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

Acceptance Criteria in DBA

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Session Outline

- Acceptance criteria in overall safety assessment process
- Definition of acceptance criteria
- Types of acceptance criteria
  - Global/high level criteria
  - Detailed level criteria
- Assumptions on acceptance criteria
- IAEA recommendations on acceptance criteria
- Regulatory review of acceptance criteria

IAEA GSR-4: R4, Purpose of the safety assessment

- The primary purposes of the safety assessment shall be to determine whether an adequate level of safety has been achieved for a facility or activity and whether the basic safety objectives and safety criteria established by the designer, the operating organization and the regulatory body, in compliance with the requirements for protection and safety as established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources have been fulfilled

Deterministic Acceptance Criteria: Definition

- **IAEA Safety glossary** explains the acceptance criteria as:
  - **‘Specified bound on the value of a functional indicator or condition indicator used to assess the ability of a structure, system or component to perform its design function.’**
- Acceptance criteria can be expressed **quantitatively or qualitatively**
- Acceptance criteria should be established **separately for each category of plant states** (NO, AOOs, DBAs, BDBAs, ...)
- **More stringent criteria should be applied for events with a higher frequency of occurrence**

Deterministic Acceptance Criteria

- Deterministic acceptance criteria should be established at two levels as follows:
  - **Global/high level criteria**
    - **Relate to radiological consequences**
      - Usually expressed in terms of releases (TBq) or doses (mSv), **typically defined by legislation (by the regulatory body)**
- **Detailed criteria**
    - **Relate to integrity of barriers**
      - Usually expressed in terms of limiting values of variables essential for integrity of barriers, such as pressures, temperatures, heat fluxes, stresses, etc.
      - **Typically defined by the designer and approved by the regulatory body**

Global/High Level

Deterministic Acceptance Criteria

(Associated with Radiological Consequences)

Examples of health effects of radiation (EIA, OL 3)

Effective dose (mSv)	Source of exposure
0.01	One dental X-ray examination, or a colour TV
0.02	Nuclear weapon tests plus deposits after Chernobyl
0.1	One X-ray examination of lungs
0.4	Natural radioactive substances present in the body
1,5 – 7,5	Average annual dose from natural sources in Europe (UK lowest, Finland highest)
12	Computerized axial tomography of stomach
1000	Symptoms of radiation sickness begin to appear if received in less than 24 hours
4000	Lethal radiation dose, the person can be saved with good care
6000	If received suddenly is likely to cause death
10 000	Life can not be saved even with best care

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Examples of doses

- 0.005 mSv/h (average value) during the flight at 10,000 m altitute
  - Alitalia flight TRS-FCO and FCO-EZE 15 hours -> 0.075 mSv

Global Acceptance Criteria

- **Normal operation**
  - Criteria typically expressed as
    - Effective dose limits for the plant staff and the members of the public
    - Acceptable releases/effluents from the plant
  - Acceptable dose limits are of order of **~0.1 mSv per year**.
- **Anticipated operational occurrences**
  - Acceptable dose limits for each event are **comparable with annual dose limits for normal operation**.

Global Acceptance Criteria

- **Design basis accidents**
  - Either **no off-site radiological impact or only minor radiological impact outside the exclusion area**
  - Very restrictive dose limits in order to **exclude the need for off-site emergency actions**
  - Acceptable dose limits are typically of order of few **(1 – 5) mSv per year**

Global Acceptance Criteria

- **Severe accidents**
  - o Consequences can be defined in terms of
    - – Effective dose to critical groups

      or

    - – A surrogate measure, such as a cumulative frequency of core damage or radioactivity release into the environment above a specified threshold.

Global Acceptance Criteria

- **Severe accidents (continued)**
  - The criteria are intended to ensure that there will be **neither short term nor long term health effects** following a severe accident
  - Typical effective dose limits are of order of **10 - 100 mSv**
  - The value **strongly depends on the conditions** considered for determination of doses (ways of exposure, duration of exposure, consideration of food stuff, weather conditions)
  - **Optionally,** radiological criteria can be expressed **in terms of acceptable releases of selected radioisotopes** (I131, Cs137) or groups of radioisotopes.

