Good Practices for DEC-A Analysis – Outcomes of the OECD/NEA DEC-A Project

R2CA Open Workshop

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Contents

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Introduction

- The concept of “design extension conditions (DECs)” was first introduced by the European Utility Requirements (EUR) in 1994 to define some selected sequences due to “multiple failures”:
  - Complex Sequences involve failures beyond those considered in the deterministic design basis but do not involve core melt;
  - Severe Accidents considered in the design, both to prevent early and delayed containment failure and to minimize radioactive releases for the remaining conditions.
- The DECs were adopted in the IAEA Safety Standards (SSR-2/1, SSG-2) since 2012 and in the WENRA Safety Reference Levels in 2014, comprising:
  - DEC-A without severe fuel damage in the core or in the spent fuel storage (i.e., DEC events without significant fuel degradation);
  - DEC-B with postulated severe fuel damage (i.e., DEC events with core melting).
- Objective: to further improve the safety of the nuclear power plants by:
  - enhancing the plant’s capability to withstand more challenging events or conditions than those considered in the design basis
  - minimizing radioactive releases harmful to the public and the environment as far as reasonably practicable, in such events and conditions.

Introduction

- The DEC-A safety analyses have been implemented in many NEA member countries, but:
  - significant differences in methodologies regarding the selection of the DEC-A scenarios, definition or justification of the acceptance criteria, validation and application of the computer codes, as well as the development and application of deterministic safety analysis methods to DEC-A.
  - lack of internationally shared experience between different stakeholders and organizations
- Objective of the OECD/NEA WGAMA/WGFS joint project on DEC-A (2021-2024):
  - Review of the definitions and requirements
  - Review of status of knowledge
  - Review of the “good practices”

  → To be documented in an OECD/ NEA Status Report

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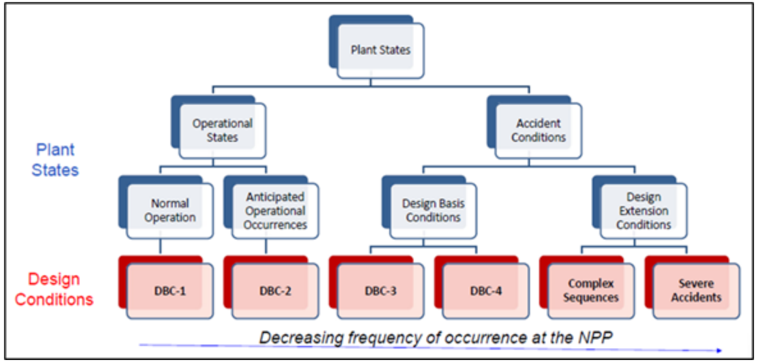
Review of Definitions and Requirements

- The European Utility Requirements (EUR) first introduced the DECs in 1994 to define some selected sequences due to “multiple failures”:
  - Complex Sequences involve failures beyond those considered in the deterministic design basis but do not involve core melt;
  - Severe Accidents considered in the design, both to prevent early and delayed containment failure and to minimize radioactive releases for the remaining conditions.
- Objective: to improve the safety of the plant extending the design basis
- Selection of DECs: should be done by plant designer and by use of probabilistic methods.
- Assessment of DECs: using best estimate (BE) methods (no need for application of single failure, etc.).



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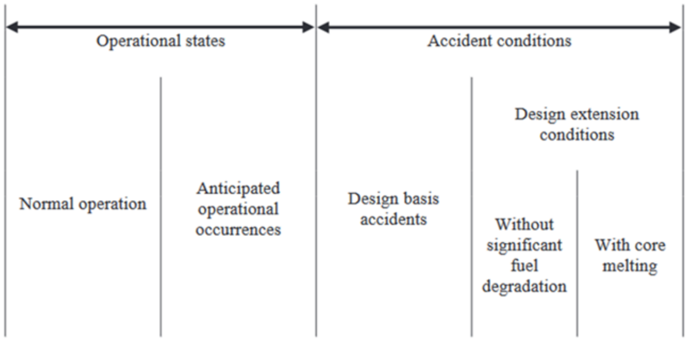
Review of Definitions and Requirements

- The DECs were first introduced in the IAEA safety standards SSR-2/1 in 2012 and revised in 2016 to define postulated accident conditions that are not considered for design basis accidents, comprising:
  - events without significant fuel degradation (=DEC-A);
  - events with melting of the reactor core (=DEC-B).
- Objective: to provide assurance that the design of the plant is such as
  - to prevent accident conditions that are not considered design basis accident conditions, or
  - to mitigate their consequences, as far as is reasonably practicable.



