ETSON

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TECHNICAL SAFETY
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TECHNICAL SAFETY ASSESSMENT GUIDE

TRANSIENTS AND DESIGN BASIS ACCIDENT ANALYSES

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FOREWORD

Since the beginning of EUROSAFE initiative (1999), IRSN, GRS and Bel V (former AVN) have pursued the objective to advance the harmonisation of nuclear safety in Europe by comparing their safety assessment methodologies. Based on a long standing experience of more than 40 years, in spite of different national nuclear safety regulatory backgrounds, they have developed practical methods to perform safety assessments that presented sufficient similarities to encourage them to persevere in building a collection of common best practices. The first version of their common Safety Assessment Guide was thus approved in 2004.

The general Safety Assessment Guide (SAG), and its specialized guides, the Technical Safety Assessment Guides (TSAG), have been written by the members of the European Technical Safety Organisations Network with progressive improvements brought by the new members of ETSON.

The SAG provides general principles such as safety assessment objectives or transparency and traceability of the process, and describes the general process for performing the safety assessment of nuclear installations. The goal of this SAG is to set down the harmonized methodology applied by ETSON organisations to ensure a common quality of safety assessment and to develop higher confidence in delivered safety assessments.

The TSAG series consists of specialized guides dedicated to specific technical domains of importance to the safety of nuclear installations. They provide an overview of the available practical knowledge gained by Technical Safety Organisations (TSO) in conducting safety assessments covering these main technical issues (use of operating experience feedback, assessment of human and organisational factors, prevention of severe accidents, probabilistic safety assessment, etc.).

Each guide published by ETSON is updated according to the extension of experience gained as well as to the new requirements in nuclear safety.

The Technical Safety Assessment Guides present the common views and practices of ETSON members:

- Bel V - Belgium
- GRS - Germany
- IRSN - France
- VTT - Finland
- CV Rez - Czech Republic
- LEI - Lithuania
- VUJE - Slovakia
- PSI - Switzerland
- JSI - Slovenia
- INRNE-BAS - Bulgaria

With the contribution of ETSON associated members:

- SSTC - Ukraine
- NRA - Japan
- SEC NRS - Russia

CONTENTS

1 SCOPE

Safety assessment is a systematic procedure carried out in order to evaluate how the relevant safety requirements are met by the design of the plant. Deterministic accident analyses of both transients and design basis accidents are one of the analytical and essential elements of the safety assessment process [1]. Generally, the deterministic accident analyses are carried out using well established computer tools aiming to confirm that the overall plant design is capable of meeting the acceptance criteria. A full range of operational modes and initiating events has to be considered for these analyses.

Any review of safety analyses requires that:

- the licensing bases are well documented;
- the reporting requirements are specified including the description of the safety cases to be presented for regulatory review;
- the methodologies, tools and procedures are well defined and documented.

Assuming as a pre-requisite that the acceptance criteria are appropriate and adequate, this guidance document addresses the review of deterministic safety analyses of both transients and design basis accidents, aiming to verify that the essential physics is correctly identified and modeled and that there are adequate safety margins to cover the remaining uncertainties.

The review process covers the following assessment steps:

1. formal review;
2. verification of the applied methodology;
3. verification of the used computer tools;
4. verification of the assumptions;
5. evaluation of the results.

The guide provides guidelines to set up the Safety Evaluation Report, including aspects related to the assessment of computer tools and analysis methodologies.

2 BASIC PRINCIPLES OF DETERMINISTIC ACCIDENT ANALYSES

The role of transient and design basis accident analyses is to verify that the measures taken in the original or upgraded design of the plant are adequate to meet the prescribed safety objectives and the underlying acceptance criteria.

The achievement of a high level of safety is mainly demonstrated in a deterministic way beside the probabilistic one. The deterministic approach is based on rules and guides established by national authorities or international organizations such as IAEA [1], WENRA [2], and USNRC [3].

