On the Use of SPAR-CSN Model for Identifying Design Extension Conditions type A Sequences. First Ideas.

César Queral, Sergio Courtin, Marcos Cabezas, Alberto García, Julia Herrero,

Universidad Politécnica de Madrid (UPM), cesar.queral@upm.es

Enrique Meléndez, Miguel Sánchez, Rafael Mendizábal

Consejo de Seguridad Nuclear (CSN), ema@csn.es

June 28th

0 CONTENTS

1 DESIGN EXTENSION CONDITION - CONCEPT

Desing Extension Conditions→ DEC

- DEC Type A (Without Significant Fuel Degradation)
- DEC Type B (With Significant Fuel Degradation)

- The term "**Design Extension conditions**" is defined as **the set of depth-safety actions focused on the improvement of NPPs safety against outside Design Basis (DB) situations.**
- The DEC sequences are usually divided into DEC type A and DEC type B.
- The concept of "Design Extension condition"(DEC) is relatively new and still **under development.**
- **The development is mainly led by WENRA, IAEA, NEA, EUR and Several Regulatory Bodies.**

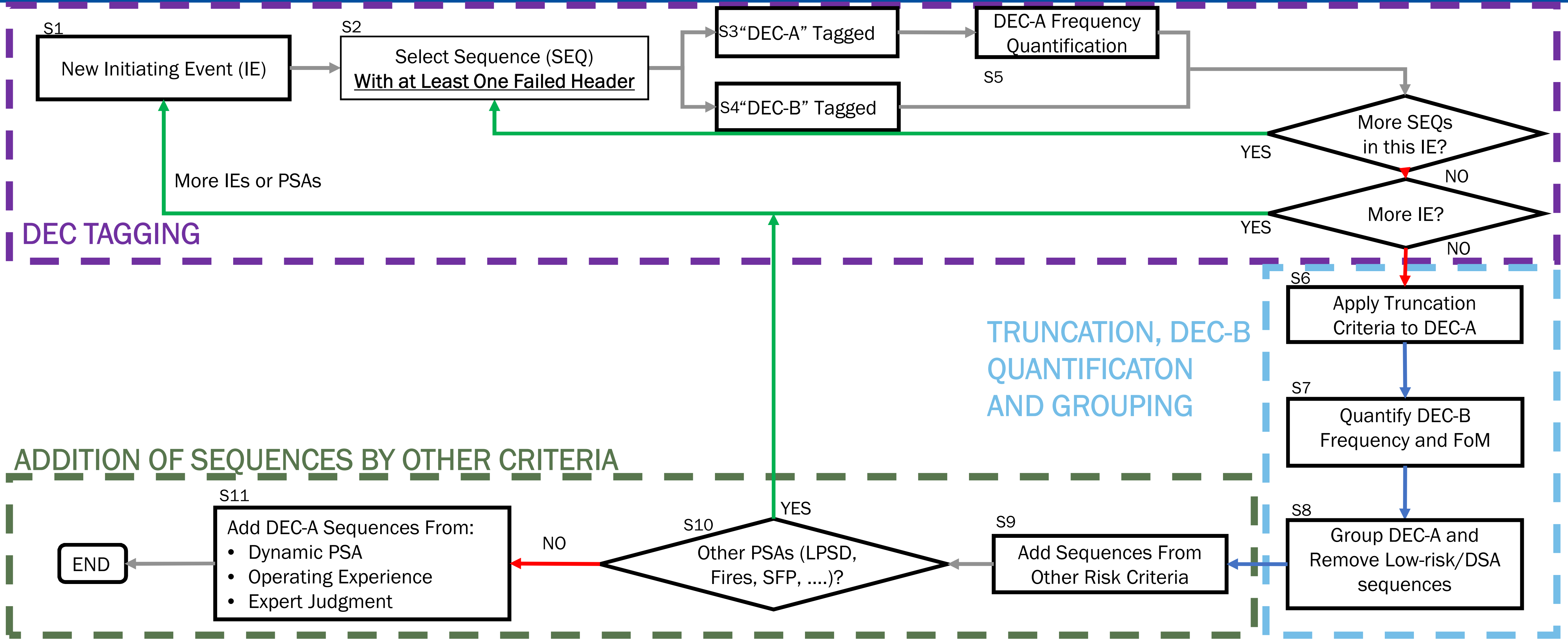
1 CURRENT PRACTICES and PSA

- Some approaches for the identification of DEC without significant fuel degradation are declared to be based on the basic principle of "engineering judgment, deterministic assessments, and probabilistic assessments" [7]. Nevertheless, there are few, if any, specific details about how this basic principle is quantitatively applied, and only some qualitative rationales can be found.
- Most common practices for identifying events to be considered as DEC inevitably fall back on the qualitative judgment of experts subsequently analyzed by Deterministic Safety Analysis (DSA), which adds notable uncertainties.
- Probabilistic Safety Analysis (PSA) could also used to help in the identification of the most significant DEC-A events from the point of view of Risk, not considered on DSA, reducing some uncertainties of the judgment of experts. Despite this, there is not a common international established methodology to use PSA models for this purpose.

