Strål
säkerhets
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Swedish Radiation Safety Authority

Computational Nuclear Power Safety and Uncertainties

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Research Goals

- SSM:s goals for safety research is to support regulation and contribute to national competence in the area of nuclear safety
- Reactor safety research reflects regulatory needs
- These needs are derived from the regulatory challenges that face SSM
- The fear is that national competence will degrade if not directed efforts, particularly towards universities are made.
- For such efforts cooperation with the industry is looked for

Review of T/H analysis

- Thermal hydraulic safety analysis for transients and design basis accidents are reviewed for the safety analysis report
- For LOCA, US 10 CFR 50 appendix K is traditionally used in Sweden
- Trend to use more best estimate methods for analysis
- For transients, a larger spectrum of more high frequent incidents which, if combined with “latent” failures or human failures, could lead to accidents will be in focus. To use all experience from many years of operation.

Computational Thermal Hydraulics

- Cornerstone is accurate codes which are adequately validated
  - Coupled neutronics and thermal hydraulics for primary system behaviour during transients and accidents
  - Containment behaviour codes for occurrences within and outside design basis
  - Detailed codes for stratification, mixing, local behaviour, assymmetries and interaction with system codes

Computational Thermal Hydraulics

- Research goals are to be able to use modern methods for licensing based on best-estimate calculations
  - Validation
  - Guidelines for modelling
  - Uncertainties
- Important regulatory challenges are:
  - Improved understanding of occurrences in power plants
  - Power uprates and core optimimizations
  - Review of safety analysis reports, SSM shall ensure that the requirements for safe operation are fulfilled

International recommendations

IAEA Safety Standards

for protecting people and the environment

Deterministic
Safety Analysis for
Nuclear Power Plants

Specific Safety Guide

No. SSG-2

IAEA

International Atomic Energy Agency

OPTIONS FOR COMBINATION OF A COMPUTER CODE AND INPUT DATA

Option	Computer code	Availability of systems	Initial and boundary conditions
1. Conservative	Conservative	Conservative	Conservative assumptions
2. Combined	Best-estimate	Conservative assumptions	Conservative input data
3. Best-estimate	Best-estimate	Conservative assumptions	Realistic plus uncertainty; partly most unfavorable conditions
4. Risk informed	Best-estimate	Derived from probabilistic safety analysis	Realistic input data with uncertainties

International applications

- Internationally all methods have been used except Category 4
- In countries like USA and Sweden categories 1 and 3 have been used
- Category 2 has mainly been used in Germany, for Swedish BWRs
- Category 4 has not been used anywhere and needs development of confidence and better coverage of risk space with PSA-technology

Computational Thermal Hydraulics

U.S. NUCLEAR REGULATORY COMMISSION May 1989

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.157
(Task RS 701-4)

BEST-ESTIMATE CALCULATIONS OF EMERGENCY CORE COOLING SYSTEM PERFORMANCE

CSAU (Code Scaling Applicability Uncertainty) Method

- One of the first uncertainty methods proposed in the year 1989
- CSAU provides a **framework** to proceed through different steps in the process of evaluating uncertainty
- Investigate uncertainty of safety related single valued parameters, e.g. peak cladding temperature (PCT) or vessel water inventory
- Evaluation of the **code applicability** to a selected plant scenario

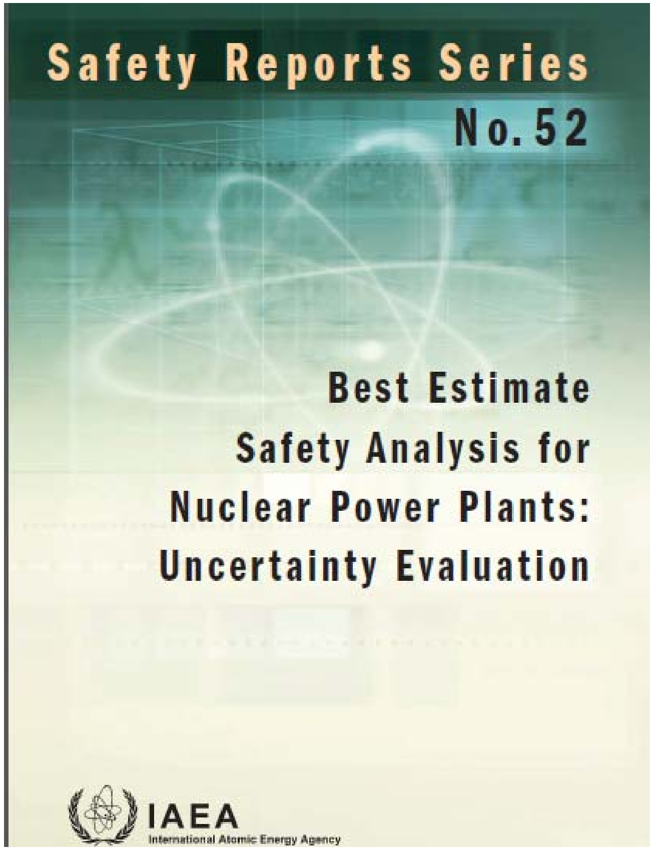
CSAU (Code Scaling Applicability Uncertainty) Method

