Hindawi Publishing Corporation

Science and Technology of Nuclear Installations
Volume 2008 (2008), Article ID 798901, 7 pages
doi:10.1155/2008/798901

**Research Article**

# GRS Method for Uncertainty and Sensiti Evaluation of Code Results and Applicat

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Received 8 May 2007; Accepted 14 February 2008

Academic Editor: Cesare Frepoli

## Abstract

During the recent years, an increasing interest in computational r evaluation model calculations by best estimate calculations supple The evaluation of the margin to acceptance criteria, for example, based on the upper limit of the calculated uncertainty range. Unc to be obtained from “best estimate” thermal-hydraulic code accuracy would be presented for comparison with regulatory acc presented to quantify the uncertainty of computer code results. Th together with applications to a large break loss of coolant accident simulating containment behaviour.

## 1. Introduction

Best estimate computer codes are used to calculate postulated l way and not in a conservative way. There is an increasing interest the conservative evaluation model calculations by best estima uncertainty analysis. The USA Code of Federal Regulation (CFR) 1 best estimate code plus identification and quantification of conservative computer code models listed in Appendix K of the CF

Code predictions are uncertain due to several sources of uncerta
plant and fuel parameters. These uncertainties, for example, com
of modelling, variation and imprecise knowledge of initial and
developed based on experiments which can simulate the comp
conditions in a simplified way only. Most of the experiments are
Uncertainty due to imprecise knowledge of parameter values in
distributions. These distributions should be taken into account for

Stochastic variability due to possible component failures of the
analysis. The single failure criterion is still taken into account in
safety analysis and requirements of redundance. The probability
analyses, not of demonstrating the effectiveness of emergency co

The aim of the uncertainty analysis is at first to identify and qua
Their propagation through computer code calculations provides
results. The evaluation of the margin to acceptance criteria, for
should be based on the upper limit of this distribution for the
analysis is needed if useful conclusions with regard to prediction
are to be obtained from "best estimate" thermal-hydraulic cod
accuracy would be presented for comparison with limits for accept

**Figure 1:** Margin illustration.

Section 2 describes the GRS method, Section 3 presents example
provides conclusions.

## 2. Description of the GRS Method

Among others, GRS method [2] has been developed for the dete
about all uncertain parameters is described by ranges and pr
information about the uncertainty of computer code results, a num
these calculation runs, all identified uncertain parameters are
uncertain input values, models, initial and boundary conditions
maximum time step size, and so forth. Model uncertainties are ex
corrective terms, or by a set of alternative model formulations.
phenomena, are to be taken into account in the code validation pr
included in the uncertainty analysis. Code validation results
uncertainties.

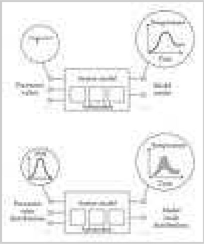

**Figure 2:** Consideration of input parameter v
method.

The selection of parameter values according to their specified p
evaluation of the calculation results requires a method. Following a
a set of statistical techniques. The advantage of using these te
needed is independent of the number of uncertain parameters. In
varied simultaneously. In order to quantify the effect of these v
Because the number of calculations is independent of the numb
input parameters is necessary to reduce their number in order to
analysis as described later.

The number of code calculations depends on the requested proba
tolerance limits used in the uncertainty statements of the res
calculation runs is given by Wilks' formula [3, 4], for example
$b \times 100$ is the confidence level (%) that the maximum code resul
(%) (percentile) of the corresponding output distribution, which i
confidence level is specified to account for the possible influenc
statements are obtained from a random sample of limited size.
formula is: $1 - a^n - n(1-a)a^{n-1} \ge b$. The minimum number of calcu

**Table 1:** Minimum number of calculations $n$
limits.

The probabilistic treatment of parameter uncertainties allows qu
addition to the uncertainty range, the knowledge is expresse
distributions. This interpretation of probability is used for a par
known value. The classical interpretation of probability as the limit
due to stochastic variability, is not applicable here.

