CSNI Workshop on Evaluation of Uncertainties in Relation to Severe Accidents and Level 2 PSA
7-9 November 2005,
Aix-en-Provence

Treatment of Uncertainties in L2 PSAs and Severe Accident Analysis – An Overview and Some Thoughts Regarding Future Challenges

Ming L Ang
ming.ang@amecnnc.com

Contents

- Uncertainty concept and sources
- Progress made in uncertainty treatment
- Uncertainty treatment in some recent PSAs
- ROAAM development and applications
- Conclusions

Uncertainty Concept

- Aleatory Uncertainty
  - is a natural randomness of a quantity. It cannot be reduced or eliminated
- Epistemic Uncertainty
  - is a lack of knowledge of a quantity. It can be reduced by processing more information. It can be classified into three classes

Aleatory uncertainty is built into the structure of the PSA model. Uncertainty in the PSA results is epistemic

Epistemic Uncertainty Classes

- ***Model uncertainty*** - due to imperfections in knowledge made in physical model formulations for description of phenomena, processes and human behaviour
- ***Parameter uncertainty*** - arises from a lack of knowledge for the most appropriate values for some model parameters to represent a physical situation
- ***Completeness uncertainty*** - arises from inadequacy in the understanding of the physical processes resulting in omission of important mechanisms

Uncertainty and Knowledge

$$K = \frac{1}{U_E}$$

K = Knowledge

U_E = Epistemic Uncertainty

When $U_E = 0$, $K = 00$, ie. Total Knowledge

When $K = 0$, $U_E = 00$, i.e. Total Uncertainty

Increasing knowledge, hence decreasing epistemic uncertainty, has a cost

Progress in Uncertainty Treatment

- Modelling and parameter uncertainties
  - Impact illustrated in ISPs
  - Significant improvement in knowledge in SA phenomena in last two decades through international R&D programmes and collaboration
  - Development in integrated SA analysis codes (MAAP, MELCOR, THALES, ASTEC) and other mechanistic codes

  The development enables meaningful treatment of these uncertainties. Modelling uncertainties have been addressed by independent code calculation
- Completeness uncertainty
  - Omission due to PSA scope (e.g. low power and shutdown faults) or other reasons (e.g. α mode failure from fci and role of SAM). This can be addressed
  - Omission due to incomplete understanding of accident phenomena/behaviour. Examples in earlier PSAs include: natural circulation induced creep rupture failure of RCS piping, HPME/DCH, shutdown fault, fission product release & transport behaviour. Difficult to address, can be reduced by peer review process
- Aleatory uncertainty
  - Exploratory treatment in small number of recent studies (e.g. IRSN, JAERI)

Key Development/Application in Uncertainty Methodology (1)

- Early PSAs (early 80s) relied largely on simple CET sensitivity analysis, some uncertainty treatment using DPD method. Issues of high uncertainty addressed by expert groups, e.g. SERG study (1985), spectral STs for Sizewell B PSA (1982)

- US NUREG-1150 study (1990) provided major milestone in 'integrated' uncertainty treatment. Formal expert elicitation addressed issues of high uncertainty. Difficulty of propagating uncertainties illustrated by the replacement of OCP method with LHS method. Notable support studies include:
  - Review of uncertainty approaches (NUREG/CR-4836)
  - Expert review of ST uncertainties (NUREG/CR-4883)

  Useability of uncertainty method (LHs) and sensitivity methods confirmed in study

- Systematic approach to ST uncertainty treatment based on STCP code in QUASAR study (1989)

Key Development/Application in Uncertainty Methodology (2)

- Development/application of ROAAM method for assessment of α-mode containment failure (1987), extended to assessment of other phenomena
- Examples of recent studies
  - Integrated ROAAM approach for SAM for Loviisa NPP
  - JAERI’s L2 PSA uncertainty approach
  - IRSN’s uncertainty treatment using grid of results method/surface response model
  - EC FWP project on expert judgement BEEJT (1999)
  - EC FWP project on SA uncertainty issues EURSAFE (2003)
  - EC FWP project on L2 PSA SARNET (ongoing)

Use of Expert Judgement

- Usefulness of expert opinion in PSA recognised in a number of early studies
- Formal knowledge elicitation formed an element of the NUREG-1150 uncertainty methodology
  - Protocol for the initial study (1987) criticised in review process
  - Revised procedure for final study (1989)
  - 25 issues addressed for L2 PSA
  - ACRS review acknowledged improvements, reservations about the process, especially choice of experts
- Expert judgement techniques for L2 PSA benchmarked in the EC FW BEEJT study based on fci experiment (L24) at FARO facility
- Expert consultation is commonly used in a number of recent L2 PSAs using different approaches, little evidence of involvement of formal elicitation
- Expert consultation/interpretation on major issues of uncertainty was beneficial in SZB PSA, via expert review of issue, including separate calculations

Severe Accident Code Uncertainty Analysis

- Systematic approach adopted in the QUASAR study
  - Based on STCP constituent codes
  - Methodology comprised of three steps: *screening sensitivity analysis, uncertainty analysis, distribution sensitivity analysis*
  - Use of expert panel opinion
  - Prob dist formulation based on information theory principles
  - Expert opinion aggregation based on information-theoretic principles
- Parametric modelling approach to deal with phenomenological uncertainties in earlier codes designed for sensitivity analysis, e.g. MAAP 3B
- Framework for uncertainty analysis for current codes is generally a variant form of QUASAR approach