- Experts identify and rank phenomena by means of a process identification and ranking table (**PIRT**) to **select highly important phenomena**
- Single parameter sensitivity calculations performed using an **optimised nodalisation** capturing important physical phenomena
- Information from experiments, manufacturing, and validation calculations utilised for defining ranges and probability distributions of the uncertain input parameters

CSAU (Code Scaling Applicability Uncertainty) Method

- **Scaling** considered by identification of several phenomena based on test facilities and on code validation
- Addition of **bias terms** on output uncertainties which are not provided through the analysis
- A **response surface approach** was used in the first demonstrations, response surface fits the code predictions obtained from selected parameters, and is further used instead of the original computer code
- Reduces the number of code runs and the cost of analysis
- Response surfaces are not mandatory within the CSAU framework, other methods for uncertainty quantification may be applied

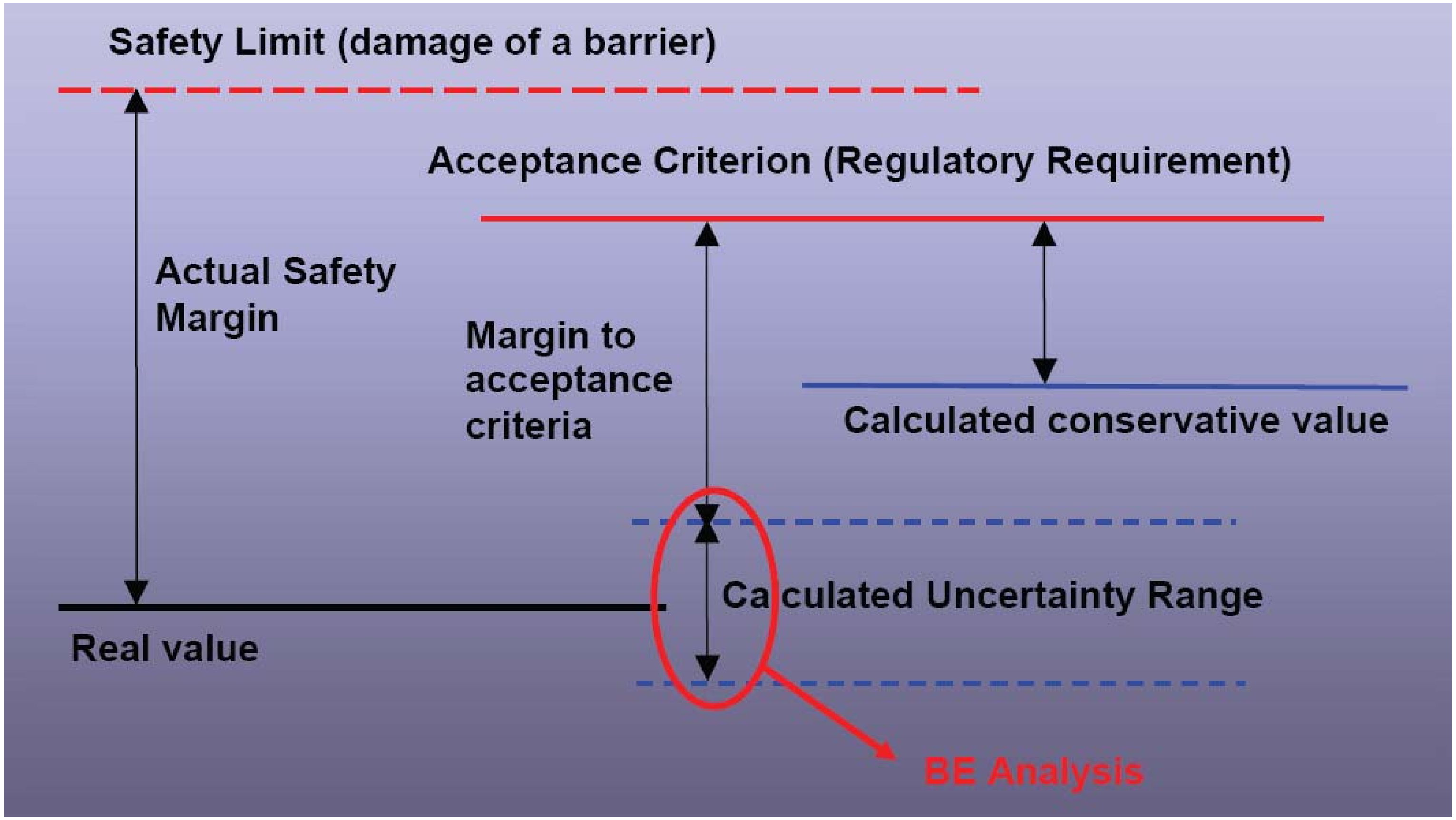
International advisory document



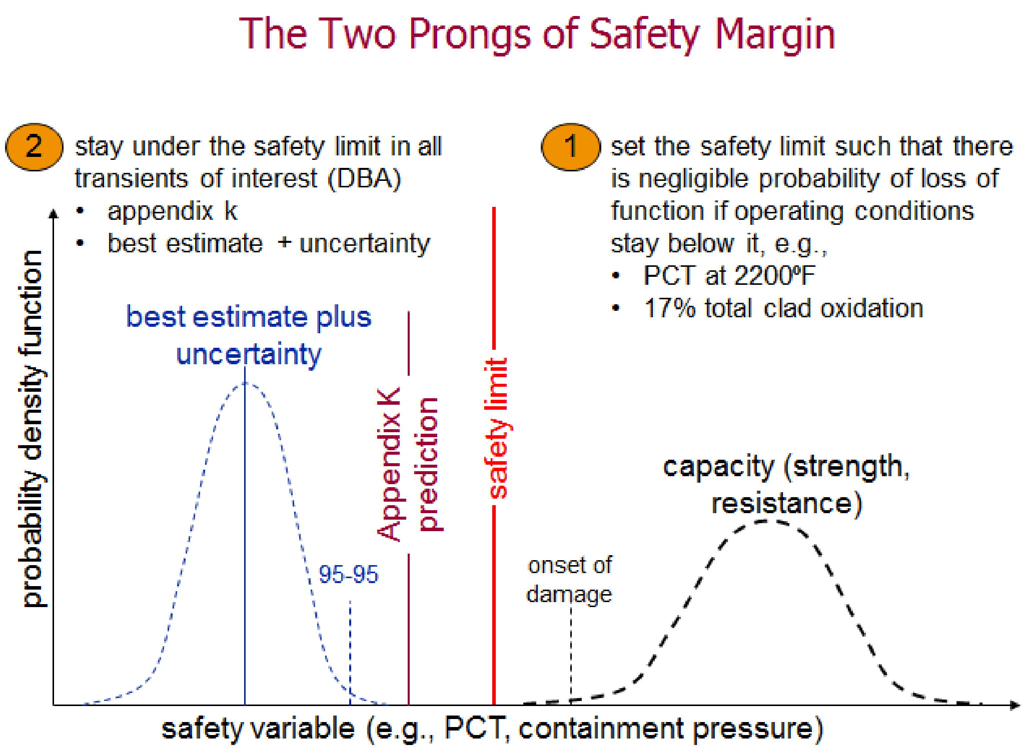
Review of licensing methodologies

- A number of best estimate methods with uncertainty assessment, both aleatory and epistemic uncertainties, have been developed
- Commercial methods developed by most fuel and reactor vendors
- Methods in the public domain: CSAU (USNRC), AEA (UK), UIP (Italy), GRS/Siemens (Germany), IPSN (France), CSN (Spain), Czech Republic,..
- Appendix K has traditionally been used In Sweden
- Best estimate methodologies have been used for PWR
- Disadvantages with the best estimate methodologies:
  - They in general require a significant initial generic investment and therefore may be considered as more complicated and costly
  - The benefit may be plant specific
- The advantage is improved safety assessment and hopefully focus on more risk dominating events than the LBLOCA.