The probability distribution can express that some values in t
appropriate parameter value than others. In the case that no pref
specified, that is, each value between minimum and maximum is e
As the consequence of this specification of probability distributio
also show a probability distribution, from which uncertainty limits c

A total number of $n$ code runs are performed varying simultane
according to their distribution. The $n$ values of the considered out
$< Y(n)$. Therefore, the name-order statistics is used for Wilks'
percentile value with a confidence level of 95% is obtained by se
limit, for example. A 5th percentile value with a confidence level
$(95\,\% / 95\,\%)$ two-sided tolerance limit is obtained by selecting $Y(1$

Another important feature of the method is that one can eva
parameter uncertainties for the uncertainties of the results. These
information provides guidance as to where to improve the st
uncertainties most effectively, or where to improve the modellin
standardised rank regression coefficients, rank correlation coeffi
uncertainties in model formulations, input data, and so forth, with
uncertainty. The difference to other known uncertainty methods,
the analysis and not of prior estimates and judgements. This pric
table (PIRT) by extensive expert staff-hours in [5] is known to be
measures are available simultaneously for all single-valued (e.g
valued (time dependent) output quantities of interest. The meth

using approximations like fitted response surfaces. Similar meth uncertainty method is presented in [6].

The different steps of the uncertainty analysis according to the GR uncertainty and sensitivity analyses (SUSA) developed by GRS [ applied during the uncertainty and sensitivity analysis.

## 3. Applications

The GRS method for uncertainty and sensitivity evaluation of investigate the combined influence of all potentially important applications have been performed in GRS to investigate loss of systems of pressurised water reactors, as well as related exper hydraulic computer code ATHLET. Another uncertainty and se experiment simulating containment behaviour using the computer

### 3.1. Thermal-Hydraulic Applications Using the ATHLET Com

Several uncertainty and sensitivity analyses were performed by ATHLET simulating breaks of the primary and secondary side cooli

(i) separate effects experiment OMEGA heater rod bundle T
(ii) integral experiment LSTF-CL-18, 5% cold leg break, acc
(iii) PWR 5% cold leg break, accumulator injection into hot le
(iv) integral experiment LOFT L2-5, $2 \times 100\,\%$ cold leg break,
(v) PWR $2 \times 100\,\%$ cold leg break, combined ECC injection in
(vi) PWR 10% steam line break,
(vii) PSB-VVER 11% upper plenum break experiment, UP-11-

One out of these applications is described in the following section.

### 3.2. Application to a German PWR Reference Reactor, $2 \times 10$

A double ended cold leg offset shear break design basis acciden investigated. The fuel rod peak linear heat generation rate is 5 assumed. ECC injection is into cold and hot legs. The accumulator the primary system below a pressure of 2.6 MPa. High- and low- assumed in the broken loop check valve for ECC injection from ac hot leg accumulator is unavailable due to preventive maintenance. unavailability, agreed between applicants and assessors.

The uncertainty analysis considered 56 uncertain input param parameters to select different model correlations for heat transfer reactor vessel, 1 for temperature of accumulator water, 1 for distribution in the core, 1 for hot channel factor, 5 for gap width and 2 for convergence criteria. The model parameters comprise cr wall and interfacial shear, form loss, main coolant pump head, and

A total number of 100 calculations were performed using the code

### 3.3. Maximum Clad Temperature

Figure 3 shows at any point of time, at least 95% of the combi calculated clad temperatures is below the presented uncertainty lir of at least 95%. For each instant of time, the desired tolerance results. A “conservative” calculation result is shown for compar default values of the models and conservative values for the init heat, gap width of fuel rods between fuel and clad, fuel pellet the water. All these conservative values were also included in the distr analysis. The maximum clad temperature of the conservative calc tolerance limits of the uncertainty analysis over the whole tra regulatory acceptance criterion for peak clad temperature is 1200°

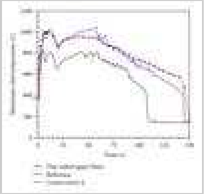

**Figure 3:** Calculated one-sided 95%/95% calculation compared with a “conservative” c reactor during a postulated double ended offse

The “conservative” calculation is representative for the use of initial and boundary conditions. Such an evaluation is possible in t in the USA . The uncertainty of code models is not taken into boundary conditions will bound these model uncertainties. That is c present example. An uncertainty analysis quantifies uncertain i uncertainties. The peak clad temperatures, however, are bounded sensitive parameters gap width and pellet thermal conductivity. I extent of conservatism implemented in the conservative calculati [1] requires that “uncertainties in the analysis method and inp uncertainty in the calculated results can be estimated” when a be

According to the US Code of Federal Regulations, Title 10, S conservative models to be applied in conformity with the requir “ECCS Evaluation Models” of the Federal Regulations [1]. This i margin to licensing criteria is available by changing from conserv uncertainty analysis.

