Conservative versus Best Estimate Safety Analysis

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Presentation content

- Background
- General discussion: conservative vs best estimate approach
- Safety margin
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- Best estimate approach - overview

Background: Deterministic Safety Analyses

- Deterministic safety analyses predict the response of a NPP to a postulated initiating event.
- The results of each analysis is compared with specific acceptance criteria.
- The computations cover predetermined operational modes and states.
- They address neutronic, thermohydraulic, radiological, thermo-mechanical and structural aspects, often using computer codes.

Conservative vs Best Estimate: Introduction (1/ 5)

Conservative analysis: this approach is conservative by an unknown amount and provides distorted information on how the plant would respond in reality

Best estimate analysis: The advantage of this approach is that the predicted safety margins can be expressed in quantitative terms (confidence levels)

Conservative vs Best Estimate: Definition of Conservatism in DSA (2/ 5)

- Conservative model: pessimistic estimate for a physical process relative to a specified acceptance criteria
- Conservative code: a combination of all of the models necessary to provide a pessimistic bound to the processes related to specified acceptance criteria
- Conservative data: plant parameters, initial plant conditions, equipment availability and accident sequence assumptions chosen to give a pessimistic result, operator actions

Conservative vs Best Estimate: Conservative Approach (3/5)

- Conservative approach is based on input data, methods and assumptions so combined to produce final results and consequences worse than expected in any real situation.
  - Conservative approach to deterministic safety analyses was introduced to define minimum set of requirements to assure prediction of safety limits with appropriate margin. The approach is prescribed by Regulatory Authorities (e.g. 10CFR50 Appendix K LOCA Evaluation Model).
- Main reason for the conservative approach were inadequate knowledge of relevant physical processes.
- The results of the conservative analysis implies large margins and can limit operation of the plant.

Conservative vs Best Estimate: Definition of the Best Estimate (4/5)

- Best estimate model: a model which provides a realistic estimate of a physical process to the degree consistent with the currently available data and knowledge of phenomena
- Best estimate code: A combination of the best estimate models necessary to provide a realistic estimate of the overall response of the plant during an accident

Conservative vs Best Estimate: Best Estimate Approach (5/5)

- Best-estimate approach assumes existence of reliable mechanistic codes and uses real assumptions about plant characteristics and operation.
- Compared to conservative approach best-estimate calculation usually needs more data of better quality, models are more complicated and time required to perform calculation is longer.

Methodology for Analysis

- **Conservative approach is typically required for the following:**
  - Design and design modifications
  - Licensing (design basis)
  - Regulatory audit calculations
- **Best estimate is appropriate for the following:**
  - Design (control systems)
  - Licensing (Design extension conditions)
  - PSA related analysis
  - Support for EOP, AM and emergency planning
  - Analysis of operational events.
  - Regulatory audit calculations

Options for accident analyses

Option	Computer code	Availability of systems	Initial and boundary conditions
1. Conservative	Conservative	Conservative assumptions	Conservative input data
2. Combined	Best estimate	Conservative assumptions	Conservative input data
3. Best estimate	Best estimate	Conservative assumptions	Realistic plus uncertainty
4. Risk informed	Best estimate	PSA based assumptions	Realistic input data with uncertainties

Option 1

- Option 1 is a conservative approach:
  - the code is conservative as it is intended to produce pessimistic results;
  - the selected initial and boundary conditions, including the time for the operator to act, are assumed to have pessimistic values;
  - no credit is taken for non safety grade equipment unless it is conservative to do so; and
  - the most severe single failure of the safety systems that are designed to mitigate the consequences of the accident is assumed.

Option 2

- Option 2 is increasingly being used for safety analyses,
  - A ‘best estimate’ computer code is used.
  - Conservative assumptions for initial and boundary conditions and for availability of safety systems.
  - An example of a conservative assumption is to assume the failure of a safety system and other safety systems may be not available due to preventive maintenance or repair.
  - It should be demonstrated that these conservatisms bounds all possible system failures and uncertainties associated with the code models.
  - This requires that the combination of the validation of the code, the conservatism in the data and sensitivity studies establish confidence in the safety of the plant.

General Considerations

- For both Options 1 and 2, it is also important to demonstrate that the calculated results are conservative for each application.
- The interaction with the set-points for the activation of the relevant safety systems or the normal control systems of the plant should be reviewed to ensure that the conservatism of the results is adequate.

Option 3

- Option 3 allows the use of best estimate models in the code instead of conservative ones together with more realistic initial and boundary conditions.
  - Uncertainties should be identified so that the uncertainty in the calculated results can be estimated.
  - A high probability that acceptance criteria would not be exceeded should be demonstrated.
  - The separate uncertainties associated with the use of a best estimate computer code and realistic assumptions for the initial and boundary conditions should be combined statistically.
  - Sensitivity studies should be performed, especially to detect any 'cliff edge effect'.

Options 1, 2 and 3

- In principle, Options 2 and 3 are distinctly different types of analysis. However, in practice, a mixture of Options 2 and 3 is employed.
- This is because, whenever extensive data are available, the tendency is to use realistic input data and vice versa, if data are scarce, to use conservative input data.
- The difference between these two options is the statistical combination of uncertainties and the realistic initial and boundary conditions.
- In Options 1, 2 and 3, conservative assumptions are made about the availability of safety systems and the acceptance criteria depend on the frequency of the initiating event.

Option 4 (1/2)

- Currently, Option 4 is not generally used for licensing but it is taken into account in the licensing of some modern reactors.
  - It requires a realistic analysis for quantifying the availability of systems that are significant for safety.
  - The availability of systems is usually quantified by a probabilistic safety analysis (PSA), and the acceptance criteria take into account the failure probability of the relevant systems or the mitigating actions.
  - Option 4 is also relevant to the future development of risk-informed decision making and it may be used as a means of verifying the deterministic design basis envelope.

Option 4 (2/2)

- When Option 4 is used, a probabilistic analysis is performed.
- For example, where four pumps are provided, analyses would be performed in which 4, 3, 2, 1 and 0 pumps are available and a probability would be associated with each sequence.
- Exceeding the acceptance criterion would be acceptable provided that the frequency of so doing is acceptably low.

SAFETY MARGIN

Background of Safety Margin
the two prongs that leave room for “unknown unknowns”

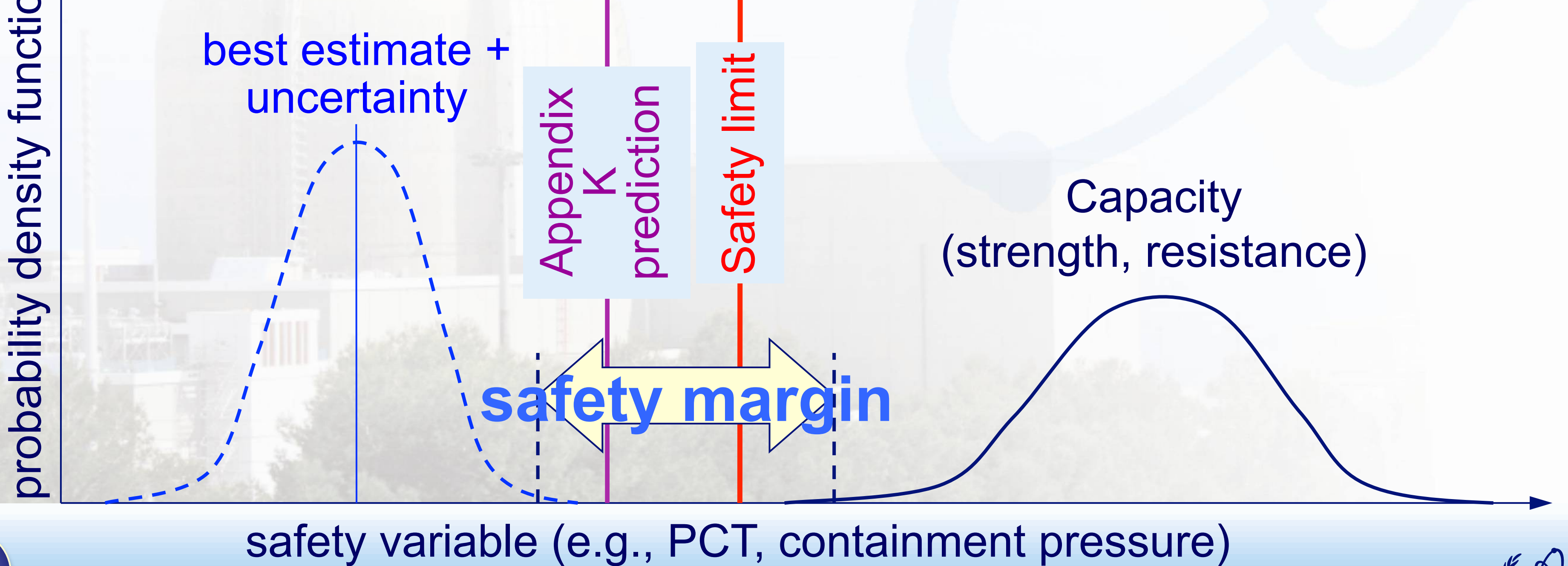
From M. Gavrilas, USNRC/RES; SMAP Madrid, 10/19-20/2006 ♪