The major steps in the deterministic approach for accident analyses are the following:

a. identification and categorization of events considered in the design basis, e.g. based on their estimated frequency of occurrence or type of event, in order to determine their relevant safety criteria. This process is generally based upon regulatory requirements and guidance, original or upgraded design, operational experience, engineering judgment, and results of deterministic and probabilistic assessments. This step results in a list of initiating events to be analyzed;

b. identification of the computer codes, models, and correlations that have been validated for analyzing the transient and accidental behavior of the plant for the selected initiating events;

c. edition of a Methodology Report (MR) for the accident analysis covering:

- identification of the enveloping scenarios;
- identification of applicable acceptance criteria, safety requirements and limits;
- description of the used approach (e.g. conservative or best-estimate approach);
- description of the initial conditions according to selected approach such as power, pressure, temperature, time in the fuel cycle, instrumentation uncertainties, etc.;
- description of assumptions regarding the system responses and performance;
- description of the most adverse single failure (plus another failure if considered in the design, e. g. unavailability due to maintenance) of a safety related component;
- identification of long term active and passive component failures if any are possible;

- ☐ taking no credit of response from non-safety related systems such as control systems, unless their response penalizes the results;
- ☐ requirements regarding consideration of loss of offsite power;
- ☐ required operator actions definition and conditions for operator interventions, and
- ☐ requirements for the documentation of the accident analysis results.

d. deterministic accident analyses of the selected enveloping events;

e. checking the compliance of the results with relevant acceptance criteria;

f. assessment and documentation of the results of the deterministic safety analyses.

3 REVIEW PROCEDURE

The purpose of the review process is to verify that the accident analysis was carried out following an agreed procedure, that the used tools were adequate to simulate the accidents under consideration, and that the obtained results are reliable, well documented, and consistent.

First, the assessment procedure of the Methodology Report (MR) is discussed. Then, the assessment of the analyses is described.

A list of questions is proposed in the Appendix in order to support the whole review process.

3.1 Review of methodology

3.1.1 FORMAL REVIEW OF THE METHODOLOGY REPORT (MR)

The objective of the formal review is to check the completeness of the documentation provided in support of the MR. The reviewer either confirms the completeness of the documentation or requests the applicant to submit the missing items.

3.1.2 REVIEW

For each set of transient and design basis accidents a MR should be set up for approval before being used in the licensing framework to perform accident analyses.

An acceptable safety case should demonstrate the respect of the acceptance criteria associated with a specific event or type of events (e.g. loss of flow, loss of heat sink, loss of coolant, etc.), using appropriate computer tools for this purpose and selecting the correct assumptions. Such MR should be updated, if necessary, after every new application in order to discuss possible new findings.

3.1.2.1 *Objective*

It will be checked that the MR justifies:

a. the identification of the key parameters to be evaluated based on the accepted licensing criteria for the targeted parameters;

b. the choice of the physical models, correlations and other options of the used code;

c. dependent on the used approach (conservative or best-estimate), initial and boundary values corresponding to the most adverse plant system conditions, including the application of the single failure concept (based on relevant sensitivity studies) and uncertainties as far as applicable;

d. the appropriate treatment of the known code deficiencies, weaknesses and uncertainties;

e. selection of input data or models by sensitivity studies used to evaluate their effect on the final results (e.g. taking into account non- or counter-intuitive behavior resulting from the coupling of particular models). The extent of the sensitivity studies depends on the selected approach;

f. the codes and models proposed for the execution of the deterministic accident analyses;

g. the nodalization proposed for the installation to be modeled (in line with the user guidelines for the code and the applicable experimental data);

h. use of engineering judgment to evaluate the credibility of the results and to trace any suspected anomaly;

i. re-assessment of previous examinations used in the MR in case of minor changes in the methodology.

3.1.2.2
Structure of a Methodology Report (MR)

A suitable table of content of a MR might be:

1. Introduction

2. Licensing bases

- **a.** Licensing requirements.
- **b.** Identification of the key parameters.
- **c.** Acceptance criteria.