Detailed Acceptance Criteria Associated with Integrity of Barriers

General Acceptance Criteria Associated with Barriers

- **An event should not generate a subsequent more serious plant condition**, without the occurrence of a further independent failure
  - Examples:
    - An AOO by itself should not generate a DBA
    - A DBA by itself should not generate a BDBA
- There should be **no consequential loss of function of the safety systems** needed to mitigate the consequences of an accident
- Systems used for accident mitigation should be designed **to withstand the maximum loads, stresses and environmental conditions** for the accidents analysed

Set of Detailed Acceptance Criteria

- Criteria related to integrity of nuclear fuel matrix:
  - Maximum fuel temperature
  - Radially averaged fuel enthalpy (with dependence on burn-up and composition of fuel / additives like burnable absorbers)
- Criteria related to integrity of fuel claddings:
  - Minimum DNBR
  - Maximum cladding temperature
  - Maximum local cladding oxidation

Set of Detailed Acceptance Criteria

- Criteria related to integrity of the whole reactor core:
  - o Subcriticality
  - o Maximum production of hydrogen
  - o Maximum damage of fuel elements
  - o Maximum deformation of fuel assemblies (as required for cooling down, insertion of absorbers, and de-assembling)

Set of Detailed Acceptance Criteria

- Criteria related to integrity of the RCS:
  - Maximum coolant pressure
  - Temperature, pressure and temperature changes
  - Resulting stresses-strains, no brittle fracture from a postulated defect of the RPV
- Criteria related to integrity of the secondary circuit
  - Maximum coolant pressure
  - Maximum temperature, pressure and temperature changes in the secondary circuit equipment

Set of Detailed Acceptance Criteria

- Criteria related to integrity of the containment and limitation of releases to the environment:
  - Maximum pressure and temperature
  - Maximum pressure differences on containment walls
  - Leakages
  - Concentration of flammable gases
  - Acceptable working environment for operation of systems

Graded Approach to Acceptance Criteria

- In general, **acceptance criteria** related to integrity of barriers should be **more restrictive for events with higher probability of occurrence**.
- **For anticipated operational occurrences**, there should be no failures of any of the physical barriers (fuel matrix, fuel cladding, reactor coolant pressure boundary or containment) and no fuel damage (or no additional fuel damage if minor fuel leakage, within operational limits, already exists)

Graded Approach to Acceptance Criteria

- **For design basis accident**, there should be no consequential damage of the reactor coolant system, containment integrity should be preserved, and damage of the reactor fuel should be limited
- **For severe accidents**, containment integrity should be maintained either infinitely or at least for sufficiently long time

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TRANSIENTS

- For transients it has to be demonstrated that the intrinsic features of the design and the systems automatically actuated by the instrumentation, particularly the reactor trip system, are sufficiently effective to ensure that:
  1. The probability of a boiling crisis anywhere in the core is low. This criterion is typically expressed by the requirement that there is a 95% probability at the 95% confidence level that the fuel rod does not experience a departure from nucleate boiling (DNB).The DNB correlation used in the analysis needs to be based on experimental data that are relevant to the particular core cooling conditions and fuel design
  2. The pressure in the reactor coolant and main steam systems is maintained below a prescribed value (typically 110% of the design pressure)
  3. There is no fuel melting anywhere in the core

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DESIGN BASIS ACCIDENTS

- For DBAs it has to be demonstrated that the design specific engineered safety features are sufficiently effective to ensure that:

4. The radially averaged fuel pellet enthalpy does not exceed the prescribed values (the values differ significantly among different reactor designs and depend also on fuel burnup) at any axial location of any fuel rod. This criterion ensures that fuel integrity is maintained and energetic fuel dispersion into the coolant will not occur (specific to RIAs)
5. The fuel rod cladding temperature does not exceed a prescribed value (typically 1200°C). This criterion ensures that melting and embrittlement of the cladding are avoided

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DESIGN BASIS ACCIDENTS

- For DBAs it has to be demonstrated that the design specific engineered safety features are sufficiently effective to ensure that:

6. Fuel melting at any axial location of any fuel rod is limited (typically, no fuel melt is allowed or a maximum 10% melt of the fuel volume at the hot spot is accepted). This criterion ensures that substantial volumetric changes of fuel and a release of radioactive elements will not occur
7. The pressure in the reactor coolant and in the main steam system is maintained below a prescribed value (typically 135% of the design value for ATWSs and 110% for other DBAs).This criterion ensures that the structural integrity of the reactor coolant boundary is maintained
8. Calculated doses are below the limits for DBAs, assuming an event generated iodine spike and an equilibrium iodine concentration for continued power operation, and considering actual operational limits and conditions for the primary and secondary coolant activity