Stay under the safety limit in all transients of interest (DBA)

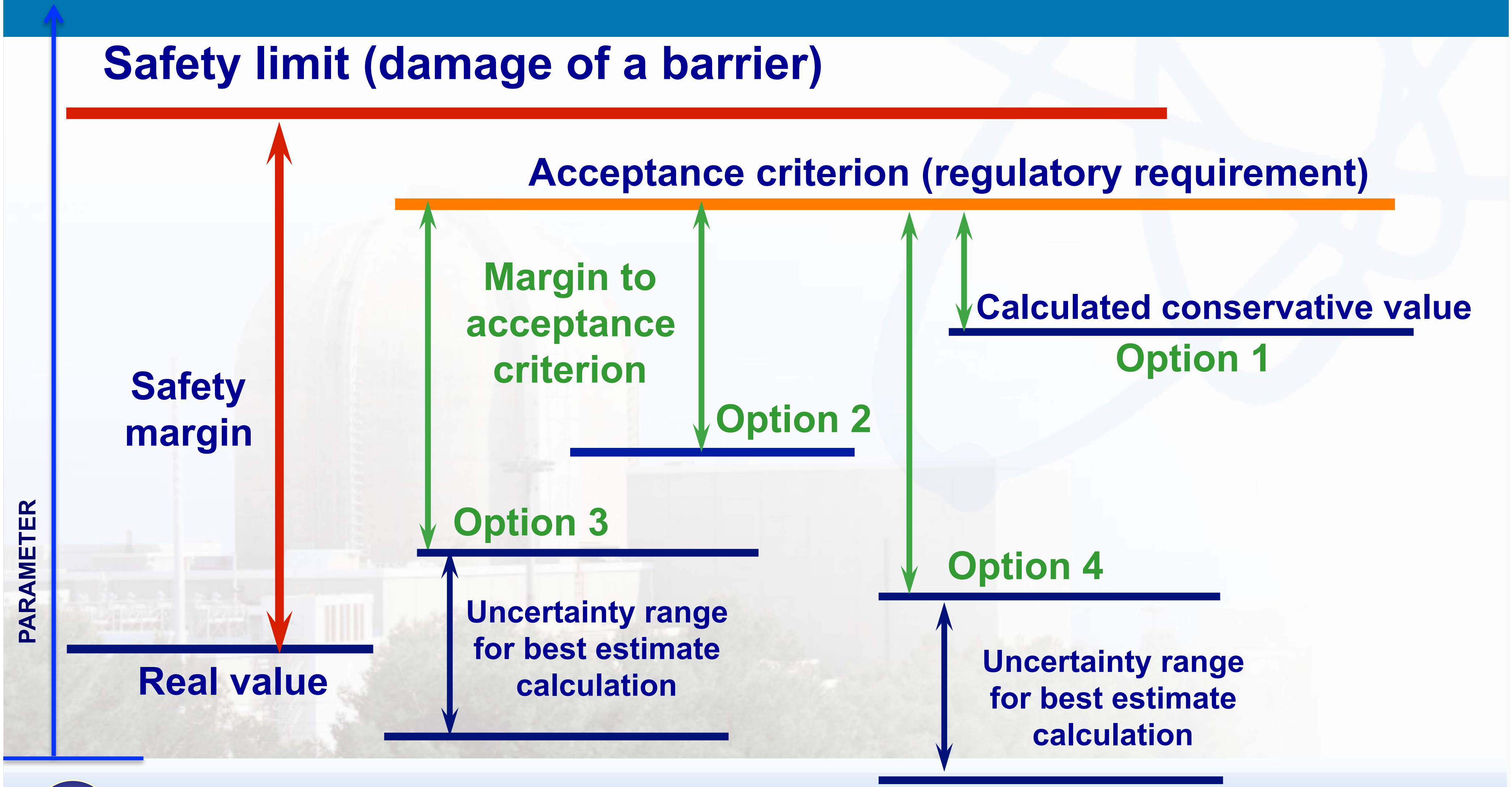
- Appendix K
- Best estimate + uncertainty♪

Set the safety limit such that there is negligible probability of loss of function if operating conditions stay below it, e.g.,

- PCT at 2200ºF (1204 °C)
- 17% total clad oxidation



Safety margins



CONSERVATIVE APPROACH

Conservative approach (1/21)

- The first one used in safety analysis
- The basic reason for developing the conservative method has been the need to circumvent the lacks of knowledge of the physical phenomena
- Approach based on the notions of consequences and criteria
  - Definition of restrictive criteria
  - Maximization of consequences
- Use of **penalizing initial and boundary conditions**
- Use of **penalizing assumptions on models**

Conservative Approach (2/21)

- A conservative approach usually means that any parameter that has to be specified for the analysis is allocated the value which will have an unfavourable impact relative to specific acceptance criteria.
  - Examples: Low gap conductance of fuel rod, decay heat 20% above ANS curve, etc.
- In a traditional conservative analysis (Option 1), both the assumed plant conditions and physical models are set conservatively.
  - Examples: 102% initial power, maximum linear heat generation rate, models in Appendix K of US Code of Federal Regulations, Chapter 10, Part 50.
- The intention is that such an approach would demonstrate that the calculated safety parameters are below the acceptance criteria and ensure that no other transient of that category would exceed the acceptance criteria.

Conservative Approach (3/21)
Initial Conditions

- The initial conditions are the plant parameters that exist at the start of the transient to be analyZed.
- Examples of these parameters are:
  - reactor power,
  - power distribution,
  - pressure,
  - temperature,
  - flow in the primary circuit,
  - etc.

Conservative Approach (4/21)
Boundary Conditions

- Boundary conditions are the parameters that are assumed to exist throughout the transient.
- Examples of boundary conditions are:
  - The actuation of safety systems, such as pumps and power supplies, leading to changes in flow rates
  - External sources and sinks for mass and energy
  - Other parameters during the course of the transient.

Conservative approach (5/21)
USA

- In 1974 the USNRC published the rules:
  - 10CFR 50.46 Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors
  - Appendix K to Part 50 - ECCS Evaluation Models
    - ✓ Established the primary safety criteria for peak cladding temperature (PCT), maximum cladding oxidation, maximum hydrogen generation, coolable geometry, and long-term cooling (these remain unchanged today in the US)
    - ✓ ECCS cooling performance shall be calculated
      - Acceptable evaluation model (App. K)
      - For a number of LOCAs of different sizes, locations and other properties to assure that entire spectrum is covered.