1 SPAR-CSN PROJECT

- The Goal of the SPAR-CSN project, developed by the Spanish Regulatory Body (CSN) in collaboration with Universidad Politécnica de Madrid (UPM), is to assemble its own generic Standardized Plant Analysis Risk (SPAR) model for 3-loop PWR-WEC designs.
- The current purpose of the project considers the elaboration of a standardized PSA model independent from the industry, providing a high-level view of risk in the evaluation of findings in Spanish NPPs, and intended to be comparable in scope to United States Nuclear Regulatory Commission (NRC) SPAR models.

2 METHODOLOGY FOR DEC-A SEQUENCES IDENTIFICATION

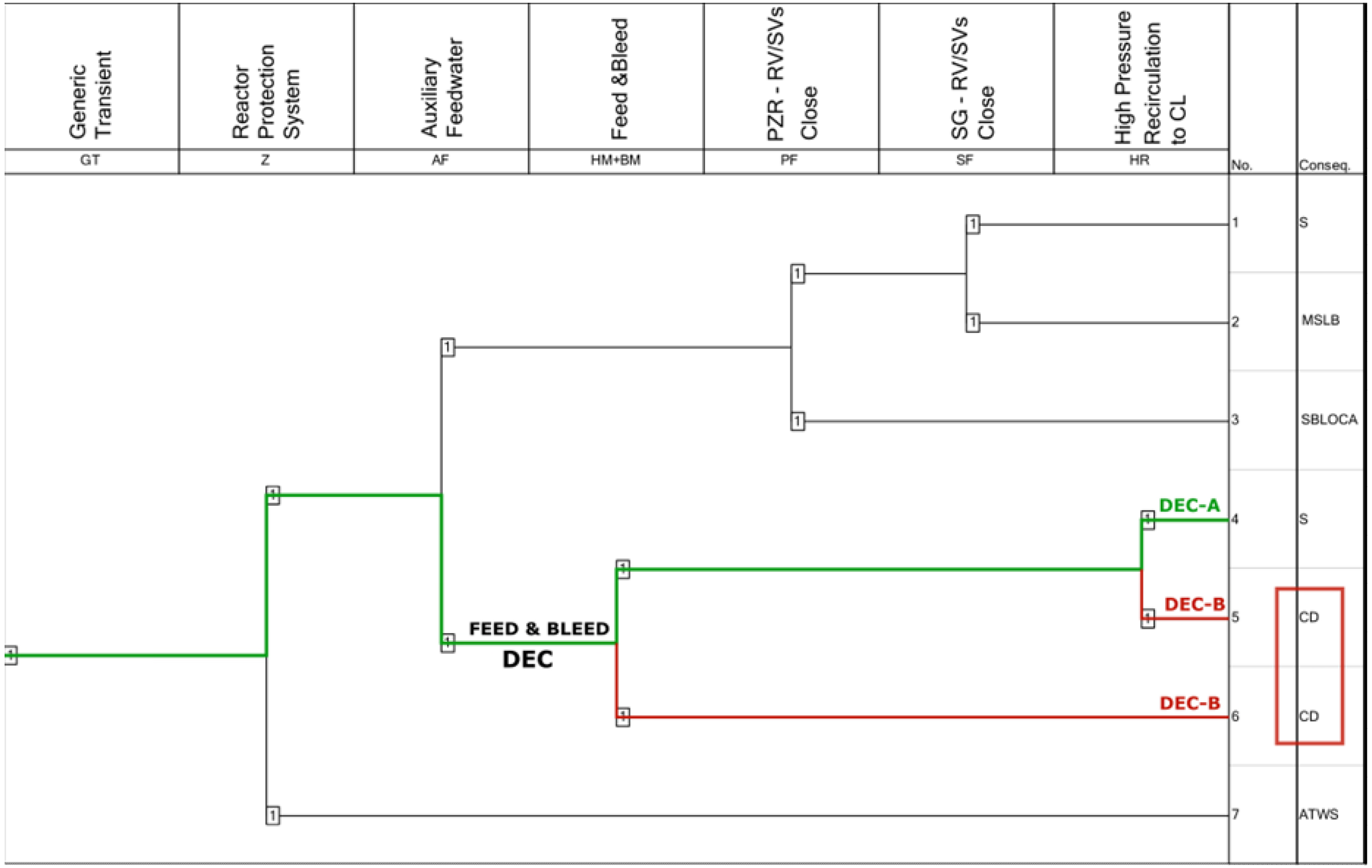


2 DEC TAGGING. STEPS S1-S5

- S1 Select an Initiating Event (IE) from the list of IEs covered in the PSA model.
- S2 Select all Sequences with at least 1 Failed Header (Sw1FH).
- S3 Identify Sw1FH leading to Success (S):
  - These are candidates to be DEC-A sequences.
  - Therefore, tag each identified sequence with "DEC-A" for the quantification process/code
- S4 From each "DEC-A" tagged sequence identify all the sequences with further failures that lead to CD:
  - These are candidates to be DEC-B-related sequences of the tagged DEC-A sequence.
  - Therefore, tag each identified sequence with "DEC-B".
- S5 Quantify the Frequency of all the DEC-A tagged sequences, "DEC-A_freq". This step will make it possible to achieve a sorted list of sequences through the subsequent steps of the method.

Repeat the previous steps for more sequences and IEs of the PSA Model.

2 DEC TAGGING. STEPS S1-S5



2 DEC TAGGING. STEPS S6-S8

- S6 Applying a truncation criterion for DEC-A list reduction. the truncation criterion depends on the analysis target, a lower frequency limit requires the analysis of a greater DEC sequences set.

- S7 Quantify the accumulated frequency of the DEC-B sequences related to each DEC-A sequence, “DEC-B_freq” (1). The method also postulates the use of the Conditional Core Damage Probability of the DEC sequence, “CCDPDEC” (2), as Figure of Merit (FoM) for each element of the collapsed list.

$$\text{DEC-B}_{\text{freq}} = \sum_{i=1}^{n} \text{Frequency}_i^{\text{DEC-B}} \qquad (1)$$

$$\text{CCDP}_{\text{DEC}} = \frac{\text{DEC-B\_freq}}{\text{DEC-A\_freq} + \text{DEC-B\_freq}} \qquad (2)$$