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Review of Definitions and Requirements

- IAEA SSG-2 states that the objective of the safety analysis of DEC-A is to demonstrate that
  - core melt can be prevented with an adequate level of confidence, and
  - there is an adequate margin to avoid any cliff edge effects.
- Selection of DECs: should use deterministic and probabilistic analysis and engineering judgement.
- Assessment of DECs:
  - Should use best estimate methodology.
  - Sensitivity analysis should be performed to avoid any cliff edge effects.

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Review of Definitions and Requirements

- The Western Europe Nuclear Regulators Association (WENRA) Safety Reference Levels (RLs) 2014 adopted DECs definitions like IAEA SSR-2/1:
  - DEC-A for which prevention of severe fuel damage in the core or in the spent fuel storage can be achieved;
  - DEC-B with postulated severe fuel damage.
- Objective: to further improve the safety of the nuclear power plant.
- Selection of DECs: consider those events and combinations of events,
  - which cannot be considered with a high degree of confidence to be extremely unlikely to occur and
  - which may lead to severe fuel damage in the core or in the spent fuel storage.
- Assessment of DECs:
  - Should rely on best estimate assumptions (all available devices can be used in the mitigation).
  - The consideration of uncertainties is useful to ensure that the best estimate results constitute a meaningful basis for the mitigation strategy.

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Review of Definitions and Requirements

- The definitions of DEC-A in EUR, WENRA and IAEA documents are similar, but with minor differences in sub-divisions and terminologies.
- The EUR requirements are applicable to new plants, the WENRA requirements are applicable to operating plants, while IAEA requirements are applicable to both (albeit more for new plants). → more detailed recommendations in the IAEA SSG-2.
- The common objective is to improve safety in plant states not considered in traditional DBA events.
- The common recommendation is to use best-estimate methods for DEC-A analysis to avoid undue conservatisms.
- IAEA recommends sensitivity analysis to avoid cliff edge effects, WENRA suggests consideration of uncertainties.
- There may exist significant differences in the interpretation and implementation by different countries and/or organizations. → need to be clarified.

Review of Current Status of Knowledge

- For certain DEC-A scenarios, complex physical phenomena could take place and may lead to the occurrence of nonlinear evolution behaviors like the cliff-edge effects.
  - For some phenomena, the current level of knowledge and modeling capabilities are limited and requires additional experimental investigations and code validation efforts.
  - Some of these topics are addressed within the OECD/NEA experimental projects like the ATLAS and ETHARINUS and in other dedicated facilities like the IRSN MIDI facility.
  - Phenomena like natural circulation flow, reversal and stability, heat and mass transfer at free boiling pool surface still require advanced experimental and analytical efforts.

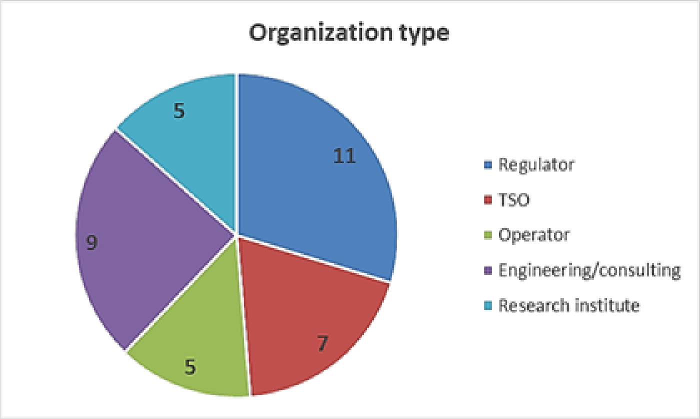
DEC-A Scenario	ATLAS	PKL
Small-Break LOCA (SB-LOCA) with additional safety system failures		PKLIII H1 test
Station Blackout (SBO) transients	ATLAS A1 & A2 tests ATLAS3 C4.1 test	PKLIII H2 test
Extended loss of alternating current power (ELAP)		PKLIII I4.2 test
IBLOCA with additional safety system failures		PKLIIIi 2.2 test PKLIII J2 test
Cool-down after multiple steam generator tube rupture (SGTR)		PKLIIIi 6.1 test PKLIII J5 test
Steam Line Break (SLB) with SGTR	ATLAS2 B4.1 test	
Shutdown Coolability without residual heat removal system (RHRS)	ATLAS2 B4.2 test	PKLIII H3 test
Total loss of heat sink	ATLAS3 C4.2 test	

Review of Current Status of Knowledge

- The current DBA design/safety limits can be used for DEC-A analysis, but alternative criteria may be proposed to simplify the analysis or be consistent with the best estimate analysis methods.
- The existing DBA analysis codes can be used for DEC-A analysis, provided extended validation for DEC-A scenarios are made.
- Best estimate (or realistic) analysis method can be used, but conservative assumptions can be used in situations where knowledge is poor.
- Consideration of uncertainties and sensitivity analysis are useful and recommended.
- The integrated DSA/PSA methods are very promising to be applied to DEC-A analysis:
  - Extended best estimate plus uncertainty (EBEPU) methodology or Integrated Probabilistic DSA (IPDSA) by adding probabilistic information on the availability of the safety functions (either systems or manual actions);
  - Integrated Dynamic PSA (IDPSA) methods by adding the influence of the dynamics onto the probabilistic modeling.