Conservative approach (6/21)
USA, 50.46 - safety criteria

- Cladding temperature (PCT) < 2200 °F (1478 K)
- Maximum cladding oxidation < 17% of the total cladding thickness before oxidation)
- Maximum hydrogen generation < 1% of the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react)
- Coolable geometry (core remains amenable to cooling)
- Long-term cooling (keeping acceptably low core temperature, remove decay heat with long-lived radioactivity remaining in the core)

Conservative approach (7/21)
(USA)10CFR 50.46 – Definition of Evaluation Model

- Definition in 50.46(c)(2): "An evaluation model is the calculational framework for evaluating the behaviour of the reactor system during a postulated loss-of-coolant accident (LOCA)."
  - one or more computer codes
  - information on mathematical models used, assumptions included in the programs, calculational procedure
- Establish required and acceptable features of the evaluation model (EM)
  - Sources of heat during the LOCA
  - Swelling and rupture of the cladding and fuel rod thermal parameters
  - Blowdown phenomena
  - Post-blowdown phenomena – Heat removal by ECCS

Conservative approach (8/21)
USA, Appendix K to Part 50 (cont'd)

- Required documentation for an evaluation model
  - description of EM
  - solution convergence
  - sensitivity studies
  - comparisons to experimental data
  - general standards for acceptability

Conservative approach (9/21)
USA, Appendix K to Part 50 (cont'd)

A. Sources of heat during the LOCA

- power level at least 102% of licensed level
- The initial stored energy in the fuel (for the burn-up that yields the highest calculated cladding temperature – stored energy)
- Fission heat (calculated using reactivity and reactor kinetics)
- Decay of actinides (for time in fuel cycle giving the highest calculated fuel temperature)
- Fission product decay (ANS 1971 standard, 1.2 multiplier)
- Metal-water reaction (Baker-Just equation)
- Reactor internals heat transfer (taken into account)
- PWR primary to secondary heat transfer (taken into account)

B. Swelling and rupture of the cladding and fuel rod thermal parameters

- EM shall include provision for predicting cladding swelling and rupture

Conservative approach (10/21)
USA, Appendix K to Part 50 (cont'd)

C. Blowdown phenomena

- Break characteristics and flow (break spectrum, Moody model with discharge coefficient (CD) range from 0.6 to 1.0 or even lower, ECCS bypass, break suitably nodalized)
- Frictional pressure drops (models for realistic variation with Reynolds number and realistic two-phase multipliers)
- Momentum equation include 7 effects: (1) temporal change of momentum, (2) momentum convection, (3) area change momentum flux, (4) momentum change due to compressibility, (5) pressure loss resulting from wall friction, (6) pressure loss resulting from area change, and (7) gravitational acceleration
- Pump modeling (allowed realistic modeling based on the applicable two-phase pump performance data)
- Critical heat flux (CHF) (specifies a number of correlations acceptable, return to nucleate boiling is not permitted during blowdown)
- Post-CHF heat transfer correlations (transition and film boiling models should not be nonconservative)
- Core flow distribution during blowdown (take into account calculated flow blockage to occur during blowdown)

Conservative approach (11/21) USA, Appendix K to Part 50 (cont'd)

D. Post-blowdown phenomena – Heat removal by ECCS

- Single failure criterion (most damaging single failure of ECCS – normally this results in loss of one ECCS train)
- Containment pressure (should not be overestimated – faster reflood)
- Calculation of reflood rate for pressurizer water reactors (primary coolant pumps locked impellers if this maximizes PCT, FLECHT-SEASET data to assess carryover fraction, effect of gas from accumulator)
- Steam interaction with emergency core cooling water in pressurized water reactors (during refill and reflood the steam flow zero)
- Refill and reflood heat transfer for pressurized water reactors (conservative correlations)
- Convective heat transfer coefficients for boiling water reactor fuel rods under spray cooling (conservative)
- The boiling water reactor channel box under spray cooling

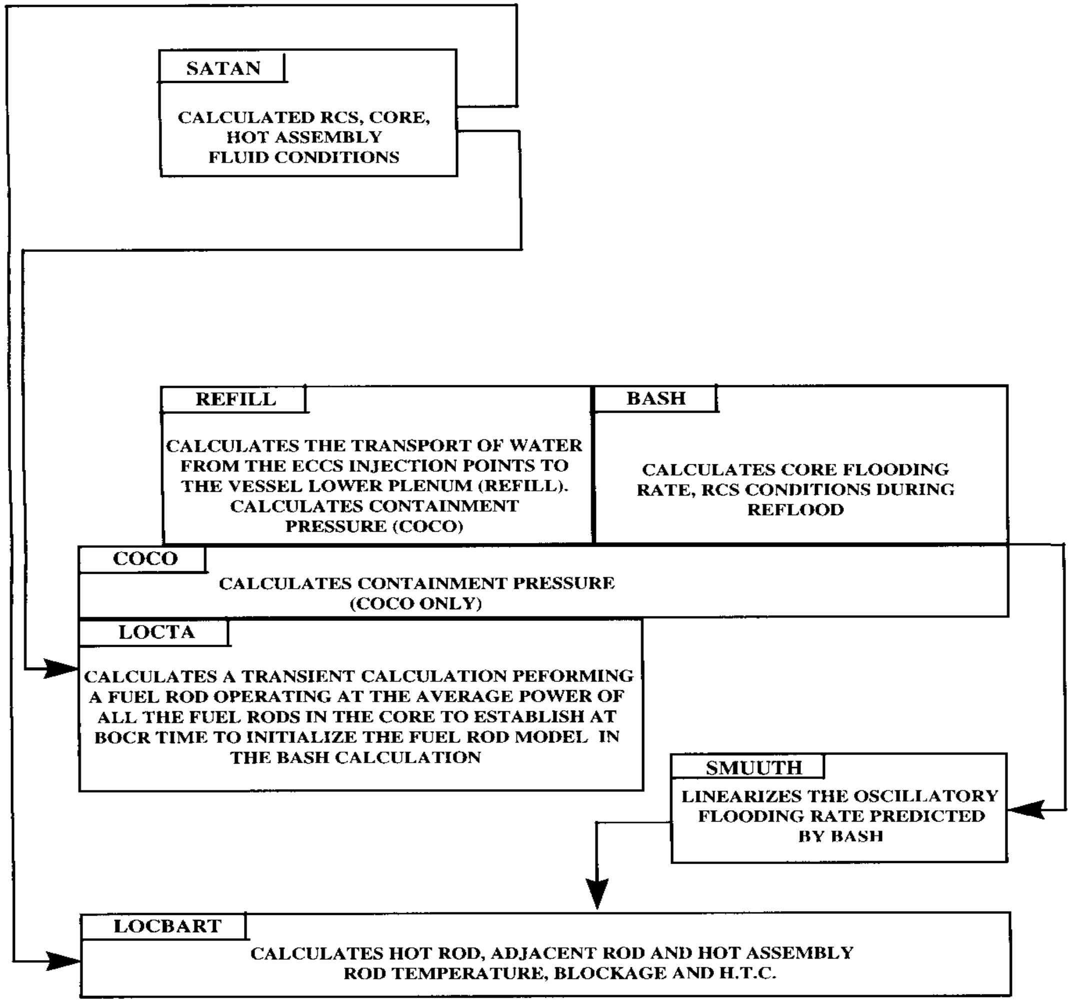
Conservative approach (12/21)
USA, Conservatism in Appendix K to Part 50

- In 1988, Dougall-Rohsenow was removed from the list of acceptable post-dryout correlations since it had been found to yield nonconservative predictions, the only part of Appendix K that was found to be nonconservative.
- Discussion of the relative importance of the various features of Appendix K is not found in Appendix K nor in the documentation of that time. Since then some studies have been carried out to provide some information in this regard.