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DESIGN BASIS ACCIDENTS

- In addition to criteria 4–8, particularly for design basis LOCAs, short term and long term core coolability should be ensured by fulfilling the following five criteria:
  9. The fuel rod cladding temperature should not exceed a prescribed value (typically 1200°C); the value is limiting from the point of view of cladding integrity following its quenching and is also important for avoiding a strong cladding–steam reaction, thus replacing criterion (5) which is valid for other accidents
  10. The maximum local cladding oxidation should not exceed a prescribed value (typically 17–18% of the initial cladding thickness before oxidation)
  11. The total amount of hydrogen generated from the chemical reaction of the cladding with water or steam should not exceed a prescribed value (typically 1% of the hypothetical amount that would be generated if all the cladding in the core were to react)
  12. Calculated changes in core geometry have to be limited in such a way that the core remains amenable to long term cooling, and the CRs need to remain movable
  13. There should be sufficient coolant inventory for long term cooling

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ALL ACCIDENTS – CONTAINMENT PRESSURIZATION

- In addition to the previous relevant criteria, the following criteria apply:

14. The calculated peak containment pressure needs to be lower than the containment design pressure and the calculated minimum containment pressure needs to be higher than the corresponding acceptable value
15. Differential pressures, acting on containment internal structures important for containment integrity, have to be maintained at acceptable values

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PRESSURIZED THERMAL SHOCK ANALYSIS OF ACCIDENTS

- Specific acceptance criteria for PTS analysis should apply, as follows:

16. There will be no initiation of a brittle fracture or ductile failure from a postulated defect of the reactor pressure vessel (RPV) during the plant design life for the whole set of anticipated transients and postulated accidents

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ACCEPTANCE CRITERIA FOR ACCIDENTS OCCURRING DURING SHUTDOWN

- The operational modes considered have several barriers partially degraded (reactor pressure vessel closed or open, containment closed or open). Besides generally applicable criteria, such as (8), the following specific (more stringent in the case of degraded barriers) criteria have to apply:

17. If both the reactor and the containment are closed, the fuel cladding temperature and oxidation have to be limited to the same values as those for a LOCA.
18. If one of the barriers (either reactor or containment) is open while the other is closed, uncovery of the fuel in the reactor needs to be avoided.
19. If both barriers (reactor and containment) are open, both coolant boiling in the core and fuel uncovery need to be avoided

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ACCEPTANCE CRITERIA FOR SEVERE ACCIDENTS

- Acceptance criteria for SAs are less prescriptive than the criteria for DBAs. Typically, the criterion is considered in relation to the very low probability associated with an SA. Examples of more specific criteria applicable for SAs with non-negligible probability are as follows:

20. There should be no failure of the containment because of pressure and temperature loads
21. There should be no immediate health effects on the population
22. For long term effects the 137Cs release limit needs to be below the prescribed value (e.g. 100 TBq), and all the other nuclides together are not to cause a larger danger after the time period specified (e.g. three months)

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Example of acceptance criteria: Integrity of the fuel and cladding

- Objective is to ensure that the fuel rods retain their geometries and hold the fuel in its inteded configuration so that fractured portions of the rods would not fall to the bottom of the core and inhibit coolability and there would be no release of the radioactive products into primary circuit

Example of acceptance criteria - PCT

- Peak cladding temperature (PCT) < 2200ºF (1204ºC)
  - Maximum calculated temperature allowable by any portion of the fuel rod cladding during the loss of coolant accident (LOCA)
- No more than 17% of the cladding wall thickness may be oxidized during the loss of coolant accident (LOCA)
  - To ensure that the cladding will retains adequate ductility to resist fracture or shattering caused by the thermal shock loads upon quenching during the reflood phase

Example of acceptance criteria - PCT

- Experimental evidence – autocatalytic temperature
  - PBF: Zircaloy-steam reaction becomes sufficiently rapid at 2600ºF (1427ºC)
  - MT-6B: Zircaloy oxidation rate easily controllable by adding more coolant at 2200ºF (1204ºC)
  - FLHT: autocatalytic reaction initiated at 2500-2600ºF (1371-1427ºC)
  - NSRR: cladding temperatures of 2750ºF (1510ºC) can be attained for a few seconds and subsequent cooling by the collapse of the steam blanket around the rod was routinely possible

