Joint ICTP-IAEA Essential Knowledge Workshop on Deterministic Safety Assessment and Engineering Aspects Important to Safety

Sensitivity and uncertainty

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Content of the lecture

- Definition sensitivity and uncertainty

- Sensitivity
  - Areas of the use
  - Limitations, examples
  - Identification of parameters
  - Application of the sensitivity analysis

- Uncertainty
  - BEPU approach
  - Identification of uncertainties
  - BEPU methods

- Regulatory review
Sensitivity and uncertainty

- ISP findings - different results with the qualified users with the same technical information
  - Practical limitations
    - Restrictions on time, financial and human resources
  - Technical reasons
    - Imperfect code models
    - Unavailability of exact information
      - User choice on various code models (e.g. heat transfer correlations)
      - BIC: variations in steady-state value (e.g. primary pressure), unavailable (heat losses, discharge coefficient)

- Sensitivity and/or uncertainty analysis to evaluate the impact of these shortcomings
Definitions (IAEA SSG-2)

- **Sensitivity Analysis**
  - Systematic variation of the code input variables and modeling parameters to determine their influence on the results of the calculations

- **Uncertainty Analysis**
  - Statistical combination of the influence of the plant conditions, code models and associated phenomena on the results
### Process of sensitivity and uncertainty

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<th>Sensitivity Analysis</th>
<th>Identification of the important parameters</th>
<th>Uncertainty Analysis</th>
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<td>PIRT, Engineering judgement</td>
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<td>Single values – e.g. min., max., nom.</td>
<td>Definition of the marginal values</td>
<td>Comprehensive definition – e.g. interval, distribution function</td>
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<td>Variation of single parameter/value – single run for each variation</td>
<td>Analysis</td>
<td>Statistic techniques to combine variation of parameters</td>
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Use of sensitivity analysis

- Before analysis
  - Optimization of the analysis (nodalization development, selection of the correlations)
  - Identification of conditions leading to the smallest margin to acceptance criteria (initial and boundary conditions)

- After analysis
  - Supplementation to the basic calculation to demonstrate the robustness of the results, no cliff edge effect

- Other applications
  - Support to uncertainty analysis – e.g. ranking of uncertain parameters
Limitations of sensitivity analysis

- Time consuming due to single variation of parameters and their values
  
  o Example:
  
  Sensitivity evaluation: 5 parameters, minimum, maximum and nominal value taken into account
  
  => 15 runs – e.g. each run ½ day => 7.5 days of computing

- Most conservative case (and cliff edge effect) can remain hidden due to limited number of variation of values – see next slides
Sensitivity analysis – Cliff edge (PRZ surge line break analysis)
Sensitivity analysis – Cliff edge (PRZ surge line break analysis)
Sensitivity analysis – finding most penalizing value

Peak Cladding Temperature

EMO12, L500, SV1

VUJE, a.s.
RELAP5

Gap conductivity [W/mK]

Temperature [°C]

\( p(\text{HA}) = 6.1 \text{ MPaabs} \)\n\( p(\text{HA}) = 5.5 \text{ MPaabs} \)
Identification of parameters for sensitivity analysis

- Engineering judgement and accumulation of the knowledge and experience
- PIRT (Phenomena Identification and Ranking Table)
- Sensitivity measures from uncertainty analysis
Typical areas for sensitivity analysis

- **Initial and boundary conditions**
  - Neutron-kinetic data
  - Levels
  - Flows
  - Temperature

- **Systems and components**
  - Valve opening times
  - Pump start-up time

- **Code models choices**
BEPU approach

- BE code available
- Sufficient information on uncertainties associated with safety analysis
- Methods how to treat uncertainties and calculate uncertainty bands
BEPU approach

- Best Estimate (BE) code is one which:
  - Models the important phenomena realistically and can simulate the behavior of the plant system
  - Is free of deliberate pessimism regarding selected acceptance criteria
  - Contains a sufficiently detailed model to describe the relevant processes that need to be modeled

- BE analysis is one which:
  - Is free of deliberate pessimism in the inputs, calculation model, chosen acceptance criteria, etc.
  - Uses a best estimate code
  - Includes an uncertainty analysis
Principal steps in BE analysis

- Selection of the facility and definition of the PIE,
- Definition of the acceptance criteria,
- Selection of the appropriate computer code(s),
- Model development and preparation of the realistic analysis,
- Selection of the uncertainty method,
- Identification of the uncertain parameters and their uncertainty ranges,
- Preparation of the uncertainty analysis,
- Evaluation of the results in regard to the relevant acceptance criteria
BEPU - uncertainties

- Code uncertainties
  - Balance equations
  - Closure and constitutive equations
  - Material properties
  - Special process and component models
  - Numerics

- Representation (nodalization) uncertainties

- Plant uncertainties

- User effect
1974-1988: Extensive research to support the development of realistic and physically based analysis methods: Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, August 1988


Code Scaling, Applicability, and Uncertainty (CSAU) uncertainty evaluation methodology to support the revised ECCS rule and illustrate its application