Conservative approach (13/21)
USA, Conservatism in Appendix K to Part 50 (cont'd)

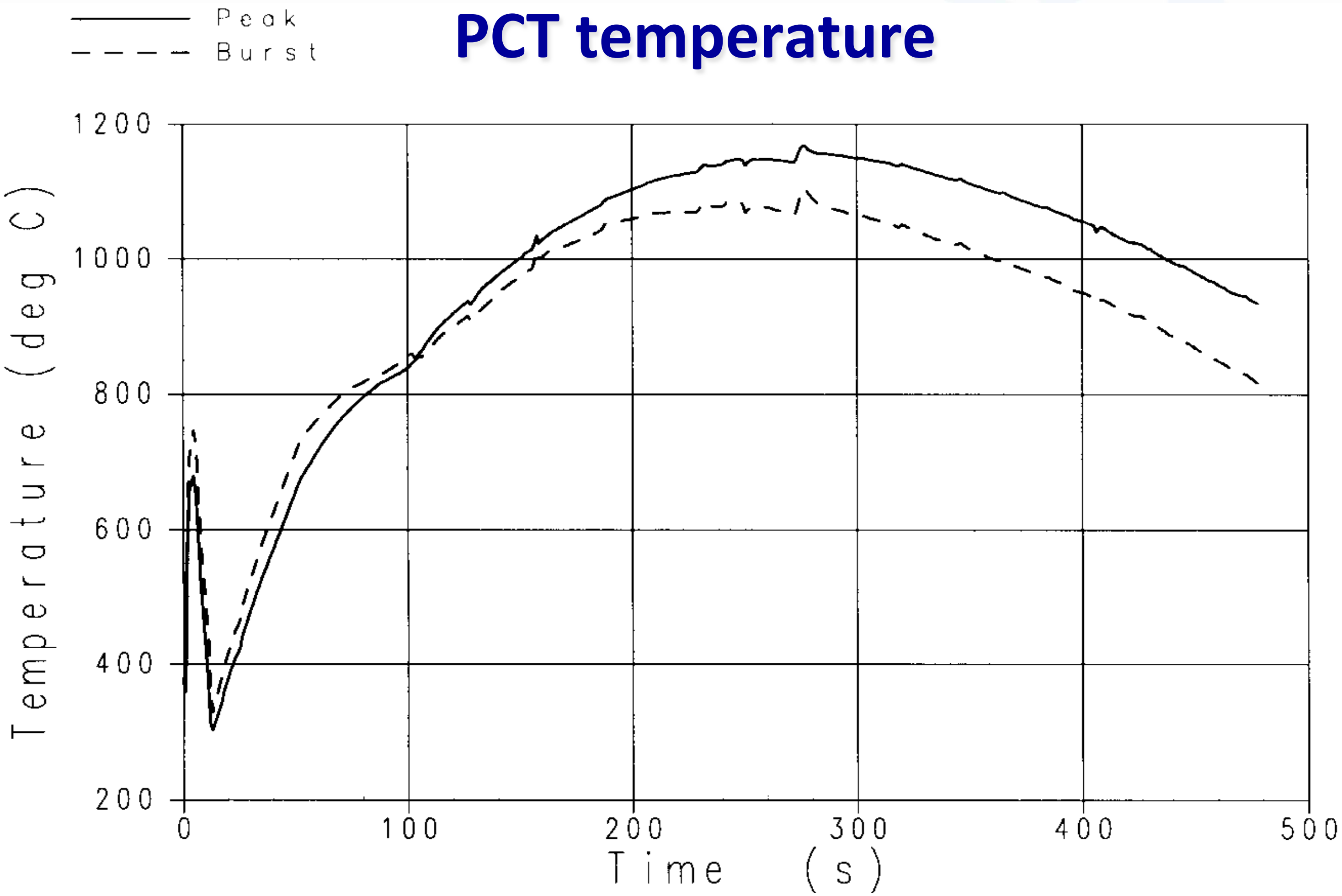
- For LBLOCA the most important features appeared to be:
  - requirement to use the peaking factor corresponding to the technical specification limit
  - lockout on return to nucleate boiling, which precludes blowdown cooling of any significance
  - steam-only cooling at reflood rates less than 2.54 cm
  - decay heat (1971 proposed ANS standard with a 1.2 multiplier)
  - single (most limiting) failure criterion
  - flow blockage (not prescriptive at all in Appendix K but in practice treated conservatively)
  - ECC bypass (not prescriptive but often relies on small scale experiments data base)
  - Zircaloy oxidation (use of Baker-Just)

Conservative approach (14/21)
USA, Example of the conservative Appendix K LOCA calculation



Applied EM methodology and used codes

Conservative approach (1521)
USA, Example of the conservative Appendix K calculation



Conservative approach (16/21)
Selection of Assumptions

- For the conservative calculations, the initial and boundary conditions should be set to values that will lead to conservative results for those parameters that are to be compared with the acceptance criteria.
- One set of conservative values for initial and boundary conditions does not necessarily lead to conservative results for every safety parameter.
  - Example: Assumed high power may not be conservative for possible recriticality due to cooling transient during a steam line break.
- The appropriate conservatism in each boundary condition should be selected depending on the specific acceptance criterion that is being addressed.

Conservative approach (17/21)
Availability of Systems and Components

- In conservative analyses, the single failure criterion should be applied when determining the availability of systems and components.
- Such a criterion stipulates that the safety systems are able to perform their specified functions even when a single failure occurs.
- A failure should be assumed in a component or function that would have the largest negative impact on the calculated safety parameter.
  - Failure on accumulator for large break of a main coolant pipe; failure of high pressure ECC injection during small break LOCA.
- All the common cause and consequential failures associated with the initiating event should also be included in the analysis in addition to the single failure.
- Further, unavailability due to on-line maintenance should be considered if this is tolerated by plant operating procedures.

Conservative approach (18/21)
Loss of Off-site Power

- In addition to the initiating event itself, a loss of off-site power should be considered when analyzing DBAs.
- A loss of offsite power implies reliance on emergency power for recovery after an accident.
- However, for some accidents, the consequences may be worse if the external power is available.

  => e.g. mild effect due to competing effects of RCP running and actuation of ECCS
- For such cases, the assumption which gives the most negative impact on the margin below the acceptance criterion should be chosen.

Conservative approach (19/21)
Equipment that is not Qualified

- Equipment that is not qualified for specific accident conditions should be assumed to fail unless its continued operation results in more unfavourable conditions.
- The analysis should take into account the malfunction of control systems and delays in the actuation of protection systems and safety systems.
- For such systems, the issue of whether their continued functioning leads to more unfavourable conditions than their non-availability should be addressed.

Conservative approach (20/21) Operator Actions

- For design purposes, credit should not be taken for operator action to limit the evolution of a DBA within a specified time.
- Exceptionally, the design may take credit for earlier operator action but, in these cases, the actuation times should be conservative and fully justified.
- Conservative assumptions should be made with respect to the time of operator actions.
- Post-accident recovery actions should in most cases be handled by the operator.

Conservative approach (21/21)
User Effects

- In some cases, the results produced by a conservative analysis are sensitive to decisions that are made by the user such as the number of nodes that is used.
- User effects such as this could be particularly large for a conservative analysis that cannot be checked using plant or experimental data.
- Experimental data should be bounded towards the direction of an acceptance criterion by a conservative calculation. The result of a conservative code should always be closer to the acceptance criterion than is the realistic value (see Validation).
- It is important that the procedures, code documentation and user guidelines be carefully followed to limit the effects of the user.
- By procedures is meant issues such as how to compile the input data set and how to select the appropriate models in the code.