Review of Good Practices

- A questionnaire with 36 questions was prepared to collect feedback from participating organizations/countries
- A review of the 25 answers from 33 participating organizations and 20 countries was made on:
  - Scenarios selection
  - Phenomenology identification and ranking
  - Acceptance Criteria Definition
  - Code selection and applicability assessment
  - Analysis methods
  - Treatment of cliff edge effects
  - Typical plant safety improvements
  - Documentation
- The key issues and challenges were identified
- Good practices were recommended for any future DEC-A analysis.



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Review of Good Practices

- Definition of DEC-A scenarios
  - Use PSA, and use time-dependent CDF to reduce engineering judgement
  - Group DEC-A scenarios as per functional challenge and identify enveloping scenario
  - Focus on most penalizing sequences and scenarios
  - Have a common list of DEC-A scenarios (albeit design specific)
  - Merge DEC-A and DEC-B events (or a clear boundary)?
- Phenomenology identification and ranking
  - No systematic PIRT for each category of DEC-A scenarios (apply the same PIRT for DBA?)
  - No new physical phenomena expected in DEC-A scenarios and different from the DBA ones, except for:
    - physical phenomena specific to shutdown states (relating to low pressure, to the presence of non-condensable gases, to the opening of manholes as for the pressurizer) and
    - physical phenomena related to the spent fuel pool.
  - PIRT is needed for the scenarios with phenomena without sufficient knowledge.

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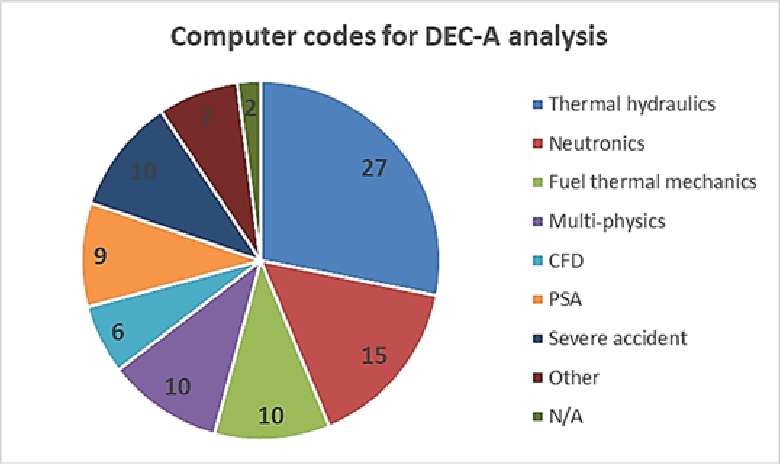
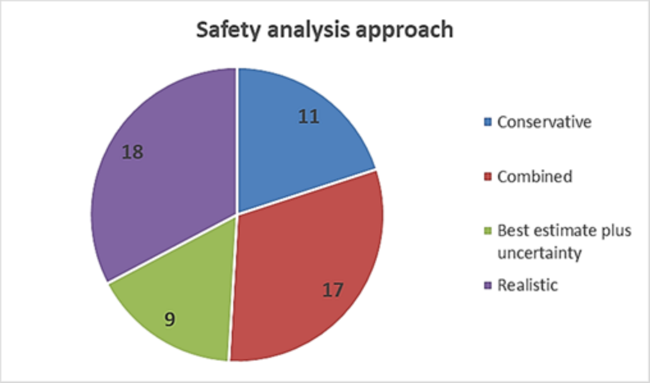
Review of Good Practices

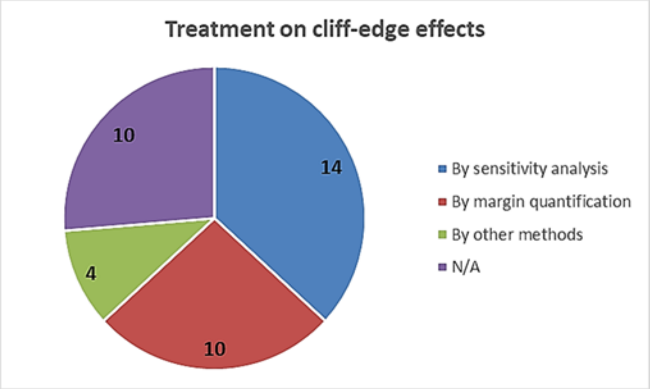
- Definition of criteria for DEC-A
  - Use DBA criteria as practical as possible
  - Use acceptance criteria generally less restrictive and based on more realistic assumptions for DEC.
  - Justify alternative criteria
    - Surrogate criterion for no uncover/no significant fuel degradation (average rod temperature, coolant level…)
    - Fraction of failed fuel rods
- Code and model development and validation:
  - Use latest and validated code versions for DBA
  - Use high fidelity thermal-hydraulics and multi-physics codes if needed (CFD, coupled neutronic-thermal hydraulics codes)
  - Extend validation of codes for covering DEC-A conditions