Safety Limits an Uncertainties

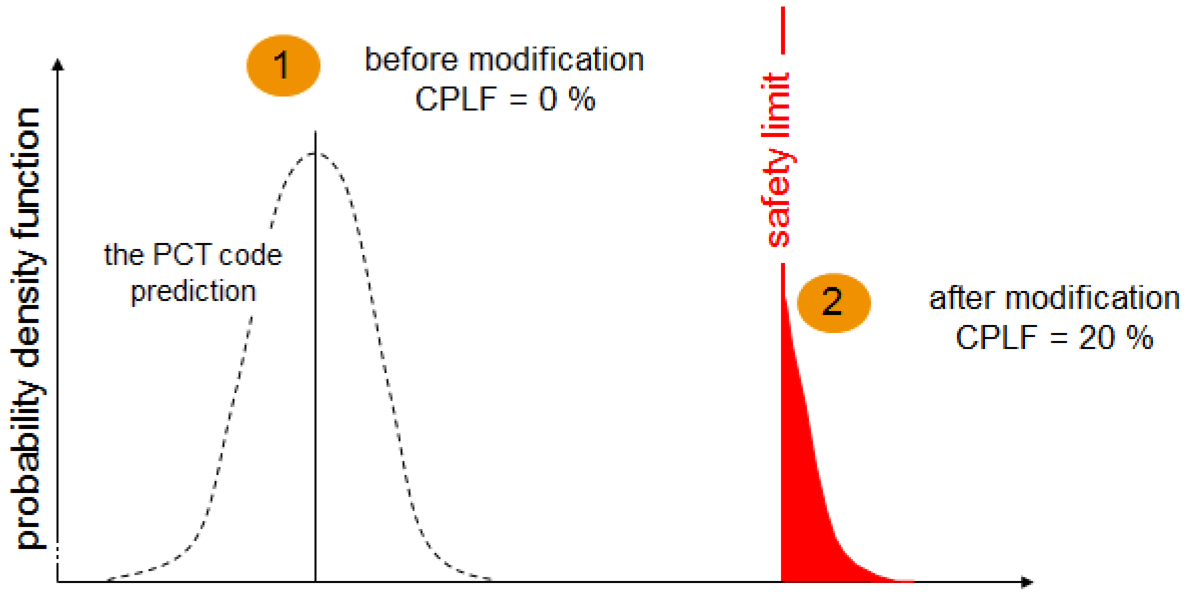


Safety Limits and Uncertainty



- Assume that the barrier looses function when the safety limit is exceeded
  The probability of exceedance of the safety limit becomes a surrogate for the conditional probability of loss of function (CPLF)

For example, after a given modification, the PCT in a specific LBLOCA sequence exceeds the safety limit: the loss of function probability goes from 0 to 20%



Statistical Methods: GRS, IRSN, AREVA, ASTRUM, GE, KREM, KINS-REM, …

- First proposed by GRS
- Input uncertainties characterized by ranges and probability distribution functions (PDFs)
- Number of input uncertainties **not** limited (number of code calculations **independent of number of uncertain parameters**)
- Uncertainty space sampled at random according to the probability distributions
- **Wilks formula** determines the number of calculations for one-sided 95% confidence limit on the 95th percentile **59 runs** are needed.
- for two-sided 95%/95% tolerance interval **93 runs** are needed.

Wilks' methodology

- **Smallest number of code runs n**
  - upper statistical tolerance limit (one-sided):
    $1 - \alpha^n \geq \beta$
  - tolerance interval (two-sided):
    $1 - \alpha^n - n\,(1 - \alpha)\,\alpha^{n-1} \geq \beta$

  α % is the desired **probability content**
  (fractile, percentile, quantile),

  β % is the **confidence limit**
  (taking into account the possible sampling error due to limited number of code calculations)

n	α	$1 - \alpha^n$
10	0,95	0,40
50	0,95	0,92
59	0,95	0,95
100	0,95	0,99
500	0,95	1,00

n	α	$1 - \alpha^n - n\,(1 - \alpha)\,\alpha^{n-1}$
10	0,95	0,09
50	0,95	0,72
93	0,95	0,95
100	0,95	0,96
500	0,95	1,00

Encountered problems

- Poor estimate when the number of uncertain parameters is large
- Caution must exercised when estimates are close to the licensing limit
- Handling of outliers
- Handling of crashed simulations