The CSAU was demonstrated first for LBLOCA (NUREG/CR-5249, 1989) and then for SBLOCA (NUREG/CR-5818, 1992)
Element 1
Requirements and code capabilities

Element 2
Assessment and ranging of parameters

Element 3
Sensitivity and uncertainty analysis
Current uncertainty principles

Input parameters
(n ~ 10^5)

1 2 n

Computer code

Output parameters
(m ~ 10^3)

1 2 m

Selected uncertain parameters
(n^* ~ 10^2)

Uncertainty range and/or PDF for each n^*

Propagation of input uncertainties

Realistic prediction of NPP performance with evaluation of uncertainty
Current uncertainty principles

Input parameters
\(n \sim 10^5\)

Computer code

Output parameters
\(m \sim 10^3\)

Accuracy (error) quantification and extrapolation
Uncertainty database (relevant experimental data)

Extrapolation of output errors

Realistic prediction of NPP performance with evaluation of uncertainty
UMAE and CIAU method

- Uncertainty method based on Accuracy Extrapolation (UMAE)
- Code with Internal Assessment of Uncertainty (CIAU)
- Extrapolation of accuracy comparing the calculated results with relevant experiments
- 
  \[ a(t) = \frac{Y_E(t)}{Y_C(t)} \]
- Accuracy
- Fourier transformation – accuracy amplitude
  \[ A(f) = \int_{-\infty}^{\infty} a(t)e^{-i2\pi ft} dt \]
- Averaging over large number of data from various experiments of different plant types, events, scales etc.
UMAE and CIAU method

a) only **Time Error** is present

b) only **Quantity Error** is present

c) Combination of Errors

d) Derivation of Continuous Uncertainty Bands
BEPU analysis – LOFT L2-3

- **LOFT**
  - Integral test facility
  - 2-loop model of Westinghouse PWR
  - Scaling ratio 1:50
  - Power 50 MWe (real fuel)

- **L2-3**
  - Double-ended break on the cold leg
  - 36 MWe initial power, linear power 39.4 kW/m
  - 1 ECCS train (HP, LP, Accu)
  - MCP running
BEPU analysis – LOFT L2-3

- BEPU analysis
  - RELAP5 + CIAU method
  - ATHLET + GRS method
  - Comparison of two computer codes and two methods with experimental results
Procedure

- Input model preparation
- Input model qualification
- Realistic simulation of the experiment and its qualification
- Uncertainty analysis
BEPU analysis – LOFT L2-3

LOFT L2-3 Test

Neurcitostna analyza metodami CIAU a GRS

- E: PE-PC-005
- A: PV-UP-M
- SUSA: Lower Band
- SUSA: Upper Band
- R5: P-120010000
- CIAU: Lower Band
- CIAU: Upper Band

P(VTC)
P(NTC)
P(HA)
BEPU analysis – LOFT L2-3

LOFT L2-3 Test

Neurcitostna analyza metodami CIAU a GRS
Loft L2-3 Test

Neurocitostní analýza metodami CIAU a GRS

Objem chladiče v PO [%]

- E: DERIVED (No QEUD)
- A: GCSM[MPCS]
- SUSA: Lower Band
- SUSA: Upper Band
- R5: CNTRLVAR-15
- CIAU: Lower Band
- CIAU: Upper Band
Uncertainty bands bound the experimental results

- **PCT**
  - 914 K (in 6 second) – experimental value
  - 983 K (in 5 second) – best estimate value of RELAP5 simulation
  - 978 K (in 6 second) – best estimate value of ATHLET simulation

- **Uncertainty bands**
  - 1214 K (during the period of time from 7 to 33 seconds) – upper band given by CIAU uncertainty evaluation
  - 1102 K (first peak at 5 second) and 1178 K (second peak at 63 second) – upper band given by GRS uncertainty evaluation
Regulatory review of the sensitivity analysis

- Challenging task
- There is no assurance that the analysis presented in safety documentation is the “right” one (e.g. most conservative, bounding etc.)
- Sufficient amount of sensitivity analysis should be presented (usually as supporting technical documentation) to demonstrate the robustness of the analysis, appropriate choice of BIC etc.
- Regulator should have the competence to evaluate this sufficiency and knowledge what to ask for
  - Practical experience with analysis
  - TSO support
Regulatory review of the uncertainty analysis

- Challenges associated with uncertainty analysis
  - New approach – few applications to serve as an example
  - Still developing – new methods, techniques
  - More complex, more sophisticated supporting procedures (FFTBM, PIRT, statistical tools for treatment of uncertainties …)

- Most important areas for review
  - Uncertainty method – areas of application, V&V, limitations
  - Identification, ranking of uncertainties, definition of the uncertainty ranges
  - QA program
Acceptance of the uncertainty analysis

- Uncertainty method is recognized and accepted on international level which gives a certain guarantee of proper application.
- Development of the uncertainty method is systematic which presumes new information, experience and progress in the area is periodically incorporated.
- Sufficient and appropriate documentation is available for correct application of the uncertainty method by the user.
- Careful verification is provided.
- Uncertainty method is systematically validated within the range of the expected application.