Some Current Guidance

- IAEA Safety Series No 50-P-8 (1995)
  - Recognised no single approach to uncertainty analysis
  - Framework for analysis defined, comprising of scope, characterisation of uncertainty and display of results
- USNRC NUREG-1335 (1989)
  - Structured sensitivity study is seen as adequate
  - List of suggested parameters
  - Guidance on sensitivity ranges provided in NUREG/CR-4551
- EPRI NSAC-159 (1991)
  - Guidelines based on sensitivity study
  - Limited list of key uncertainty issues, choice guided by IDCOR/NRC issue resolution
- IAEA-TECDOC-1229 (2001), Regulatory Review of PSA L2
  - CET sensitivity analysis seen as a minimum requirement
  - Highlighted potential bias introduced by exclusive use of a SA code

Uncertainty Treatment in Some L2 PSAs – Personal Observation

- Recognised as an integral part of L2 PSA
- Quantification is based almost entirely on simple sensitivity analysis for CET, chosen ranges typically unrelated to any rationale
- CET uncertainty analysis is rare, prob dists are not justified
- Simple sensitivity analysis is also adopted for SA code analysis, emphasis on ST uncertainty
- Little coupling between CET and ST analyses
- Propagation of uncertainties through L1 & L2 PSAs not performed

Comparison of some European L2 PSA uncertainty treatment performed in the ongoing EC SARNET project

Common Difficult Issues to Overcome

Difficulties may be conceptual or due to other aspects, e.g:

- Reconciliation of DOB concept in L2 PSA
- Difficulty in interpreting:
  - regulatory requirement
  - national/international guidance
- Awareness of status of SA issues
- **Access to international R&D studies/data**
- Management of PSA study
  - reliance on single SA code
  - performance of tasks by different organisations
- **Resource allocation does not permit in-depth study**

Risk Oriented Accident Analysis Methodology (ROAAM)

- Some Level 2 PSA model limitations
  - weaknesses in dealing with phenomenological uncertainties
  - assumption that every degree of uncertainty is quantifiable
  - scenarios are allowed to proceed in an open ended way; every branch is approached in a best estimate way
- ROAAM has been developed to overcome some of these problems
- Basic idea of ROAAM
  - phenomenological uncertainties (**epistemic** uncertainties) kept separate from **stochastic** probabilities

Risk Oriented Accident Analysis Methodology (ROAAM) (cont)

- ROAAM bypasses the above difficulties by
  - decomposition
  - conservative evaluation of “intangibles”
  - splintering
    (RESS **54** (1996) 243-257)

- Peer review + seek consensus on
  - decomposition framework
  - probability distributions

- Application of ROAAM
  - issue resolution: in-vessel FCI, Mark – 1 liner attack,
    DCH, AP-600 in-vessel retention
  - SAM development of Loviisa NPP

Treatment of Issues of High Uncertainty
An Example on FCI Studies

- Following WASH-1400, SERG-1 study (1985) concluded low prob of α mode failure. Most experts made use of DET approach. Confirmation by more recent SERG-2 study (1995). Concurrence from IDCOR study (1985)
- ROAAM model was used for more detailed evaluation (1987). Parameters considered include:
  - mass of melt in premixture
  - size of pour area
  - thermal energy in premixture
  - conversion ratio vs thermal energy in premixture
  - upward slug energy vs mechanical energy release
  - energy transferred to vessel head
  - vessel head missile energy vs net energy in vessel head
  - missile energy after shield impact
  - containment failure frequency vs missile energy

Study concluded that it is ‘physically unreasonable’ for the α mode failure to occur more frequently than 10^{-4} per core melt. Recent study (1995) further concluded that even vessel failure may be regarded as physically unreasonable.

FCI Studies (cont.)

- Extended ROAAM model used in SZB PSA estimated prob of 5.7×10^{-4} and 1.9×10^{-4} at 6 MPa and 15 MPa
- Excluded as credible in a number of PSAs
- Further R&D needs to plug knowledge gaps addressed in international expert reviews (e.g. EURSAFE [2003], OECD [1999]
- Detailed comparison of PSA/ROAAM models in the treatment of H_2 combustion and IVR (e.g. level of decomposition, data generation and probabilistic interpretation) performed in the EC 4th FW SAMEM study

Conclusions

- Significant progress has been made in achieving better understanding of SA phenomena for LWRs, the epistemic uncertainty has been reduced accordingly
- Broad consensus on key uncertainty issues has been achieved
- No accepted procedure for uncertainty analysis in a L2 PSA, CET sensitivity analysis is generally seen as a minimum requirement
- Methods for uncertainty analysis have been developed and successfully applied
- CET sensitivity analysis has been performed for majority of L2 PSAs, a more rigorous uncertainty treatment has been adopted in a limited number of studies
- ROAAM has been applied in a number of issue resolutions and may provide the framework for future assessment of key uncertainty issues
- Demand on PSA quality for a variety of applications may require an uncertainty approach beyond what is currently acceptable