Note:
This is a translation of the RSK statement entitled
"Anforderungen an die statistische Nachweisführung bei Kühlmittelverluststörfall-Analysen"
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK statement
(475th meeting of the Reactor Safety Commission (RSK) on 15.04.2015)

Requirements for LOCA analyses using statistical methods

1 Background

According to the RSK recommendation of 20./21.7.2005 (385th RSK meeting) [1], the most unfavourable values that may occur during specified normal operation, taking into account the limitations for integral power and power density, shall be assumed for the initial core power at the onset of the accident (apart from the statistical consideration of measurement and calibration errors) also when using a so-called best estimate approach (with explicit consideration of uncertainties) for the safety analysis.

In practice, this stipulation leads to the use of maximum values for the integral power and local power densities which can only be achieved theoretically in the case of a best estimate safety analysis.

Furthermore, it is to be stated that the mixture of deterministic-conservative and statistical methods makes it difficult to assess the influence of individual parameters, whereas a statistical treatment of further parameters, in this case integral power and power density, allows a more precise assessment.

Based on the consultations in the RSK Committee on PLANT AND SYSTEMS ENGINEERING (AST) (92nd meeting), the BMUB suggested reviewing the recommendation of the RSK of its 385th meeting for the need for an update on this issue.

2 Consultations

At its 93rd meeting on 24.10.2013, the AST Committee had set up an ad hoc working group on the topic "statistical LOCA analysis[1]" to clarify which initial and boundary conditions should be set conservatively for a statistical LOCA analysis and which ones can be treated statistically. In this respect, the issue of updating the RSK's recommendation on requirements for loss-of-coolant accident analyses (Annex 1 to the minutes of the 385th RSK meeting on 20/21.07.2005) should be primarily addressed.

[1] In this statement, statistical LOCA analysis is referred to as a best estimate analysis with statistical treatment of uncertainties in which individual parameters can be set conservatively.

The ad hoc working group has dealt, among other things, with the question of whether and with which requirements it is possible to deviate from setting values conservatively as defined in [1] in a best estimate safety analysis such that in the analysis by means of statistical methods, apart from measurement and calibration errors, the integral power and the maximum local power density can be handled by determining corresponding probability distributions.

The working group met on 07.11.2013 and on 17.12.2013 and prepared a draft statement on the requirements for loss-of-coolant-accident analyses using statistical methods. Following interim discussions on the statement at the 96th, 97th and 98th meeting of the AST Committee on 28.03.2014, on 08./09.05.2014 and on 17.07.2014, the working group continued its consultations on 23. and 24.07.2014. At its 4th meeting on 17.10.2014, it concluded its discussions. The prepared document was discussed and adopted by the AST Committee at its 101st meeting on 23.10.2014. The RSK adopted the statement at its 475th meeting on 15.04.2015.

3 Assessment criterion

According to the RSK recommendation of the 385th meeting [1], demonstrating fulfilment of the acceptance criteria with high reliability is considered a general assessment criterion for an accident analysis. Regarding the demonstration of safety for loss-of-coolant accidents (LOCAs), the following is stated in [1]:

> "Following the international approach, the RSK states that it has to be demonstrated within the frame of a best estimate analysis that the quantitative demonstration criteria are fulfilled with a high degree of certainty. A high degree of reliability of the results is given if the averaged result is below the demonstration criteria with a probability of at least 95 % and a statistical certainty of 95 %.
>
> The RSK is of the opinion that with the deterministic requirements (see 4.2.) and by quantification of the uncertainties of calculation results with these tolerance limits it is ensured with sufficient reliability that the requirements for LOCA safety analyses are fulfilled."

This approach has been incorporated into the "Safety Requirements for Nuclear Power Plants" [2], ibid Annex 5, No. 3.3 (3)[2], as well as regarding to "deterministic requirements" for safety analyses relating to loss-of-coolant accidents into Appendix 1 to Annex 5, No. A1 (1).

In addition to the use of a methodology suitable for statistical analyses and in line with the basic approach of the RSK statement described above,

- distributions of input parameters for the quantification of uncertainties shall be determined, insofar as this is possible on the basis of an adequate data basis or through comprehensible assumptions and consideration of marginals,

[2] Quotation from [2]:
"If statistical methods are applied for the determination of the overall uncertainty, the one-sided tolerance limit in the direction of the acceptance criterion shall be determined, with a probability of at least 95% with a statistical confidence level of at least 95% to demonstrate the fulfilment of the acceptance criterion."

