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QUASAR: A Methodology for Quantification of Uncertainties in Severe Accident Source Terms*

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Summary

The radiological consequences of severe nuclear reactor accidents are governed, in large part, by the magnitude and characteristics of the radioactivity release, or radiological "source term," from the plant.

Over the last decade, substantial development and progress has been made in the state of knowledge concerning the nature of severe accidents and associated fission product release and transport. As part of this continuing effort, the United States Nuclear Regulatory Commission (USNRC) has sponsored the development of the Source Term Code Package (STCP), which models core degradation, fission product release from the damage fuel, and the subsequent migration of the fission products from the primary system to the containment and finally the environment.

In order to better establish the validity and potential applications of source term predictions from these phenomenological models, quantification of the uncertainties associated with the STCP calculated source terms is essential.

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An initial attempt at quantifying the uncertainties in the source term estimates based upon the BMI-2104[1] methodology was completed at Sandia as part of the QUEST[2] program. However, this study was preliminary and limited in scope. Comparable studies have also been performed by the Nuclear Industry as part of the Industry Degraded Core Rulemaking (IDCOR) program using the MAAP code.[3]

The purpose of the present paper is to describe a methodology which was developed as part of the QUASAR[4] (Quantification and Uncertainty Analysis of Source Terms for Severe Accidents in Light Water Reactors) program at BNL. QUASAR is a large program which will apply the methodology described in this paper to severe accident sequences in LWRs using the STCP.[5]

The QUASAR approach consists of the following steps:

1. Screening Analysis: This stage is necessary to reduce the number of input variables to a manageable size. This has been accomplished by parametric sensitivity studies on the various codes in the STCP. The results of the QUEST program were a useful starting point for this exercise.

2. Uncertainty Analysis: This stage consists of: (a) Identification and Classification; (b) Quantification; and (c) Propagation. Identification and Classification of uncertainties entails a detailed examination of the various models and their associated computer codes in the STCP. In general QUASAR addresses uncertainties in input parameters, modeling options, and unmodeled phenomena. The quantification process in QUASAR uses the available experimental data-base to establish reasonable upper and lower bound estimates together with Probability Density Functions (PDFs) for the sensitive input parameters/options to the STCP. The propagation of input uncertainties through the STCP is accomplished through a stratified Monte Carlo simulation using the Latin Hypercube Sampling approach.

It must be noted that, in assigning the PDFs, various dependencies between the parameters are included. Furthermore, uncertainties due to significant unmodeled physical phenomena (models not included in the STCP) will also be addressed in the second phase of the study.

3. Sensitivity Analysis: Following the completion of the uncertainty analysis stage, a sizeable number of STCP generated samples became available which enables the use of a regression type technique, such as the Response Surface Method (RSM) for sensitivity analysis. In this stage, the sensitivity of the output PDFs to the input PDFs are established.

4. Importance Analysis: In this stage of the study, an importance ranking of the sensitive input parameters/models are established by defining an appropriate unit of importance.

The resulting PDFs for the radionuclide releases are then used to calculate corresponding statistical parameters such as mean, median, and upper and lower percentiles.

This comprehensive methodology is being applied to several risk dominant accident sequences in LWRs. Table 1 summarizes the resulting sensitive parameters for the STCP as calculated for an Anticipated Transient Without Scram (ATWS) sequence in a BWR with Mark I containment. The PDFs for these parameters are established based on the available experiments and/or detailed mechanistic code calculations followed by an extensive expert review process.

In conclusion, the QUASAR methodology: (1) addresses the uncertainties associated with input parameters and phenomenological models used in the STCP, and (2) defines reasonable technically defensible ranges and assumptions for use in the STCP.

References

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Table 1 Sensitive Input Parameters/Variables to the STCP for a TC-Sequence (ATWS) in a BWR with Mark I Containment

STCP Code	Input	Definition
MARCH2	TMELT	Fuel melting temperature
	TFUS	A temperature reflecting energy content of the molten fuel
	FDROP	Whole core melt fraction upon core slump
	WGRIDX	Mass of steel that falls with the melt into the bottom head
	FZMCR	Zr fraction in the central core of debris particles in the bottom head
	DPART	Debris particle size in the bottom head
	FHEAD	Fraction of the lower head steel available for ex-vessel interaction
	AVBRX	Break area of drywell
	C3	Break area of reactor building
CORCON/MOD2	TW	Concrete ablation temperature
	RAD	Radius of corium pool
	EO, EM, EW	Emissivities of melt phases and concrete
CORSOR		Transient release rate coefficients for I, Cs, Te
		Te-cladding interaction threshold
TRAPMERGE	VD	Te group deposition velocity
	CHI	Dynamic shape factor
	GAM	Collision shape factor
SPARC	DIAM	Mean bubble diameter
	RATIO	Bubble aspect ratio
	VSWARM	Bubble swarm velocity
VANESA		Condensed phase diffusivities
		Condensation coefficient
		Activity coefficients
NAUA	FORM	Dynamic shape factor
	FORMC	Coagulation shape factor
	DELD	Diffusional boundary layer thickness

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