- S8 Group similar DEC-A sequences and remove sequences covered by the Deterministic Safety Analysis and low-risk ones DEC-B_freq < f0 or CCDPDEC < p1 (low-risk criterion is still under discussion),

- The outcome would be a collapsed list of DEC-A sequences and DEC-B-related sequences.

2 ADDITIONAL CRITERIA TO ADD SEQUENCES. STEPS S9-S11

- S9 Add new sequences in terms of other eventual criteria not considered up to now (e.g., Large Early Release Frequency (LERF), Releases, Regulations, ...)
- S10 Apply steps S1 to S9 to other PSA models, such as Fire, Spent Fuel Pool (SFP), External events, Low Power and Shutdown Probabilistic Risk Assessment (LPSD), ...
- S11 Add new sequences in terms of other sources of DEC-A identification, such as Operating Experience, Expert Judgment, Regulatory Statements, Experience from other countries, dynamic PSA, etc.

3 APPLICATION TO THE GENERIC SPAR-CSN MODEL
DEC TAGGING AND APPLICATION OF TRUNCATION CRITERION

- Initial identification and quantification of 185 DEC-A sequences (Success Sequences with at least one header failed) and their related DEC-B sequences (Steps S1 to S5). Initiating Events (IEs): LOOP, LOCA, Steam-Line Break (SLB), Steam Generator Tube Rupture (SGTR).

- **Truncation Rules** are applied to the initial DEC-A sequence list (Step S6), the criteria to choose a cut-off frequency set at 1.00E-08 1/y have been
  - **Include all DEC-A sequences with a significant frequency.**
  - **Sequences recognized on international DEC-Based ,**

➢ **69 DEC-A Sequences with their related frequency and associated DEC-B sequences**

3 APPLICATION TO THE GENERIC SPAR-CSN MODEL
DEC-B FREQUENCY QUANTIFICATION AND DEC-A GROUPING

- At this point, **DEC-B Frequencies and $CCDP_{DEC}$ related to DEC-A sequences are quantified** (Step S7).
- Subsequent grouping of sequences according to similarity, risk relevance, and other criteria (i.e. A quantitative informed expert judgment process) is implemented with the following steps:

1) **Take out the sequences covered by DSA** (7 sequences) **analyzed in the safety analysis report** (Step S8).
   - e.g. Success on actuation of safety systems after a Main Steam-Line Break (MSLB) derived from the Generic Transient IE.