- and parameters to which probability distributions were not assigned shall be set such that proof of compliance with the acceptance criteria is given with high reliability according to [1].

The "deterministic requirements (4.2)" stated in [1] also include the values to be used for the integral power of the reactor core and the maximum local power density at the onset of the accident (in the following quotation marked by underlining)

> *"In the following, postulates on the scenario are defined deterministically by which the effectiveness of the emergency cooling system is to be demonstrated and which have a conservative effect regarding the fulfilment of demonstration criteria.*
> *Within the framework of an emergency cooling analysis, e. g. system losses are not treated probabilistically. Consequently, for the analyses, the most unfavourable combinations is defined from:*
>
> - *a single failure to be postulated,*
> - *a loss due to maintenance work,*
> - *break location,*
> - *size and type of the break,*
>   *- double-ended break from 1F to 2F,*
>   *- small leak,*
> - *the loss of offsite power,*
> - *nominal thermal power (in case of incidents, the most unfavourable values have to be considered which can occur during specified normal operation under consideration of the limitation systems in the integral power and power density. Measurement and calibration errors can be considered statistically), and*
> - *the cycle time."*

(see also in [2], ibid Appendix 1 to Annex 5, No. A1 (1)).

As to the question whether in safety analyses relating to loss-of-coolant accidents,

- apart from measurement and calibration errors, the settings for the integral power and the maximum local power density can be handled by means of statistical methods according to their probability distributions,

the RSK therefore deems it necessary to investigate and assess

- with which requirements the integral power and the maximum local power density can be handled in the LOCA analysis also without "deterministic requirements" according to [1], Section 4.2, and according to [2], Annex 5, Appendix 1.

4 Consultation results

From the point of view of the RSK, deviation from the requirement set out in [1] or [2] (see also RSK LL of 1981, Section 22.1.3 (1), No. 12) according to which the most unfavourable values that may occur during specified normal operation, taking into account the limitations for integral power and power density, shall be assumed for the initial core power at the onset of the accident is admissible if using statistical methods under the following conditions:

1 Statement on the entirety of the fuel rods:

Regardless of which methodology is chosen for the safety analysis, the statement obtained must apply to the entirety of the fuel rods. It is therefore not sufficient to only demonstrate for the "most unfavourable" real (without penalisation) fuel rod in the reactor core that it meets the acceptance criterion with a probability of at least 95% and a statistical confidence level of 95%. Since there may be several thousand fuel rods in reactor cores which are relatively close to the "most unfavourable" fuel rod, it may be that despite demonstrating fulfilment of the acceptance criterion for the "most unfavourable" fuel rod, several fuel rods will not meet the criterion with significant probability. For this reason, the criterion must be applied such that with a probability of at least 95% and a statistical confidence level of 95%, not more than one fuel rod exceeds the acceptance criterion in case of statistical treatment of uncertainties.

In practice, a safety analysis according to [1] can lead to the analysis being based on a single rod approach in such a way that a fictitious fuel rod is constructed and penalised with predefined boundary conditions (in particular with regard to the local power density, the power of the surrounding fuel element and the axial power distribution) ("single hot rod approach"). If it is shown for this hot rod that it meets the acceptance criterion with a probability of at least 95% and a statistical confidence level of 95%, it was assumed in [1] due to the penalisation that the criterion is fulfilled for the entirety of the real fuel rods of a core loading[3] (contribution of all real fuel rods to the probability of exceeding the acceptance criterion is negligible in comparison to the fictitious fuel rod).

From the point of view of the RSK, any other single rod approach which makes other specifications for the above-mentioned parameters or their probability distributions is also be regarded as suitable, provided that the requirements of the whole core approach are met (see first paragraph of this section).

From the point of view of the RSK, a method can also be used which obtains a statement about the entirety of the fuel rods by analysing not a single fictitious fuel rod but a sufficiently large number of unfavourable real fuel rods in the core[4].

[3] In practice, it is no longer possible to use a single fuel rod for all burn-up conditions. Instead, one fuel rod is considered for one burn-up range since burn-up effects cannot be covered by power allowances.