3. Definition of the event

- **a.** Identification of the initiator, of limitation system, reactor protection system, and safeguard system to be considered, of operator actions and related response delays.
- **b.** Description of the event.
- **c.** Identification of the key phenomena.

4. Description of the computer tool and the input deck

- **a.** Nodalization.
- **b.** Physical options.
- **c.** Numerical options.
- **d.** Review and verification of code limitations.
- **e.** Review and treatment of code uncertainties.
- **f.** Review and coverage of code deficiencies.

5. Model sensitivity studies

- **a.** Modelling options.
- **b.** Correlations options.
- **c.** Time steps options.

6. Selection of plant and system assumptions (for base case and sensitivity cases):

- **a.** Initial conditions.
- **b.** Boundary conditions.
- **c.** Instrumentation errors/uncertainties.
- **d.** Set points errors/uncertainties.
- **e.** Systems performance.
- **f.** Control systems.
- **g.** Single failure concept.

7. Conclusion

3.2 Review of the study

3.2.1 FORMAL REVIEW

The objective of the formal review is to check the completeness of the documentation provided in support of the safety study. The reviewer either confirms the completeness of the documentation or requests the applicant to submit the missing items.

The formal review should include the following checks:

a. the objectives of the analysis are indicated as well as the acceptance criteria to be met;

b. the actual plant state is documented;

c. the assumptions selected for the analyses (like boundary conditions, decoupling assumptions) are clearly defined;

d. classification of the analyzed events into the plant specific event list is discussed;

e. the analysis methodology (like input deck, model parameters, etc.) is documented;

f. the computer tools are referenced, in particular the versions and options of the codes used;

g. the use of these computer tools has previously been accepted in the framework of the applied methodology;

h. detailed documentation of the calculational results is provided;

i. results of uncertainty analyses are documented in case of the best-estimate approach;

j. the set of presented results is adequate and sufficient for judging the acceptability of the analysis.

3.2.2
VERIFICATION AND ASSESSMENT OF THE APPLIED METHODOLOGY

This step has to:

a. identify the references of the followed methodology;

b. verify that this methodology has been approved;

c. check that this methodology is applicable to the considered case, and

d. check that the methodology has been correctly applied taking into account the characteristics of the plant under review, the experience feedback from previous analyses for other plants, and operational experience.

3.2.3
VERIFICATION OF THE USED COMPUTER TOOLS

This step should include the following checks:

a. the used versions of the tools have been approved for the purpose of the analysis;

b. the input decks are being set up following a Quality Assurance (QA) process;

c. code supporting documentation (model description, input description, documentation of code validation and verification, etc.) are up-to-date and made available;

d. the code is validated against the transient phenomena under consideration.

Next, the approval process for using a computer tool is described in more details.

3.2.3.1
Review process of the computer tools

a. Physical background documentation:

- a review of the existing code documentation is performed to check its completeness;

b. Models assessment:

- the objective is to evaluate the accuracy and the validity limits of the code;
- the used physical models are reviewed with a special attention given to their validity limits, and

- ☐ checking the code documentation pertaining to its verification and validation.

3.2.3.2
QA for computer codes

The following QA records should be available for the review process:

a. code description manual (theoretical manual);

b. input/output data description (user's manual, user's guidelines, best-practice guidance);

c. validation manual (qualification file).

3.2.4
VERIFICATION OF THE ASSUMPTIONS

The verification of the assumptions like boundary conditions, model parameters etc. should be done according to the following:

a. check the justifications of the chosen models and numerical assumptions;

b. check that the used data reflect accurately the NPP configuration;

c. check any conservatism claimed for the analyses;

d. check the appropriate application of the single failure concept.

3.2.5
LICENSING AUDIT CALCULATIONS

The safety assessment may require the reviewer to perform his own counter-calculations for various reasons, such as complicated combinations of uncertain phenomena (such as e.g. stratification, loss and retrieval of natural circulation,) uncertainties regarding decoupling assumptions, assessment of conservatism of certain assumptions, phenomenological or modelling uncertainties, inquiry into cliff-edge effects or tracking suspicions of anomaly, etc.).