The confidence level 95% denominates that the 95th percentile i providing a (95%, 95%) statement. This conservatism is the rea (95%, 95%) statement by a conservative calculation is not nee methods for comparison and quantification of “conservatisms’ additional statistical test proving that the conservative calculation l

### 3.3.1. Sensitivity Measures

Sensitivity measures indicate the influence of the uncertainty in in the Spearman rank correlation coefficient is used as sensitivity sensitivity of the respective input parameter uncertainty on the fi blowdown phase; see Figure 4. The sensitivity measure gives deviations when the input uncertainty varies by one standard dev Positive sign means that input parameter value and result tend to uncertain input parameter value tends to increase the clad tempe parameter value and the result tend to move in opposite direction to decrease the clad temperature and vice versa.

**Figure 4:** Sensitivity measures of the blowdo
input parameters (rank correlation coefficient)

The most important parameter uncertainties, out of 56 identified
the blowdown peak clad temperature uncertainty are

(i) fuel rod gap width for low burn up (positive sign),
(ii) fuel heat conductivity (negative sign),
(iii) minimum film boiling temperature (negative sign),
(iv) model for critical heat flux (negative sign: Biasi correlat
change from nucleate to transition boiling compared to the Her
(v) reactor initial power (positive sign),
(vi) 2-phase multiplier in horizontal pipe (negative sign: higl
⇒higher water content in core due to lower break flow ⇒lower

The most important parameters for the peak clad temperature unc

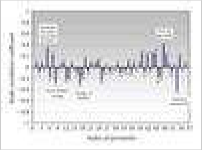

**Figure 5:** Sensitivity measures of the refloo
input parameters (rank correlation coefficient)

(i) fuel heat conductivity (negative sign),
(ii) fuel rod gap width for low burn up (positive sign),
(iii) model for 1-phase convection to steam (positive sign, i.
temperatures than Dittus-Boelter II),
(iv) number of droplets (negative sign: number of droplets h
(v) steam-droplet cooling (negative sign: higher cooling ten

### 3.4. Application to the Experiment HDR T31.5 Simulating Co

The experiment T31.5 on the HDR containment facility simulates
steam and gas release into the containment according to the low
term phase was performed with emphasis on pressure buildup in t
hydrogen distribution was measured during a long term phase o
mixture were injected.

A total number of 200 calculations were performed using the code
influence of all considered uncertainties on the calculated pressure
of time is shown in Figure 6. A total of 79 uncertain parameters we
experimental facility, initial and boundary conditions.

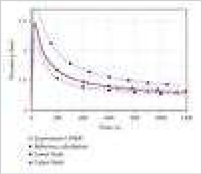

**Figure 6:** $95\%/95\%$ uncertainty interval, r
pressure in the upper part of the containment

Sensitivity measures about the influence of the uncertainty in inp
the HDR containment versus time are presented in Figure 7. W
versus time on the maximum pressure. Decreasing influence wit
decreasing convection for

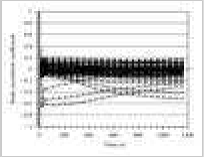

**Figure 7:** Sensitivity measures for pressure in

(i) free convection, parameter 72, negative sign,
(ii) forced convection, parameter 73, negative sign,
(iii) condensation at wall, parameter 74, negative sign.

Increasing with time are the following parameters because of decre

(i) thickness of liner, parameter 79, negative sign,
(ii) surface of liner, parameter 77, negative sign,
(iii) heat capacity of concrete structures, parameter 69, nega

## 4. Conclusions

Two applications of the uncertainty method proposed by GRS
methodology is that no a priori reduction in the number of un
screening calculations is necessary to limit the calculation effort. A
in the uncertainty analysis. The method accounts for the combined
results. This would be difficult or even impossible to achieve by a
or transients.

The number of calculations needed is independent of the numb
analysis. It does, however, depend on the requested tolerance
(percentile) of the combined effect of the quantified uncertainties,
results. The tolerance limits can be used for quantitative statemen

Another important feature of the method is that it provides sensiti
parameter uncertainties on the results. The measures permit an
provides guidance as to where to improve the state of knowledg
effectively, or where to improve the modelling of the computer co
the ranking is a result of the analysis and its inputs and not of an
and sensitivity measures are available simultaneously for all singl
as continuous valued (time dependent) output quantities of i
calculations without the use of approximations like fitted response
used in different applications by various international institutions i

A challenge in performing uncertainty analyses is the specificati
parameters. Investigations are underway to transform data meas
thermal-hydraulic model parameters with uncertainties. Care m
analytical information to specify uncertainty distributions. This is
uncertainty methods.

## Acknowledgments

This work performed by GRS was funded by the German Federal
The significant contributions of my colleagues H. Bartalsky, A. H
paper are gratefully acknowledged.

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