Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Derived Acceptance Criteria (DAC) of Anticipated Operational Occurrences (AOOs) in Deterministic Safety Analysis for CANDU Reactors

Chul-Kyu Lim[a*], Hyeon-Sik Chang[a], Han-Rim Choi[a], Hyun-Sik Kang[a], Chang-Sup Lee[a], Jin Yoo[a], Hyun-Woo Park[a], Beom-Seock Kim[a], Seong-Kyu Park[a], Chul-Jin Choi[a], Chang-Sok Cho[a] and Mi-Suk Jang[a]
[a] *Nuclear Engineering Services & Solutions Co., Ltd., Sejong Daemyung Valeon B811, 6, Jiphyeonjungang 7-ro, Sejong-si, Rep. of KOREA 30141*
[*]*Corresponding author: cklim@ness.re.kr*

***Keywords:** *REGDOC-2.4.1, CANDU-6, Safety Analysis, AOOs, Defence-in-Depth (DID), Acceptance Criteria*

1. Introduction

REGDOC-2.4.1 [1], which was published in 2014, replaces the previous standards, C-6 Rev.0 (1980), and C-6 Rev.1 (1999), which have served as the standard and basis documents for the safety analysis in existing CANDU-6 reactors [2]. REGDOC-2.4.1 represents a significant change, including the reclassification of single/dual failures and class 1 to 5 events into Anticipated Operational Occurrences/Design Basis Accidents/Beyond Design Basis Accidents (AOO/DBA/BDBAs). Additionally, REGDOC-2.4.1 mandates the establishment of qualitative and quantitative acceptance criteria for AOOs. Therefore, the objective of this paper is to provide a brief overview of AOO events and to delineate both qualitative and quantitative acceptance criteria for AOO events.

2. Anticipated Operational Occurrences (AOOs)

Events in the current Safety Analysis Reports (SAR) are classified as single failures, dual failures, or as one of five event classes, roughly based on frequency. All are considered as part of the design basis under the Siting Guide and C-6 Rev.0, respectively.

REGDOC-2.4.1 has revised the boundary between design basis events and beyond design basis events and has further subdivided the design basis events to include another classification, AOOs, which are expected to occur during the station's lifetime. AOOs are events of higher frequency that were previously classified as single failures under the Siting Guide or as class 1 events under C-6 Rev.0.

AOO events have the potential to pose challenges to the safety of the reactor and may reasonably be expected to occur during the lifetime of a plant, with frequencies of occurrence equal to or greater than 10^{-2} per reactor year. With the goal of operating the plant safely following an AOO event, the AOOs are subdivided as follow.

2.1 Defence-in-Depth (DID) Level 2

AOOs are scrutinized to showcase the effectiveness of control systems, such as the Reactor Regulating System (RRS) setback/stepback, in mitigating most AOOs and preventing damage to Structures, Systems, and Components (SSCs) not involved in triggering the AOO. The primary focus is on determining the promptness and efficacy of control system actions in mitigating AOOs until operator intervention can be acknowledged.

For certain AOOs, it may become necessary to activate elements of Shutdown Systems One or Two (SDS1 or SDS2), which are recognized as qualified, reliable, and swift-acting systems typically designated as part of level 3 defense. The unique features of the CANDU reactor, which facilitate three independent means of reactor shutdown (RRS setback/stepback and two independent shutdown systems), enable the utilization of either SDS1 or SDS2 trip parameters in achieving the objectives of level 2 defense in specific AOO scenarios, if the conventional level 2 defense provisions (i.e., RRS parameters for initiating protective action) prove ineffective. Credit is attributed solely to the SDS trip signal since, the stepback is automatically triggered upon any SDS trip. Owing to the additional defense-in-depth (DID) inherent in the CANDU reactor design, the systems credited with a level 2 defense role may vary in some instances from those credited in other reactor designs.

2.2 Defence-in-Depth (DID) Level 3

In scenarios where initiating events within the AOO range are scrutinized to showcase the efficacy of level 3 defense, if the combined event frequency (AOO + failure of level 2 defense) falls within the DBA range, the analysis is conducted according to DBA rules.

3. Acceptance Criteria

Acceptance criteria play a crucial role in evaluating the integrity of physical barriers and ensuring an appropriate response from the plant and its systems during accidents. The integrity of these barriers is contingent upon specific threshold values, which represent the design limits with a safety margin.