In such cases, licensing audit calculations are to be performed, mainly for the most challenging events with respect to the integrity of fission product barriers. The licensing audit calculations have to be defined by the reviewer.

The reviewer evaluates the results of these licensing audit calculations and uses them to support his assessment of safety analysis under review.

3.2.6
EVALUATION OF THE RESULTS

The analyses should provide appropriate level of confidence, therefore this step should allow to:

a. check that all the applicable acceptance criteria are met;

b. identify the corresponding safety margins and the related degree of conservative assumptions;

c. judge the adequacy and relevance of the chosen assumptions;

d. judge the credibility and consistency of the presented results. The reviewer should ensure that the results are comprehensively explained and that there are no contradictions with the assumptions or conflicting trends between related parameters;

e. verify that the analyses are performed with the appropriate version of the code.

4 DOCUMENTATION OF REVIEW FINDINGS

The following information should be documented in the Safety Evaluation Report (SER) to be set up at the end of the review:

- what has been analyzed (scope of the accident analyses)?
- how it was analyzed (description of the followed methodology: calculation method, assumptions, assessment criteria, etc.)?
- which results are acceptable, and why?
- which results are not acceptable, and why?
- comments, questions and requests that are to be discussed.

A suitable table of content of the Safety Evaluation Report might be:

a. framework of the analysis;
b. subject of the analysis;
c. objective of the analysis;
d. scope and results of the formal review;
e. evaluation of the followed methodology;
f. evaluation of the used codes;
g. evaluation of the assumptions;
h. evaluation of the results;
i. summary and justification of the evaluation of the analyses;
j. finalized technical conclusions and requirements proposed to the Safety Authority for defining its position with regard to the accident analysis.

5 REFERENCES

- [1] IAEA SAFETY GUIDE SSG-2, 2009 "Deterministic Safety Analysis for Nuclear Power Plants".
- [2] WENRA Reactor Safety Level: Appendix E, January 2008.
- [3] NUREG-0800: Standard Review Plan.

APPENDIX

QUESTIONNAIRE

6.1 Formal review

Objective is to decide whether the submitted accident analysis is comprehensive enough to be analysed or not.

Output is the decision to proceed with safety assessment or to ask for completion through identification of missing information and justification of the need-to-know:

1. is the regulatory frame well defined? (First-of-a-kind, submittal for operation license, license renewal or extension, etc.);
2. is the purpose of the submitted accident analysis comprehensively stated?
3. have applicable law and regulations been referred to?
4. are the applicable objectives and relevant criteria stated or referred to? (they may be defined in a higher level design document or at least in the preliminary safety report);
5. are the scenarios to be analysed well defined and justified? (notably with regard to the list of initiating events);
6. have all necessary references used in the submitted accident analysis been provided?

6.2 Verification of the applied methodology

1. Is the methodology used for producing the safety case well defined? (Identification, reference to methodology report - MR)?
2. Has use of this methodology already been approved?
3. Is the domain of application strictly the same as already approved?
4. Has the feedback of previous methodology application been taken into account?
5. For a new methodology, does the related MR provide an identification of physical phenomena to be addressed and a ranking table according to importance of these phenomena for the transients to be analysed?

6. Have all steps of the method been consistently described, i.e. comprehensively, without missing, hidden or overlapping steps?

7. Is the documentation of computer codes used in the methodology identified and available?

8. Have possible use of tables, auxiliary calculations and post- or pre-processors of any kind been listed and adequately described?

6.2.1
ASSESSMENT OF METHODOLOGY

A methodology merges different subjects together: use of computer codes, input data such as initial and boundary conditions, initiating event specifications, modelling of the system under analysis, local and global modelling, computer options used, etc. For each subject, specific questions may arise such as:

1. what type of methodology is used? Best-estimate, conservative or a combination of both?

2. how is the "best-estimate" character of models and selected values justified?