Review of Good Practices

- DEC A analysis method:
  - Adopt a commensurate approach with the main objective to improve the safety of the NPPs.
    - Use conservative (Option 1) or combined methods (Option 2) as for DBAs for DEC-A scenarios with sufficient margins
    - Use realistic method (Option 4): BE assumptions for initial and boundary conditions should be used if necessary and possible, conservative assumptions must be avoided or minimized.
    - Use BEPU method (Option 3) to consider uncertainties for limiting DEC-A scenarios with insufficient margins
  - Justify the timings for operator actions.
  - Use PSA to evaluate proposed changes in SSCs or accident procedures, by ensuring a good cooperation between DSA and PSA specialists.
- Treatment of cliff edge effects:
  - Use of sensitivity analysis or uncertainty quantification methods





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Key Issues and Challenges

- Definition of “Significant fuel degradation” or “Core melt” for DEC-A scenarios
  - The definition of DEC without “Significant fuel degradation” or “Core melt” is fuzzy in different documents (IAEA, WENRA, EUR)
  - The boundary between DEC-A and DEC-B is subject to interpretations (by occurrence frequency, consequence?) → clarifications needed
  - Use of PSA in selection and grouping of DEC-A scenarios is not a common practice → Combined with engineering judgement
- Objective of DEC-A analysis
  - The objective of DEC-A analysis is subject to interpretations (safety improvements to prevent or avoid “Significant fuel degradation” or “Core melt”, or compliance with criteria) → clarifications needed
- Criteria for DEC-A analysis
  - The DBA design or safety criteria are commonly used for DEC-A → consistency with the realistic method?
  - Conservative surrogate design or safety criteria are sometimes defined to accommodate the realistic (or best estimate) analysis method → to compensate the unquantified uncertainties or “cliff edge effect”?
  - Alternative criteria may be defined (e.g., Beta layer oxidation thickness, number of burst rods…)?

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Key Issues and Challenges

- Codes for DEC-A analysis
  - In addition to the thermal hydraulics, neutron physics and fuel rod thermal mechanical codes as used for the DBA analysis, multi-physics codes, severe accident codes and computational fluids dynamics codes are also used for DEC-A analysis
  - Extended validation of these codes under DEC-A conditions are needed → validation database sufficient?
- Methods for DEC-A analysis
  - Conservative, combined, best estimate plus uncertainty (BEPU) and realistic methods are used in a hybrid manner
  - Use of the recommended realistic method may not be enough (e.g., in case of insufficient margins or lack of knowledge) → BEPU method is recommended for limiting DEC-A scenarios with insufficient margins
  - Integrated DSA and PSA (IDPSA) would be a promising method, but practical tools are needed
- Assumptions for DEC-A analysis
  - No single failure, but only qualified safety features are credited
  - Operator actions are considered, but how to account for the (large) uncertainties?

Conclusions/Perspectives

- Despite of certain small differences in the EUR, WENRA, and IAEA definitions and requirements for the DEC-A analysis, the common objective is to improve safety in plant states not considered in traditional DBA events.
  - There may exist significant differences in the interpretation and the implementation by different countries and/or organizations, which need to be clarified.
- The current level of knowledge and modeling capabilities for some DEC-A relevant phenomena are still limited and require advanced experimental and analytical efforts.
- Good practices in the general approach to DEC-A analysis, the code and model development, uncertainty and sensitivity analysis and use of PSA were identified.
- The outcomes of the review as well as the recommendations will be documented in a NEA status report on Good practices for analysis of DEC-A (to be published in 2024).
- New activities are recommended to OECD/NEA WGAMA, WGFS and WGRISK on DEC analysis beyond 2024.

Acknowledgements

- 31 organizations, including regulatory safety authorities, TSOs, utilities, research institutes, and universities, from 20 countries participate in this NEA DEC-A project.
- A coordination group, composed of 17 experts from 11 organizations is tasked with conducting the review and writing the status report: Tractebel, Bel V, CTU, UJV, EK, ENEA, NINE, SNSA, CSN, UPM, CIEMAT.
- The DEC-A project is supported by the WGAMA and WGFS secretariate.

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Further Reading

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