3.1 Qualitative Acceptance Criteria

Acceptance criteria strive to attain a sufficient level of defense-in-depth, which entails the effectiveness of plant systems in upholding the integrity of physical barriers against the release of radioactive material. To achieve an adequate level of defense-in-depth, the following principles should govern acceptance criteria:

- Ensuring that the dose to the public does not surpass authorized dose limits
- Preventing the occurrence of a more severe plant condition due to an initiating event without an additional independent failure

3.2 Quantitative Derived Acceptance Criteria (DAC)

Quantitative DACs are determined for each event to ensure the presence of sufficient safety margins within authorized limits, thereby accommodating uncertainties and offering defense-in-depth. Examples of quantitative DACs encompass restrictions on fuel, fuel sheath, or pressure tube temperatures set for a specific event.

3.3 AOO Derived Acceptance Criteria

The AOOs are established to prevent any substantial plant damage, with the aim of quickly restoring plant operation after an AOO.

Dose limits for AOOs can be regarded as goals, as the existing dose limits outlined in the Siting Guide (Regulatory Document R-10) and C-6 Rev.0 will continue to apply after the implementation of REGDOC-2.4.1, as depicted in Table 1.

Table 1. Radiological Acceptance Criterion

Classification		**Dose limits**		
		Part	**Individual**	**Population**
R-10	Single failure ($\sim\geq10^{-2}$)	Whole body Thyroid	5 mSv 30 mSv	10^4 man-Sv 10^4 man-Sv
C-6 Rev.0	Class 1 ($\sim\geq10^{-2}$)	Whole body Thyroid	0.5 mSv 5 mSv	- -

In addition, AOO analysis incorporates preset thresholds in the realistic assessment of setback/stepback standard level 2 defense, as well as for the initiation of supplementary level 2 defense based on 1st SDS/1st trip parameter. The DAC for the performance of shutdown systems in AOO level 3 defense-in-depth remains consistent with those previously utilized. Table 2 outlines the methods of shutdown for AOO events.

Table 2. Means of Shutdown for AOO Events

Classification (REGDOC-2.4.1)		**Means of shutdown**	**Ideal trip parameter (TP)**	**Trip parameter total**
AOO Level 2 DID	Single failure ($\sim\geq10^{-2}$)	RRS	Setback, Stepback or SDS 1st trip signal used to initiate RRS, not SDS action	One setback (stepback) or One SDS TP

The DAC for Heat Transport System (HTS) overpressure protection remains unchanged from those previously applied: the American Society of Mechanical Engineers (ASME) service limits. For moderately frequent events, with a probability of occurrence greater than 10^{-2}/reactor-year, a service limit of Level B is assigned when the RRS is credited, as shown in Table 3.

Table 3. ASME Service Limits for AOO Events

Classification (REGDOC-2.4.1)		**ASME service limits**	
		Level	**Limit**
AOO	Single failure ($\sim\geq10^{-2}$)	Level B (“Upset”)	Below 110% of design pressure (11.9 MPa(a))

In the Canadian CANDU industry, the DACs applied for AOOs focus on the fitness-for-service criteria for fuel and pressure tubes. Typically, if the analysis shows that the maximum temperature of the fuel sheath following the event remains below 450°C, it ensures the fitness for service of both fuel and pressure tubes. Table 4 shows the DAC for fuel and fuel channel integrity of AOO events.

Table 4. DAC for Fuel & Fuel Channel Integrity

Classification (REGDOC-2.4.1)		**Evaluation method**	**DAC**
AOO Level 2 DID	Single failure ($\sim\geq10^{-2}$)	Sheath temperature	Below 450°C

4. Conclusions

This paper examines AOOs and identifies the DACs essential for deterministic safety analysis for AOO events, aligning with the implementation of REGDOC-2.4.1 for CANDU reactors. A concise overview of both qualitative and quantitative acceptance criteria was provided, and the specific details of DAC for AOO events were examined. This work is expected to offer valuable insights for enhancing safety analysis in future domestic CANDU-6 reactor operations.

REFERENCES

[1] CNSC, REGDOC-2.4.1, Deterministic Safety Analysis, May, 2014.

[2] Jong-Hyun Kim and Sang-Koo Han, Introduction to New Regulatory Document on the Deterministic Safety Analysis in Canada (REGDOC-2.4.1), Transactions of the KNS Spring Meeting, Jeju, Korea, May 12-13, 2016.