Example of acceptance criteria - PCT

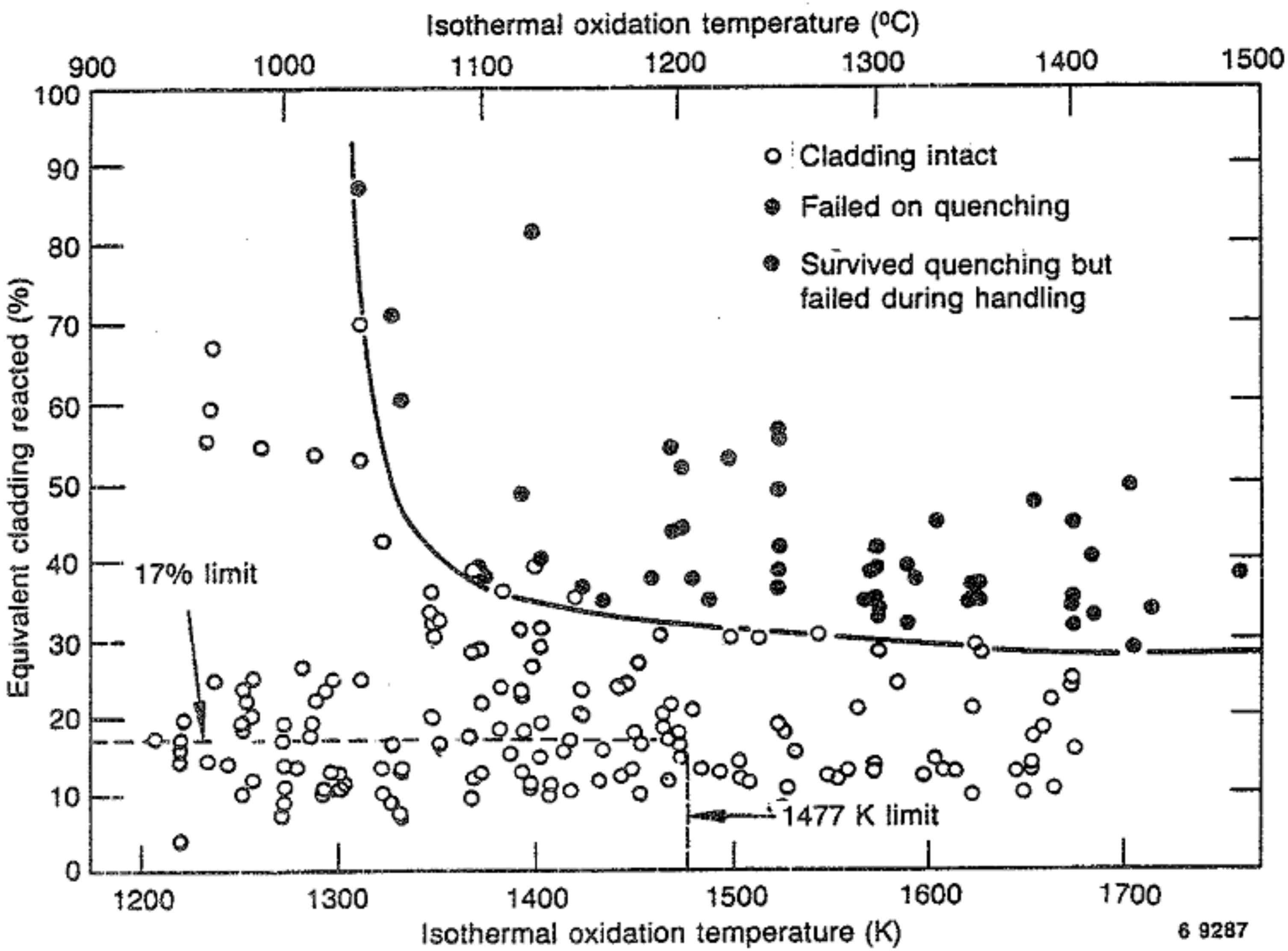
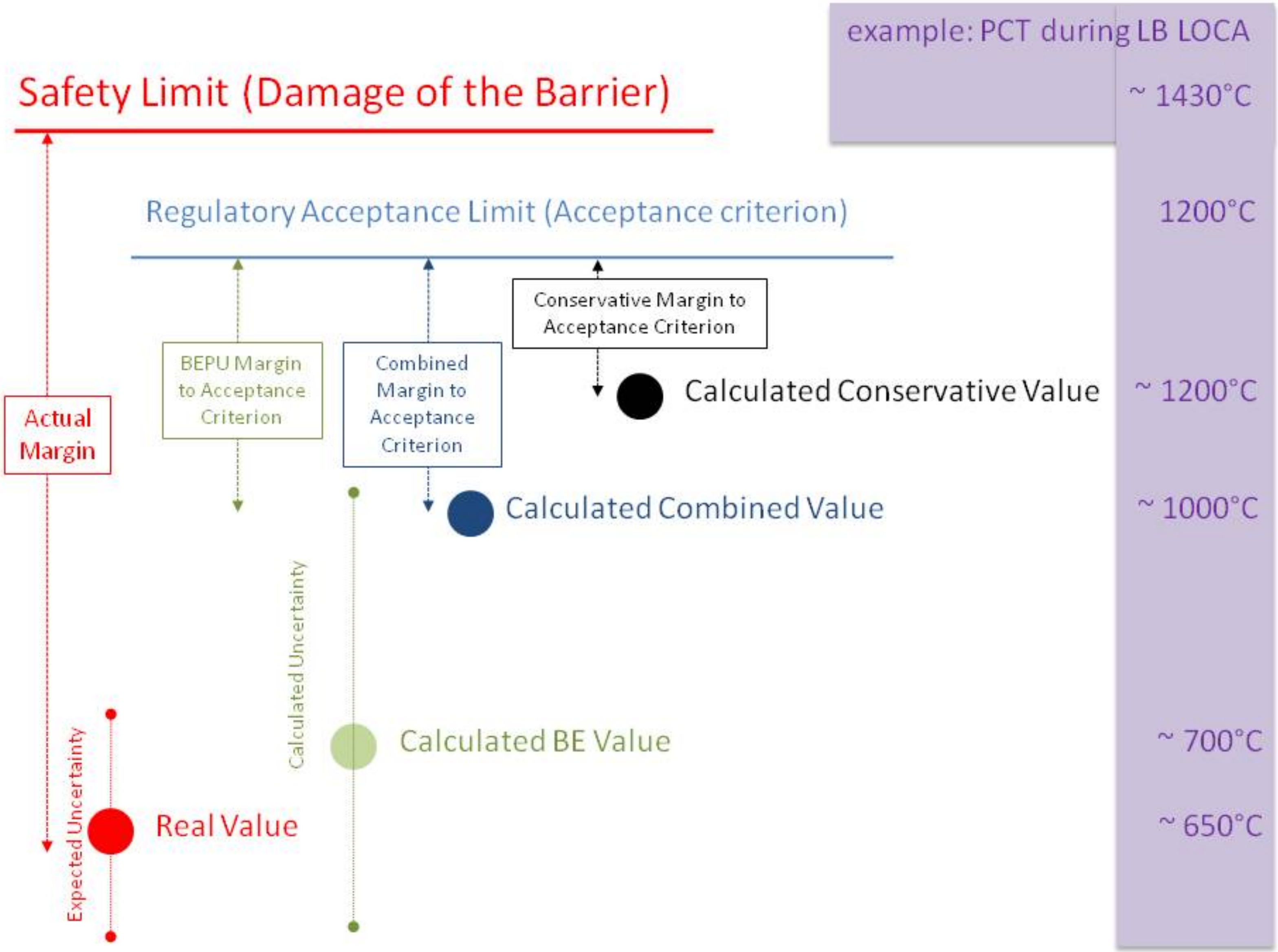


Illustration of safety margins



Regulatory review of acceptance criteria

- Review process includes
  - How acceptance criteria were established and how the critical values were defined or calculated
  - Check if acceptance criteria are complete
  - Review each individual PIE and check if acceptance criteria correspond to the probability of the event
  - Review each individual PIE and check if acceptance criteria were fulfilled
  - Make assessment of safety margins
  - Document the review process and results of the review!