[4] For this purpose, a preselection can be made from the total number of fuel rods in the reactor core or the total number of calculation cases, e.g. on the basis of results of calculations for the fuel rod state before LOCA or engineering evaluations in order to limit the number of required thermal-hydraulic calculations to a practicable extent.

2 Selection of probability distributions:

If the integral power and the maximum local power density are treated statistically in the analysis, it must be shown that the probability distributions used in the cycle to be considered are adhered to with sufficient reliability (or, if appropriate, across cycles). This also applies to all other parameters used in the analysis in such a way.

For determining the probability distributions, full load conditions are to be postulated conservatively. In addition to cycle pre-planning and operating experience, the operating modes to be expected during the cycle due to setpoints of limitations and, if applicable, other existing measures and provisions (e.g. administrative provisions for load cycles) which ensure compliance with the values and distributions used in the analyses are also to be considered for the integral power and the maximum local power density. The setpoints of the respective limitations are to be included in the distributions considered in the analysis. For the maximum power density, the effects of fuel assembly deformations are to be assessed additionally and taken into account where applicable (see [3]).

When selecting the parameter combinations for analyses using statistical methods, care should be taken to ensure that the combinations represent physically consistent data sets, taking into account potential dependencies such as, for example, on burnup.

3 Additional conditions

The deterministic requirements of [1] for the integral power of the reactor core and the maximum local power density at the onset of the accident tend to lead to less favourable analysis results compared to an analysis in which these two influencing parameters are also treated statistically since these are sensitive input parameters.

Main objective of the application of the statistical LOCA analysis with statistical treatment of the integral power and the power density is to allow for clearer and thus better quantification of the impacts of effects and their combinations as well as deterministic settings on the analysis results. However, the results of such analyses should not be used to increase the setpoints in the power and power density limitation systems compared to current licensed levels.

For further developing the level of knowledge on relevant effects in the analysis of the loss-of-coolant accident, any effect which has not been considered in the analysis or not adequately is to be assessed with regard to its impacts on the analysis result and taken into account where appropriate.

Explanations on application

According to [2], statistical and conservative-deterministic methods are equally permissible for the safety analysis. For the conservative-deterministic safety analyses, on which the licences have been based so far, it is to be noted that, to a certain extent, they also include margins for effects not considered due to conservative settings in the analyses. If due to new knowledge on effects for a conservative-deterministic safety analysis the question arises as to whether these effects continue to be covered by these margins, this can also be checked by means of a statistical analysis in which the current knowledge on the effects is considered quantitatively.

If the result of the unchanged conservative-deterministic safety analysis has a smaller distance from the acceptance criterion than the result of the statistical safety analysis, taking into account the entire current knowledge on the effects[5], conservative-deterministic methods can continue to be used. Otherwise, the conservative-deterministic analysis – if it should continue to be used – has to be supplemented in such a way that it covers the result of the statistical safety analysis. In the case of changes in the core design or mode of operation of the reactor that are relevant for the effects analysed, the continued validity of the results of these analyses is to be assessed.

If not using the statistical safety analysis, a sufficient margin of the conservative-deterministic analysis can also be ensured alternatively by means of an appropriate allowance for an input parameter or by an allowance on the conservative-deterministic calculation result which takes into account non-modelled effects (see also [2] Annex 5, Section 3.4), but preferably by conservative modelling of the effects not previously considered.

5 References

[1] RSK-Empfehlung „Anforderungen an die Nachweisführung bei Kühlmittelverluststörfall-Analysen“, Anlage 1 zum Ergebnisprotokoll der 385. Sitzung der Reaktor-Sicherheitskommission (RSK) am 20./21.07.2005

[2] Sicherheitsanforderungen an Kernkraftwerke
3. März 2015, BAnz AT 30.03.2015 B2

[3] RSK-Empfehlung „Verformungen von Brennelementen in deutschen Druckwasserreaktoren (DWR)“, Anlage zum Ergebnisprotokoll der 474. Sitzung der Reaktor-Sicherheitskommission (RSK) am 18.03.2015

[5] For the verification of the result of the conservative-deterministic safety analysis, the value from the set of Monte Carlo runs (e.g. with regard to the maximum cladding temperature) is to be used which ensures compliance with the statistical acceptance criteria according to the single rod or whole core approach. If, for example, a method according to Wilks is used in the lowest order (i.e. the minimum number of Monte Carlo calculations performed), this is the maximum value (e.g. the maximum cladding temperature) of all computer runs.