouple temperature(shroud) axial level: 123,153,183,218,273 (SHR28) 73 (HFR28) thermocouple temperature (debris bed) axial level: 70 (PBED4) 153, 193, 322 (BED4) maximum temperature (shroud) (SHR11) (SHR20) (HFR20) axial level for max shroud temp. gas temperature at outlet axial level: 914 (CHAN1)	 TCRSHR1- TCRSHR6 TCRBED1- TCRBED4 TMPMAX 1 TMPMAX 2 TMPMAX 3 LVLMAX1 LVLMAX2 LVLMAX3 GASOUT		 √ √ √ √ √ √ √ √ √ √ √	 √ √ √ √ √ √	 √	 √ √ √ √

Note: - [1]: not considered in this study (to be considered in the final analysis)

TABLE 3.1 Results for TMI2 Case : Statistical Values

Response Parameters	Statistical Values			
	Min	Max	Mean	S.D[1]
MASSH2	240.7	342.3	289.6	19.8
TEMPUP	1125.2	1511.1	1298.6	106.8
MASSMM	11833.7	79686.4	43768.5	19792.3
COMPDB	0.0752	0.4662	0.2779	0.0958
MASSDB	62064.6	120172	91532.4	16085.5
TIMEPL	3045.0	4340.6	3355.4	259.6
COMPPL	$9.90e^{-4}$	0.504	0.145	0.117
BTCRST	0.0	4.2	0.220	0.844
SDCRST	0.0	0.42	0.264	0.075
TIMBFL	N.A	N.A	N.A	N.A

Note: S.D[1] Standard deviation

TABLE 3.2 Results for FPT4S Case : Statistical Values

Response Parameters	Statistical Values			
	Min	Max	Mean	S.D
TCRSHR1	801.1	1517.6	1161.0	227.0
TCRSHR2	997.4	1653.6	1376.5	216.0
TCRSHR3	1105.9	1703.3	1469.0	173.9

TCRSHR4	1234.9	1807.8	1477.8	132.6
TCRSHR5	1311.9	1773.9	1414.2	73.6
TCRSHR6	574.1	901.5	708.9	77.9
TCRBED1	851.7	2335.7	1486.2	296.5
TCRBED2	2161.1	3572.9	2876.9	205.5
TCRBED3	2493.0	3650.9	2956.6	156.9
TCRBED4	2686.1	2957.8	2795.7	43.9
TMPMAX1	2506.1	3263.6	2808.2	211.7
TMPMAX2	612.7	1131.5	813.6	120.5
TMPMAX3	2282.5	2923.7	2531.9	171.6
LVLMAX1	0.15	0.31	0.217	0.0432
LVLMAX2	0.07	0.07	0.07	0.0
LVLMAX3	0.15	0.31	0.217	0.0437
GASOUT	707.3	882.2	757.6	37.2
MASSMM	$5.54e^{-3}$	4.28	2.33	1.00
BTCRST	0.0	0.16	0.0483	0.0528
SDCRST	0.0	0.024	$3.33e^{-3}$	$4.69e^{-3}$