Option 2 - Use of BE codes with conservative assumptions (1/2)

- In case of EM model needed to demonstrate that initial and boundary conditions imposed yield to "worst" result

- In case of BE Code needed to provide confidence that "worst" case has been demonstrated (alternative method for the identification of the uncertainties, in terms of critical parameters)

Option 2: Use of BE codes with conservative assumptions (2/2)

- How to define conservative assumptions?
- Best estimate codes generally do not allow to impose initial and boundary conditions that are not consistent.
- Outcome: Imposing one parameter generally leads to shift in others: e.g. increase of power causes increase of RCS temperatures and requires increased heat removal by SG s. To accommodate some secondary side parameters should be altered: FW temp, SG pressure or heat transfer area parameters
- Solution: Sensitivity studies

Option 2: Typical Areas of Sensitivity Studies

- Initial and Boundary Conditions:
  - Neutronic dana input BOC/MOC/EOV
  - PRZ level
  - SG level
  - Primary flow
- Models of certain components
  - Valve opening times
  - Pump start-up time
- Code internal choices

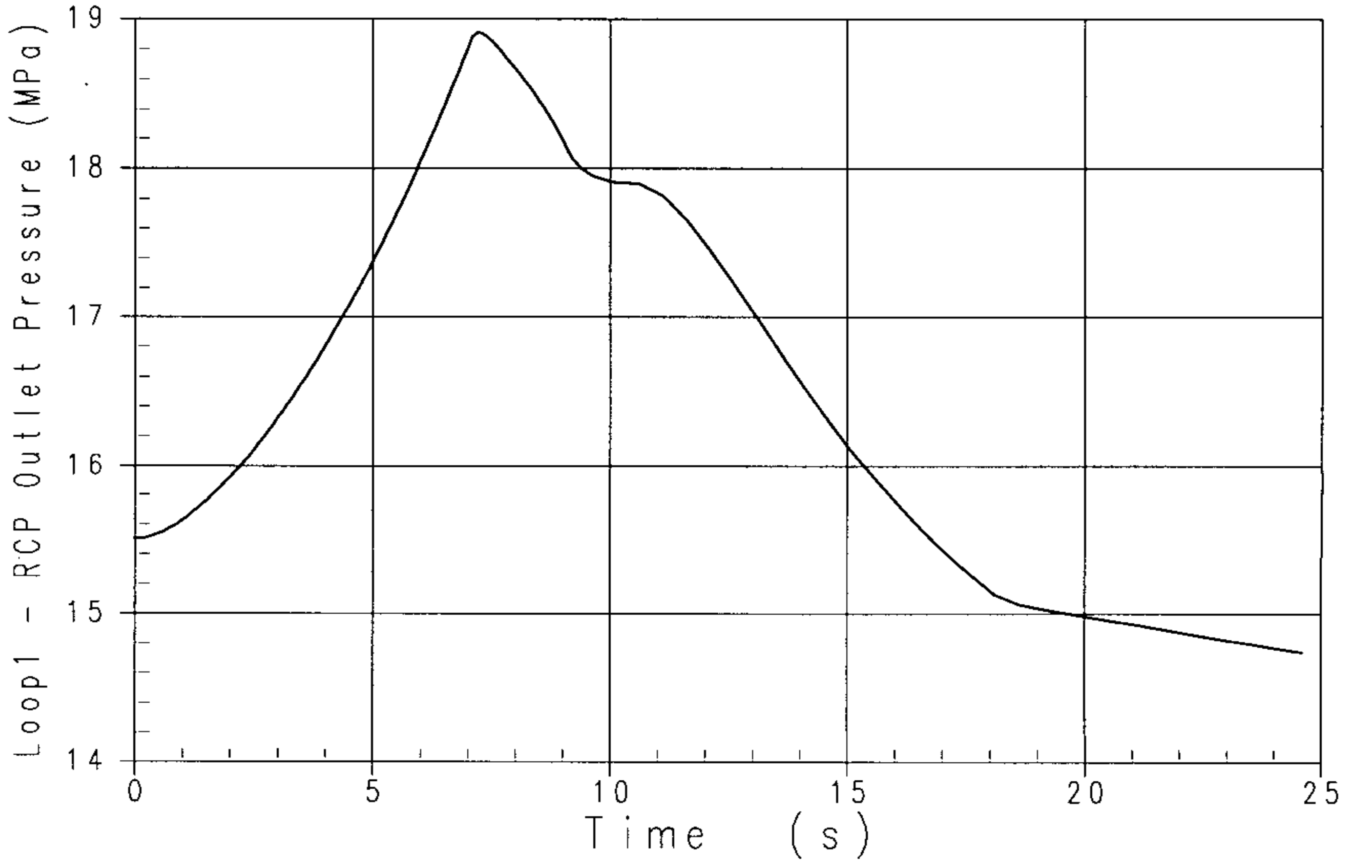
Disadvantages of a Conservative Approach

- Considerable increase in knowledge since the 1970s
- Conservative methodology may mask important safety issues.
- For example, the assumption of high core power may lead to high levels of the steam-water mixture level in the core in the case of small break LOCA.
- Consequently, the calculated peak clad temperature may not be conservative.
- Another example is assuming reduced interfacial shear may lead to higher clad temperature in the upper core region, but this may reduce the refill/ reflood time.

Problems raised by conservative approach

- Difficulty to prove that the conservatism's which are verified on scaled down experiments are also valid at full scale reactor size
- Due to nonlinearity, adding of several conservative measures cannot be verified
- Method unsuitable for emergency operating procedures (EOP) studies (especially obvious after TMI2 accident)
- All these limitations have been the motivation for developing best estimate codes and for launching in the late seventies the considerable experimental programme
- In cases where a realistic analysis could demonstrate that important safety issues may be masked, the conservative licensing calculations should be accompanied by a best estimate analysis, without an evaluation of the uncertainties.
- Conservative approach often does not show margins to acceptance criteria.
- It may be preferable to use a best estimate approach together with an evaluation of the uncertainties (Option 3 - BEPU).

Non-LOCA conservative calculation
Loss of Load/Turbine Trip (LOL/TT)



Assumptions:

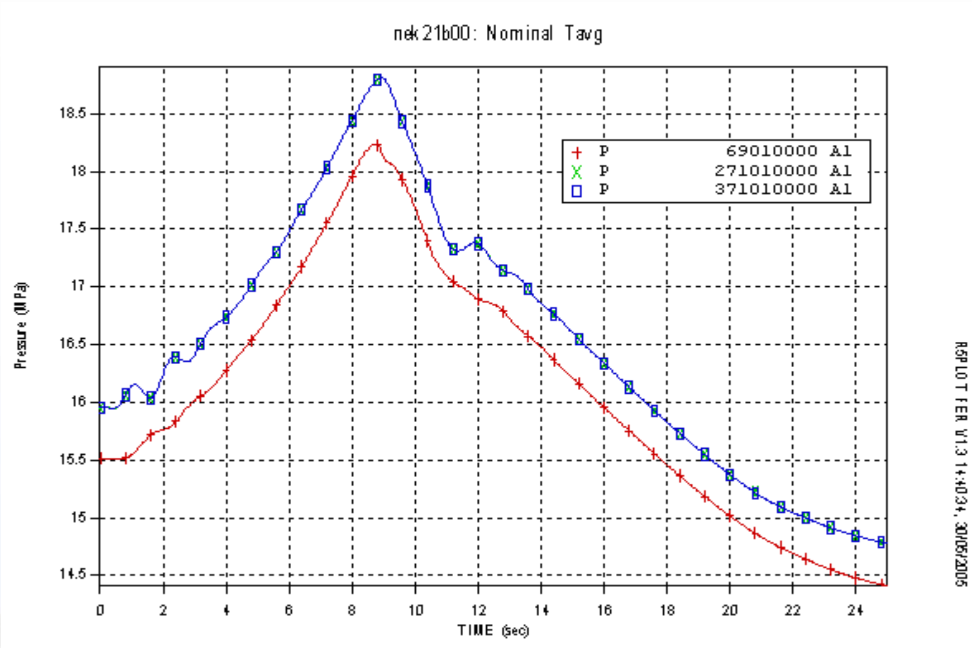
- Min. Feedback
- FW trip at time of LOL
- No credit on Rx tip on turbine trip
- PORV and steam dump not functional
- Rod and press. control negl.
- Measurement unc. applied on I&B parameters
- Considered delay in clearing of loop seal for safety valves