3. to what extent is the domain of validity of the code relevant to the problem addressed? (status of the physical capability of the code compared to the needed capabilities, identification and assessment of main simplifications and/or shortcomings used in geometrical and physical models)

4. does the methodology cover the whole physical range of the accident analysis?

5. are there decoupling assumptions between different phenomena or bounding assumptions?

6. is the modelling in the code and the nodalisation of the systems under analysis described and justified?

7. which conservatisms are used in the code, in the models of the code, in the input data?

8. for example, are there specific developments or methodological layers added to a previous version of used code for performing the safety case and if so, are these specific additions described and justified in the MR?

6.3
Verification of the used computer tools - Computer code assessment

6.3.1
CODE QUALITY ASSURANCE (QA)

1. Is the code developed inside or outside the user's organisation?

2. Along which QA process is the code developed or appropriated by the user?

3. For "on-the-shelf" type codes, is there a process for agreeing the code provider at the user's organisation and a receipt process of the code?

4. How does the Quality Management System of the user's organisation provide for the development and maintenance of the code?

5. What are the rules and methods for updating the code and managing its versions and ensure control of its proper use for accident studies?

6. Are there rules and methods to ensure portability of results on different machines and different compilers/options?

7. Are code versions used fully identified?

6.3.2
COMPUTER CODE VERIFICATION AND VALIDATION (V&V)

1. Which validation is presented in the V&V file? (Such as e.g. comparisons to analytical solutions, benchmark with other assessed codes, comparisons to national or international standard problems, etc.).

2. Does the V&V file address adequately the safety case applications?

3. If results obtained on reduced scale experiments are used for comparison with code results, are scaling factors identified and taken into account for the reactor application?

4. If correlations and closure laws are used in the code, how have they been obtained and qualified?

5. Are the applicability domain of used correlations and closure laws relevant for the analysis under review? (example: flow regime maps, interphase exchange parameters such as friction, heat transfer, etc.).

6. Is there a need to request additional test problems during the review in order to enhance the assurance of the code capability to handle the analysis under review?

7. In case of coupled codes (such as e.g. between thermal-hydraulic and neutronic codes for reactivity driven accidents), how is the coupling physically validated?

6.4
Verification of the assumptions

1. Are all necessary input data listed (with their evaluation method if necessary)?

2. Are assumptions regarding the initial state of the computation adequately taken into account?

3. Have plant parameter uncertainties been taken into account?

4. Are accident analysis rules and mandatory assumptions (e.g. single failure assumption, operator actions and delays) listed and justified?

5. Have possible unfavourable effects of automatic or operator actions, connected subsystems function conditions (e.g. rod drop, function of primary pumps, cooling through steam generator, boron injection) been taken into account?

6. Is the accident sequence described with regard to all (thermal-hydraulic, neutronic, etc.) main phenomena to be represented?

7. For realistic approaches or best-estimate values of reactor parameters, are selected values clearly indicated and justified?

8. If statistically defined values are used, are their probability distribution functions defined and justified?

9. In the case of best-estimate approach with uncertainty propagation, are the probabilistic methods and criteria used described?

6.5
Evaluation of the results

1. Are all of the acceptance criteria met?

2. Have the computational results converged with regard to space and time?

3. Are all relevant output parameters listed and their time dependent behaviour presented in figures having adapted scales?

4. Do the results show physically reasonable trends, no conflicting patterns between related parameters or contradictions with assumptions?

5. Are there sensitivity studies provided to show the influence of main or critical parameters, and notably to demonstrate absence of cliff edge effects?

6. Are main results commented and explained, even if summarily?

7. Are margins with regard to the criteria quantified?

8. Are any main results or trends of main parameters amenable to simple evaluations in order to check their behaviour and physical meaning in the calculations?

9. Are the mass and energy balances correct?

10. Is it verified that no unexpected systems or signals are triggered during the calculation?

11. Is it possible and/or necessary to perform comparative calculations (so-called licensing audit calculations) for assessing these results?

12. Is it possible to compare with existing similar or reference results (e.g. from previous accident analyses, from plant data)?

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