TABLE 4.1 Results for TMI2 Case : Normalized Regression Coefficients

Responses Inputs	MASSH2	TEMPUP	MASSMM	COMPDB	MASSDB	TIMEPL	COMPPL	BTCRST	SDCRST
UO2SOL	0.0266423	0.0565181	0.0811620	0.0653080	0.0897081	0.0369833	0.0405970	0.0657311	0.0619492
UO2LIQ	0.0108255	0.0623868	0.0235595	0.0242788	0.0267016	0.0755602	0.0353468	0.0086591	0.0004615
ZROSOL	0.0150509	0.0314797	0.0189236	0.0228773	0.0109870	0.0944508	0.0364622	0.0361744	0.0134633
ZROLIQ	0.0423794	0.0368786	0.0075040	0.0081191	4.388e-05	0.0045969	0.0097516	0.0721989	0.0112611
EMSUO2	0.0173161	0.0467654	0.0399086	0.0284917	0.0344047	0.0081254	0.0253139	0.0298010	0.0268976
EMSZRO	0.0761197	0.0161871	0.0376454	0.0514099	0.0527902	0.0184844	0.0378320	0.0217236	0.103104
VISUO2	0.0101728	0.0071243	0.0107495	0.0341167	0.0026599	0.0326900	0.0603936	0.0440456	0.0033291
VISZRO	0.0445773	0.0738950	0.0167580	0.0308954	0.0148615	0.0566162	0.0176871	0.0118131	0.0180853
VISSTL	0.0399424	0.0437736	0.0239556	0.0227096	0.0260801	0.0319063	0.0098859	0.0075651	0.0061990
VISZRR	0.0811725	0.0222768	0.0099271	0.0049380	0.0124681	0.0448950	0.0209325	0.0332834	0.0508244
SUFUO2	0.0009050	0.0105167	0.0446283	0.0419054	0.0529278	0.0481339	0.0082003	0.0956944	0.0348709
SUFZRO	0.0350528	0.0475686	0.0221439	0.0445548	0.0299530	0.0323437	0.0633149	0.0244070	0.0206488
SUFSTL	0.0430917	0.0308080	0.0214708	0.0277460	0.0326228	0.0019403	0.0400589	0.0016497	0.0223726
SUFZRR	0.0392547	0.0090434	0.0308974	0.0551296	0.0277780	0.0559106	0.0414398	0.0809018	0.0317223
CONUO2	0.0381102	0.0075993	0.0011591	0.0101845	0.0289140	0.0446539	0.0855833	0.0573516	0.0142580
CONZRO	0.0413136	0.0392051	0.0879664	0.0784168	0.0913609	0.0162290	0.0232695	0.0669397	0.0432262
CONSTL	0.0133043	0.0022689	0.0454321	0.0131396	0.0450623	0.0551151	0.0150368	0.0248415	0.0149760
CONZRR	0.0441305	0.0272112	0.0072917	0.0002052	0.0201605	0.0059296	0.0240225	0.0275073	0.0389775
THCLAD	0.0275932	0.0832964	0.0490820	0.0018907	0.0238034	0.0496126	0.0113460	0.0125508	0.0560898
TMCLAD	0.0148204	0.0240236	0.0765435	0.0916228	0.0735140	0.0444630	0.0643423	0.0127803	0.0220797
PARDST	0.101536	0.115465	0.140910	0.145369	0.102680	0.0884010	0.100217	0.0024657	0.0417151
RADCON	0.0146998	0.0058500	0.0001025	0.0357534	0.0138394	0.0129154	0.0499214	0.0457680	0.0878062
FSHAPE	0.0366956	0.0198795	0.0206025	0.0274901	0.0404637	0.0453900	0.0291541	0.0637676	0.0614011
MFACTR	0.0073038	0.0435515	0.0346109	0.0515055	0.0305407	0.0296509	0.0346697	0.0013723	0.0387425
RLPERM	0.104687	0.0087331	0.0210141	0.0001356	0.0238654	0.0270145	0.0095348	0.0406387	0.0563947
CONVHT	0.0114564	0.0107309	0.0254705	0.0211271	0.0292177	0.0071564	0.0286106	0.0007339	0.0282832
TCRUST	0.0235796	0.0478942	0.0302771	0.0046515	0.0082335	0.0064519	0.0190560	0.0233671	0.0410155
MNPORO	0.0382663	0.0690690	0.0703042	0.0560280	0.0543578	0.0243800	0.0580193	0.0862671	0.0498457

TABLE 4.2 Results for FPT4S Case : Normalized Regression Coefficients

Response Inputs	TCRSHR1	TCRSHR2	TCRSHR3	TCRSHR4	TCRSHR5	TCRSHR6	TMPMAX1	TMPMAX2	TMPMAX3
TPOWER	0.143980	0.145586	0.147168	0.108458	0.0567920	0.167606	0.191236	0.171003	0.190405
QSTEAM	0.0274715	0.0361498	0.0551070	0.0543785	0.0686660	0.0035867	0.0447916	0.0041195	0.0470419
QHYDRO	0.0375561	0.0282226	0.0038625	0.0016645	0.0266801	0.0181231	0.0228727	0.0223066	0.0165098
DBPORO	0.117138	0.147708	0.225177	0.311778	0.181772	0.140392	0.242731	0.142660	0.254489
PSZDST	0.0810573	0.0792462	0.0727636	0.0132791	0.0397720	0.0079619	0.0291998	0.0024298	0.0332616
SHIELD	0.128085	0.112246	0.103731	0.0824577	0.0441947	0.152795	0.159595	0.163046	0.156135