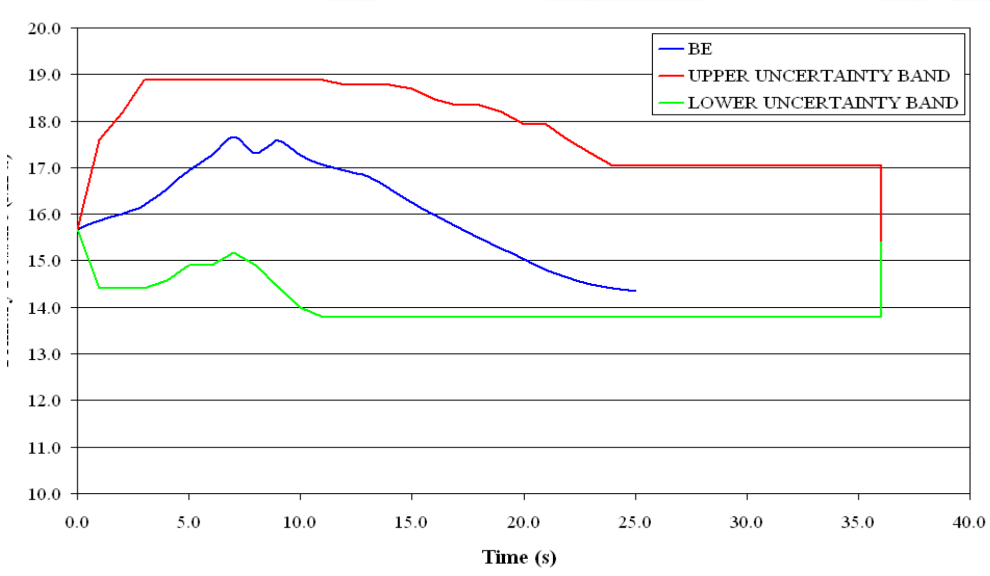
Revisited conservatism for LOL/TT

- Applied guidance for conservative analysis recommends for the initial RCS average temperature the use of nominal full power temperature plus the temperature uncertainty.
- Analyses on some plants showed that the use of a lower initial temperature condition could delay the actuation of the secondary-side main steam safety valves and result in higher peak RCS pressure than that obtained for the higher initial RCS temperature recommended in the standard guidance.
- Significant potential safety concern for plants that are adversely affected by a lower initial RCS average temperature in the LOL/TT analysis: violation of the RCS pressure limit (110 % of design pressure: 18.95 MPa).

BEST ESTIMATE PLUS UNCERTAINTY

Results of the Conservative vs. BEPU

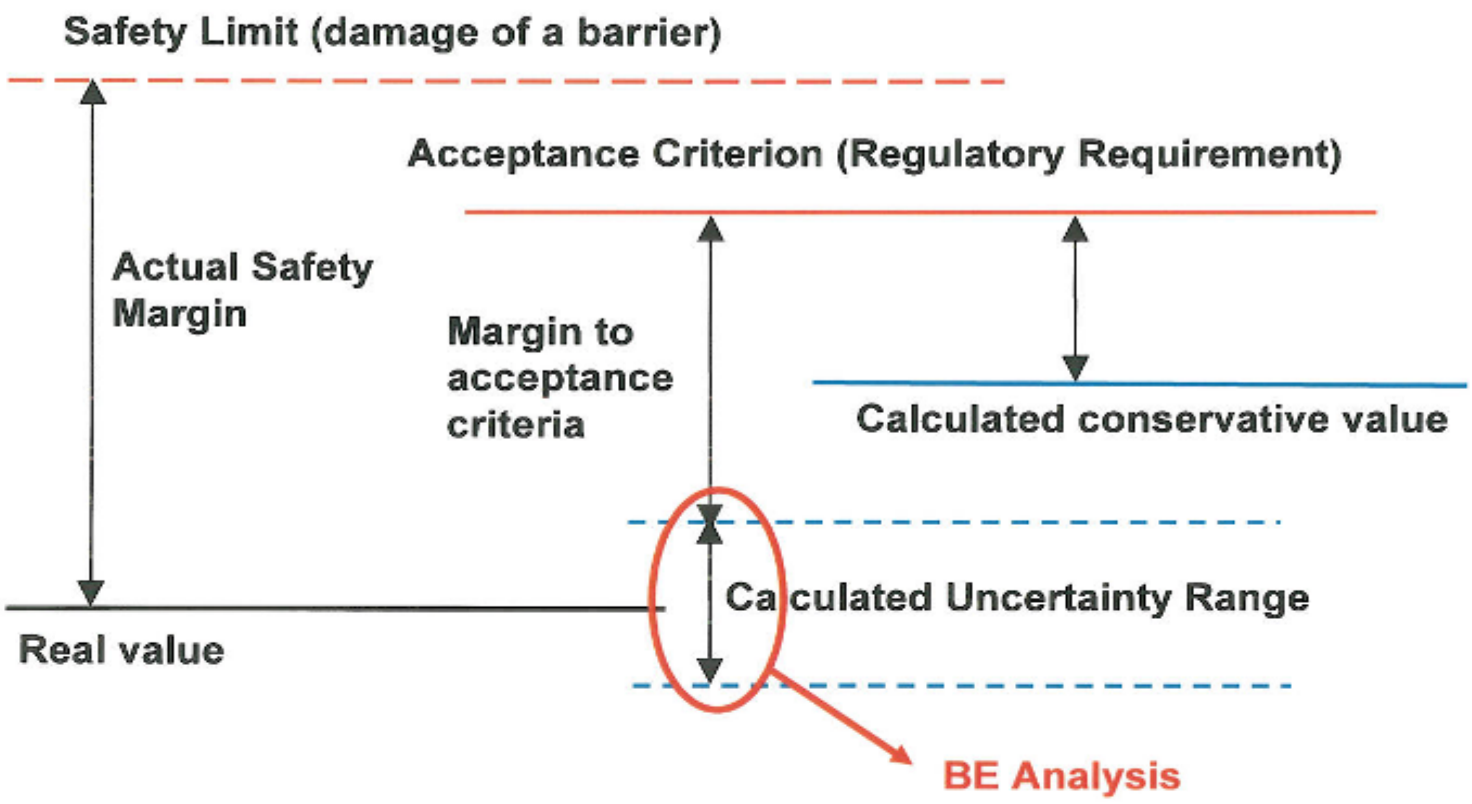




Results show that upper uncertainty limit and "conservative" assumptions are at design limit