3 APPLICATION TO THE GENERIC SPAR-CSN MODEL
DEC-B FREQUENCY QUANTIFICATION AND DEC-A GROUPING

2) Sequence grouping by similarity allows reducing the list from 62 to 14 sequences (Step S8). e.g.:

- SBO with Off-site Power Recovery (with/without battery failure).
- SBLOCA/MBLOCA + Failure to cool down and depressurize RCS + Success of HPSI on recirculation mode.

The Outcome of these first steps is a list of 15 DEC-A Sequences with their respective frequencies and their related DEC-B accumulated frequency.

3 APPLICATION TO THE GENERIC SPAR-CSN MODEL SELECTED DEC-A SEQUENCES

- T1. Station Blackout (SBO) with offsite power recovery.
- T2. Total Loss of Feedwater (TLFW) with successful Feed & Bleed action.
- T3. SGTR consequential of a SLB with successful performance of the HPSI.
- *T4. SBLOCA (Stuck-Open Relief Valve) after SLB with successful HPSI (injection and recirculation).*
- T5. Seal LOCA consequential of an SBO with offsite power recovery.
- *T6. SBLOCA after SGTR with successful HPSI (injection and recirculation).*
- T7. Anticipated Transient Without SCRAM (ATWS).
- *T8. SBLOCA/MBLOCA with failure to cool and depressurize RCS with successful HPSI (recirculation).*
- T9. Loss CCWS with successful performance of the Passive thermal RCP seals or RCP seals injection by Hydrostatic Test Pump.
- T10. SGTR with SG isolation failure and successful automatic Feed & Bleed (automatic injection).
- T11. SBLOCA/MBLOCA with HPSI Failure and success to depressurize RCS and LPSI actuation.
- E-J: MSGTR, Boron dilution, Loss RHRS, Loss SFP cooling

3 APPLICATION TO THE GENERIC SPAR-CSN MODEL
DEC-B FREQUENCY QUANTIFICATION AND DEC-A GROUPING

No.	Sequences	DEC-A Freq. (1/y)	DEC-B Freq. (1/y)	$CCDP_{DEC-B}$	Included on any DEC list?
T1	SBO with offsite power recovery	7.6E-05	5.3E-08	7.E-04	Yes
T2	TLFW + Success on F&B	5.8E-05	7.8E-06	1.E-01	Yes
T3	SLB + SGTR + Success on HPSI	4.8E-05	1.1E-07	2.E-03	Yes
T4	SLB + SBLOCA + Success on HPSI and HR	2.1E-05	1.4E-06	6.E-02	No
T5	SBO + SLOCA with offsite power recovery	4.0E-06	3.7E-08	9.E-03	Yes
T6	SGTR + SBLOCA + Success on HPSI and HR	3.4E-06	3.3E-06	5.E-01	No
T7	ATWS	1.9E-06	5.7E-08	3.E-02	Yes
T8	SBLOCA/MBLOCA + Failure to depressurize RCS + Success on HR	8.8E-07	1.2E-07	1.E-01	No
T9	LCCWS + Success on RCP seals	2.6E-07	7.2E-10	3.E-03	Yes
T10	SGTR + Isolation Failure + Success on F&B (automatic injection)	1.8E-07	2.4E-08	1.E-01	Yes
T11	SBLOCA/MBLOCA + HPSI failure + success to depressurize RCS and LPSI	3.3E-08	1.8E-08	4.E-01	Yes
E-J	MSGTR, Boron dilution, Loss RHRS, Loss SFP cooling				Yes

4 SUMMARY

- The methodology allows for quantifying the risk of DEC-A sequences by means of two FoM: DEC-B_Freq and $CCDP_{DEC}$.
- 11 DEC-A sequences have been identified in the SPAR-CSN model, with high quantitative relevance (+4 E-J).
- Three potential DEC-A sequences, not included in other DEC-Based lists so far, with a high relative risk ($CCDP_{DEC}$ > 1E-02 and DEC-B_Freq > 1E-07 1/y).
    1. SLB with SBLOCA (Stuck-Open Relief Valve (SORV)) and successful HPSI (injection and recirculation)
    2. SGTR with SBLOCA and successful HPSI (injection and recirculation), and
    3. SBLOCA/MBLOCA with failure to cool and depressurize RCS with successful HPSI (recirculation).
- Rank four high relative risk DEC-A sequences ($CCDP_{DEC}$ > 1E-02), included on international DEC-based lists.
- Dependency between human actions influences the potential risk of DEC-A sequences.
- The low-risk criterion should be reviewed and agreed upon.

Thank You