SOLMLT	0.0152487	0.0154616	0.0321681	0.0119605	0.0561870	0.0191494	0.0352169	0.0172717	0.0328882
LIQMLT	0.0039457	0.0006305	0.0253209	0.0247805	0.0083062	0.0062169	0.0013282	0.0037841	0.0008798
EMSUO2	0.0282935	0.0153458	0.0034259	0.0531863	0.0122409	0.0298124	0.0360530	0.0275697	0.0349556
EMSZRO	0.0344314	0.0262841	0.0213712	0.0479560	0.0591372	0.0399968	0.0189598	0.0416530	0.0203609
VISUO2	0.0765440	0.0510364	0.0532019	0.0248207	0.0407555	0.0896894	0.0147900	0.0892331	0.0152750
VISZRO	0.0193069	0.0235593	0.0001016	0.0043756	0.0297999	0.0438069	0.0081735	0.0444903	0.0016023
SUFUO2	0.0091969	0.0071782	5.397e-05	0.0126070	0.0272406	0.0211750	0.0335259	0.0245510	0.0334632
SUFZRO	0.0108670	0.0087719	0.0291562	0.0037330	0.0296902	0.0250172	0.0370688	0.0205998	0.0332564
CONUO2	0.0984722	0.0896747	0.0709367	0.0237722	0.0765259	0.0928407	0.0044786	0.0933853	0.0152480
CONZRO	0.0419769	0.0434126	0.0302777	0.0270311	0.0242751	0.0201747	0.0189358	0.0150206	0.0220515
RADCON	0.0044177	0.0124116	0.0039155	0.0101288	0.0284238	0.0006379	0.0052879	0.0011043	0.0036284
FSHAPE	0.0258403	0.0302210	0.0302891	0.0213148	0.0081912	0.0277603	0.0019927	0.0239618	0.0028547
MFACTR	0.0230546	0.0272746	0.0201730	0.0278733	0.0421393	0.0339198	0.0076605	0.0353681	0.0038204
RLPERM	0.0160246	0.0020087	0.0192277	0.0311117	0.0136308	0.0190750	0.0125388	0.0210682	0.0081638
CONVHT	0.0236372	0.0452975	0.0329411	0.0463781	0.0568421	0.0126993	0.0221701	0.0066518	0.0291702
TCRUST	0.0306806	0.0287307	0.0158133	0.0321462	0.0212561	0.0237937	0.0016835	0.0245423	0.0049215
MNPORO	0.0027735	0.0235420	0.0038170	0.0248083	0.0474816	0.0037706	0.0497095	0.0041804	0.0396182

Response Inputs	TCRBE1	TCRBE2	TCRBE3	TCRBE4	GASOUT	MASSMM	BTCRST	SDCRST
TPOWER	0.115674	0.0884335	0.0843005	0.0386337	0.0021353	0.100594	0.0775514	0.0913718
QSTEAM	0.0328538	0.0896447	0.0758710	0.0077948	0.126316	0.0515038	0.0221111	0.0157411
QHYDRO	0.0337333	0.0244303	0.0028765	0.0544101	0.0590919	0.0022925	0.0345914	0.0369841
DBPORO	0.0973628	0.126619	0.134217	0.0131488	0.0763264	0.340033	0.0780043	0.0949315
PSZDST	0.0477868	0.0577432	0.0342479	0.0714084	0.124556	0.0402539	0.111126	0.0957259
SHIELD	0.142361	0.110735	0.0978688	0.0578864	0.0367950	0.122626	0.0193346	0.0347143
SOLMLT	0.0431382	0.0400772	0.0199196	0.142764	0.0521387	0.0349974	0.0322796	0.0615315
LIQMLT	0.0346676	0.0311292	0.0165124	0.0084508	0.0024075	0.0003166	0.0768022	0.0206125
EMSUO2	0.0271675	0.0105095	0.0040859	0.0296615	0.0428529	0.0167014	0.0011307	0.0587766
EMSZRO	0.0360508	0.0104486	0.0209685	0.0813496	0.0325018	0.0101691	0.0102384	0.0869562
VISUO2	0.0592780	0.0140656	0.0254510	0.0127903	0.0479052	0.0262969	0.0014717	0.0750508
VISZRO	0.0642563	0.0528487	0.0223243	0.0087818	0.0019335	0.0144489	0.0742146	0.0110709
SUFUO2	0.0155306	0.0131852	0.0072495	0.0301297	0.0342236	0.0124941	0.0305358	0.0060392
SUFZRO	0.0359116	0.0264701	0.0164933	0.0731311	0.0393234	0.0126194	0.0532950	0.0016280
CONUO2	0.0892856	0.0469199	0.141155	0.0930659	0.106034	0.0692249	0.0866461	0.0548145
CONZRO	0.0031077	0.0236424	0.0689800	0.0485653	0.0069305	0.0330092	0.0361934	0.0144430
RADCON	0.0412675	0.0724143	0.0416839	0.0196933	0.0460458	0.0004721	0.0050595	0.0551795
FSHAPE	0.0228333	0.0052507	0.0098249	0.0087205	0.0202168	0.0161266	0.0427335	0.0204859
MFACTR	0.0219163	0.0406191	0.0124269	3.024e-05	0.0633963	0.0311278	0.0769519	0.0597438
RLPERM	0.0117878	0.0119373	0.0223924	0.0294454	0.0436733	0.0158683	0.0257811	0.0363493
CONVHT	0.0013416	0.0571412	0.0117281	0.0488757	0.0048979	0.0298411	0.0658321	0.0384399
TCRUST	0.0213331	0.0032745	0.0417327	0.0123186	0.0267799	0.0022801	0.0203201	0.0226553
MNPORO	0.0013541	0.0424608	0.0876888	0.108944	0.003518	0.0167032	0.0177954	0.0067542