NEEDS IN LICENSING

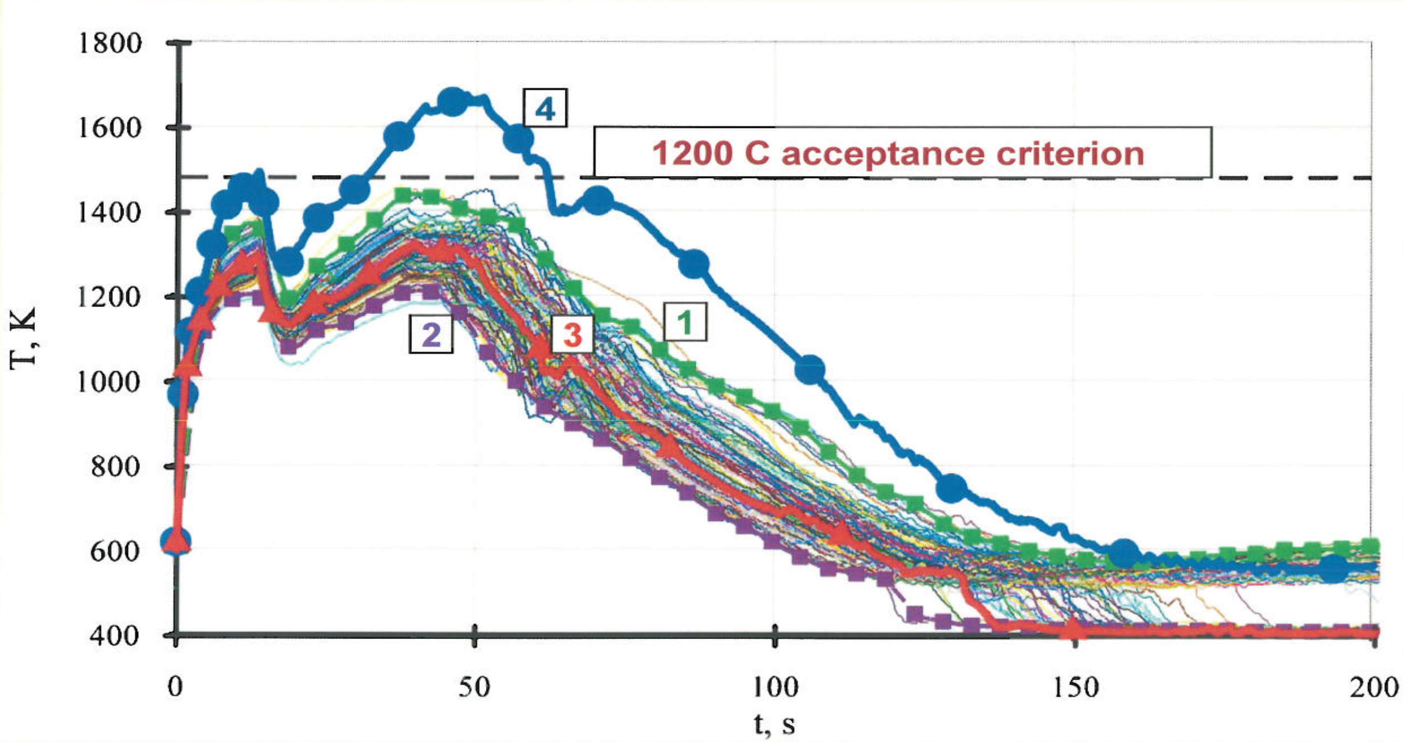
Way of exploiting the Best-Estimate codes (H. Glaser, 2000) *



* **Best-Estimate** is alternative to **Conservative** or **Evaluation Model** Codes

Shifting to BEPU

Example of TRAP-97 calculation for BEMUSE-IV

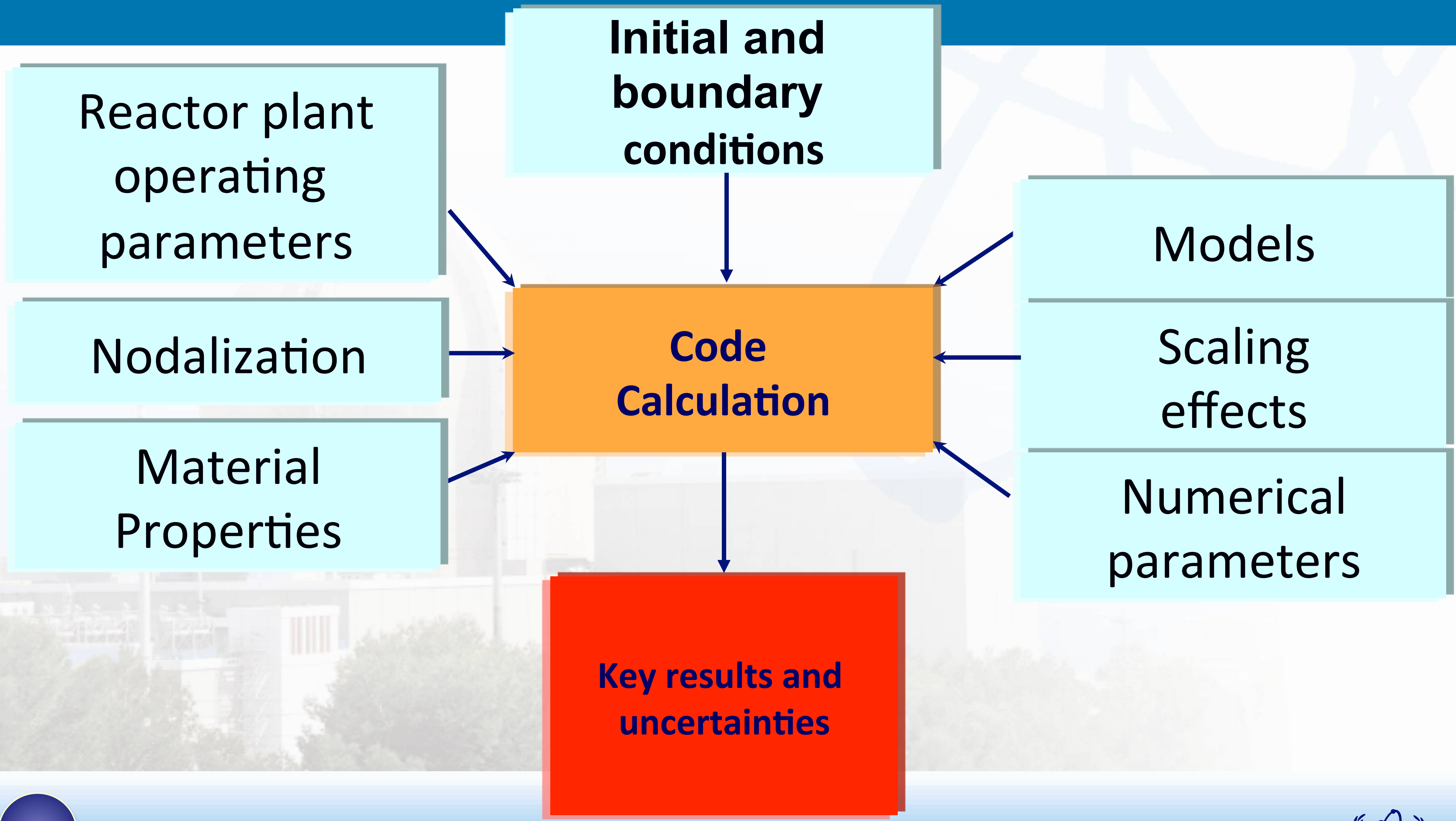


1, 2 – upper/lower 95/95 limit for BEPU; 3 – realistic input;
4 – conservative input

Option 3: Uncertainties

- Best estimate codes do not provide conservative results.
- Uncertainties in the results should be quantified.
- Important when values of safety parameters approach acceptance criteria.
- Evaluation of the uncertainties based on one calculation may not be adequate.

Uncertainty of Calculation Results



Option 3: Acceptability of Exceeding Acceptance Criteria

- Option 3 should be based on statistically combined uncertainties to establish, that the calculated results do not exceed the acceptance criteria.
- It is common practice that assurance has to be provided with a probability of 95% or more.
- A probability of 100% can not be provided because only a limited number of calculations can be performed.
- The basis for selecting the 95% probability level is primarily to be consistent with standard engineering practice in regulatory matters.

Research Background for Best Estimate Approach

- International research after formulation of the original licensing requirements:
- Large number of experimental programs were completed internationally
  - Semi-Scale, LOFT, CCTF, UPTF, SCTF, FLECHT, FLECHTSEASET, CREARE, THTF, LOBI, PKL, NEPTUNUS, MARVIKEN
- A number of advanced computer codes (best estimate) were developed in parallel with experiments for replacing EM
  - RELAP, TRAC, COBRA-TRAC, RETRAN, CATHARE, ATHLET etc.

Development of BEPU

- Original criteria for LOCA were formulated at a time when limitations in knowledge made conservative approaches necessary
- Research during 1974-1988 provided a foundation sufficient for use of realistic and physically based analysis methods: Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, August 1988.
- In September 1988, the NRC approved a revised rule for the acceptance of ECCSs: USNRC, "Emergency Core Cooling Systems, Revisions to Acceptance Criteria", Federal Register 53, 180, September 16, 1988.

Development of BEPU (cont.)

- In May 1989, the NRC provided guidance for the use of best-estimate codes: USNRC Regulatory Guide 1.157, “Best-Estimate Calculations of Emergency Core Cooling System performance”, May 1989.
- Revised rule for LOCA/ECCS analysis of light water reactors allow the use of best-estimate computer codes in safety analysis as an option.
- A key feature of this option requires the licensee to quantify the uncertainty of the calculations and include that uncertainty when comparing the calculated results with acceptance limits provided in 10CFR50.

Revised rule of ECCS

The revised rule of ECCS in 1989 contains three key features:

- The existing acceptance criteria were retained
- EM methods based on Appendix K may continue to be used as an alternative to best estimate methodology
- An alternate ECCS performance, based on BE methods, may be used to provide more realistic estimates of plant safety margins, provided the licensee quantifies the uncertainty of the estimates and includes the uncertainty when comparing the calculated results with prescribed acceptance limits.

USNRC Regulatory Guide 1.157

"Best-Estimate Calculations of Emergency Core Cooling System Performance"

- The initial stored energy in the fuel – should be calculated in best-estimate manner for the assumed initial conditions, fuel conditions and operating history)
- Fission heat (calculated using best-estimate reactivity and reactor kinetics)
- Decay of actinides (best estimate models)
- Fission product decay (best-estimate manner)
- Metal-water reaction (best-estimate models)
- Reactor internals heat transfer (best-estimate manner)

Best-estimate code features: Regulatory Guide 1.157 (cont.)

- Pressurized water reactor primary to secondary heat transfer (taken into account, best-estimate)
- Break characteristics and flow (best-estimate models)
- ECCS bypass (best-estimate manner)
- Noding near the break and ECCS injection point (**sensitivity study** on noding and other parameters to ensure realistic results)
- Frictional pressure drops (best-estimate models)
- Momentum equation (best-estimate models)
- Critical heat flux (CHF) (best-estimate models)
- Post-CHF heat transfer correlations (best-estimate models)

Best-estimate code features: Regulatory Guide 1.157 (cont.)

- Pump modeling (best-estimate models)
- Core flow distribution during blowdown (best-estimate models)
- Containment pressure (best-estimate)
- Calculation of post-blowdown thermal hydraulics for pressurized water reactors (best-estimate models)
- Steam interaction with emergency core cooling water in pressurized water reactors (taken into account, best-estimate models)
- Post-blowdown heat transfer for pressurized water reactors (best estimate models)
- Convective heat transfer coefficients for boiling water reactor fuel rods under spray cooling (models will be considered acceptable provided their technical bases can be justified with appropriate data and analyses)
- The boiling water reactor channel box under spray cooling (best estimate models)

Regulatory Guide 1.157 (cont'd)

SBLOCA considerations:

- Break flow may be greatly influenced by the location and specific geometry of the break
- Pump operations assumptions should be the most likely (EOP)
- Level depression in the core
- Reflux mode

Regulatory Guide 1.157 (cont'd)

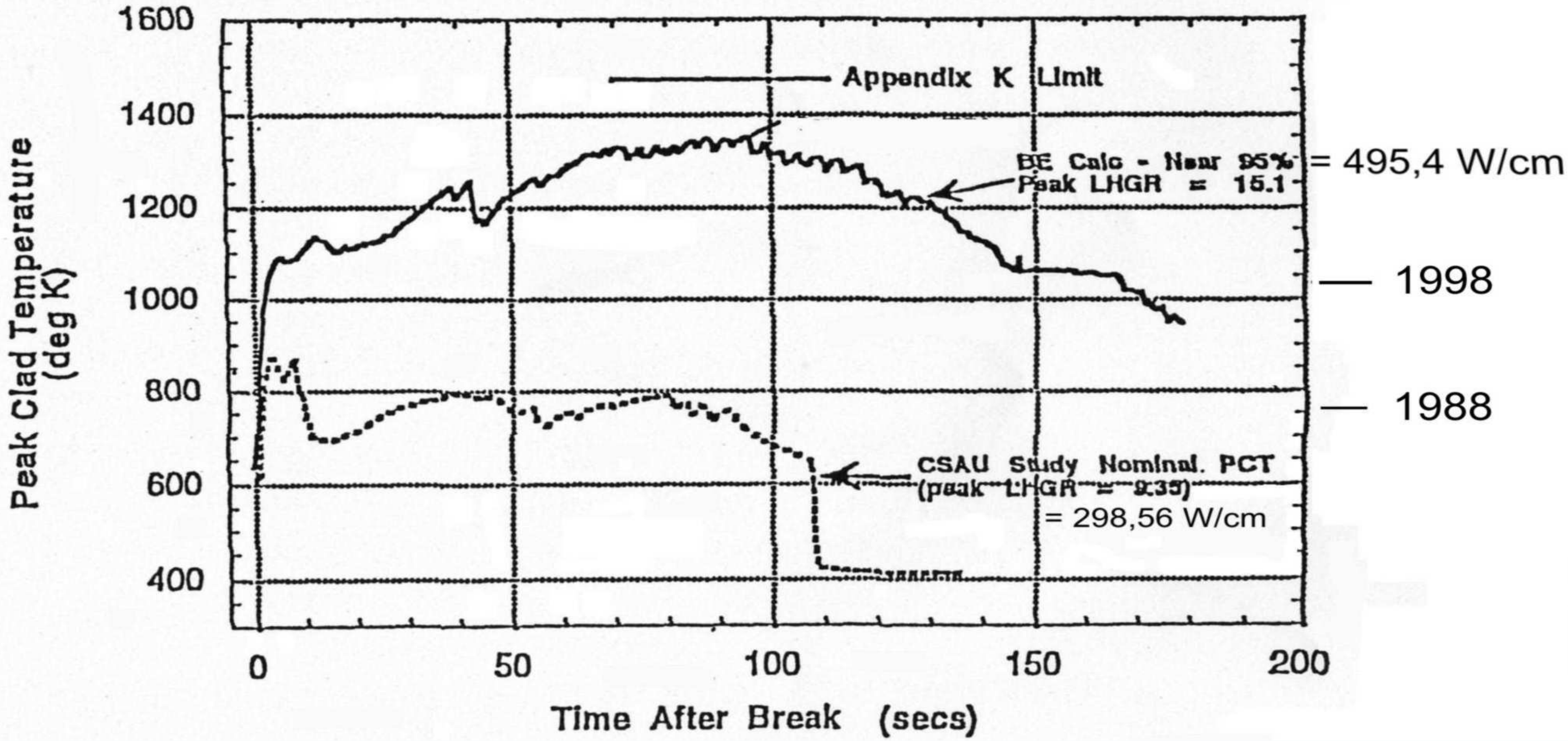
Other features of BE codes (examples):

- Best estimate models should contain models in sufficient detail to predict the phenomena that are important to demonstrate compliance with acceptance criteria
- Individual models should be compared to applicable experimental data

Example Best-Estimate Calculation (USA)

- Peak LHGR = 15.1 (kW/ft) = 495.4 W/cm

→ Peak Clad Temperature is representative of 95th percentile value



...Thank you for your attention

Thermal-Hydraulic Codes

System Codes
Representation of NSSS
Coarse Mesh, 1D (RPV: 2D/3D)
Based on Euler Equation

1965

- 3 Balance Equations (HEM)
  BRUCH, FLASH, RELAP3,….
- 4 Balance Equations with Drift
  (Thermo-dynamic Nonequilibrium
  one Phase saturated)
- 5 Balance Equations with Drift
  (Thermo-dynamic Nonequilibrium
- 6 Balance Equ. 2-Fluid Model
  ATHLET, APROS
  CATHARE, RELAP, TRAC, …

2000

Number of meshes

~10 → **~10^3**

~10^3 → **~10^6**

CFD Codes
Representation of Components
2D/3D Fine Mesh
Based on Navier-Stokes Equations

- Single- Phase Modelling
  Teach, TEAM, …
- Two-Phase Modelling
  limited to small void fraction
  FLOW-3D, CFX, FLUENT, …
- Two-Phase Modelling
  Entire range of voidfraction
  (has to be developed)

Simulation of total NSSS with detailed
representation of components